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# COMPARISON OF MULTI-CRITERIA DECISION MAKING METHODS USING THE SAME DATA STANDARDIZATION METHOD

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**Abstract:** The ranking results of the alternatives are heavily influenced by the decision making method, data normalization method, and calculation method for criterion weights. In this study, five multi-criteria decision-making methods were compared: *MABA*C, *COCOSO*, *MAIRCA*, *VIKOR*, and *ROV*. All of these methods use the same data normarmalization method. The weights for the criteria were determined using four methods: Equal, ROC, RS, and Entropy. In two different examples, the combination of multi-criteria decision-making methods with weighting methods for ranking alternatives is demonstrated. In each example, the number of options and the number of criteria are also different. The results in both examples show that regardless of the weighting method, multi-criteria decision-making methods always determine the same best solution. Furthermore, the direction of future research has been mentioned in the final section of this paper.

***Keywords:*** MCDM, MABAC, COCOSO, MAIRCA, VIKOR, ROV, Data normalization

## 1 Introduction

The decision to choose one of many options always takes place in practice. Each option requires different criteria, some of which are as large as possible, while others are as small as possible. The decision making to choose an alternative is then known as *"multi-criteria decision making - MCDM"*. Over time, multi-criteria decision-making methods have gained more and more attention from scholars. Table 1 presents a summary of names, data normalization methods and data normalization formulas for each type of indicator (the larger the better, and the smaller the better) of some multi-criteria decision making methods.

Table 1. Summary of some information of *MCDM* methods

| Method | Abbreviation | Data normalization method | Data normalization equation | | Ref. |
|---|---|---|---|---|---|
| | | | Criterion as large as better | Criterion as small as better | |
| Simple Additive Weighting | *SAW* | Linear normalization | $n_{ij} = \frac{x_{ij}}{maxx_{ij}}$ | $n_{ij} = \frac{minx_{ij}}{x_{ij}}$ | [1] |
| Preference Selection Index | *PSI* | Linear normalization | $n_{ij} = \frac{x_{ij}}{maxx_{ij}}$ | $n_{ij} = \frac{minx_{ij}}{x_{ij}}$ | [2] |
| Measurement Alternatives and Ranking according to COmpromise Solution | *MARCOS* | Linear normalization | $n_{ij} = \frac{x_{ij}}{maxx_{ij}}$ | $n_{ij} = \frac{minx_{ij}}{x_{ij}}$ | [3] |
| COmbinative Distance-based ASsessment | *CODAS* | Linear normalization | $n_{ij} = \frac{x_{ij}}{maxx_{ij}}$ | $n_{ij} = \frac{minx_{ij}}{x_{ij}}$ | [4] |

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| | | | | | |
|---|---|---|---|---|---|
| Vlsekriterijumska optimizacijaI KOmpromisno Resenje (in Serbian) | *VIKOR* | Max - Min linear normalization | $n_{ij} = \frac{x_{ij} - maxx_{ij}}{minx_{ij} - maxx_{ij}}$ | $n_{ij} = \frac{x_{ij} - minx_{ij}}{maxx_{ij} - minx_{ij}}$ | [5] |
| Multi-Attributive Border Approximation area Comparison | *MABAC* | Max - Min linear normalization | $n_{ij} = \frac{x_{ij} - minx_{ij}}{maxx_{ij} - minx_{ij}}$ | $n_{ij} = \frac{x_{ij} - maxx_{ij}}{minx_{ij} - maxx_{ij}}$ | [6] |
| Combined Compromise Solution | *COCOSO* | Max - Min linear normalization | $n_{ij} = \frac{x_{ij} - minx_{ij}}{maxx_{ij} - minx_{ij}}$ | $n_{ij} = \frac{x_{ij} - maxx_{ij}}{minx_{ij} - maxx_{ij}}$ | [7] |
| Multi Atributive Ideal-Real Comparative Analysis | *MAIRCA* | Max - Min linear normalization | $n_{ij} = \frac{x_{ij} - minx_{ij}}{maxx_{ij} - minx_{ij}}$ | $n_{ij} = \frac{x_{ij} - maxx_{ij}}{minx_{ij} - maxx_{ij}}$ | [8] |
| Range Of Value | *ROV* | Max - Min linear normalization | $n_{ij} = \frac{x_{ij} - minx_{ij}}{maxx_{ij} - minx_{ij}}$ | $n_{ij} = \frac{x_{ij} - maxx_{ij}}{minx_{ij} - maxx_{ij}}$ | [9] |
| Proximity Indexed Value | *PIV* | Vector normalization | $n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}$ | $n_{ij} = 1 - \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}$ | [10] |
| Technique for Order Preference by Similarity to Ideal Solution | *TOPSIS* | Vector normalization | $n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}$ | $n_{ij} = 1 - \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}$ | [11] |
| COmplex PRroportional ASsessment | *COPRAS* | Vector normalization | $n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}$ | $n_{ij} = 1 - \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}$ | [12] |
| Mixed Aggregation by Comprehensive Normalization Technique | *MACONT* | Linear normalization; Max - Min linear normalization; Sum linear normalization | $n_{ij} = \frac{x_{ij}}{maxx_{ij}}$; $n_{ij} = \frac{x_{ij} - minx_{ij}}{maxx_{ij} - minx_{ij}}$; and $n_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}}$ | $n_{ij} = \frac{minx_{ij}}{x_{ij}}$; $n_{ij} = \frac{x_{ij} - maxx_{ij}}{minx_{ij} - maxx_{ij}}$; and $n_{ij} = \frac{\frac{1}{x_{ij}}}{\sum_{i=1}^{m} \frac{1}{x_{ij}}}$ | [13] |
| Preference Analysis for Reference Ideal Solution | *PARIS* | Linear normalization; Max - Min linear normalization; Vector normalization | $n_{ij} = \frac{x_{ij}}{maxx_{ij}}$; $n_{ij} = \frac{x_{ij} - minx_{ij}}{maxx_{ij} - minx_{ij}}$; and $n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}$ | $n_{ij} = \frac{minx_{ij}}{x_{ij}}$; $n_{ij} = \frac{x_{ij} - maxx_{ij}}{minx_{ij} - maxx_{ij}}$; and $n_{ij} = 1 - \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}$ | [14] |

