SELECTION OF APPLE HARVESTING MACHINE BY THE USE OF FUZZY METHOD OF MULTI-CRITERIA ANALYSIS

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Abstract

Rapid development of agricultural production has imposed the need for use of modern machines for the realization of required production operations. In line with that, according to the multi-criteria decision-making, i.e., by the use of CRITIC method and MARCOS fuzzy method, the selection of a machine for apple harvesting (apple tree shaking) was performed. Gained results show that selection among three alternatives, i.e. manual apple tree shaker with hydraulic or pneumatic drive, tractor carried (hydraulic) apple tree shaker, apple tree shaker on a towed machine, proved the second alternative to be the best. The choice among the offered options was made based on seven predefined criteria set by the experts from the researched subject area. The importance of research is found in adequate application of the multi-criteria analysis methods, especially fuzzy methodology, in the process of selecting the most suitable option in apple harvesting machines (apple tree shakers).

Key words: *apple harvesting, multi-criterion decision making, method CRITIC, method MARCOS, fuzzy logic.*

Introduction

Along with the growth of the global population, and the rise of demand for food products, traditionally used agricultural mechanization have been more and more replaced by the modern mechanical and technological procedures, certainly including the harvesting (considering tree shaking) of fruits. Previously mentioned are confronting the agricultural producers with the special challenge, especially

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in decision making situations towards the proper selection of modern agricultural machines. Such an example is harvesting (apple tree shaking) of apple fruits.

The apple appertains to the group of roses, while this is the fruit that is globally produced the most. Currently, it is grown in many countries, mostly in north hemisphere, while commercial production covers around couple hundred varieties (Ivanović, Jeločnik, 2009). High adaptability of the plant, as well as expressed quality of its fruits has been ensured the apples good ranking among globally produced fruit species (Užar et al., 2019). From the aspect of technology, apples production requires complex approach. It involves quite a lot of labour and other inputs (mostly agri-chemicals), initiating the significant investments. At same time, apple production represents greatly accumulative line in fruit sector (Nedeljković, Potrebić, 2020). Besides, as a fruit species, apples have highly pronounced healthy and medicinal features, while they are used as fresh or processed agri-food product (Jeločnik et al., 2019).

Decision-making in agriculture is a complex activity. Due to the impossibility of quantification decisions are usually made according to available qualitative data, or even more often combining with existing quantitative data (Blagojević, et al., 2017). For this reason, in recent years multi-criteria analysis has found great application in sector of agriculture, especially in fruits and grape production (Draginčić et al., 2015; Milovanović, Stojanović, 2016; Rozman et al., 2017; Maksimović et al., 2017; Paunović et al., 2018; Maksimović et al., 2018). Besides, application of multi-criteria decision-making with its associated fuzzy methods has been already done in selection of different types of basic or specific machines in agriculture. This is confirmed by several scientific papers prepared by foreign authors in last decade (Sahu et al., 2015; Khandekar, Chakraborty, 2015; Turskis et al., 2015; Wu et al., 2016).

Main goal of paper is to conduct, according to multi-criteria decision-making, the selection of appropriate machine for apple harvesting (apple tree shaking).

Used Methodology

Decision making what is the best fruit harvesting machine (fruit tree shaker) is based on the CRITIC (*CRiteria Importance Through Inter-criteria Correlation*) and fuzzy MARCOS (*Measurement Alternatives and Ranking according to COmpromise Solution*) methods. The research methodology was based on previously created questionnaire that was sent to certain number of experts from the observed field of science/economy to give the adequate answers. The survey was conducted during the October 2020. In order to avoid the subjectivity in determination of the criteria's weights, the CRITIC method was used.

