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Evaluation of criteria when selecting agricultural machinery suppliers

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Abstract

The aim of this paper is to apply a modern decision-making method to select the given criteria that would help in selecting the most favourable supplier of sowing equipment. For that purpose, DEMATEL (*The Decision Making Trial and Evaluation Laboratory*) is a suggested method for multi-criteria decision-making, i.e. its *fuzzy* logic. The reason for this is the use of professional judgment of experts in a given field of analysis where the *fuzzy* logic of decisions tried to approach human thinking. The paper focus is the equipment for sowing of an agricultural farm in the municipality of Bijeljina, and the obtained results show the influence of certain criteria that are crucial in the selection of suppliers. Also, the benefit of the research stems from the observation of shortcomings, i.e. improving the quality of the subject of work according to certain processed criteria.

Key words: multicriteria decision making, DEMATEL method, fuzzy logic, agricultural mechanization

Introduction

Modern agricultural production is inconceivable without the use of adequate agricultural machinery, which should provide the most productive production process within the given agro-technical deadline. Particularly sensitive periods from the agrotechnical point of view in the production process are certain plant species at the time of sowing. In that case, the correct choice of a particular seed drill is an essential measure of a well-run production process. The important thing of every business entity is that the supplier should be someone they can rely on. As Aguezzoul (2012) points out, choosing a supplier is a strategic purchasing decision that affects the overall success of any company. According to some authors, improper selection and evaluation of potential suppliers can overshadow the performance of supply chains within an organization (Jafarnejad, Salimi, 2013). The choice of suppliers is influenced by many factors (Puška, 2015). It is extremely important to identify the most important factors that influence the choice of suppliers. Using previous research, some of the authors cite a number of different factors that influence supplier selection. Thus, Liao and Kao (2011) highlight 29 different factors, while Aguezzoul (2012) as many as 36.

Considering the subject of this paper, 8 economic and social criteria were selected (delivery costs, payment flexibility, quality of delivered goods, applied production technology, supplier reputation, innovation in production, distance of suppliers, importance for the local community) and their importance was confirmed based on some of the earlier research by several authors (Bai and Sarkis, 2009; We et al., 2013; Jain et al.,, 2013; Liu, 2010; Mwikali and Kavale, 2012 etc.). Multi-criteria decision-making methods are mainly used to assess the criteria needed to select suppliers. Decisions are made by assessing alternatives according to defined criteria (Rozman et al., 2017), which in turn can be qualitative and quantitative (Rozman et al., 2016). In addition to the use of classical methods of multi-criteria decision-making, their fuzzy methods (variants) are increasingly being used. The reason for that lies in the fact that some of the given criteria can be qualitative, as is the case in this paper. Thus, in the subject area, we have previous research that has just used this method (Govindan et al., 2013; Stević et al., 2019, Nedeljković et al., 2021a; Nedeljković et al., 2021b, Nedeljković, 2022, etc.). Therefore, the aim of the paper is to use a modern decision-making method to select the set criteria that would lead to the selection of the most favourable supplier, which in this case is sowing equipment on a family farm in the municipality of Bijeljina.

Material and Methods

The source of data in this paper is the relevant literature in the field of analysis as well as expert assessment by five experts in the observed field. The experts filled in the questionnaire, giving certain weights to the analyzed criteria and according to the given *fuzzy* scale. The DEMATEL method was used in the research, and the reason for its use lies in the fact that it represents an adequate method of multicriteria analysis when it comes to the subject area. This is confirmed by its considerable use in previous research (Gharakhani, 2012; Govindan et al., 2013; Govindan, Chaudhuri, 2016; Shaik, Abdul-Kader, 2018; Hsu, Yeh, 2017; Jarosz, 2019; Yildirim and Koca, 2021 itd.). DEMATEL (*The Decision Making Trial and Evaluation Laboratory*), one of the MCDM (*Multi-Criteria Decision Making*) methods, was developed in 1972 by the Battelle Memorial Institute of Geneva Research Center. The DEMATEL method allows separating a factor into cause and effect groups and identifying the most important criteria from the group of all criteria indicated as crucial in the decision-making process according to stakeholder needs. (Chang et al., 2011) Also, one of the reasons for the application of the DAMATEL method is its popularization in solving the problem of determining the weight of certain criteria needed for the decision-making process. Using fuzzy logic, this method attempts to bring the final decision closer to human thinking. Chen (2000) extended this method using triangular fuzzy numbers that replace numerical language scales for grading and weighting. The steps used in the application of this method are listed in the chapter research results, where through a case study in the paper it tries to make a selection of given criteria that are important in decision making.