Table 1 shows that the data normalization by the Max-Min linear normalization method is most commonly used. This is also consistent with the statement in the studies of A. Aytekin [15, 16]. It can also be easily explained that the Linear normalization method will not be possible if there exists $x_{ij} = 0$ or $max(x_{ij}) = 0$. The Sum linear normalization method will also be unusable if there exists $x_{ij} = 0$. Another field, when $max(x_{ij}) = 0$, the Logarithmic normalization method will also not be applicable. Whereas the Max-Min linear normalization method can be used for any value of $x_{ij}$. The multi-criteria decision making methods using the Max - Min linear normalization method include *MABAC*, *COCOSO*, *MAIRCA*, *VIKOR* and *ROV*.

The *MABAC* method was proposed in 2015 [6]. It has been used in many applications such as evaluating the economic performance of companies in Serbia [17], selection of a flood control method of the city of Arilje in Serbia [18], selection of pharmaceutical suppliers [18] during the Covid 19 epidemic [19], and so on. Comparison of the *MABAC* method with other methods has also been found in several studies. In [20], the *MABA*C method was compared with the *AHP* method and the *TOPSIS* method to select the mode

of transport. The results showed that the three methods used all identified the same best solution. The comparison of five methods including *MABAC*, *EDAS*, *ARAS*, *COPRAS* and *MARCOS* in mobile crowd computing decision-making was done in [21]. The results have shown that the *COPRAS* method is better than the other four methods. In [22], *MABAC* was compared with *TOPSIS*, *COPRAS* and *EDAS* methods in choosing solutions to manage construction projects. It was reported that all four methods identify the same best solution. Comparison of *MABAC*, *ELECTER* and *TOPSIS* methods of railway station selection in a transport operation in Serbia. It was noted that all three methods identified a best solution [23], ect.

The *COCOSO* method was found in 2019 [7]. This method has been applied to multi-criteria decision making for many problems such as: Evaluation of the efficiency of private companies in electricity generation in Turkey [24], selection of materials in construction, etc. [25]. All six methods including *COCOSO*, *MARCOS*, *WASPAS*, *ARAS*, *TOPSIS* and *EDAS* were used to select the medical waste treatment solution and all identified the same best option [26]. The *COCOSO* and *COPRAS* methods were also used to select suppliers for a construction company in Madrid. Both methods determine the best solution [27]. *COCOSO*, *TOPSIS* and *CODAS* methods have been used to assess financial risk for businesses. All three methods identified the best method to reduce the problem of risk [28]. Five methods including *COCOSO*, *MOORA*, *ARAS*, *WASPAS*, *COPRAS* all give the best option in choosing a transport company for enterprises [29], ect.

The *MAIRCA* method was proposed in 2018 [8]. This method has also been applied to multi-criteria decision making in many different fields. It has been used to evaluate the effectiveness of mergers/acquisitions of companies in Turkey [30], and to assess the sustainable development of the economies of several countries [31]. A comparison of the *MAIRCA* method with *MABAC*, *VIKOR* and *CODAS* methods in city and job selection for immigrants to Chile has been reported in [32]. As a result, all four methods indicate the best solution. Three methods including *MAIRCA*, *TOPSIS* and *MARCOS* jointly determine the values of powder-mixed electrical discharge machining (PMEDM) process parameters to ensure the highest precision and highest productivity of the machining process simultaneously [33]. Four methods including *MAIRCA*, *EAMR*, *MARCOS* and *TOPSIS* jointly determine the value of the SKS3 steel milling process parameters to ensure the best quality and the highest productivity at the same time [34].