After the weights of the criteria were determined, the all alternatives were ranked by the use of the fuzzy MARCOS method. All steps considered in implementing the CRITIC and fuzzy MARCOS methods will be later presented in detail. At the end, a sensitivity analysis was performed in order to examine how certain criteria are affecting the alternatives' ranking. Definition of research problem and goal are marked as initial step in any research. The main issue in this research is to find the best alternative for the fruit harvesting (by the method of tree shaking), as well as to find what alternative achieves the best results, while it minimally affects the fruit tree. During the fruit tree shaking, it is required to harvest all fruits but without damaging the trunk and branches. According the previously defined research problem, it was determined the main goal of research, i.e. the enabling the decision making and selection of the best possible alternatives (the alternative that optimally solves the research problem) based on application of different combinations of multi-criteria analysis methods (MCDA). In line to research problem and goal, it was defined the proper direction of research.

In order to evaluate fruit harvesting alternatives (based on tree shaking), the collection of adequate data is previously required. Due to the specificity of the research problem, expert decision-making was used. Therefore, the next step in offered methodology was the experts' selection. Researchers from the Faculty of Agriculture in Belgrade and Novi Sad are served as experts. Research considers ratings collected from the four experts. All experts are involved in fruit production for many years.

Before all, with experts were conducted the selection of criteria that will be used for evaluation of the fruit harvesting machines (based on tree shaking). Selected criteria are:

C1 – *Costs of utilisation*,
C2 – *Vibration*,
C3 – *Efficiency of usage*,
C4 - *Convenience of handling*,
C5 – *Possibilities of malfunction/Period of usage*,
C6 – *Possibility for automatization of activity,*
C7 – *Working capacity of the machine,*
C8 – *Ergonomics*,
C9 – *Safety at work.*

Since there are differences in nature of chosen criteria, it is important that experts' mark/rating of some of them have to be as higher as possible (these are so-called benefit criteria), while for others expert's mark/rating has to be as lower as possible (these are so-called cost criteria). Thus, criteria C3, C4, C6, C7 and C8 are representing benefit criteria, so for the potential alternative is better that these criteria have the maximally possible mark/rating, while for criteria C1, C2, C5 and C9 it is better that make/rating is at the much possible lower level.

After that, together with experts all alternatives that will be evaluated were defined. Selected alternatives are: A1 – manual apple tree shaker with hydraulic or pneumatic drive, A2 - by tractor carried (hydraulic) apple tree shaker, and A3 – apple tree shaker on a towed machine. According to previously defined criteria and alternatives, the proper questionnaire was created. Expert's responsibilities were only to give the marks/ratings for the selected alternatives by the use of previously defined criteria. For that purpose they were used previously determined scale of attributive values, as well as seven degrees scale in which the marks/ratings have been ranged from very poor to very good (Table 1.).

CRITIC method

CRITIC method has been established by Diakoulaki et al. (1995). Method is used to define the objective values of the criterions' weight, including the intensity of contrast and conflict contained within the structure of the decision-making issue (Puška et al., 2018). For determination contrasts of criteria, the standard deviations of the normalized values of the variants per columns are used, as well as the correlation coefficients of all columns' pairs. Steps used during the realisation of CRITIC method are:

Step 1. Deffuzification of initial matrix of decision making. Before the other steps of the CRITIC method are conducted, the fuzzy numbers have to be transferred into the numeric values (Table 1.).

Table 1. Membership function of fuzzy numbers for criterions weighting and alternatives assessment.

Linguistic values	Fuzzy numbers
Very bad (VB)	(0,0,1)
Bad (B)	(0,1,3)
Medium bad (MB)	(1,3,5)
Medium (M)	(3,5,7)
Medium good (MG)	(5,7,9)
Good (G)	(7,9,10)
Very Good (VG)	(9,10,10)

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

Deffuzification is done based on following mathematic formula:

$$P(\tilde{m}) = \frac{1}{6}(m_1 + 4 m_2 + m_3)$$

Where:

m_1 – first value of the *fuzzy* number,

m_2 – second value of the *fuzzy* number, and

m_3 – third value of the *fuzzy* number.