Results and Discussion

Further in the paper, the procedures (steps) of the applied methodology are presented, through which the results of the obtained research are shown.

Generate the fuzzy direct- relation matrix

In order to identify the model of the relations among the n criteria, an n × n matrix is first generated. The influence of the element in each row exerted on the element in each column of this matrix can be represented a fuzzy number. If multiple experts' opinions are used, all experts must complete the matrix. Arithmetic mean of all of the experts' opinions is used to generate the direct relation matrix z.

$$z = \begin{bmatrix} 0 & \cdots & \tilde{z}_{n1} \\ \vdots & \ddots & \vdots \\ \tilde{z}_{1n} & \cdots & 0 \end{bmatrix}$$

The table below indicates the direct relation matrix, which is the same as pairwise comparison matrix of the experts.

Table 1. The direct relation matrix

	Shipping costs	Payment flexibility	Quality of goods	Technology used	Reputation	Innovation	Location (distance)	Significance for local community
Shipping costs	(0.000,0.000,0.000)	(5.000,7.000,8.600)	(3.800,5.800,7.800)	(5.000,7.000,7.800)	(5.800,7.800,9.000)	(5.000,7.000,7.800)	(4.600,6.600,8.600)	(4.600,6.600,8.200)
Payment flexibility	(5.400,7.400,8.600)	(0.000,0.000,0.000)	(4.200,6.200,8.200)	(5.000,7.000,8.200)	(4.200,6.200,8.200)	(5.400,7.000,7.800)	(5.000,7.000,9.000)	(5.400,7.400,8.200)
Quality of goods	(6.200,8.200,8.600)	(6.200,8.200,9.000)	(0.000,0.000,0.000)	(5.000,6.600,7.800)	(5.400,7.400,9.000)	(6.200,8.200,9.000)	(6.200,8.200,9.000)	(5.800,7.800,8.600)
Technology used	(1.800,3.000,5.000)	(1.800,3.800,5.800)	(1.000,2.600,4.600)	(0.000,0.000,0.000)	(1.800,3.800,5.800)	(4.200,6.200,8.200)	(2.200,3.800,5.800)	(3.800,5.800,7.800)
Reputation	(3.800,5.800,7.800)	(3.800,5.800,7.800)	(3.000,5.000,7.000)	(5.400,7.400,9.000)	(0.000,0.000,0.000)	(5.800,7.800,9.000)	(4.200,6.200,8.200)	(5.800,7.800,9.000)
Innovation	(1.400,2.600,4.600)	(1.400,3.000,5.000)	(1.000,1.800,3.800)	(3.800,5.800,7.800)	(1.800,3.800,5.800)	(0.000,0.000,0.000)	(1.800,3.800,5.800)	(3.000,5.000,7.000)
Location (distance)	(3.400,5.400,7.400)	(3.000,5.000,7.000)	(2.200,4.200,6.200)	(5.000,7.000,9.000)	(3.000,5.000,7.000)	(5.800,7.800,9.000)	(0.000,0.000,0.000)	(4.600,6.600,8.600)
Significance for local	(1.400,2.600,4.600)	(1.400,3.400,5.400)	(1.400,3.400,5.400)	(4.600,6.600,8.600)	(3.000,5.000,7.000)	(5.400,7.400,9.000)	(2.600,4.200,6.200)	(0.000,0.000,0.000)

community								

Source: Authors' calculation

The following table shows the fuzzy scale used in the model.

Table 2. Fuzzy Scale

	Linguistic terms	L	M	U
1	Very Low	1	1	3
2	Low	1	3	5
3	Medium	3	5	7
4	High	5	7	9
5	Very high	7	9	9

Source: According to Kiani Mavi et al., 2016; Mijajlović et al., 2020.