*VIKOR* is a well-known multi-criteria decision making method. This method was proposed in 2004 [5]. It has been applied by many scientists for multi-criteria decision making in many fields. Recently, this method is still widely used. Seven methods including *VIKOR*, *SAW*, *WASPAS*, *TOPSI*S, *MOORA*, *COPRA*S, and *PIV* all determine the best solution when turning 150Cr14 steel to ensure simultaneously the most expensive surface quality, the three smallest cutting force components, and the highest cutting yield [35]. Determining the machining conditions to ensure simultaneously the best surface quality, the three smallest cutting force components, the three smallest cutting tool dynamics, and the maximum cutting productivity when turning EN 10503 steel has been reported in [36]. Three methods including *VIKOR*, *TOPSIS* and *PROMETHEE* have determined the same best solution in two cases, when choosing

materials for making cryogenic tanks, and choosing materials for building naval speedboats [37], ect.

The *ROV* method was proposed in 1993 [9]. It has been applied to decision making in many cases such as: Selection of apples for making apple juice concentrate [38], selection of suppliers for industries [39]. Both R*OV* and *EDAS* point to a best practice in supplier selection in the supply chain [40]. In the selection of the cutting fluid type, the best alternative determined by the *ROV* method is similar when using the *SAW*, *WPM*, *AHP*, *TOPSIS* methods [41]. *ROV* method together with *PIV*, *SAW*, *TOPSIS*, *COCOSO* and MABAC all show a best option in selecting materials for automobile manufacturing [42], ect.

From the above analysis, *MCDM* methods are very diverse and have been applied in many different situations. To have a basis to confirm the results obtained when using a certain method, scientists have also compared *MCDM* methods with each other, and in most cases, they all indicate the same best solution. The five methods including *MABAC*, *COCOSO*, *MAIRCA*, *VIKOR* and *ROV* all use the same data normalization technique (refer to Table 1). A comparison of one/some of these five methods with others (usually those using other data normalization techniques) was also made. However, it is strange that no study has been published that compares these five methods with each other. One question is whether these five methods all use the same data normalization technique, whether the ranking results of the alternatives when using these five methods are similar or not. This study was conducted to answer this question.

The structure of the next sections of this paper is as follows: (1) briefly introduce the steps to implement the five *MCDM* methods; (2) brief introduction of four methods of determining the weights for the criteria; (3) Compare the combination of *MCDM* methods with weight determination methods in two different examples; (4) Discuss the results obtained, conclusions and directions for future work.

## 2 Several MCDM used methods

### *2.1 MABAC method*

The steps to follow the MABAC method are as follows [6].

Step 1. Create a dicision matrix

$$X = \left[x_{ij}\right]_{n\times m} = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ x_{21} & \cdots & x_{2n} \\ \vdots & \cdots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \quad (1)$$

Where, *m* and *n* are the number of alternatives and the number of criteria, respectively.

Step 2. Normalize the data

$$n_{ij} = \frac{x_{ij} - min\ x_{ij}}{max\ x_{ij} - min\ x_{ij}} \quad (2)$$

$$n_{ij} = \frac{x_{ij} - max\ x_{ij}}{min\ x_{ij} - max\ x_{ij}} \quad (3)$$

Formula (2) applies to criteria as large as better, and formula (3) applies to criteria as small as better.

Step 3. Determine the matrix V according to the formula.

$$V = \begin{bmatrix} v_{11} & \cdots & v_{1n} \\ v_{21} & \cdots & v_{2n} \\ \vdots & \cdots & \vdots \\ v_{m1} & \cdots & v_{mn} \end{bmatrix} \quad (4)$$

In (4), $v_{ij}$ is found by Equation (5).

$$v_{ij} = w_j \left(n_{ij} + 1\right) \quad (5)$$

In Equation (5), $w_j$ is the weight of criterion $j$.

Step 4. Determine the matrix $G$ according to the formula:

$$G = [g_1 \quad \cdots \quad g_n] \quad (6)$$

In Equation (6), $v_{ij}$ is calculated by:

$$g_j = \left(\prod_{i=1}^{m} v_{ij}\right)^{1/m} \quad (7)$$

Step 5. Determine the matrix $Q$ according to the formula.

$$Q = V - G = \begin{bmatrix} v_{11} & \cdots & v_{1n} \\ v_{21} & \cdots & v_{2n} \\ \vdots & \cdots & \vdots \\ v_{m1} & \cdots & v_{mn} \end{bmatrix} - \begin{bmatrix} g_1 & \cdots & g_n \\ g_1 & \cdots & g_n \\ \vdots & \cdots & \vdots \\ g_1 & \cdots & g_n \end{bmatrix} = \begin{bmatrix} q_{11} & \cdots & q_{1n} \\ q_{21} & \cdots & q_{2n} \\ \vdots & \cdots & \vdots \\ q_{m1} & \cdots & q_{mn} \end{bmatrix} \quad (8)$$

Step 6. Calculated *Si* by the following formula.

$$S_i = \sum_{j=1}^{n} q_{ij} \quad (9)$$

Step 7. Rank the alternatives according to the principle that the best solution is the one with the largest $S_i$.

### *2.2 COCOSO method*

The steps to implement the COCOSO method are as follows [7].

