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DETERMINING THE IMPORTANCE OF THE CRITERIA OF TRAFFIC ACCESSIBILITY USING FUZZY AHP AND ROUGH AHP METHOD

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Abstract: *A large number of authors base research on a small number of traffic access criteria using one of the decision-making methods. The methods on which research can be based are multi-criteria decision-making in combination with fuzzy logic and rough numbers that give relevant results and are widely applied in all fields of science today. When using these methods, it is necessary to emphasize that there is a certain degree of subjectivity of the decision maker, but this can be minimized using fuzzy or rough numbers. This research refers to traffic accessibility of suburban areas, where the system of urban public transport is operational. The aim of this paper is to compare the significance of particular criteria using the Fuzzy AHP method and the Rough AHP method, which would show differences in the values of weight significance criteria and their ranking. The research has shown that the factors such as a network of public transport (PT) lines, the network of accessible roads in a settlement, Built infrastructure, travel time and the timetable have the greatest importance in description of traffic accessibility.*

Key words: *Traffic Accessibility; Multi-crteria decision making; Rough Numbers; Fuzzy AHP; Rough AHP Method.*

1. Introduction

Traffic accessibility as a function of public transport strengthens the economy, deals with the conservation of energy and resources, reduces congestion, improves the quality of air and our health, provides critical assistance in emergency situations and catastrophes, increases the development and value of real estate, increases mobility in small urban and rural communities, and reduces health costs. All of this contributes to a better quality of life.

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This paper gives a qualitative approach, not an analytical one. Experts are consulted to measure different criteria. The approach is in essence based upon opinion and not mathematical or scientific accuracy. Therefore, the starting point in this paper is the fact that it is possible, based on the experience so far, to gain an insight in the potentials of a new approach to observing traffic accessibility, especially in suburban areas where the system of urban public transport is operative.

Relevant criteria for traffic accessibility were described and measured (taking into account social equality). These criteria influence the reduction of the usage of passenger vehicles in suburban areas and create a more favorable environment for urban public transport in view of improving efficiency of the transport system and its sustainable development. As instruments of transport policy, measures that can be taken to manage the transportation needs of users (passengers) do not ask for great material investment, making them even more attractive.

The selection criteria for traffic accessibility that have an impact on the development of suburbs is a complicated process. It requires a detailed and permanent analysis of all relevant factors, which can have a smaller or greater impact. In order to identify the right criteria and sub-criteria that affect traffic accessibility, it is necessary to possess real knowledge of transportation systems, city infrastructure, demographic conditions, geographical surroundings, and fields related to decision-making and management. The choice of the criteria of traffic accessibility affecting different suburban communities is a complex process. Problems of finding an optimal solution, that is, tasks of optimization, are found and solved in every day life. They are found almost everywhere, in technical and economic systems, in the family, companies, sports clubs etc. (Vujošević, 2012). The decision-making process and the choice of "best" alternatives are usually based on more than one criterion and a set of constraints.

The decision maker should ultimately adopt a solution. The decision taken by the decision maker is called the best or preferred solution. The task of multi-criteria optimization is to help the decision-maker choose the solution he considers to be the best in the given conditions. Therefore, efforts to solve the set multi-criteria problem are often called multi-criteria analysis. When making a decision, the choice of some of the alternatives is assessed to solve a particular problem. In the decision-making issue there are goals that are to be achieved by decision, the criteria that measure the achievement of these goals, the weight of those criteria that reflect their importance and alternative solutions to the problem (Hot, 2014).

At the beginning of the paper, a general introduction with an overview of existing research and literature dealing with similar issues was given. In the second section, the concept of accessibility is explained and traffic accessibility criteria relevant for further research are presented. The third section describes the methodology that has been applied and the methods used to compare the significance of the criterion. The fourth section presents the results of the research, followed by a discussion of the results obtained and a conclusion.

2. Literature review

The international project MORECO (mobility and residence costs) explains the conjuncture between future places of living and accessibility. Special emphasis is put on the consequences that the uncontrollable spread of settlements causes to public transport services. The main goal of the project was to promote sustainable mobility through the development of a polycentric system of settlements. The main operative goal of the project was to promote the implementation of decisions made by private and public actors on locations that are close to public transport stops (Gulič, 2015). Litman (2017) wrote about the concept of accessibility and the ways it can be incorporated into transport planning. Many factors can have an impact on accessibility, including movability (physical motion), quality of transport, networking of traffic systems, mobility, and land use.

The main aim of paper (Stanković et al., 2018) is the definition and quantification of criteria that have the greatest impact on the traffic accessibility of suburban settlements, and development of a model for assessing traffic accessibility. This model refers to the traffic accessibility of suburban settlements in which the public transport system functions and represents a qualitative approach to research. One of the most popular methods of multi-criteria decision making, FAHP was used. Daily use of multi-criteria decision-making methods (Mardani et al., 2015; Gul et al., 2016) certainly contributed to the growing popularity of this area. In the paper (Akkaya et al., 2015) an integrated fuzzy AHP and fuzzy MOORA model is proposed for solving problems in the field of industrial engineering. Chen and Yang (2011) used limited Fuzzy AHP and Fuzzy TOPSIS for selection suppliers. There are a considerable number of publications dealing specifically with the comparison of classical AHP and fuzzy AHP (Stević, 2018). AHP is often used in combination with other methods where authors use AHP to estimate the weight of the criteria (Stević et al., 2015).

In addition to the fuzzy theory, a very suitable tool for treating uncertainty without the influence of subjectivism is the theory of rough sets, first presented (Pawlak, 1982). Unlike fuzzy theory and probability theory in which the degree of indeterminacy is defined on the basis of the assumption, in the theory of rough sets, indeterminacy is determined by the approximation which is the basic concept of the theory of rough sets. The theory of rough sets uses only internal knowledge, that is, operational data, and there is no need to rely on modeling assumptions. In rough sets, measurement of uncertainty is based on the uncertainty already contained in the data (Khoo & Zhai, 2011). This leads to objective indicators that are contained in the data. In addition, the theory of rough sets is suitable for applications that are characterized by a small number of data, and for which statistical methods are not suitable (Pawlak, 1991, 1993; Stević, 2018).

3. Methodology

In selecting the best assessment or decision-making method for criteria selection, research and the scientific literature in this field show that the problem could be solved by applying the multi-criteria decision-making method. The analytic hierarchy process (AHP) is a multi-criteria method that supports decision making with conflict criteria and alternatives. It has been thoroughly studied and improved through various scientific papers at prestigious universities worldwide (Roy et al., 2018; Badi et al., 2018; Lukovac et al., 2018). The AHP method has great significance for problem structuring and the decision-making process. Comparison was later carried out by pairs of elements in the hierarchy (aims, criteria and alternatives). These assessments can be made as comparisons between two elements at a set level of the hierarchy, taking into account their influence at a higher level. The comparison of the elements in pairs reveals the relevance of a specific element in comparison to another to meet the level of the aims and the criteria (Saaty et al. 1991).

