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APPLICATION OF AHP AND MABAC METHODS IN THE FRAMEWORK OF MULTI-CRITERIA DECISION-MAKING IN THE SELECTION OF INVESTMENT PROJECTS

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Abstract: *A multi-attribute decision-making process and ranking of investment projects is almost inevitable today in order to realize and achieve an investment project. We can observe the given process from the aspect of decision theory. Today, it is unthinkable to make a decision on the acceptance of an investment project, without looking at different criteria, the only option is to set the choice of an investment project as a multi-attributive decision-making problem. The goal of this paper is to present a multi-attribute decision-making model, when we have several proposed investment projects and when I want to evaluate the given projects and just rank them for choosing the best method. Based on its wide application, the AHP method will be used to determine the weights of the criteria themselves during the decision-making process, while the MABAC method will be used for the further process of ranking investment projects in order to obtain a single-investment ranking of proposed alternatives, more precisely, proposed investment projects.*
Keywords: *multi-attribute decision making, investment projects, AHP method, MABAC method*

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1. Introduction

One of the branches of operational research that deals with the problems of the decision-making process itself, within which there are often conflicting criteria, is called multi-criteria decision-making. With such problems in the decision-making process, it is not possible to implement the optimal decision process itself, so it is necessary to look at and evaluate the preferences of the decision-maker, in line with the values of the best alternatives.

With multi-criteria decision-making analysis (abbreviated in the literature as VKAO) it is necessary to ensure, or rather to find a solution that satisfies several different criteria, or more precisely to perform a composite (aggregate) indicator for the evaluation of different

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alternatives, this is the key difference of multi-criteria decision-making analysis compared to other decision-making methods (Čupić & Suknović, 2010).

By applying multi-criteria decision-making analysis, we are not talking directly about looking for an optimal solution, but rather about looking for a compromise solution, which aims to help decision-makers to see a more realistic decision-making situation, through the prism of multi-criteria decision-making analysis, and to find a compromise between different criteria, which are in reality opposed to each other (Stamenković, 2021).

Each criterion is characterized by the value, nature and importance of the criterion itself. The value of the criteria is reflected in deterministic or descriptive independent numbers, based on which it is easier to see the value of the criteria than in a linguistic format (Božanić-Pamučar et al., 2013).

According to the classification of the nature of the criteria, they can be of benefit nature or cost nature. If a criterion is of a beneficial nature, then it has the characteristic "the higher the value of the criterion, the better, and vice versa". While with the cost criterion, we have a nature that characterizes the criterion with the feature "the lower the validity of the criterion, the better, and vice versa". It is very important to look at the very nature of the criteria when carrying out the normalization, more precisely the transformation of the criteria (Tadić, 2009).

Within the model of the multi-attribute approach in the assessment of investment projects, the method of comparing the criteria in pairs is used to determine the weight of the criteria, more precisely the assessment matrix within the AHP (Analytical Hierarchy Process) method, while the MABAC method is used in the analysis and ranking of investment projects (Tošev & Kankaraš, 2011).

2. Application of the proposed model in multi-criteria decision-making when choosing investment projects

In this section, the model for evaluation and ranking of investment projects will be presented. The model consists of two parts. In the first part, the weight of the criteria is determined using the AHP method, while in the second part, the ranking of investment projects is realized using the MABAC method.

2.1. The proposed multi-criteria decision-making model

The criteria used in the process of evaluating the economic and social effectiveness of investment projects should show the degree of achievement of goals, include all types of investment, all initial and incurred costs of realization and exploitation of the investment, include the time factor, provide objective and accurate evaluation, exclude extensive and complex the process of evaluating investment projects, as well as to reduce the risk of making bad investment decisions (Mishra-Chandel et al., 2018).

Formally, the criteria can be represented by the set: {1, ..., k, ..., K}. The total number of considered criteria is denoted as K. The criteria index is denoted as $k, k = 1, .., K$.

With investment projects, the main focus is on economic and social effectiveness, so it is necessary to adequately assess the fulfillment of the given criteria, evaluate and compare different alternatives, since it is not always the case that the most favorable alternative is automatically an acceptable investment alternative (Suknović-Delibašić et al., 2021).