Step 1. Similar to step 1 of the MABAC method.

Step 2. Similar to step 2 of the MABAC method.

Step 3. Calculate the *Si* and *Pi* values according to the formula.

$$S_i = \sum_{j=1}^{n} \left(w_j n_{ij}\right) \quad (10)$$

$$P_i = \sum_{j=1}^{n} \left(n_{ij}\right)^{w_j} \quad (11)$$

Where, $w_j$ is the weight of the $j^{th}$ criterion.

Step 4: Determine the other values $k_{ia}$, $k_{ib}$, $k_{ic}$ using the corresponding formulas:

$$k_{ia} = \frac{P_i + S_i}{\sum_{j=1}^{n}(P_i + S_i)} \tag{12}$$

$$k_{ib} = \frac{S_i}{\min S_i} + \frac{P_i}{\min P_i} \tag{13}$$

$$k_{ic} = \frac{\lambda S_i + (1-\lambda)P_i}{\lambda \max S_i + (1-\lambda)\max P_i} \tag{14}$$

In (8), $\lambda$ is a coefficient, usually chosen to be 0.5 [2].

Step 5. Calculate the $k_i$ values according to the formula.

$$k_i = (k_{ia}k_{ib}k_{ic})^{1/3} + \frac{1}{3}(k_{ia} + k_{ib} + k_{ic}) \tag{15}$$

Step 6. Rank the alternatives, the best option is the one with the largest $k_i$.

### *2.3 MAIRCA method*

The steps to implement the MAIRCA method are as follows [8].

Step 1. Similar to step 1 of the *MABAC* method.

Step 2. Calculate the quantities $P_{A_j}$ according to the following formula.

$$P_{A_j} = \frac{1}{m} \tag{16}$$

Step 3. Calculate $t_{p_{ij}}$ by:

$$t_{p_{ij}} = P_{A_j} \cdot w_j \tag{17}$$

Wherein, $w_j$ is the weight of the $j^{th}$ criterion.

Step 4. Find the values of $t_{r_{ij}}$ by the following formulas.

$$t_{r_{ij}} = t_{p_{ij}} \frac{x_{ij} - min\, x_{ij}}{max\, x_{ij} - min\, x_{ij}} \tag{18}$$

$$t_{r_{ij}} = t_{p_{ij}} \frac{x_{ij} - max\, x_{ij}}{min\, x_{ij} - max\, x_{ij}} \tag{19}$$

Formula (16) applies to criteria as large as possible, and (17) to criteria as small as possible.

Step 5. Calculate $g_{ij}$ by:

$$g_{ij} = t_{p_{ij}} - t_{r_{ij}} \tag{20}$$

Step 6. Sum the $g_j$ values according to the formula.

$$Q_i = \sum_{i=1}^{m} g_{ij} \tag{21}$$

Step 7. Rank the alternatives based on the principle that the one with the smallest $Q_i$ is the best one.

### *2.4 VIKOR method*

The VIKOR method is implemented in the following steps [5]:

Step 1. Similar to step 1 of the *MABAC* method.

Step 2. Normalize the data. This step is performed in reverse of the *MABAC* method. Specifically, formula (2) applies to criteria as small as possible, and formula (3) applies to criteria as large as possible.

Step 3. Calculate Si values according to formula (10) in *COCOSO* method.

Step 4. Calculate the $R_i$ values by:

$$R_i = max\left[w_j n_{ij}\right] \tag{22}$$

In which, $w_j$ is the weight of the $j^{th}$ criterion.

Step 5. Determine $Q_i$ by the following Equation:

$$Q_i = \nu \frac{S_i - \min S_i}{\max S_i - \min S_i} + (1 - \nu) \frac{R_i - \min R_i}{\max R_i - \min R_i} \tag{23}$$

In (23), ν is a coefficient, satisfying $0 \le \nu \le 1$, usually chosen as 0.5 [5].

Step 6: Rank the options according to the principle: the option with the lowest $Q_i$ is the best.

### *2.5 ROV method*

The *ROV* method is applied according to the following steps [9].

Step 1. Similar to step 1 of the *MABAC* method.

Step 2. Similar to step 2 of the *MABAC* method.

Step 3. Calculate the $u_i$ values according to the following formula:

$$u_i = \sum_{j=1}^{n} \left(w_j n_{ij}\right) \tag{24}$$

In which, $w_j$ is the weight of the $j^{th}$ criterion.

Step 4: Sort the alternatives based on the principle; the one with the highest $u_i$ is the best.