3.1. Fuzzy AHP method

Let X = {x_1, x_2, . . . , x_n} be a set of objects, and U = {u_1, u_2, . . . , u_m} set of goals. According to the methodology of the expanded analysis by Chang (1996), for each taken object, an expanded analysis of the goal uj was carried out. The values of the extended analysis m for each object can be presented as follows (Chang, 1996):

$$M_{gi}^1, M_{gi}^2, M_{gi}^m, i = 1, 2, \dots, n., \tag{1}$$

where is $M_g^j, j = 1, 2, \dots, m.$, fuzzy triangular numbers.

Chang's extended analysis contains the following steps:

Step 1: Values of fuzzy extensions for *i-th* object are:

$$S_i = \sum_{j=1}^{n} M_{gi}^j \times \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^j\right]^{-1}, \tag{2}$$

In order to get the expression $\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^j\right]^{-1}$, it is necessary to carry out additional fuzzy operations with m values of extended analysis, given in the following expressions:

$$\sum_{j=1}^{m} M_{gi}^j = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right); \tag{3}$$

and

$$\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^j = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i\right). \tag{4}$$

Inverse vector:

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^j\right]^{-1} = \left[\frac{1}{\sum_{i=1}^{n} l_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} u_i}\right]. \tag{5}$$

Step 2: Level of probability $S_2 > S_1$ is defined as:

$$V(S_2 \geq S_1) = \begin{Bmatrix} 1, & if\ m_2 \geq m_1 \\ 0, & if\ l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & other \end{Bmatrix} \tag{6}$$

For comparison of S_1 and S_2, both values are required $V(S_1 \geq S_2)$ и $V(S_2 \geq S_1)$.

Step 3: Level of probability which states that convex fuzzy number is greater than *k* convex number S_i *(i=1, 2,..., k)* can be defined by the expression:

$$V(S_i \geq S_1, S_2, \dots, S_k) = minV(S_i \geq S_k), \quad i = 1, 2, \dots k \tag{7}$$

Weight vector is given by the following expression:

$$W' = \left(d'(A_1), d'(A_2), \dots, d'(A_n)\right)^T, \tag{8}$$

where is:

$$d'(A_i) = \min V(S_i \geq S_k), \quad k \neq i, \quad k = 1, 2, \dots, n; \tag{9}$$

and A_i (i = 1, 2, ..., n) n of the element.

Step 4: Through normalization, weight vector is:

$$W = \left(d(A_1), d(A_2), \dots, d(A_n)\right)^T, \tag{10}$$

where W does not represent a fuzzy number.

Through the application of the fuzzy AHP method, the main disadvantage of the classical AHP method is alleviated, and this is indicated by an insufficiently large scale of comparisons. To this end, different scale have been developed based on fuzzy triangular numbers, where the decision-maker has the ability to evaluate the significance of the criteria much more closely and more easily. Within Table 2, linguistic variables are converted into triangular fuzzy numbers:

Table 2. Linguistic scale of significance (Srichetta & Thurachon, 2012)

Linguistic Scale	TFNs	Reciprocal TFNs
Equally important	(1, 1, 1)	(1,1,1)
Weakly more important	(1/2, 1, 3/2)	(2/3, 1, 2)
Strong more important	(3/2, 2, 5/2)	(2/5, 1/2, 2/3)
Very strong more important	(5/2, 3, 7/2)	(2/7, 1/3, 2/5)
Absolutely more important	(7/2, 4, 9/2)	(2/9, 1/4, 2/7)

3.2. Rough AHP method

The rough AHP consists of the following steps (Zhai et al., 2009; Stević, 2018):

Step 1: Identification of the target of the research, followed by identification of the criteria and potential solutions. In this step, it is necessary to form a hierarchical structure, as is the case with the classic AHP.

Step 2: Formation of a group matrix of pairs in pairs from e_{th} experts, expressed as:

$$B_e = \begin{bmatrix} 1 & x_{12}^e & \cdots & x_{1m}^e \\ x_{21}^e & 1 & \cdots & x_{2m}^e \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1}^e & x_{m2}^e & \cdots & 1 \end{bmatrix} \tag{11}$$

where is x_{gh}^e ($1 \le g \le m$, $1 \le h \le m$, $1 \le e \le s$) the relative importance of the criteria g on the criterion h expressed by the expert e, m represents the number of criteria, while with the number of decision makers (DM) or experts.

Calculate the maximum of its own vector λ_{max}^e from B_e, then calculate the consistency index CI = (λ_{max}^e - n) / (n - 1).

Get out of the table (RI) depending on n and calculate the degree of consistency CR=CI/RI.

Subsequently, the group matrix of comparison $\tilde{B}$ is expressed as:

$$\tilde{B} = \begin{bmatrix} 1 & \tilde{x}_{12}^e & \cdots & \tilde{x}_{1m}^e \\ \tilde{x}_{21}^e & 1 & \cdots & \tilde{x}_{2m}^e \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1}^e & \tilde{x}_{m2}^e & \cdots & 1 \end{bmatrix} \tag{12}$$

where is $\tilde{x}_{gh}$ $\{x_{gh}^1,\ x_{gh}^2, \dots,\ x_{gh}^s\}$, $\tilde{x}_{gh}$ the sequence of the relative importance of the criteria g on the criterion h.

Step 3: *In this step, a rough matrix of comparisons needs to be formed.*

All elements x_{gh}^e in $\tilde{B}$ must be translated into a rough number $RN(x_{gh}^e)$:

$$RN\ (x_{gh}^e)\ =\ [x_{gh}^{eL},\ x_{gh}^{eU}] \tag{13}$$

where is x_{gh}^{eL} lower limit of rough numbers $RN\ (x_{gh}^e)$, while x_{gh}^{eU} the upper limit of the rough number.