The set of possible investment projects is represented by the set of indexes of possible investment projects: *{1, ..., i, ..., I}* (Dubonjić-Milanović et al., 2016).

The total number of considered investment projects is marked as I. The criteria index is marked as $i, i = 1, .., I$.

Furthermore, the proposed algorithm is shown, which is realized through the following steps:

Step 1. The relative importance matrix of each pair of considered criteria is evaluated by the decision makers:

$$[W_{kk'}]_{KxK} \qquad (1)$$

Decision makers base their evaluations on a scale of measures from 1 to 9. A value of 1 means that criterion k has equal importance. A value of 9 indicates that criterion k is extremely important than criterion . If the criterion is more important than the criterion k then the value in the matrix of comparison pairs is reciprocal (Borović & Milić, 2001).

Step 2. Let's check the consistency of the relative importance matrix of the criteria using the eigenvector method:

The coefficient of consistency, C.I., is obtained:

$$C.I. = \frac{\frac{\lambda_{max} - K}{K - 1}}{R.I.} \qquad (2)$$

R.I. is a factor that depends on the dimension of the matrices.

Step 3. The criteria weight vector is determined by applying AHP: $[\omega_k]$

Step 4. Let's set up the decision matrix, $[x_{ik}]_{IxK}$.

The values of the decision matrix were obtained based on the assessment of the decision makers and data from the records (Božanić-Pampučar et al., 2016).

Step 5. The normalized decision matrix $[r_{ik}]_{IxK}$ was obtained by applying the linear normalization procedure, so that:

a) for the beneficial type of criteria

$$r_{ik} = \frac{x_{ik}}{\sum_{i=1,\dots,I} x_{ik}} \qquad (3)$$

б) for the cost type criteria

$$r_{ik} = 1 - \frac{x_{ik} - x^{min}}{x^{max}} \qquad (4)$$

$$x^{min} = \min_{i=1,\dots,I} x_{ik},\ x^{max} = \max_{i=1,\dots,I} x_{ik} \qquad (5)$$

Step 6. Let's set up a difficult normalized decision matrix $[v_{ik}]$, wherein:

$$v_{ik} = \omega_k \cdot (r_{ik} + 1) \qquad (6)$$

Step 7. Determine the boundary approximation matrix G= $[g_k]$ wherein:

$$g_k = \sqrt[k]{v_{ik}} \quad (7)$$

Step 8. Determine the distances from the matrix, G:

$$Q = V - G \quad (8)$$

Belonging to the upper approximate area (G+), the lower approximate area (G-), and the neutral approximate area (G) within each criterion is determined according to the rules (Krčevinac-Čangalov et al., 2006):

If qik >0→ and ε G+
If qik <0→ and ε G-
If qik = 0 → i ε G

Step 9. The sum of the distances of the alternatives from the approximate areas is calculated according to the expression (Letić & Jevtić, 2007):

$$S_i = \sum_{k=1,..,} q_{ik} \quad (9)$$

Step 10. The ranking of alternatives according to all criteria respecting their weights is determined according to the total distance, Si. In the first place is the alternative with the highest value Si (Pamučar & Ćirović, 2015).

2.2. Application of the proposed model

Within this section, the case study and the decision-making problem itself will be presented, as well as the practical application of the model in the process of ranking and selecting investment projects.

The corporation located in central Serbia, whose main activity is the production of textile materials, which has over 150 employees and whose market is focused on the territory of the entire country and the Balkans, has decided to support one of the investment projects.

Based on its successful business and the realization of higher business income than expected and projected last year, it decided to support one of the five investment projects.

As it is necessary to evaluate different investment projects, as well as to rank them at the meeting of the Board of Directors of the given corporation, it was decided that the president of the Board of Directors should determine the importance of the criteria when choosing a given investment project.

Based on that, the members of the Management Board unanimously defined and decided that in the evaluation and ranking process, it is necessary to decide on the basis of the following criteria, which are ordered based on the given importance:

- K1 - Return period of invested funds
- K2 - The period of reaching the critical point in the operation of the investment
- K3 - Period of immobilization of investment assets
- K4 - Present value of the investment
- K5 - Actualized net profit
- K6 - Foreign exchange investment coefficient of raw materials
- K7 - Adjusted unit actualized profit
- K8 - Internal rate of return
- K9 - Work intensity of the investment

By announcing a public call for the development team to apply for the realization of investment projects, within a period of 30 days, more precisely from 1.8. – 28.8.2023. year, the following 5 offers were received for the selection of one investment project that will be supported in the process of realization and implementation of the given idea.