Normalize the fuzzy direct-relation matrix

The normalized fuzzy direct-relation matrix can be obtained using the following formula:

$$\tilde{x}_{ij} = \frac{\tilde{z}_{ij}}{r} = \left(\frac{l_{ij}}{r}, \frac{m_{ij}}{r}, \frac{u_{ij}}{r}\right)$$

where

$$r = \max_{i,j}\left\{\max_{i}\sum_{j=1}^{n} u_{ij}, \max_{j}\sum_{i=1}^{n} u_{ij}\right\} \qquad i,j \in \{1,2,3,\dots,n\}$$

Table 3. The normalized fuzzy direct-relation matrix

	Shipping costs	Payment flexibility	Quality of goods	Technology used	Reputation	Innovation	Location (distance)	Significance for local community
Shipping costs	(0.000,0.000,0.000)	(0.082,0.115,0.141)	(0.062,0.095,0.128)	(0.082,0.115,0.128)	(0.095,0.128,0.148)	(0.082,0.115,0.128)	(0.075,0.108,0.141)	(0.075,0.108,0.134)
Payment flexibility	(0.089,0.121,0.141)	(0.000,0.000,0.000)	(0.069,0.102,0.134)	(0.082,0.115,0.134)	(0.069,0.102,0.134)	(0.089,0.115,0.128)	(0.082,0.115,0.148)	(0.089,0.121,0.134)
Quality of goods	(0.102,0.134,0.141)	(0.102,0.134,0.148)	(0.000,0.000,0.000)	(0.082,0.108,0.128)	(0.089,0.121,0.148)	(0.102,0.134,0.148)	(0.102,0.134,0.148)	(0.095,0.128,0.141)
Technology used	(0.030,0.049,0.082)	(0.030,0.062,0.095)	(0.016,0.043,0.075)	(0.000,0.000,0.000)	(0.030,0.062,0.095)	(0.069,0.102,0.134)	(0.036,0.062,0.095)	(0.062,0.095,0.128)
Reputation	(0.062,0.095,0.128)	(0.062,0.095,0.128)	(0.049,0.082,0.115)	(0.089,0.121,0.148)	(0.000,0.000,0.000)	(0.095,0.128,0.148)	(0.069,0.102,0.134)	(0.095,0.128,0.148)
Innovation	(0.023,0.043,0.075)	(0.023,0.049,0.082)	(0.016,0.030,0.062)	(0.062,0.095,0.128)	(0.030,0.062,0.095)	(0.000,0.000,0.000)	(0.030,0.062,0.095)	(0.049,0.082,0.115)
Location (distance)	(0.056,0.089,0.121)	(0.049,0.082,0.115)	(0.036,0.069,0.102)	(0.082,0.115,0.148)	(0.049,0.082,0.115)	(0.095,0.128,0.148)	(0.000,0.000,0.000)	(0.075,0.108,0.141)
Significance for local community	(0.023,0.043,0.075)	(0.023,0.056,0.089)	(0.023,0.056,0.089)	(0.075,0.108,0.141)	(0.049,0.082,0.115)	(0.089,0.121,0.148)	(0.043,0.069,0.102)	(0.000,0.000,0.000)

Source: Authors' calculation

Calculate the fuzzy total-relation matrix

In step 3, the fuzzy total-relation matrix can be calculated by the following formula:

$$\tilde{T} = \lim_{k \to +\infty} (\tilde{x}^1 \oplus \tilde{x}^2 \oplus \dots \oplus \tilde{x}^k)$$

If each element of the fuzzy total-relation matrix is expressed as $\tilde{t}_{ij} = (l''_{ij}, m''_{ij}, u''_{ij})$, it can be calculated as follows:

$$[l''_{ij}] = x_l \times (I - x_l)^{-1}$$

$$[m''_{ij}] = x_m \times (I - x_m)^{-1}$$

$$[u''_{ij}] = x_u \times (I - x_u)^{-1}$$

In other words, the normalized matrix the inverse is first calculated, and then it is subtracted from the matrix I, and finally the normalized matrix is multiplied by the resulting matrix. The following table shows the fuzzy direct-relation matrix.