Then a rough sequence $RN\ (\tilde{x}_{gh}^e)$ is presented as:

$$RN\ (\tilde{x}_{gh})\ =\ \{[x_{gh}^{1L}, x_{gh}^{1U}], [x_{gh}^{2L}, x_{gh}^{2U}], \dots, [x_{gh}^{sL}, x_{gh}^{sU}]\} \tag{14}$$

After that, conversion to an average rough number is carried out $RN\ (x_{gh})$:

$$RN(x_{gh}^e) = [x_{gh}^{eL}, x_{gh}^{eU}] \tag{15}$$

$$x_{gh}^{L} = \frac{x_{gh}^{1L} + x_{gh}^{2L} + \cdots + x_{gh}^{sL}}{s} \tag{16}$$

$$x_{gh}^{U} = \frac{x_{gh}^{1U} + x_{gh}^{2U} + \cdots + x_{gh}^{sU}}{s} \tag{17}$$

where is x_{gh}^{L} lower limit of rough numbers $RN\ (x_{gh})$ and x_{gh}^{U} the upper limit of the rough number.

Then, the rough matrix of the comparison of M is expressed as:

$$M = \begin{bmatrix} [1,1] & [x_{12}^{L}, & x_{12}^{U}] & \cdots & [x_{1m}^{L}, x_{1m}^{U}] \\ [x_{21}^{L}, x_{21}^{U}] & [1,1] & & \cdots & [x_{2m}^{L}, x_{2m}^{U}] \\ \vdots & \vdots & & \ddots & \vdots \\ [x_{m1}^{L}, x_{m1}^{U}] & [x_{m2}^{L}, x_{m2}^{U}] & & \cdots & [1,1] \end{bmatrix} \tag{18}$$

Step 4: Calculating the rough weight w_g for each criterion using the following two equations:

$$w_g = \left[\sqrt[m]{\prod_{h=1}^{m} x_{gh}^{L}},\ \sqrt[m]{\prod_{h=1}^{m} x_{gh}^{U}} \right] \tag{19}$$

$$w'_g = W_g / \max(w_g^{U}) \tag{20}$$

where is w'_g normalized weight of the criterions.

3.3. Set of Criteria of Traffic Accessibility

Accessibility as a term should be regarded as the extent to which potential passengers, who have certain transportation needs, have access to the city area.

The SEU (2003) report determines that accessibility depends upon:

- Existence of transport services connecting people and content;
- Informing people about transport services;
- Physical and financial limitations of access to transportation services
- Remoteness of content and activities

Accessibility can be:

- Spatial—referring to the spatial arrangement of contents in relation to users who set the requirements for their use;
- Temporal—referring to the time when a certain service is offered during the day, week or a longer period of time in relation to the available time of users for this service.

The first phase involves the identification and classification of criteria. In this phase, it is recommendable to use information on the functioning of the analyzed systems. It was also necessary to classify criteria according to their type, sub-system they belong to, and the level of decision-making.

A certain number of set elements of the preliminary criteria were identified on the basis of physical, functional and other characteristics of the system, which was the subject of the study. The second part of the preliminary criteria was defined on the basis of scientific and practical research and the analysis of literature on the subject. The third part of the set of preliminary criteria was identified on the basis of earlier experience with similar projects worldwide. Combining these three approaches, the number of set elements of the preliminary criteria for the assessment of the impact of traffic accessibility was obtained. Respecting experience and recommendations mentioned above, it is suggested that the assessment of traffic accessibility is made based on 13 factors (sub-criteria) grouped in 4 groups of criteria (Table 1).

Table 1. Impact criteria of traffic accessibility on suburb development

Criteria	Sub-criteria
Transport	Network of PT lines Remoteness of the railway Characteristics of the settlement Possesion of a car in the household
Space	Built infrastructure Network of access roads Remoteness from the most significant contents
Quality of service	Comfort in a vehicle Travel time Transfer points
System quality	Timetable Transport costs Tariff system

The surveys method, as one of the most commonly used methods for data collection in surveys (whose optimal size is 5 ± 2 members), gathered data, information, attitudes and opinions about the relevance of the given criteria in the preliminary meeting. The questionnaire consists of two basic elements: an introduction to the survey and questionnaire (questions). Given that this is an evaluation of predetermined criteria where respondents should only give preference to the importance, respondents were personally given a closed questionnaire type, that is, the one with the offered responses in the form of intensity of importance (optimal 5 intensities). The second part of the questionnaire consisted of a question of a closed type, by which the participants in the survey evaluated the importance of the criteria by rounding out one of the grades of 1-5 (1-smallest importance, 5-major importance).

Decision makers at this level are relevant experts who have knowledge and experience and who are directly related to the topic that is being processed. All interviewees have a master's degree.

4. Results

When defining the set of criteria and sub-criteria for assessment of the impact of traffic accessibility on development of suburbs, an expert team from economy made up of 5 professionals in the field of Transport systems and Public transport of passengers was consulted in the city of Niš. The number of experts who took part in this research is limited due to the impossibility to involve a greater number of experts who live and work on the territory of the city of Nis. It was required that all experts from the area of research they are relevant in, be from the territory of the urban unit. The matrices of the comparison of the value of the estimation by the experts for the Fuzzy AHP analysis are given in Table 3.

Table 3. Compatibility matrix for a group of transport criteria

		A_1	A_2	A_3	A_4
A_1	E_1	(1,1,1)	(5/2,3,7/2)	(1,1,1)	(1,1,1)
	E_2	(1,1,1)	(1,1,1)	(1,1,1)	(3/2,2,5/2)
	E_3	(1,1,1)	(3/2,2,5/2)	(3/2,2, 5/2)	(1/2,1,3/2)
	E_4	(1,1,1)	(3/2,2,5/2)	(1/2,1, 3/2)	(3/2,2,5/2)
	E_5	(1,1,1)	(3/2,2,5/2)	(3/2,2, 5/2)	(1,1,1)
A_2	E_1	(2/7,1/3, 2/5)	(1,1,1)	(2/7,1/3, 2/5)	(2/7,1/3, 2/5)
	E_2	(1,1,1)	(1,1,1)	(1,1,1)	(3/2,2,5/2)
	E_3	(2/5,1/2, 2/3)	(1,1,1)	(1,1,1)	(2/3, 1, 2)
	E_4	(2/5, 1/2, 2/3)	(1,1,1)	(2/3,1,2)	(1,1,1)
	E_5	(2/5,1/2, 2/3)	(1,1,1)	(2/5,1/2, 2/3)	(2/9,1/4, 2/7)
A_3	E_1	(1,1,1)	(5/2,3,7/2)	(1,1,1)	(1,1,1)
	E_2	(1,1,1)	(1,1,1)	(1,1,1)	(3/2,2,5/2)
	E_3	(2/5,1/2, 2/3)	(1,1,1)	(1,1,1)	(2/3, 1, 2)
	E_4	(2/3,1,2)	(1/2,1,3/2)	(1,1,1)	(1/2,1,3/2)
	E_5	(2/5, 1/2, 2/3)	(3/2,2,5/2)	(1,1,1)	(2/5,1/2, 2/3)
A_4	E_1	(1,1,1)	(5/2,3,7/2)	(1,1,1)	(1,1,1)
	E_2	(2/5,1/2, 2/3)	(2/5,1/2, 2/3)	(2/5,1/2, 2/3)	(1,1,1)
	E_3	(2/3,1,2)	(1/2,1,3/2)	(1/2,1, 3/2)	(1,1,1)
	E_4	(2/5,1/2, 2/3)	(1,1,1)	(2/3,1,2)	(1,1,1)
	E_5	(1,1,1)	(7/2,4,9/2)	(3/2,2, 5/2)	(1,1,1)