## 3 Several used methods of determining weights

### *3.1 EQUAL weight*

*EQUAL* weights are determined by the following formula [43].

$$w_j = \frac{1}{n} \tag{25}$$

### *3.2 ROC weight*

*ROC* weights are calculated by [44]:

$$w_j = \frac{1}{n} \sum_{k=i}^{n} \frac{1}{k} \tag{26}$$

### *3.3 RS weight*

*RS* weights are found by the following Equation [44].

$$w_j = \frac{2\,(n+1-i)}{n(n+1)} \tag{27}$$

### *3.4 Entropy weight*

Entropy weights are determined according to the following steps [45]:

Step 1. Determine the normalized values for the indicators.

$$p_{\mathrm{ij}} = \frac{x_{\mathrm{ij}}}{m + \sum_{i=1}^{m} x_{\mathrm{ij}}^2} \tag{28}$$

Step 2. Calculate the value of the Entropy for each indicator.

$$e_{\mathrm{j}} = -\sum_{i=1}^{m}\left[\, p_{\mathrm{ij}} \times \ln(\mathrm{p_{ij}})\right] - \left(1 - \sum_{i=1}^{m} p_{\mathrm{ij}}\right) \times \ln\left(1 - \sum_{i=1}^{m} p_{\mathrm{ij}}\right) \tag{29}$$

Step 3. Determine the weight for each indicator.

$$w_j = \frac{1 - e_j}{\sum_{j=1}^{m}\left(1 - e_j\right)} \tag{30}$$

## 4 Examples for comparing MCDM methods

### *4.1 Example 1*

A milling experiment consists of nine experimental runs. In the experiment, two parameters were selected for investigation, namely *Ra* (μm) and *MRR* ($mm^3$/min). The data of the experiment are shown in Table 2 [46]. Also, the criterion of Ra is as small as possible, and the criterion of MRR is as large as possible. The task of multi-criteria decision making is to determine the solution that simultaneously guarantees minimum *Ra* and maximum *MRR*.

Table 2 Data of experiment 1 [46]

| Alternative | Ra (μm) | MRR ($mm^3$/min) |
|---|---|---|
| A1 | 0.97 | 25.465 |
| A2 | 1.085 | 305.577 |
| A3 | 2.032 | 1145.916 |
| A4 | 0.746 | 318.31 |
| A5 | 0.609 | 190.986 |
| A6 | 1.001 | 286.479 |
| A7 | 0.858 | 343.775 |
| A8 | 0.326 | 381.972 |
| A9 | 1.083 | 229.183 |

The formulas in section 3 were used to determine the weights for the criteria. The results are presented in Table 3.

Table 3 Weight of criteria in example 1

| Weight method | Ra | MRR |
|---|---|---|
| EQUAL | 0.5 | 0.5 |
| ROC | 0.75 | 0.25 |
| RS | 0.6667 | 0.3333 |
| ENTROPY | 0.6618 | 0.3382 |

The multi-criteria decision-making is done by different weighting methods in turn. First, the *EQUAL* weight method will be used. For other weighting methods, *MCDM* methods will also be used in turn.

*Application of the MABAC method*

Formula (1) is used to construct the decision matrix, which is created by column 2 and column 3 in table 2. The normalized value of the criteria ($n_{ij}$) is calculated according to the formulas (2) and (3). The matrix *V* is determined according to formulas (4) and (5). The matrix *Q* is determined by formula (6), (7) and (8). Formula (9) is used to find the *Si* values. The results of ranking the alternatives according to the value of *Si* were also performed. All data are summarized in Table 4.

Table 4. Calculation data for example 1 using MABAC method

| Alternative | $n_{ij}$ | | *V* | | *Q* | | *Si* | Rank |
|---|---|---|---|---|---|---|---|---|
| | *Ra* | *MRR* | *Ra* | *MRR* | *Ra* | *MRR* | | |
| A1 | 0.623 | 0.000 | 0.811 | 0.500 | 0.012 | -0.138 | -0.126 | 9 |
| A2 | 0.555 | 0.250 | 0.778 | 0.625 | -0.022 | -0.013 | -0.035 | 7 |
| A3 | 0.000 | 1.000 | 0.500 | 1.000 | -0.300 | 0.362 | 0.063 | 3 |
| A4 | 0.754 | 0.261 | 0.877 | 0.631 | 0.077 | -0.007 | 0.070 | 2 |
| A5 | 0.834 | 0.148 | 0.917 | 0.574 | 0.117 | -0.064 | 0.054 | 4 |
| A6 | 0.604 | 0.233 | 0.802 | 0.616 | 0.003 | -0.021 | -0.019 | 6 |
| A7 | 0.688 | 0.284 | 0.844 | 0.642 | 0.044 | 0.004 | 0.049 | 5 |
| A8 | 1.000 | 0.318 | 1.000 | 0.659 | 0.200 | 0.021 | 0.222 | 1 |
| A9 | 0.556 | 0.182 | 0.778 | 0.591 | -0.021 | -0.047 | -0.068 | 8 |

*Application of the COCOSO method*

The normalized matrix and normalized values are determined similarly to the MABAC method. The *Si*, *Pi* values are calculated according to the formulas (10) and (11). The other values $k_{ia}$, $k_{ib}$, $k_{ic}$ and $k_i$ are determined according to the respective formulas (12), (13), (14) and (15). The results of ranking the alternatives according to the value of $k_i$ were also performed. Calculation data and ranking of alternatives are given in table 5.

