15-May-2020

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- Grey Incidence Analysis Model
- Grey Clustering Evaluation Model
- Grey Programming
- Grey Input-output
- Grey Matrix Game Model
- Uncertain Systems
- Practical Applications of Grey Methods
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- Cloud computing
  - Industrial Engineering
  - Complex Equipment Development
  - Quality and reliability management
- Cost management
- Risk management
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- Technical Innovation management
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- Feb. 10, 2020: Deadline for submission of full papers.
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A New MABAC and GRA-based Reference Point Methods for Weights of Decision Makers and Decision Making

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Abstract

Multi-criteria decision-making (MCDM) problems are expanding rapidly in the realities. In this paper, a new MCDM method based on the grey relational analysis (GRA) and the reference point approach is introduced to achieve reliable and stable results. Also, in group decision-making problems, the weight of experts is different from each other because of different views, experiences, skills, and level of education. To consider the influence of experts in the decision-making process, a new version of the multi-attributive border approximation area comparisons (MABAC) method is extended based on the average ideal solution. Moreover, the proposed MCDM method is developed under the grey numbers to cope with vagueness and uncertainty. Finally, the calculation process and ability of the proposed method are examined by solving an illustrative example from the literature.

Keywords: Multi-attributive border approximation area comparisons (MABAC); Grey relational analysis (GRA); Reference point approach; Weight of experts; Grey numbers.

1. Introduction

Choosing the best alternative among a set of alternatives according to the applicable criteria is always one of the most critical issues of reality. Some multi-criteria decision-making (MCDM) methods have been developed in the last decade to solve this problem. One of the well-known MCDM methods is grey relational analysis (GRA) was initially proposed by Deng (1989). The relationships among criteria can be considered by applying the GRA method (Wei et al., 2011). This method can detect the correlation among the reference and comparable sequence for making the right decisions. Then, the alternatives were ranked by using the computed correlation amounts (Chen, 2019). Furthermore, the GRA method has received considerable attention from researchers because of being easy to understand, easy to use, and does not require mathematical or statistical data (Liu et al., 2019).

One of the well-known MCDM methods that has greatly used by researchers in the last decade is the reference point approach. The reference point approach uses the Tchebycheff’s min-max metric and computes the only distance from the ideal solution (Baležentis and Zeng, 2013). Dorfeshan et al. (2018) extended the reference point approach based on the distance from the
negative ideal solution. The reference point approach has significantly been used owing to the being easy to use, considering the positive and negative ideal solutions (PANIS), and simple calculation process (Dorfoeshan et al., 2018; Stanujkic et al., 2019). To use the benefits of both the GRA method and the reference point approach, the GRA method is developed by the reference point approach to make the right decisions. Also, in group MCDM problems, the weight of each expert is different from each other because of different skills and varied experience and views.

To consider the weight of experts in the MCDM procedure, many MCDM methods have been applied in recent years. Yue (2012) introduced a new TOPSIS method based on the average ideal solution for specifying the weight of experts. Haghighi et al. (2019) proposed a new MCDM method for determining the weight of experts. Mohagheghi et al. (2019) identified the importance of experts based on the new extended TOPSIS method under interval type-2 fuzzy sets. Dorfoeshan and Mousavi (2019) applied a newly developed COPRAS method to the weight of experts’ determination. All of the previous extended methods are based on the average ideal solutions; one of MCDM methods that is initially based on the average ideal solution to the rank of alternatives is a multi-attributive border approximation area comparisons (MABAC) method.

One of the newly presented MCDM methods is MABAC that is basically proposed by Pamučar and Ćirović (2015). The MABAC method due to the stability in solution, easy to use, and potential quantity of merits and demerits that to be defined in such a manner that the final outcome can be tremendous (Dorfoeshan and Mousavi, 2019). Liang et al. (2019) evaluated risks of rockburst by using a new MABAC method under a fuzzy environment. Wei et al. (2019) selected the best supplier for medical consumption products based on a newly extended MABAC method. In this paper, because of the nature of the MABAC method, this method is developed and used for the experts’ weight determination.

Moreover, to address the uncertainty of the proposed approach, grey numbers are applied. The grey numbers are used in this paper because 1) the grey numbers in comparisons of other uncertainty approaches require fewer data and 2) the ability of grey numbers to tackle the uncertainty of real-world MCDM problems (Stanujkic et al., 2017; Chalekaee et al., 2019). Oztaysi (2014) used the TOPSIS and AHP methods for the ranking of information technology under the environment. Chalekaee et al. (2019) evaluated the delay change response problem with the new MCDM model under the grey numbers. The proposed GRA based on the reference point approach and the new MABAC method for weighting of experts are developed under the grey numbers to cope with the vagueness and uncertainty.

Based on the above statements, the GRA method is developed by the reference point approach to use both merits of these two methods. Furthermore, new experts’ weight determination based on the MABAC method is expanded. Finally, all extended methods for ranking and weighting are developed utilizing grey numbers. The paper’s novelties are explained below:

- A new MCDM method based on the GRA method and reference point approach is introduced for the ranking of alternatives.
- A new weighting method for determining the weight of experts is defined based on the MABAC method.
• The new weighting and ranking methods are developed under the grey numbers to tackle the vagueness and uncertainty.