Step 2. Normalization of the deffuzificated initial decision-making matrix by the use of next mathematic formulas:

For criteria that have to be maximized:

$$r_{ij} = \frac{x_j - x_r^{**}}{x_j^{*} - x_j^{**}}$$

For criteria that have to be minimized:

$$r_{ij} = 1 - \frac{x_j - x_r^{**}}{x_j^{*} - x_j^{**}}$$

Where:

x_j^* – maximal attributes' value for the observed criteria,
x_j^{**} – minimal attributes' value for the observed criteria.

Step 3. Calculating the values of the standard deviation and the symmetric linear correlation matrix of all pairs per column.

Step 4. Determining the volume of information by the use of following mathematic formula:

$$C_j = \sigma_j \sum_{k=1}^{m} (1 - r_{jk}) \quad j = \overline{1, m}$$

Where:

σ_j standard deviation of the criteria, and

r_{jk} correlation coefficient for the criteria.

Step 5. Calculating the final values by the use of following mathematic formula:

$$w_j = \frac{C_j}{\sum_{j=1}^{m} C_j}$$

CRITIC method assigns the larger weights to a criterion that has higher value of standard deviation, and which link to the other criteria is weaker (Zavadskas et al., 2019).

Fuzzy MARCOS method

MARCOS method is established by Stević et al. (2020). Method is in line to determined relations among alternatives and referent values of observed alternatives which are shown by ideal and ant-ideal points (coordinates). Process of decision making according the use of mentioned method is done in line to utility functions (Puška et al., 2020). Utility function represents an alternative towards the ideal and anti-ideal solution. The highly desired alternative is the closest to the ideal solution, while simultaneously the farthest to the anti-ideal solution (Stević, Brković, 2020; Mijajlović et al., 2020). Fuzzy version of the MARCOS method is developed by the Stanković et al. (2020). This method is conducting throughout the next steps:

Step 1. Forming of initial *fuzzy* matrix for the decision-making.

Step 2. Extension of initial *fuzzy* matrix for the decision-making.

Within the mentioned step the initial matrix is enlarging with the anti-ideal (AAI) and ideal solution (AI). AAI represents the alternative that has the worst characteristics, while AI represents the alternative with the best possible characteristics (Mijajlović et al., 2020).

Anti-ideal solution (AAI) is calculating by the use of next mathematic formula:

$$\mathrm{AAI} = \min_{j} x_{ij} \quad \text{if } j \in B \quad \text{and} \quad \max_{j} x_{ij} \quad \text{if } j \in C$$

Ideal solution (AI) is calculating by the use of next mathematic formula:

$$\mathrm{AI} = \max_{j} x_{ij} \quad \text{if } j \in B \quad \text{and} \quad \min_{j} x_{ij} \quad \text{if } j \in C$$

B is the benefit criteria which have to be maximized. C is the cost criteria which have to be minimized.

Step 3. Normalization of initial *fuzzy* matrix for decision-making. Normalization is conducting by the use of next mathematic formulas, depending which criterion is observed:

$$\tilde{n} = \left(n_{ij}^{l}, n_{ij}^{m}, n_{ij}^{u}\right) = \left(\frac{x_{id}^{l}}{x_{ij}^{u}}, \frac{x_{id}^{l}}{x_{ij}^{m}}, \frac{x_{id}^{l}}{x_{ij}^{l}}\right) \; if\; j \in C$$

$$\tilde{n} = \left(n_{ij}^{l}, n_{ij}^{m}, n_{ij}^{u}\right) = \left(\frac{x_{ij}^{l}}{x_{id}^{u}}, \frac{x_{ij}^{m}}{x_{id}^{u}}, \frac{x_{ij}^{u}}{x_{id}^{u}}\right) \; if\; j \in B$$

Where:

l – first *fuzzy* number,

m – second *fuzzy* number, and

i – third *fuzzy* number.