Table 5. Calculation data for example 1 using *COCOSO* method

| Alternative | $n_{ij}$ | | *Si* | *Pi* | $k_{ia}$ | $k_{ib}$ | $k_{ic}$ | $k_i$ | Rank |
|---|---|---|---|---|---|---|---|---|---|
| | *Ra* | *MRR* | | | | | | | |
| A1 | 0.623 | 0.000 | 0.311 | 0.789 | 0.072 | 2.000 | 0.495 | 1.271 | 9 |
| A2 | 0.555 | 0.250 | 0.403 | 1.245 | 0.108 | 2.871 | 0.741 | 1.853 | 6 |
| A3 | 0.000 | 1.000 | 0.500 | 1.000 | 0.099 | 2.874 | 0.675 | 1.792 | 7 |
| A4 | 0.754 | 0.261 | 0.508 | 1.379 | 0.124 | 3.379 | 0.849 | 2.159 | 2 |
| A5 | 0.834 | 0.148 | 0.491 | 1.298 | 0.118 | 3.222 | 0.805 | 2.054 | 4 |
| A6 | 0.604 | 0.233 | 0.419 | 1.260 | 0.110 | 2.942 | 0.755 | 1.895 | 5 |
| A7 | 0.688 | 0.284 | 0.486 | 1.363 | 0.122 | 3.289 | 0.832 | 2.107 | 3 |
| A8 | 1.000 | 0.318 | 0.659 | 1.564 | 0.146 | 4.100 | 1.000 | 2.592 | 1 |
| A9 | 0.556 | 0.182 | 0.369 | 1.172 | 0.101 | 2.671 | 0.693 | 1.728 | 8 |

*Application of the MAIRCA method*

The normalized matrix is determined similarly to the MABAC method. Formulas (16) and (17) are used to calculate the $t_{pij}$ values. The $t_{rij}$ values are calculated according to the formula (18) and (19). The values of *gi* and *Qi* are calculated according to the formulas (20) and (21), respectively. The calculated data and the results of ranking the alternatives according to the value of *Qi* are presented in Table 6.

Table 6. Calculation data for example 1 using *MAIRCA* method

| Alternative | $n_{ij}$ | | $t_{pij}$ | | $t_{rij}$ | | $g_i$ | | Qi | Rank |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ra | MRR | Ra | MRR | Ra | MRR | Ra | MRR | | |
| A1 | 0.623 | 0.000 | 0.056 | 0.056 | 0.035 | 0.000 | 0.021 | 0.056 | 0.077 | 9 |
| A2 | 0.555 | 0.250 | 0.056 | 0.056 | 0.031 | 0.014 | 0.025 | 0.042 | 0.066 | 7 |
| A3 | 0.000 | 1.000 | 0.056 | 0.056 | 0.000 | 0.056 | 0.056 | 0.000 | 0.056 | 3 |
| A4 | 0.754 | 0.261 | 0.056 | 0.056 | 0.042 | 0.015 | 0.014 | 0.041 | 0.055 | 2 |
| A5 | 0.834 | 0.148 | 0.056 | 0.056 | 0.046 | 0.008 | 0.009 | 0.047 | 0.057 | 4 |
| A6 | 0.604 | 0.233 | 0.056 | 0.056 | 0.034 | 0.013 | 0.022 | 0.043 | 0.065 | 6 |
| A7 | 0.688 | 0.284 | 0.056 | 0.056 | 0.038 | 0.016 | 0.017 | 0.040 | 0.057 | 5 |
| A8 | 1.000 | 0.318 | 0.056 | 0.056 | 0.056 | 0.018 | 0.000 | 0.038 | 0.038 | 1 |
| A9 | 0.556 | 0.182 | 0.056 | 0.056 | 0.031 | 0.010 | 0.025 | 0.045 | 0.070 | 8 |

*Application of the VIKOR method*

The normalized matrix and normalized values are determined similarly to the *MABAC* method. The *Si* values are calculated according to formula (10). Formulas (22) and (23) are used to calculate the *Ri* and *Qi* values. Table 7 shows the calculation data and the ranking results of the alternatives.

Table 7. Calculation data for example 1 using *VIKOR* method

| Alternative | $n_{ij}$ | | Si | Ri | Qi | Rank |
|---|---|---|---|---|---|---|
| | Ra | MRR | | | | |
| A1 | 0.623 | 0.000 | 0.689 | 0.500 | 1.000 | 9 |
| A2 | 0.555 | 0.250 | 0.597 | 0.375 | 0.476 | 4 |
| A3 | 0.000 | 1.000 | 0.500 | 0.500 | 0.729 | 8 |
| A4 | 0.754 | 0.261 | 0.492 | 0.369 | 0.307 | 3 |
| A5 | 0.834 | 0.148 | 0.509 | 0.426 | 0.510 | 6 |
| A6 | 0.604 | 0.233 | 0.581 | 0.384 | 0.480 | 5 |
| A7 | 0.688 | 0.284 | 0.514 | 0.358 | 0.302 | 2 |
| A8 | 1.000 | 0.318 | 0.341 | 0.341 | 0.000 | 1 |
| A9 | 0.556 | 0.182 | 0.631 | 0.409 | 0.631 | 7 |

*Application of the ROV method*

The normalized matrix and normalized values are determined similarly to the *MABAC* method. Formula (24) is used to calculate the $u_i$ values. Table 8 describes the calculation results and ranks the alternatives.