Table 4. The fuzzy total-relation matrix

	Shipping costs	Payment flexibility	Quality of goods	Technology used	Reputation	Innovation	Location (distance)	Significance for local community
Shipping costs	(0.047,0.158, 0.591)	(0.121,0.267, 0.738)	(0.093,0.221, 0.664)	(0.145,0.320, 0.847)	(0.138,0.291, 0.781)	(0.153,0.336, 0.864)	(0.123,0.277, 0.784)	(0.137,0.311, 0.840)
Payment flexibility	(0.128,0.267, 0.717)	(0.046,0.165, 0.617)	(0.099,0.227, 0.672)	(0.146,0.321, 0.856)	(0.116,0.271, 0.774)	(0.160,0.338, 0.868)	(0.130,0.284, 0.793)	(0.149,0.323, 0.844)
Quality of goods	(0.149,0.299, 0.742)	(0.148,0.305, 0.772)	(0.042,0.153, 0.577)	(0.159,0.344, 0.882)	(0.143,0.310, 0.812)	(0.186,0.383, 0.915)	(0.157,0.324, 0.820)	(0.168,0.356, 0.879)
Technology used	(0.049,0.140, 0.516)	(0.048,0.156, 0.545)	(0.032,0.121, 0.481)	(0.033,0.132, 0.551)	(0.051,0.165, 0.574)	(0.101,0.234, 0.682)	(0.058,0.166, 0.580)	(0.090,0.215, 0.654)
Reputation	(0.099,0.233, 0.695)	(0.098,0.239, 0.719)	(0.077,0.201, 0.645)	(0.145,0.313, 0.854)	(0.045,0.166, 0.643)	(0.158,0.333, 0.871)	(0.111,0.260, 0.769)	(0.148,0.314, 0.841)
Innovation	(0.040,0.124, 0.481)	(0.040,0.134, 0.503)	(0.029,0.101, 0.443)	(0.087,0.204, 0.627)	(0.048,0.153, 0.541)	(0.032,0.126, 0.525)	(0.049,0.154, 0.546)	(0.074,0.191, 0.607)
Location (distance)	(0.086,0.212, 0.654)	(0.079,0.212, 0.671)	(0.060,0.176, 0.601)	(0.129,0.286, 0.810)	(0.084,0.224, 0.707)	(0.147,0.311, 0.826)	(0.039,0.150, 0.611)	(0.121,0.277, 0.793)
Significance for local community	(0.046,0.145, 0.539)	(0.045,0.161, 0.569)	(0.040,0.140, 0.517)	(0.109,0.243, 0.709)	(0.072,0.192, 0.620)	(0.124,0.265, 0.728)	(0.068,0.183, 0.616)	(0.036,0.142, 0.575)

Source: Authors' calculation

Defuzzify into crisp values

The CFCS method (*Converting Fuzzy data into Crisp Scores*) has been used to obtain a crisp value of total-relation matrix. The steps of CFCS method are as follows:

$$l_{ij}^{n} = \frac{\left(l_{ij}^{t} - \min l_{ij}^{t}\right)}{\Delta_{min}^{max}}$$

$$m_{ij}^{n} = \frac{\left(m_{ij}^{t} - min\ l_{ij}^{t}\right)}{\Delta_{min}^{max}}$$

$$u_{ij}^{n} = \frac{(u_{ij}^{t} - min\ l_{ij}^{t})}{\Delta_{min}^{max}}$$

So that

$$\Delta_{min}^{max} = \max u_{ij}^{t} - \min l_{ij}^{t}$$

Calculating the upper and lower bounds of normalized values:

$$l_{ij}^{s} = {m_{ij}^{n}}/{(1 + m_{ij}^{n} - l_{ij}^{n})}$$

$$u_{ij}^{s} = {u_{ij}^{n}}/{(1 + u_{ij}^{n} - l_{ij}^{n})}$$

The output of the CFCS algorithm is crisp values.

Calculating total normalized crisp values:

$$x_{ij} = \frac{[l_{ij}^{s}(1 - l_{ij}^{s}) + u_{ij}^{s} \times u_{ij}^{s}]}{[1 - l_{ij}^{s} + u_{ij}^{s}]}$$

Table 5. The crisp total-relation matrix

	Shipping costs	Payment flexibility	Quality of goods	Technology used	Reputation	Innovation	Location (distance)	Significance for local community
Shipping costs	0.228	0.332	0.284	0.39	0.358	0.405	0.349	0.383
Payment flexibility	0.329	0.238	0.289	0.392	0.342	0.408	0.355	0.392
Quality of goods	0.355	0.365	0.22	0.412	0.375	0.446	0.387	0.419
Technology used	0.203	0.219	0.181	0.202	0.232	0.304	0.234	0.285
Reputation	0.3	0.309	0.266	0.387	0.244	0.405	0.334	0.386
Innovation	0.184	0.195	0.159	0.273	0.217	0.193	0.219	0.258
Location (distance)	0.279	0.282	0.241	0.362	0.298	0.383	0.227	0.352
Significance for local community	0.21	0.227	0.201	0.315	0.261	0.336	0.253	0.215