The relative fuzzy weights of each sub-criterion for the Transport group of criteria are shown in Table 4:

Table 4. Average and normalized weight criteria for the transport group of criteria

Sub-criteria	W'	W	Rank
Network of PT lines - A1	1	0.435	1
Remoteness of the railway - A2	0.070	0.031	4
Characteristics of the settlement - A3	0.610	0.265	3
Possesion of a car in the household - A4	0.619	0.269	2

Similarly, a comparative analysis of the obtained results was performed and they are presented in Table 5 and graphical way.

Table 5. Relative rank of significance of particular criteria based on comparison with Fuzzy AHP method

Criteria	Sub-criteria	W'	W
Transport	***Network of PT lines***	***1***	***0.435***
	Remoteness of the railway	0.070	0.031
	Characteristics of the settlement	0.610	0.265
	Possesion of a car in the household	0.619	0.269
Space	Built infrastructure	0.961	0.333
	Network of access roads	***1***	***0.347***
	Remoteness from the most significant contents	0.920	0.319
Quality of service	Comfort in a vehicle	0.502	0.206
	Travel time	***1***	***0.411***
	Transfer points	0.931	0.383
System quality	***Timetable***	***1***	***0.378***
	Transport costs	0.934	0.354
	Tariff system	0.708	0.268

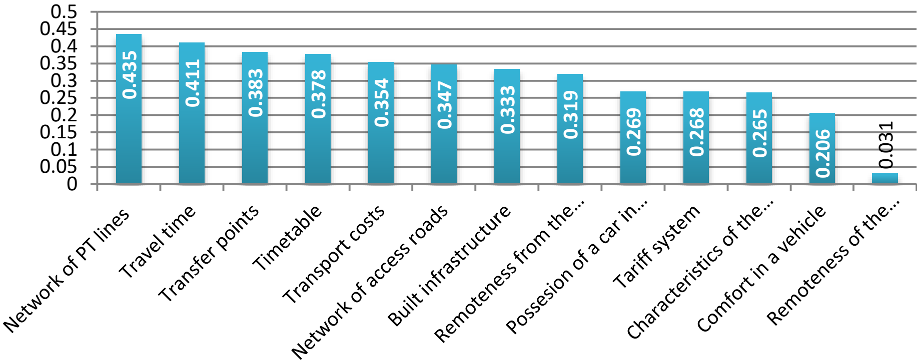


Figure 1. Relative weight of sub-criterion for all groups of criteria

If in general the relative weight of the sub-criterion were observed, the highest values are found in the sub-criteria of Network of PT lines, Travel time, Transfer points and Timetable. The smallest weights have the sub-criteria such as Comfort in a vehicle and Remoteness of the railway.

In the second case, using the Rough AHP method, after a comparison, a group matrix of comparisons in pairs was formed. A group matrix for the transport group of criteria looks like this:

$$\tilde{E}\begin{bmatrix} 1,1,1 & 2,4,1 & 4,4,3 & 2,5,4 \\ \frac{1}{2},\frac{1}{4},1 & 1,1,1 & 3,1,3 & 1,2,4 \\ \frac{1}{4},\frac{1}{4},\frac{1}{3} & \frac{1}{3},1,\frac{1}{3} & 1,1,1 & \frac{1}{3},2,2 \\ \frac{1}{2},\frac{1}{5},\frac{1}{4} & 1,\frac{1}{2},\frac{1}{4} & 3,\frac{1}{2},\frac{1}{2} & 1,1,1 \end{bmatrix}$$

Based on the group matrix, the rough weight of the sub criterion for the transport group of criteria is obtained:

$$w = \{[1.99, 2.67];\ [1.04, 1.61];\ [0.57, 0.80];\ [0.53, 0.89]\}$$
$$w' = \{[0.75, 1.00];\ [0.39, 0.60];\ [0.21, 0.30];\ [0.20, 0.33]\}$$

The values of the rough weight of all sub-criteria are given in Figure 2:

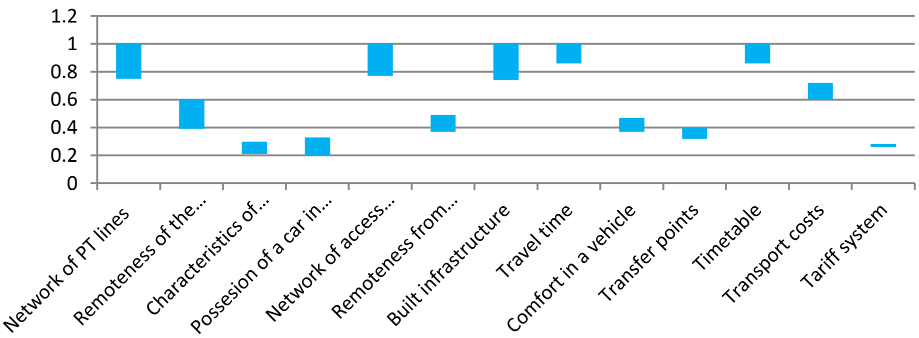


Figure 2. Rough weight of the sub-criteria using the rough AHP method

The greatest rough weights, in general, have the sub-criteria such as Built infrastructure, Network of PT lines and Network of access roads. Unlike the arrangement using the Fuzzy AHP method, the sub-criterion Remoteness of the railway using the rough AHP method is highly ranked and has a significant relative weight. The minimum value of relative weight is provided by the Tariff system and Transfer points.

4.1. Comparison Analysis of Results

After obtaining the results using the Fuzzy AHP method and the Rough AHP method, a comparison of the significance of the criteria can be made, and the results are presented graphically.