Thus, the ranking of alternatives when the weight of the criteria determined by the *EQUAL* method is completed. For the remaining weight methods (including *ROC* weight, *RS* weight, *ENTROPY* weight) are also performed similarly. Table 9 presents the results of ranking the

alternatives of Example 1 using different *MCDM* methods as well as different weighting methods.

Table 8. Calculation data for example 1 using *ROV* method

| Alternative | $n_{ij}$ | | ui | Rank |
|---|---|---|---|---|
| | Ra | MRR | | |
| A1 | 0.623 | 0.000 | 0.311 | 9 |
| A2 | 0.555 | 0.250 | 0.403 | 7 |
| A3 | 0.000 | 1.000 | 0.500 | 3 |
| A4 | 0.754 | 0.261 | 0.508 | 2 |
| A5 | 0.834 | 0.148 | 0.491 | 4 |
| A6 | 0.604 | 0.233 | 0.419 | 6 |
| A7 | 0.688 | 0.284 | 0.486 | 5 |
| A8 | 1.000 | 0.318 | 0.659 | 1 |
| A9 | 0.556 | 0.182 | 0.369 | 8 |

Table 9. Ranking results in example 1 when using different *MCDM* and weighting methods

| Weight | *EQUAL* weight | | | | | *ROC* weight | | | | | *RS* weight | | | | | *ENTROPY* weight | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alternative | *MABAC* | *COCOSO* | *MAIRCA* | *VIKOR* | *ROV* | *MABAC* | *COCOSO* | *MAIRCA* | *VIKOR* | *ROV* | *MABAC* | *COCOSO* | *MAIRCA* | *VIKOR* | *ROV* | *MABAC* | *COCOSO* | *MAIRCA* | *VIKOR* | *ROV* |
| A1 | 9 | 9 | 9 | 9 | 9 | 7 | 8 | 7 | 6 | 7 | 8 | 9 | 8 | 8 | 8 | 8 | 9 | 8 | 8 | 8 |
| A2 | 7 | 6 | 7 | 4 | 7 | 6 | 6 | 6 | 7 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| A3 | 3 | 7 | 3 | 8 | 3 | 9 | 9 | 9 | 9 | 9 | 9 | 8 | 9 | 9 | 9 | 9 | 8 | 9 | 9 | 9 |
| A4 | 2 | 2 | 2 | 3 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 3 | 2 | 3 | 3 | 2 | 3 | 2 | 3 |
| A5 | 4 | 4 | 4 | 6 | 4 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 2 | 3 | 2 | 2 | 3 | 2 | 3 | 2 |
| A6 | 6 | 5 | 6 | 5 | 6 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| A7 | 5 | 3 | 5 | 2 | 5 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| A8 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| A9 | 8 | 8 | 8 | 7 | 8 | 8 | 7 | 8 | 8 | 8 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |

Table 9 shows that the ranking order of alternatives depends on the decision making method as well as the weighting method. This is also consistent with the statement of many published studies [16, 47]. However, the results in this table again provide an interesting point that all five *MCDM* methods including *MABAC*, *COCOSO*, *MAIRCA*, *VIKOR* and *ROV* all show that *A8* is the best option. This result is independent of the weighting method used.

### *4.2 Example 2*

In this example an in-office climate assessment was performed [48]. There are fourteen options with six criteria including The amount of air per head (*TH*), Relative air humidity (*RH*), Air temperature (*AT*), Illumination during work hours (*IH*), Rate of air flow (*RF*), and Dew points (*DP*). In which, *TH*, *RH*, *AT* and *IH* are criteria as large as better; while *RF* and *DP* are criteria as small as better (in Table 10).

The formulas in section 4 were also used to determine the weights for the criteria. The results are presented in Table 11.

Table 10. Data of example 2 [48]

| Alternatives | *TH* ($m^3/h$) | *RH (percent)* | *AT* ($^0C$) | *IH (lx)* | *RF (m/s)* | *DP* ($^0C$) |
|---|---|---|---|---|---|---|
| *A1* | 7.6 | 46 | 18 | 390 | 0.1 | 11 |
| *A2* | 5.5 | 32 | 21 | 360 | 0.05 | 11 |
| *A3* | 5.3 | 32 | 21 | 290 | 0.05 | 11 |
| *A4* | 5.7 | 37 | 19 | 270 | 0.05 | 9 |
| *A5* | 4.2 | 38 | 19 | 240 | 0.1 | 8 |
| *A6* | 4.4 | 38 | 19 | 260 | 0.1 | 8 |
| *A7* | 3.9 | 42 | 16 | 270 | 0.1 | 5 |
| *A8* | 7.9 | 44 | 20 | 400 | 0.05 | 6 |
| *A9* | 8.1 | 44 | 20 | 380 | 0.05 | 6 |
| *A10* | 4.5 | 46 | 18 | 320 | 0.1 | 7 |
| *A11* | 5.7 | 48 | 20 | 320 | 0.05 | 11 |
| *A12* | 5.2 | 48 | 20 | 310 | 0.05 | 11 |
| *A13* | 7.1 | 49 | 19 | 280 | 0.1 | 12 |
| *A14* | 6.9 | 50 | 16 | 250 | 0.05 | 10 |