Step 4. Weighting of normalized decision-making matrix is conducting by the use of next mathematic formula:

$$\tilde{v}_{ij} = \left(v_{ij}^{l}, v_{ij}^{m}, v_{ij}^{u}\right) = \tilde{n}_j \times \tilde{w}_j$$

Step 5. Calculating the matrix *Si* considers the summing of all values per the rows, i.e. summing of all alternatives including the anti-ideal and ideal solutions by the use of next mathematic formula:

$$S_i = \sum_{i=1}^{n} v_{ij}$$

Step 6. Calculating the level of efficiency K_i towards the anti-ideal and ideal solution is conducting by the use of next mathematic formulas:

$$\tilde{K}_i^{-} = \left(\frac{\tilde{S}_i}{\tilde{S}_{ai}}\right) = \left(\frac{s_i^{l}}{s_{ai}^{u}}, \frac{s_i^{m}}{s_{ai}^{u}}, \frac{s_i^{u}}{s_{ai}^{u}}\right)$$

$$\tilde{K}_i^{+} = \left(\frac{\tilde{S}_i}{\tilde{S}_{id}}\right) = \left(\frac{s_i^{l}}{s_{id}^{u}}, \frac{s_i^{m}}{s_{id}^{u}}, \frac{s_i^{u}}{s_{id}^{u}}\right)$$

Step 7. Calculating the fuzzy matrix $\tilde{T}_i$ is conducting by the use of next mathematic formula:

$$\tilde{T}_i = \tilde{t}_i = \left(t_i^{l}, t_i^{m}, t_i^{u}\right) = \tilde{K}_i^{-} + \tilde{K}_i^{+} = (\tilde{k}_i^{-l} + \tilde{k}_i^{+l}, \tilde{k}_i^{-m} + \tilde{k}_i^{+m}, \tilde{k}_i^{-u} + \tilde{k}_i^{+u})$$

Determination of fuzzy number $\tilde{D}$ is done according the next mathematic formula:

$$\tilde{D} = (d^l, d^m, d^u) = \max_i \tilde{t}_{ij}$$

Step 8. Defuzzification of fuzzy numbers is done in line to following mathematic formula:

$$df_{def} = \frac{l + 4m + u}{6}$$

Step 9. Defining the utility function *f(Ki)* considers summing of all utility functions towards to a) anti-ideal and b) ideal solution.

a) Utility function in line to anti-ideal solution

$$f(\tilde{K}_i^+) = \frac{\tilde{K}_i^-}{df_{def}}$$

b) Utility function in line to ideal solution

$$f(\tilde{K}_i^-) = \frac{\tilde{K}_i^+}{df_{def}}$$

Step 10. Calculating the final utility function is conducting towards the next mathematic formula:

$$f(K_i) = \frac{K_i^+ + K_i^-}{1 + \frac{1 - f(K_i^+)}{f(K_i^+)} + \frac{1 - f(K_i^-)}{f(K_i^-)}};$$

Step 11. Ranking the alternatives. As optimal alternative could be considered alternative that has the highest value. As unattractive alternative could be considered alternative that has the minimal value.

Research results

First step in calculating the MCDA (Multiple-criteria decision analysis) is forming of the initial decision-making matrix. As research assumes expert decision-making based on attributive values of the alternatives, before all, the initial decision-making matrix will be presented (Table 2.). Within the table, engaged experts are marked as decision makers (DM), so the first DM represents the first expert from the observed field of expertise.