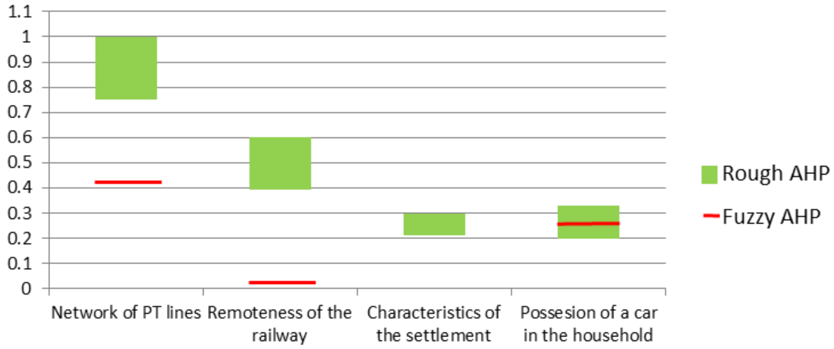


Figure 3. Sub-criteria values for the Transport group of criteria obtained using the Fuzzy AHP and Rough AHP methods

Figure 3 shows the comparative values of the weight of the sub-criterion for the Transport Criteria Group using the Fuzzy AHP and Rough AHP methods. Although there is a difference in the value between these two methods, the significance of the sub-criteria Network of PT lines is dominant in relation to others. Also, using Rough AHP method, the sub-criterion Remoteness of the railway showed greater significance than in the case when the analysis was performed using the Fuzzy AHP method.

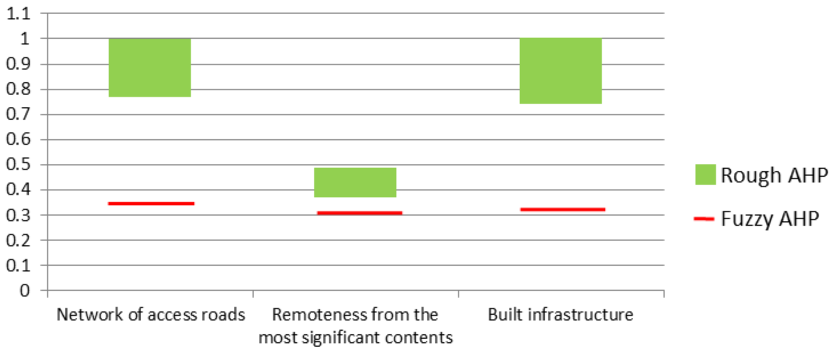


Figure 4. Sub-criteria values for a Spatial group of criteria obtained using the Fuzzy AHP and Rough AHP methods

Similarly, in Figure 4, the values of the sub-criterion for the Spatial Criteria group are shown using the methods indicated.

Subcriteria values using the Fuzzy AHP method are approximately similar, as can be seen in Figure 4. On the other hand, the Rough AHP method shows that the significance of the sub-criterion of Network of access roads and the Built infrastructure are approximately equal, but that the Built Infrastructure has a dominant significance.

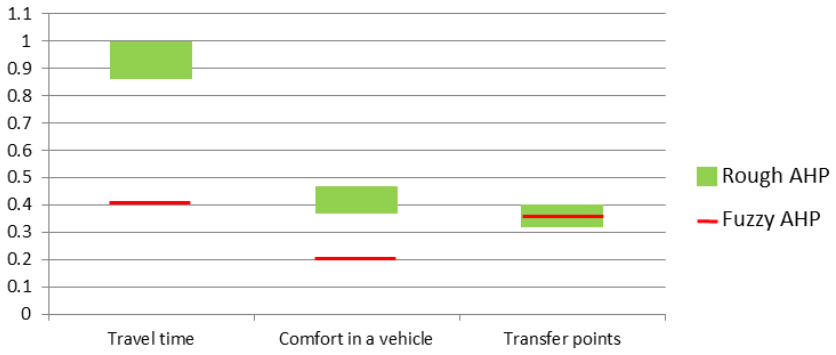


Figure 5. Sub-criteria values for the Quality of services criteria group obtained using Fuzzy AHP and Rough AHP methods

Figure 5 shows the values of the sub-criterion of the Quality of service group where we can see similar weights of the criteria of the Travel time and Comfort in a vehicle. Only the last sub-criterion (Transfer points) of the Fuzzy AHP method is more important than the Rough AHP method.

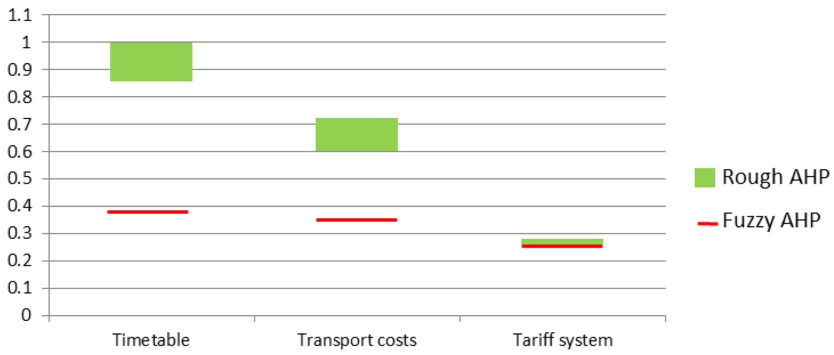


Figure 6. Sub-criteria values for the Quality of system criteria group obtained using Fuzzy AHP and Rough AHP methods

Using both methods, in Figure 6, it can be seen that the values of the weight of the significance of the sub-criterion of the Quality of system group are similarly distributed.

Comparative weighting criteria for both methods of multi-criteria decision making are given in Table 6:

Table 6. Weight values of all sub-criteria using Fuzzy AHP and Rough AHP methods

Criteria	Fuzzy AHP	Rank	Rough AHP	Rank
Network of PT lines	0.435	*1*	(0.75; 1.0)	*2*
Remoteness of the railway	0.031	*13*	(0.39; 0.60)	*4*
Characteristics of the settlement	0.265	*11*	(0.21; 0.30)	*11*
Possesion of a car in the household	0.269	*9*	(0.20; 0.33)	*7*
Network access roads	0.347	*6*	(0.77; 1.0)	*3*
Remoteness from the most significant contents	0.319	*8*	(0.37; 0.49)	*8*
Built infrastructure	0.333	*7*	(0.74; 1.0)	*1*
Travel time	0.411	*2*	(0.86; 1.0)	*5*
Comfort in a vehicle	0.206	*12*	(0.37; 0.47)	*10*
Transfer points	0.383	*3*	(0.32; 0.40)	*12*
Timetable	0.378	*4*	(0.86; 1.0)	*6*
Transport costs	0.354	*5*	(0.60; 0.72)	*9*
Tariff system	0.268	*10*	(0.26; 0.28)	*13*