On the part of the President of the Board of Directors, the relevant importance of the criteria was assigned based on the application of the matrix of comparison of the criteria themselves, which is the first step in the process of applying the AHP method.

The data matrix of the relative importance of the criteria is shown below:

$$\begin{bmatrix} - & 2 & 3 & 4 & 5 & 7 & 7 & 8 & 9 \\ & - & 2 & 4 & 5 & 6 & 6 & 7 & 7 \\ & & - & 1 & 3 & 4 & 6 & 6 & 8 \\ & & & - & 2 & 2 & 4 & 5 & 6 \\ & & & & - & 1 & 4 & 5 & 7 \\ & & & & & - & 2 & 5 & 6 \\ & & & & & & - & 3 & 5 \\ & & & & & & & - & 4 \\ & & & & & & & & - \end{bmatrix}$$

Applying the given formula, as well as calculating the consistency coefficient, C.I., it was determined that the decision-maker made decisions by ensuring the consistency of the assessment, so that C.I. is 0.1 (Suknović & Delibašić, 2010).

The weight values of the criteria were obtained using AHP:

$$[0{,}24 \quad 0{,}20 \quad 0{,}16 \quad 0{,}11 \quad 0.10 \quad 0{,}08 \quad 0{,}06 \quad 0{,}03 \quad 0{,}01]$$

The decision matrix is given in table number 1.

Table 1. Decision matrix

	K1	K2	K3	K4	K5	K6	K7	K8	K9
i = 1	25	20	18	120.000	210.000	2	3	8	6
i = 2	19	15	13	54.000	66.000	4	7	2	7
i = 3	23	16	12	30.000	49.000	5	2	9	2
i = 4	16	13	10	108.000	120.000	1	8	1	9
i = 5	11	9	7	40.000	98.000	3	1	5	4

Source: authors of the paper

By applying form (1) of linear normalization to the benefit criterion r_{14}, the following values are obtained based on the given procedure, which is also valid for all other procedures:

$$\in X_{ik} = 352.000$$

$$X_{ik} = 120.000$$

$$r_{14} = \frac{120000}{352000} = 0.34$$

By applying form (2) of linear normalization to cost criterion r_{11}, the following values are obtained based on the given procedure, which is also valid for all other procedures:

$$X_{ik} = 25$$

$$X^{min} = 11$$

$$X_{max} = 25$$

$$r_{11} = 1 - \frac{25 - 11}{25} = 1 - 0.56 = 0.44$$

In a similar way, the normalized criteria values are calculated for each investment project, as shown in the table below:

Table 2. Normalized elements of the initial matrix

	K1	K2	K3	K4	K5	K6	K7	K8	K9
i = 1	0.44	0.45	0.39	0.34	0.39	0.80	0.14	0.32	0.21
i = 2	0.68	0.70	0.67	0.15	0.12	0.40	0.33	0.08	0.25
i = 3	0.52	0.65	0.73	0.09	0.09	0.20	0.10	0.36	0.07
i = 4	0.80	0.80	0.83	0.31	0.22	1	0.38	0.04	0.32
i = 5	1	1	1	0.11	0.18	0.60	0.05	0.20	0.14

Source: authors of the paper

With the difficult normalized matrix v_{31}, the following values are obtained based on the given procedure, which is also valid for all other procedures:

$$\omega_3 = 0.16$$

$$r_{13} = 0.39$$

$$v_{13} = 0.16 \cdot (0.39 + 1) = 0.16 \cdot 1.39 = 0.22$$

In a similar way, other values of the difficult normalized matrix are obtained, which is shown in the following table:

Table 3. Values of the normalized matrix

	K_1	K_2	K_3	K_4	K_5	K_6	K_7	K_8	K_9
i = 1	0.35	0.29	0.22	0.15	0.14	0.14	0.07	0.04	0.01
i = 2	0.40	0.34	0.27	0.13	0.11	0.11	0.08	0.03	0.01
i = 3	0.36	0.33	0.28	0.12	0.10	0.10	0.07	0.04	0.01
i = 4	0.43	0.36	0.29	0.14	0.12	0.16	0.08	0.03	0.01
i = 5	0.48	0.40	0.32	0.12	0.12	0.13	0.06	0.04	0.01