Source: Authors' calculation

Set the threshold value

The threshold value must be obtained in order to calculate the internal relations matrix. Accordingly, partial relations are neglected and the network relationship map (NRM) is plotted. Only relations whose values in matrix T is greater than the threshold value are depicted in the NRM. To compute the threshold value for relations, it is sufficient to calculate the average values of the matrix T. After the threshold intensity is determined, all values in matrix T which are smaller than the threshold value are set to zero, that is, the causal relation mentioned above is not considered. In this study, the threshold value is equal to 0.2980.298

All the values in matrix T which are smaller than 0.2980.298 are set to zero, that is, the causal relation mentioned above is not considered. The model of significant relations is presented in the following table.

Table 6. The crisp total- relationships matrix by considering the threshold value

	Shipping costs	Payment flexibility	Quality of goods	Technology used	Reputation	Innovation	Location (distance)	Significance for local community
Shipping costs	0	0.332	0	0.39	0.358	0.405	0.349	0.383
Payment flexibility	0.329	0	0	0.392	0.342	0.408	0.355	0.392
Quality of goods	0.355	0.365	0	0.412	0.375	0.446	0.387	0.419
Technology used	0	0	0	0	0	0.304	0	0
Reputation	0.3	0.309	0	0.387	0	0.405	0.334	0.386
Innovation	0	0	0	0	0	0	0	0
Location (distance)	0	0	0	0.362	0	0.383	0	0.352
Significance for local community	0	0	0	0.315	0	0.336	0	0

Source: Authors' calculation

Final output and create a causal relation diagram

The next step is to find out the sum of each row and each column of T (in step 4). The sum of rows (D) and columns (R) can be calculated as follows:

$$D = \sum_{j=1}^{n} T_{ij}$$

$$R = \sum_{i=1}^{n} T_{ij}$$

Then, the values of D+R and D-R can be calculated by D and R, where D+R represent the degree of importance of factor i in the entire system and D-R represent net effects that factor *i* contributes to the system.

The table below shows the final output.

Table 7. The final output

	R	D	D+R	D-R
Shipping costs	2.088	2.73	4.818	0.641
Payment flexibility	2.168	2.745	4.913	0.577
Quality of goods	1.842	2.979	4.821	1.137
Technology used	2.733	1.861	4.594	-0.872
Reputation	2.326	2.631	4.958	0.305
Innovation	2.881	1.699	4.58	-1.182
Location (distance)	2.357	2.423	4.781	0.066
Significance for local community	2.69	2.018	4.708	-0.672

Source: Authors' calculation

The following figure shows the model of significant relations. This model can be represented as a diagram in which the values of (D+R) are placed on the horizontal axis and the values of (D-R) on the vertical axis. The position and interaction of each factor with a point in the coordinates (D+ R, D-R) are determined by coordinate system.