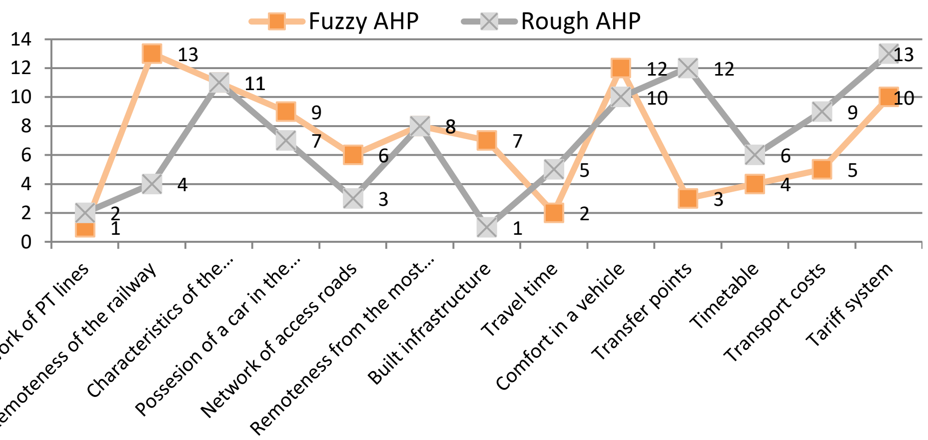


Figure 7. Ranking the sub-criterion using the Fuzzy AHP and the Rough AHP methods

Generally, according to the Fuzzy AHP method, Network of PT lines is in the first place, while the second place is occupied by Travel time (Figure 7). By using the Rough AHP method, the criterion of Built infrastructure was ranked first, followed by Network of PT lines. The sub-criterion Remoteness of the railway is at the last place based on the Fuzzy AHP method, while according to Rough AHP method, it is on the high fourth position. According to the same method, the Tariff system is last ranked.

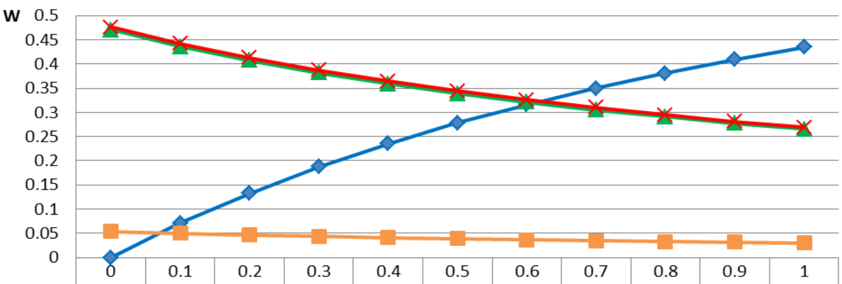
4.2. Analysis of the sensitivity of the criterion values

When choosing the relevant criteria, one of the important characteristics of the applied methods is the analysis of the sensitivity of the final solution, which allows the decision maker to examine different variants. The sensitivity analysis shows the relations of priority change as a function of the significance of the attributes (Batinić, 2013). Several methods are used to analyze the sensitivity of the solution:

– dynamic sensitivity analysis;
– gradient sensitivity analysis;
– performance sensitivity analysis;
– „head of the head“ analysis (one to one);
– two-dimensional analysis.

Dynamic sensitivity analysis shows that the change in the priorities of one criterion influences the change in the priorities of other criteria and the priorities of the alternatives within the observed criterion. The importance of implementing a dynamic sensitivity analysis is also the ability to determine the individual participation of the criteria in the priorities of the alternative. Changing the priorities of one criterion to change the priority of the criteria and alternatives, or finally the final ranking of alternatives as results can be more clearly followed in the gradient analysis graph. Performance sensitivity analysis summarizes the presentation of the criteria and alternatives for all criteria individually and collectively at the global level and at the criteria levels. The significance of the performance sensitivity analysis is that it is possible to determine the final solution, that is, the result - ranking for any node on the tree of the criteria within the associated level. An analysis of the sensitivity of the "head of the head" determines for which percentage the significance of the considered criterion in relation to the other is higher. To determine this percentage, a specific scale of the set of criteria for which the required value is determined is used. The graph of two-dimensional sensitivity shows how alternatives behave according to two criteria.

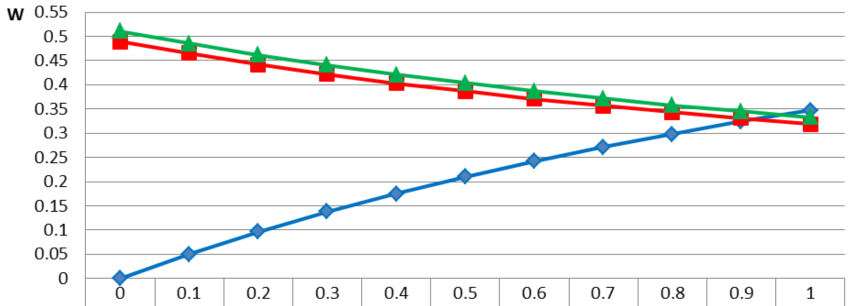
To ensure that the results obtained are valid and applicable in the real world, it is necessary to perform sensitivity analysis and check the stability of the final results. Changes in the weight values of the criteria are analyzed to determine how their significance affects the results.



	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
1	0	0.071	0.133	0.188	0.235	0.278	0.316	0.35	0.381	0.409	0.435
2	0.054	0.05	0.047	0.044	0.041	0.039	0.037	0.035	0.033	0.032	0.03
3	0.47	0.436	0.407	0.382	0.359	0.339	0.321	0.305	0.291	0.277	0.265
4	0.476	0.442	0.413	0.387	0.364	0.344	0.326	0.31	0.295	0.281	0.269

Figure 8. Results of the sensitivity analysis for the Transport Criteria Group

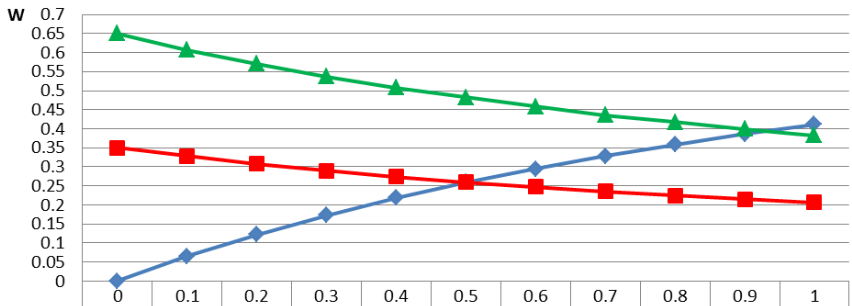
In Figure 8, the sensitivity of the significance of the criterion, which has the greatest value in relation to the other criteria, was analyzed. The dominant significance of the Network of PT lines has a weight vector of 0.65 in relation to the sub-criteria of the Characteristics of the Settlement and the Possession of a Car. The Remoteness of the railway has a slight dominance of up to 0.1. A small change in value (10-20%) would not affect the change in the significance of the sub-criterion.