Table 2. Initial matrix of decision making

DM1	C1	C2	C3	C4	C5	C6	C7	C8	C9
A1	G	MG	G	G	MG	M	MB	M	G
A2	MB	M	MB	MB	M	M	MG	MG	MG
A3	B	M	MB	B	M	M	MG	G	M
DM2	C1	C2	C3	C4	C5	C6	C7	C8	C9
A1	VG	G	MB	VG	G	M	MB	MG	MG
A2	MB	M	G	MB	MB	G	MG	M	M
A3	M	B	G	MB	M	G	G	M	M
DM3	C1	C2	C3	C4	C5	C6	C7	C8	C9
A1	G	MG	MB	G	MB	MB	B	MB	MB
A2	B	M	M	MB	MG	MG	MG	M	MG
A3	M	M	MG	B	MG	MG	G	M	MG
DM4	C1	C2	C3	C4	C5	C6	C7	C8	C9
A1	G	MG	B	G	MG	M	B	MB	M
A2	MB	MB	M	MB	M	MG	MG	M	MG
A3	MB	M	MG	MB	MB	MG	MG	M	MG

Source: According to authors' calculation.

Next step in MCDA method represents the transformation of attributive, i.e. linguistic values into the numeric values using the membership function (Table 1.). In order to respect the opinion of all experts the common matrix of decision making is formed. Forming of mentioned matrix is based on the use of arithmetic mean (Mijajlović et al., 2020).

This matrix is the base for the calculation of the criterions' weights by the CRITIC method, as well as for the ranking of alternatives by the fuzzy MARCOS method. Firstly, the weight of criterions will be determined, while later it will be made the ranking of all alternatives. The main reason should be find in fact that it is necessary to know all weights of criterion during the alternatives' ranking.

First step at CRITIC method is deffuzification of cumulative fuzzy matrix of decision-making. After that are conducted steps defined for CRITIC method, before all normalization, and later calculation of standard deviation and correlation, in order to determine the volume of information and then to determine the weights of criteria.

Table 3. Calculating the weight of the criteria based on CRITIC method

Standard deviation								
C1	C2	C3	C4	C5	C6	C7	C8	C9
0,539	0,543	0,503	0,544	0,577	0,577	0,538	0,511	0,556
Correlation								
C1	C2	C3	C4	C5	C6	C7	C8	C9
1,000	0,965	0,848	-0,966	0,990	0,990	0,959	0,898	-0,671
0,965	1,000	0,958	-1,000	0,992	0,992	1,000	0,982	-0,452
0,848	0,958	1,000	-0,957	0,915	0,915	0,964	0,995	-0,175
-0,966	-1,000	-0,957	1,000	-0,993	-0,993	-1,000	-0,982	0,455
0,990	0,992	0,915	-0,993	1,000	1,000	0,989	0,952	-0,559
0,990	0,992	0,915	-0,993	1,000	1,000	0,989	0,952	-0,559
0,959	1,000	0,964	-1,000	0,989	0,989	1,000	0,986	-0,431
0,898	0,982	0,995	-0,982	0,952	0,952	0,986	1,000	-0,277
-0,671	-0,452	-0,175	0,455	-0,559	-0,559	-0,431	-0,277	1,000
$\sum_{k=1}^{m}(1-r_{jk})$								
C1	C2	C3	C4	C5	C6	C7	C8	C9
0,000	0,035	0,152	1,966	0,010	0,010	0,041	0,102	1,671
0,035	0,000	0,042	2,000	0,008	0,008	0,000	0,018	1,452
0,152	0,042	0,000	1,957	0,085	0,085	0,036	0,005	1,175
1,966	2,000	1,957	0,000	1,993	1,993	2,000	1,982	0,545
0,010	0,008	0,085	1,993	0,000	0,000	0,011	0,048	1,559
0,010	0,008	0,085	1,993	0,000	0,000	0,011	0,048	1,559
0,041	0,000	0,036	2,000	0,011	0,011	0,000	0,014	1,431
0,102	0,018	0,005	1,982	0,048	0,048	0,014	0,000	1,277
1,671	1,452	1,175	0,545	1,559	1,559	1,431	1,277	0,000
$C_j = \sigma_j \sum_{k=1}^{m}(1-r_{jk})$								
C1	C2	C3	C4	C5	C6	C7	C8	C9
2,148	1,934	1,780	7,845	2,144	2,144	1,906	1,787	5,937
w								
C1	C2	C3	C4	C5	C6	C7	C8	C9
0,078	0,070	0,064	0,284	0,078	0,078	0,069	0,065	0,215

Source: According to authors' calculation

The highest weight was given to the criterion C4 - Convenience of handling, as at this criterion there was the greatest dispersion in answers of experts that are observed the alternatives.