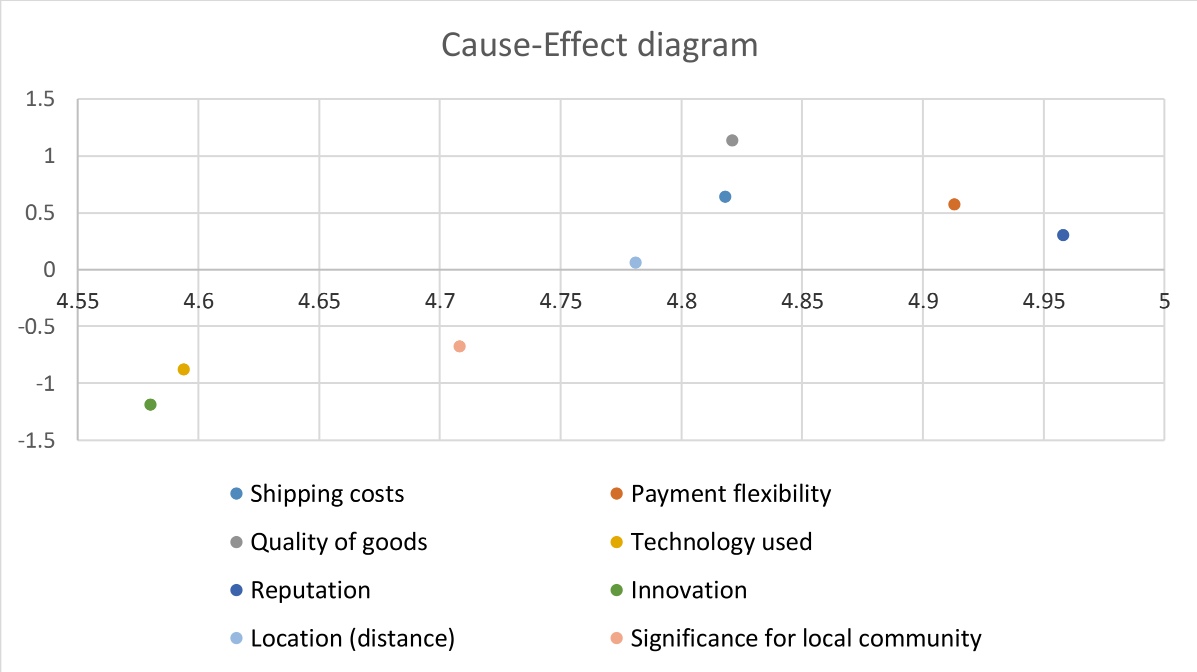

Figure 1. Cause-effect diagram

Interpret the results

According to the diagram and table above, each factor can be assessed based on the following aspects:

Horizontal vector (D + R) represents the degree of importance between each factor plays in the entire system. In other words, (D + R) indicates both factor i's impact on the whole system and other system factors' impact on the factor. In terms of degree of importance, Reputation is ranked first followed by Payment flexibility, Quality of goods, Shipping costs, Location (distance), Significance for local community, Technology used and Innovation. In this study, Shipping costs, Payment flexibility, Quality of goods, Reputation, Location (distance) are considered to be as a causal variable, Technology used, Innovation, Significance for the local community are regarded as an effect. The vertical vector (D-R) represents the degree of a factor's influence on system. In general, the positive value of D-R represents a causal variable, and the negative value of D-R represents an effect. In terms of degree of importance, Reputation is ranked in first place and Payment flexibility, Quality of goods, Shipping costs, Location (distance), Relevance to the local community, Technology used and Innovation, are ranked the next. In this study, Shipping costs, Payment flexibility, Quality of goods, Reputation, Location (distance) are considered to be a causal variable, Technology used, Innovation, Significance for the local community are regarded as an effect.

Conclusion

From the above we can conclude that the process of choosing a supplier is a complex problem for rational decision makers, and that the rationality in its decision making can be increased by applying modern methods of multi-criteria decision making. In previous research, fuzzy logic is imposed as a solution when it comes to selection among qualitative criteria. In addition to the applicative significance that was elaborated in the last step of this paper, this research brings with it a good basis for improving the characteristics of some of the given criteria, which could be the subject of some new research in the coming period.

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Ocjena kriterijuma prilikom izbora dobavljača poljoprivredne mehanizacije

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Sažetak

Cilj rada je da se primjenom savremene metode odlučivanja izvrši selekcija zadatih kriterijuma koji bi pomogli u odabiru najpovoljnijeg dobavljača opreme za sjetvu. Tom prilikom korišćenja je DEMATEL (*The Decision Making Trial and Evaluation Labaratory*) metoda višekriterijskog odlučivanja, odnosno njena *fuzzy* logika. Razlog za to je upotreba ekspertske ocjene stručnjaka iz date oblasti analize gdje se *fuzzy* logikom odluka pokušala približiti ljudskom razmišljanju. Predmet rada predstavlja oprema za sjetvu (sijačica) jednog poljoprivrednog gazdinstva na području opštine Bijeljina, a dobijeni rezultati pokazuju uticaj pojedinih kriterijuma koji su odlučujući kod izbora dobavljača. Takođe, korist istraživanja proizilazi i iz uočavanja nedostataka, odnosno unapređenja kvaliteta predmeta rada po pojedinim obrađenim kriterijumima.

Ključne riječi: višekriterijumsko odlučivanje, DEMATEL metod, fuzzy logika, poljoprivredna mehanizacija