	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
1	0	0.05	0.096	0.138	0.175	0.21	0.242	0.271	0.298	0.324	0.347
2	0.489	0.465	0.442	0.422	0.403	0.387	0.371	0.357	0.343	0.331	0.319
3	0.511	0.485	0.462	0.441	0.421	0.404	0.387	0.372	0.358	0.345	0.333

Figure 9. Results of sensitivity analysis for the Space group of criteria

Sub-criteria The Built infrastructure and the Remoteness from the most significant contents have a dominant value of the weight of significance up to a value of 0.95 (Figure 9). This practically means that a small change in the value of the sub-criterion of the Network of access roads (10%) will cause a change in the weight of the significance and the dominance of the sub-criterion within the space group of criteria.

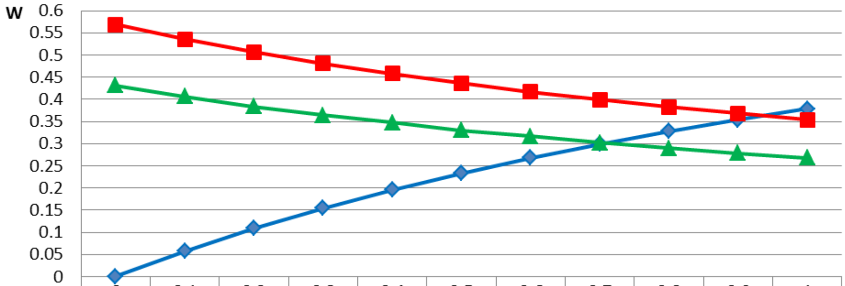


	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
1	0	0.065	0.122	0.173	0.218	0.259	0.295	0.328	0.358	0.386	0.411
2	0.35	0.328	0.308	0.29	0.274	0.26	0.247	0.235	0.225	0.215	0.206
3	0.65	0.607	0.57	0.537	0.508	0.482	0.458	0.436	0.417	0.399	0.383

Figure 10. Results of the sensitivity analysis for the Group of criteria Quality of service

In Figure 10, the sensitivity of the significance of the sub-criterion was analyzed. Travel time in relation to other criteria. The dominant significance for the Transfer points has the value of the weight vector 0.5, and in relation to the sub-criterion of the

Comfort in a vehicle of 0.95. With a change of less than 10%, the weight value of the sub-criterion changes and the sub-criterion Comfort in the vehicle becomes dominant.



	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
1	0	0.057	0.109	0.154	0.196	0.233	0.268	0.299	0.328	0.354	0.378
2	0.569	0.536	0.507	0.481	0.458	0.436	0.417	0.399	0.383	0.368	0.354
3	0.431	0.406	0.384	0.364	0.347	0.33	0.316	0.302	0.29	0.278	0.268

Figure 11. Results of the sensitivity analysis for the Group of criteria Quality of the system

Sub-criteria the Transport cost and the Tariff system have a dominant value of the weight of importance up to a value of 0.7 and 0.95 (Figure 11). This practically means that a change of less than 10% triggers a change in significance according to the sub-criterion of Transport cost, while the change of significance of 30% would trigger the dominance of the sub-criterion Tariff system.

5. Discussion

By reviewing the literature, scientific papers and research, as well as consulting with experts from relevant fields, a total of 13 criteria for assessing the impact of traffic accessibility in suburban settlements were identified. They are classified into four groups: transport, space, quality of service and system quality. Economic experts who are directly in touch with the analyzed problematics were involved in assessing the significance of certain criteria within each group of criteria.

In order to solve the problem of evaluating and selecting priority criteria from individual groups, one of the decision-making methods - the Fuzzy Analytical Hierarchical Process (FAHP) was used, since it is known from previous experiences and from literature that such problems should be addressed by methods of multi-criteria decision-making. Also, in defining the significance of the sub-criterion, in addition to the FAHP method, a coarse theory was applied, among which the Rough AHP method is most suitable for testing uncertainty when it is necessary to exclude subjectivism in the choice of the importance of the significance of criteria.

A multi-criterion analysis of four sets of criteria, using the FAHP method, has shown from each group those that are a priority for assessing the impact of traffic accessibility. Criteria that in the normalized ranks gained an advantage over other criteria from their group are:

1. From the Transport Criteria Group, the Network of PT lines has the highest relative weight;
2. From the Space group of criteria, the highest relative weight has the Network of access roads;

3. From the Group of criteria Quality of service, Travel time has the relative weight;
4. From the Group of criteria Quality of the system, the Timetable has the highest relative weight.

In the theory of rough numbers, the application of the Rough AHP method showed from each group those that are a priority for assessing the impact of traffic accessibility. Criteria that in the normalized ranks gained an advantage over other criteria from their group are:

1. From the Transport Criteria Group, the Network of PT lines has the highest relative weight;
2. From the Space group of criteria, the highest relative weight is possessed by the Built infrastructure;
3. From the Group of criteria Quality of service, the relative weight is possessed by the Travel time;
4. From the Group of criteria Quality of the system, the highest relative weight is possessed the Timetable.

By analyzing the obtained results of the applied methods, it was determined that there is only the difference in the Space group of criteria, where in the first method the dominant sub-criterion is the Network of PT lines, while in the second method the significance was assigned to the sub-criterion Built Infrastructure. Generally, according to the Fuzzy AHP method, Network of PT lines is in the first place, while the second place is occupied by Travel time (Figure 7). By using the Rough AHP method, the criterion of Built infrastructure was ranked first, followed by Network of PT lines. The sub-criterion Remoteness of the railway is at the last place based on the Fuzzy AHP method, while according to the Rough AHP method, it is on the high fourth position. According to the same method, the Tariff system is ranked at the last place.

By defining a greater number of different impact factors on traffic accessibility and by applying the method for multicriteria decision making, it was possible to select dominant criteria that represent the generators of development and sustainability of suburban areas, in a similar way as the accessibility criteria have been defined by Litman (2017). Ranković-Plazinić (2015) defined the types of rural settlements in relation to accessibility, which is a good predisposition for the implementation of some future models. This created an opportunity for assessment of criteria for traffic accessibility.