Source: authors of the paper

The value of the limit approximation for the first criterion is:

$$g_1 = \sqrt[5]{0.35 * 0.40 * 0.36 * 0.43 * 0.48} = \sqrt[5]{0.01} = 0.46$$

$g_1=0.46$ $g_2=0.34$

$g_3=0.27$ $g_4=0.13$

$g_5=0.12$ $g_6=0.13$

$g_7=0.07$ $g_8=0.04$

g_9=0.003

A certain boundary approximation matrix:

G= [0.46; 0.34; 0.27; 0.13; 0.12; 0.13; 0.07; 0.04; 0.003]

The given values of the boundary approximation matrices are given in table 4.

Table 4. Uterus values of the limit approximation

	K_1	K_2	K_3	K_4	K_5	K_6	K_7	K_8	K_9
i = 1	-0.11	-0.05	-0.05	0.02	0.02	0.01	0	0	-0.02
i = 2	-0.06	0	0	0	-0.01	-0.02	0.01	-0.01	-0.02
i = 3	-0.1	-0.01	0.01	-0.01	-0.02	-0.03	0	0	-0.02
i = 4	-0.03	0.02	0.02	0.01	0	0.03	0.01	-0.01	-0.02
i = 5	0.02	0.06	0.05	-0.01	0	0	-0.01	0	-0.02

Source: authors of the paper

In the seventh step of applying the MABAC method, it is necessary to calculate the sum of the distances of the alternatives from the approximate areas, which is calculated according to the following expression:

$$S_i = \sum_{k=1,..,} q_{ik} \quad (6)$$

The value of the sums obtained based on the application of form number 6 is given in table number 5, while the application of the form is shown in example S_1.

S_1 = - 0.11 + (-0.05) + (-0.05) + 0.02 + 0.02 + 0.01 + 0 + 0 + (-0.02) + (-0.18) = - 0.18

Table 5. Values of the uterus of the limit approximation

	K_1	K_2	K_3	K_4	K_5	K_6	K_7	K_8	K_9	Si
i = 1	-0.11	-0.05	-0.05	0.02	0.02	0.01	0	0	-0.02	-0.36
i = 2	-0.06	0	0	0	-0.01	-0.02	0.01	-0.01	-0.02	-0.11
i = 3	-0.1	-0.01	0.01	-0.01	-0.02	-0.03	0	0	-0.02	-0.18
i = 4	-0.03	0.02	0.02	0.01	0	0.03	0.01	-0.01	-0.02	0.03≈0
i = 5	0.02	0.06	0.05	-0.01	0	0	-0.01	0	-0.02	0.10

Source: authors of the paper

After the calculated and obtained sums of the distances of the alternatives from the approximate areas, in the last eighth step of applying the MABAC method, it is necessary to rank the alternatives according to all criteria, respecting and their weights are determined according to the total distance Si. The alternative with the highest Si value is on the first place, while the alternative with the lowest Si value is on the last place, the given ranking is shown in table 6.

Table 6. Ranking of investment projects

	K1	K2	K3	K4	K5	K6	K7	K8	K9	Si	РАНГ
i = 1	-0.11	-0.05	-0.05	0.02	0.02	0.01	0	0	-0.02	-0.36	5
i = 2	-0.06	0	0	0	-0.01	-0.02	0.01	-0.01	-0.02	-0.11	3
i = 3	-0.1	-0.01	0.01	-0.01	-0.02	-0.03	0	0	-0.02	-0.18	4
i = 4	-0.03	0.02	0.02	0.01	0	0.03	0.01	-0.01	-0.02	0.03≈0	2
i = 5	0.02	0.06	0.05	-0.01	0	0	-0.01	0	-0.02	0.10	1

Source: authors of the paper

Based on belonging to the upper approximate area (G), the lower approximate area (G), and the neutral approximate area G within each criterion, as well as the ranking of alternatives based on the application of the MABAC method in the last step, a graph of belonging to the approximate area and a display of the considered and ranked ones is obtained an alternative.