After the criterion weights were calculated, the steps from the fuzzy MARCOS method were applied. The first step after the forming of cumulative fuzzy matrix of decision-making was the finding of ideal and anti-ideal solutions. First one represents the highest value of alternatives for a certain criterion, while the anti-ideal solution represents the lowest value of alternatives for a certain criterion. In this way, the decision-making matrix is enlarged with ideal and anti-ideal solution. Further step in the fuzzy MARCOS method is normalization of the cumulative fuzzy matrix of decision-making. Since the nine criteria were used in observed research, where 5 of them represent benefit criteria, while 4 of them are the cost criteria, both normalization formulas were used. After normalization of the cumulative fuzzy matrix of decision-making, its weighting was done. This process is done by multiplying the values of normalized matrix of decision-making with the appropriate weights for certain criteria. Next step considers calculating the values of the *Si* matrix, which involves summing of all alternatives' values including the anti-ideal and ideal solution. After that, the level of efficiency *Ki* related to value of anti-ideal and ideal solution was calculated. Further, the fuzzy matrix that represents the sum of levels of efficiency related to ideal and anti-ideal solution was calculated. Then, at fuzzy matrix the maximal values for the certain fuzzy numbers are determining, while it was done the defuzzification of obtained values, so on that way was gained the value df_{def} = 2.50. This value is required in order to calculate the utility function.

Table 4. Calculation of sum, level of efficiency and fuzzy matrix $\tilde{T}_i$

	S_i	K_i^-	K_i^+		$\tilde{T}_i$	
Ideal	1,62 0,92 0,74	2,18 1,00 0,46	3,59 1,86 1,07			
A1	0,94 0,72 0,63	1,26 0,78 0,39	2,08 1,45 0,91		3,34 2,23 1,30	
A2	1,35 0,70 0,58	1,82 0,76 0,36	2,99 1,42 0,83		4,81 2,18 1,19	
A3	1,15 0,70 0,57	1,55 0,75 0,35	2,56 1,40 0,82		4,11 2,15 1,17	
Anti-ideal	0,69 0,50 0,45	0,93 0,54 0,28	1,53 1,00 0,65	max	4,81 2,23 1,30	2,50

Source: According to authors' calculation

Calculating the utility function was based on the values of level of efficiency and df_{def}. After that, it was done the defuzzification of the levels' of efficiency and utility function, while the final utility function was calculated. Based on the value of the final utility function, the ranking of all alternatives was performed. In this research, the best ranked alternative is A2 – by tractor carried (hydraulic) apple tree shaker. Next one is A3 - apple tree shaker on a towed machine, while the last one alternative is A1 – manual apple tree shaker with hydraulic or pneumatic drive.

Table 5. Calculation of utility function, defuzzification and ranking of alternatives

	$f(\widetilde{K}_i^-)$	$f(\widetilde{K}_i^+)$	DK_i^-	DK_i^+	D	D	$f(K_i)$	Rank
A1	0,83 0,58 0,36	0,50 0,31 0,16	0,794	1,463	0,585	0,317	0,584	3
A2	1,20 0,57 0,33	0,73 0,30 0,14	0,869	1,581	0,632	0,347	0,708	1
A3	1,02 0,56 0,33	0,62 0,30 0,14	0,819	1,497	0,598	0,327	0,622	2

Source: According to authors' calculation

In order to confirm the obtained results and determine the sensibility of alternatives towards the change in criteria' weights, the sensitivity analysis was performed.