Table 11. Weight of criteria in example 2

| Weight method | *TH* | *RH* | *AT* | *IH* | *RF* | *DP* |
|---|---|---|---|---|---|---|
| *EQUAL* | 1/6 | 1/6 | 1/6 | 1/6 | 1/6 | 1/6 |
| *ROC* | 0.4083 | 0.2417 | 0.1583 | 0.1028 | 0.0611 | 0.0278 |
| *RS* | 0.2857 | 0.2381 | 0.1905 | 0.1429 | 0.0952 | 0.0476 |
| *ENTROPY* | 0.1167 | 0.1115 | 0.1103 | 0.1123 | 0.4323 | 0.1169 |

The ranking of alternatives has been done with different weighting methods and *MCDM* methods. Table 12 presents the ranking results of the alternatives of example 2.

Table 12. Ranking results in example 2 when using different MCDM and weighting methods

| Weight | *EQUAL* weight | | | | | *ROC* weight | | | | | *RS* weight | | | | | *ENTROPY* weight | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alternative | *MABAC* | *COCOSO* | *MAIRCA* | *VIKOR* | *ROV* | *MABAC* | *COCOSO* | *MAIRCA* | *VIKOR* | *ROV* | *MABAC* | *COCOSO* | *MAIRCA* | *VIKOR* | *ROV* | *MABAC* | *COCOSO* | *MAIRCA* | *VIKOR* | *ROV* |
| A1 | 6 | 7 | 6 | 7 | 6 | 4 | 5 | 4 | 3 | 4 | 4 | 5 | 4 | 3 | 4 | 9 | 9 | 9 | 9 | 9 |
| A2 | 5 | 6 | 5 | 6 | 5 | 8 | 8 | 8 | 9 | 8 | 8 | 8 | 8 | 9 | 8 | 5 | 6 | 5 | 6 | 5 |
| A3 | 9 | 9 | 9 | 9 | 9 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 8 | 8 | 8 | 8 | 8 |
| A4 | 8 | 5 | 8 | 5 | 8 | 9 | 7 | 9 | 8 | 9 | 9 | 7 | 9 | 8 | 9 | 7 | 5 | 7 | 5 | 7 |
| A5 | 14 | 13 | 14 | 14 | 14 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 14 | 13 | 14 | 14 | 14 |
| A6 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 13 | 12 | 13 | 13 | 13 |
| A7 | 13 | 14 | 13 | 13 | 13 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 12 | 14 | 12 | 12 | 12 |
| A8 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| A9 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| A10 | 11 | 10 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 10 | 11 | 11 | 11 |
| A11 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 5 | 3 | 3 | 3 | 3 | 5 | 3 | 3 | 3 | 3 | 3 | 3 |
| A12 | 4 | 4 | 4 | 4 | 4 | 5 | 4 | 5 | 6 | 5 | 5 | 4 | 5 | 6 | 5 | 4 | 4 | 4 | 4 | 4 |
| A13 | 10 | 11 | 10 | 10 | 10 | 6 | 9 | 6 | 4 | 6 | 6 | 9 | 6 | 4 | 6 | 10 | 11 | 10 | 10 | 10 |
| A14 | 7 | 8 | 7 | 8 | 7 | 7 | 6 | 7 | 7 | 7 | 7 | 6 | 7 | 7 | 7 | 6 | 7 | 6 | 7 | 6 |

Table 12 shows that the ranking order of alternatives depends on the decision making method as well as the weighting method. This is also consistent with the statement of many published studies [16, 47]. However, the results in this table again provide an interesting point that all five *MCDM* methods including *MABAC*, *COCOSO*, *MAIRCA*, *VIKOR* and *ROV* all show that *A8* is the best option. This result is independent of the weighting method used.

According to the aggregated data in two examples (Table 8 and Table 12), it is shown that when using five methods including *MABAC*, *COCOSO*, *MAIRCA*, *VIKOR* and *ROV*, and four methods of determining the weights for criteria (*EQUAL*, *ROC*, *RS*, and *ENTROPY*) the best solution is consistently found.

## CONCLUSIONS

The results of the ranking of alternatives depend on the decision making method used as well as the data normalization and weighting method. The application of five methods including *MABAC*, *COCOSO*, *MAIRCA*, *VIKOR* and *ROV* also brings results that are not out of this observation. However, the great thing is that these five methods together determine the best solution. Comparison of these five methods using other data normalization methods (eg Vector normalization, Sum linear normalization, ect) will be done by the author of this study in the future.

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