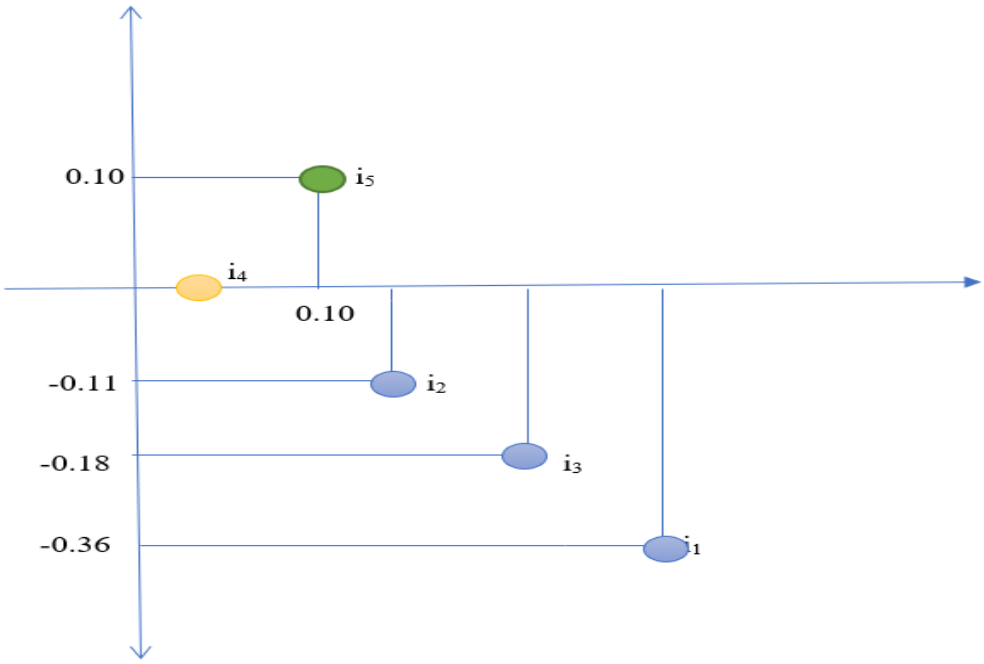

Figure 1. Graphic representation of ranked investment projects
Source: authors of the paper

Based on picture number 1, as well as belonging to the approximate area and ranked alternatives, it is concluded that alternative i_5 is the best alternative, while alternative i_4=0, so it will not be taken into further consideration, while alternatives i_2, i_3 and i_1 are excluded from further consideration since they did not meet the given defined criteria according to the approximate area.

3. Conclusion

Considering and adopting investment projects is not such a simple decision-making process at all, it is precisely one of the most complex problems in the decision-making process itself.

One of the main characteristics of investments and the investment projects themselves is the significant presence of uncertainty and risk, as well as adequate consideration and minimization of the risk itself in the process of making decisions about the actual implementation of investment projects. Looking at all the characteristics and results that can be achieved within one investment project and making a multi-attribute decision excluding risk is an absurd decision-making process.

The previous practice in decision-making on the selection of investment projects has so far been reflected in the choice of such a decision-making model, where only one criterion is in focus, which is very important for the selection of the best alternative.

Based on the very specificity of investment projects and numerous characteristics, complexity and volume of the investment process, there is a need to apply a multi-attribute decision-making model. Today, it is unthinkable to make a decision on the acceptance of an investment project, without looking at different criteria, the only option is to set the choice of an investment project as a multi-attributive decision-making problem.

Decisions made about the realization of an investment project are investment decisions, where, based on numerous and substantial analyses, they are directly based on forecasts, forecasts and experiences. It can be argued with high probability that such decisions made without clear criteria are not valid decisions and that there is a high probability that given investments carry a high risk and lead to the process of realization in a desirable direction.

Due to its wide application, as well as a unique model based on a pairwise comparison of criteria, the AHP method was used to determine the weights of the criteria on the basis of which investment projects were evaluated. Within the given model, nine criteria were defined, on the basis of which the alternatives themselves were evaluated through Satie's measurement scales.

After the evaluated alternatives and certain weights of the criteria, the MABAC method was used for the further decision-making process and obtaining the single-investment rank of the proposed alternatives, more precisely the proposed investment projects.

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