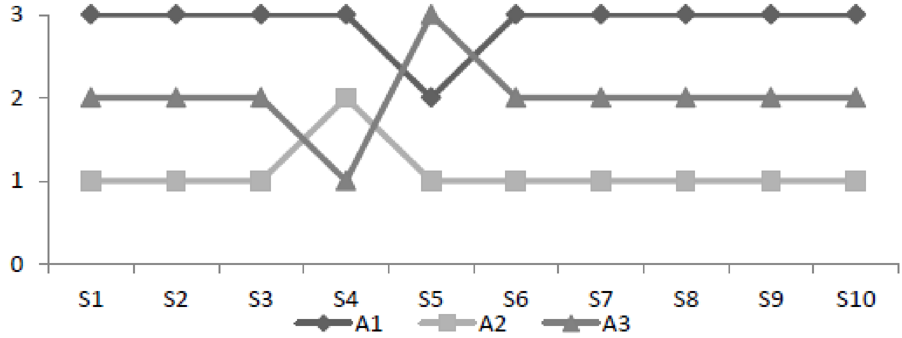
Table 6. Scenarios for sensitivity analysis implementation

	C1	C2	C3	C4	C5	C6	C7	C8	C9
Scenario 1	0,111	0,111	0,111	0,111	0,111	0,111	0,111	0,111	0,111
Scenario 2	0,360	0,080	0,080	0,080	0,080	0,080	0,080	0,080	0,080
Scenario 3	0,080	0,360	0,080	0,080	0,080	0,080	0,080	0,080	0,080
Scenario 4	0,080	0,080	0,360	0,080	0,080	0,080	0,080	0,080	0,080
Scenario 5	0,080	0,080	0,080	0,360	0,080	0,080	0,080	0,080	0,080
Scenario 6	0,080	0,080	0,080	0,080	0,360	0,080	0,080	0,080	0,080
Scenario 7	0,080	0,080	0,080	0,080	0,080	0,360	0,080	0,080	0,080
Scenario 8	0,080	0,080	0,080	0,080	0,080	0,080	0,360	0,080	0,080
Scenario 9	0,080	0,080	0,080	0,080	0,080	0,080	0,080	0,360	0,080
Scenario 10	0,080	0,080	0,080	0,080	0,080	0,080	0,080	0,080	0,360

Source: According to authors' calculation

The main task of sensitivity analysis is to examine how many certain criterions affect the alternatives' ranking. According to that 10 scenarios were created (Table 6.). First scenario gives the unique importance to the all criteria, so in line to that they were assigned the weight of 0.111. Other scenarios are giving the advantage to the one of the criteria, while to this a criterion is assigned the 4.5 times higher importance compared to other criteria. As there are 9 criteria, there will be 10 scenarios in line to different criteria' weight. Visual presentation of the results of sensitivity analysis is done by the next picture (Picture 1.).

Figure 1. Results of sensitivity analysis



Source: According to authors' calculation

Conclusion

The results of the performed research and sensitivity analysis are showing that at eight scenarios the ranking of alternatives have not been changed. In scenario 4 and 5 there comes to the change in alternatives' ranking. In scenario 4, advantage has the alternative A3 related to alternative A2. This scenario shows that alternative A3 has better efficiency of usage compared to the alternatives A2 and A1, so according to that, alternative A3 in this scenario is better ranked towards the other alternatives. In scenario 5 is shown that alternative A1 has better convenience of handling related to alternative A3. Respecting the all results for the alternative ranking it could be concluded that the alternative A2 – by tractor carried (hydraulic) apple tree shaker has the best performances related to other alternatives. It is followed by the alternative A3 - apple tree shaker on a towed machine, while the worst results after expert analysis are gained to the alternative A1 – manual apple tree shaker with hydraulic or pneumatic drive. At the end, as the best choice for the apple harvesting (considering tree shaking) was considered by the tractor carried (hydraulic) apple tree shaker.

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