6. Conclusions

The context in which decisions, regarding the implementation of measures, are made should have strong ties with the impacts that will be assessed, the aims that should be reached and the target groups (users of public transport) that should be taken into consideration. Contribution of this paper is to make settlements competitive for life and to make them attractive for economic investments. Through definition and quantification of significant criteria for traffic accessibility, first steps were made towards the development of a future research.

In order to strengthen the bond between the parameters, it is necessary to have a broad knowledge of natural, social, economic and other characteristics. Also, for a similar research in the future, the research area would need to be broader, that is with less limitations than having them now. This means that the number of experts would need to be greater and their professional interests would need to encompass wider social and natural areas. The application of these results in real life is multifaceted and refers to the improvement of life quality, accessibility of different services, systematic development of settlements and a possible decrease in migration of residents from suburban areas.

This paper presents a new way of determining the importance of accessibility criteria, which involves the application of two methods of multi-criteria decision making Fuzzy AHP and Rough AHP. By applying these methods, with the help of relevant experts, the importance of each criterion is determined individually from the group of 13 criteria and the results are mutually compared. The sensitivity analysis showed the relationship of priority change as a function of the significance of the attributes, that is, the criteria.

References

Akkaya, G., Turanoğlu, B., & Öztaş, S. (2015). An integrated fuzzy AHP and fuzzy MOORA approach to the problem of industrial engineering sector choosing. Expert Systems with Applications, 42(24), 9565-9573.

Badi, I.A.; Abdulshahed, A.M.; Shetwan, A.G. (2018). A case study of supplier selection for a steelmaking company in Libya by using the Combinative Distance-based ASsessment (CODAS)model. Decision Making: Applications in Management and Engineerin, 1, 1–12.

Batinić, M. (2013). Analysis of selection criteria and the sensitivity of solutions in selecting candidates for a job position. Military technical courier, 61(3), 268-279.

Chang, D.Y. (1996). Applications of the extent analysis method on fuzzy AHP. European Journal of Operational Research, 95(3), 649–655.

Chen, Z., & Yang, W. (2011). An MAGDM based on constrained FAHP and FTOPSIS and its application to supplier selection. Mathematical and Computer Modelling, 54(11), 2802-2815.

Gul, M., Celik, E., Aydin, N., Gumus, A. T., & Guneri, A. F. (2016). A state of the art literature review of VIKOR and its fuzzy extensions on applications. Applied Soft Computing, 46, 60-89.

Gulič, A., (2015). Mobilnost i Troškovi Stanovanja: Saznanja i Usmerenja Projekta MORECO. Naučno Stručni Skup Palić. (In Serbian)

Jeuring, R., Lightfoot, G., Sanfeliu, R., Majano, A., Prastacos, P., Vanseveren, J., & Anderson, P.G. (2000). Verifying and Strengthening Rural Access to Transport Services: Deliverable 1 Final Report for WP1—Overview of Best Practices in Rural Transport; ETT SA: Madrid, Spain.

Khoo, L. P., & Zhai, L. Y. (2001). A prototype genetic algorithm-enhanced rough set-based rule induction system. Computers in Industry, 46(1), 95-106.

Litman, T. (2017). Evaluating Accessibility for Transportation Planning - Measuring People's Ability to Reach Desired Goods and Activities; Victoria Transport Policy Institute: Victoria, BC, Canada.

Logan, P. (2007). Best practice demand-responsive transport (DRT) policy. Road and Transport Research, 16(2), 50–59.

Lukovac, V., & Popović, M. (2018). Fuzzy Delphi approach to defining a cycle for assessing the performance of military drivers. Decision Making: Applications in Management and Engineering, 1(1), 67–81.

Mardani, A., Jusoh, A., & Zavadskas, E. K. (2015). Multiple criteria decision-making techniques and their applications–a review of the literature from 2000 to 2014. Economic Research, 28(1), 516-571.

Northern Ireland Statistics and Research Agency. (2005). Report of the Inter-Departmental Urban-Rural Definition Group: Statistical Classification and Delineation of Settlements; National Statistics Publication: Belfast, UK.

Pawlak, Z. (1982). Rough sets. International Journal of Computer & Information Sciences, 11(5), 341–356.

Pawlak, Z. (1991). Rough sets: Theoretical aspects of reasoning about data. Dordrecht & Boston: Kluwer Academic Publishers.

Pawlak, Z. (1993). Anatomy of conflicts, Bulletin of the European Association for Theoretical Computer Science, 50, 234-247.

Ranković-Plazinić, B. (2015). Održivo planiranje saobradaja za ruralna područja. Ph.D. Thesis, Saobraćajni Fakultet u Beogradu, Univerzitet u Beogradu, Belgrade, Serbia. (In Serbian)

Roy, J., Pamučar, D., Adhikary, K., & Kar, S. (2018). A rough strength relational DEMATEL model for analysing the key success factors of hospital service quality. Decision Making: Applications in Management and Engineering, 1(1), 121–142.

Saaty, T.L., & Kearns, P.K. (1991). Analytical Planning, The Organization of Systems; The Analytic Hierarchy Process Series; RWS Publications: Pittsburgh, PN, USA, Volume IV.

Social Exclusion Unit. (2003). Making the Connections: Final Report on Transport and Social Exclusion; Social Exclusion Unit: London, UK.

Srichetta, P., & Thurachon, W. (2012). Applying Fuzzy Analytic Hierarchy Process to Evaluate and Select Product of Notebook Computers. International Journal of Modeling and Optimization, 2(2), 168–173.

Stanković, M., Gladović, P., Popović, V., & Lukovac, V. (2018). Selection Criteria and Assessment of the Impact of Traffic Accessibility on the Development of Suburbs. Sustainability, 10(6), doi:10.3390/su10061977.

Stević, Ž. (2018). Integrisani model vrednovanja dobavljača u lancima snabdevanja. Doktorska disertacija. Fakultet tehničkih nauka Novi Sad. Univerzitet u Novom Sadu. (In Serbian)

Stević, Ž., Alihodžić, A., Božičković, Z., Vasiljević, M., & Vasiljević, Đ. (2015). Application of combined AHP-TOPSIS model for decision making in management. V International conference „Economics and Management - based On New Technologies "EMONT/Vrnjačka Banja, 33-40.

White, P. (2011). Equitable Access: Remote and Rural Communities' Transport Needs, International Transport Forum on Transport for Society: Leipzig, Germany, Paper No. 2011-19.

Zhai, L. Y., Khoo, L. P., & Zhong, Z. W. (2009). A rough set based QFD approach to the management of imprecise design information in product development. Advanced Engineering Informatics, 23(2), 222-228.