This paper is formed from the following sections. Section 2 proposes a new MCDM method. Section 3 presents an illustrative example for illustrating the calculation process of the proposed method (PM). Section 4 concludes the important remarks.

2. New MCDM method

In this part, the GRA method is extended based on the reference point approach and the Tchebycheff’s min-max metric. Furthermore, determining the weight of experts is very necessary for making the right decision in the group decision-making procedure. Hence, a new MABAC method is developed for experts’ weight determination. Then, the extended ranking and weighting methods are expanded under the weight of the grey environment.

Step 1. A group of experts is formed, and the ratings of alternatives based on the essential criteria and the weight of essential criteria are gathered from the experts. The linguistic variables and their equivalents for grades and weighting are tabulated respectively in Tables 1 and 2.

<table>
<thead>
<tr>
<th>Linguistic variables</th>
<th>Equivalent grey number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Poor (VP)</td>
<td>(0, 1)</td>
</tr>
<tr>
<td>Poor (P)</td>
<td>(1, 3)</td>
</tr>
<tr>
<td>Medium Poor (MP)</td>
<td>(3, 5)</td>
</tr>
<tr>
<td>Fair (F)</td>
<td>(5, 7)</td>
</tr>
<tr>
<td>Medium Good (MG)</td>
<td>(7, 8)</td>
</tr>
<tr>
<td>Good (G)</td>
<td>(8, 9)</td>
</tr>
<tr>
<td>Very Good (VG)</td>
<td>(9, 10)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Linguistic variables</th>
<th>Equivalent grey number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very low (VL)</td>
<td>(0.0, 0.1)</td>
</tr>
<tr>
<td>Low (L)</td>
<td>(0.1, 0.3)</td>
</tr>
<tr>
<td>Medium low (ML)</td>
<td>(0.3, 0.5)</td>
</tr>
<tr>
<td>Medium (M)</td>
<td>(0.5, 0.7)</td>
</tr>
<tr>
<td>Medium high (MH)</td>
<td>(0.7, 0.8)</td>
</tr>
<tr>
<td>High (H)</td>
<td>(0.8, 0.9)</td>
</tr>
<tr>
<td>Very high (VH)</td>
<td>(0.9, 1)</td>
</tr>
</tbody>
</table>

Step 2. The \( z \)-th decision matrix is formed based on the \( Z \) experts’ opinions. The decision matrices are constructed as follows:
\[
\left[ Z_{qs}^\gamma \right]_{Q \times S} = \\
\begin{bmatrix}
(Z_{11}^\gamma, \bar{Z}_{11}^\gamma) & \cdots & (Z_{1s}^\gamma, \bar{Z}_{1s}^\gamma) \\
\vdots & \ddots & \vdots \\
(Z_{q1}^\gamma, \bar{Z}_{q1}^\gamma) & \cdots & (Z_{qs}^\gamma, \bar{Z}_{qs}^\gamma)
\end{bmatrix}
\]

(1)

where 1 ≤ q ≤ Q depicts the number of alternatives, 1 ≤ s ≤ S represents the number of important criteria, 1 ≤ γ ≤ β illustrates the number of experts.

**Step 3.** The experts’ weights are determined based on the new MABAC method. The following sub-steps are used to the weight determination process.

**Step 3-1.** The border approximation area (i.e., average ideal solution) matrix is specified by:

\[
\left[ Z_{qs}^\gamma \right]_{Q \times S} = \\
\begin{bmatrix}
\sum_{\gamma=1}^{\beta} \frac{Z_{1\gamma}}{\beta} & \sum_{\gamma=1}^{\beta} \frac{\bar{Z}_{1\gamma}}{\beta} \\
\vdots & \ddots & \vdots \\
\sum_{\gamma=1}^{\beta} \frac{Z_{q\gamma}}{\beta} & \sum_{\gamma=1}^{\beta} \frac{\bar{Z}_{q\gamma}}{\beta}
\end{bmatrix}
\]

(2)

Step 3-2. The distance of each matrix from the average ideal solution matrix is specified as follows:

\[
\left[ \Theta_{qs}^\gamma \right]_{Q \times S} = \\
\begin{bmatrix}
(Z_{1\gamma} - \frac{\sum_{\gamma=1}^{\beta} Z_{1\gamma}}{\beta}, Z_{11}^\gamma - \frac{\sum_{\gamma=1}^{\beta} \bar{Z}_{1\gamma}}{\beta}) & \cdots & (Z_{1s}^\gamma - \frac{\sum_{\gamma=1}^{\beta} \bar{Z}_{1s}^\gamma - \sum_{\gamma=1}^{\beta} \bar{Z}_{1s}^\gamma}{\beta}) \\
\vdots & \ddots & \vdots \\
(Z_{q\gamma} - \frac{\sum_{\gamma=1}^{\beta} Z_{q\gamma}}{\beta}, \bar{Z}_{q1}^\gamma - \frac{\sum_{\gamma=1}^{\beta} \bar{Z}_{q1}^\gamma}{\beta}) & \cdots & (Z_{qs}^\gamma - \frac{\sum_{\gamma=1}^{\beta} Z_{qs}^\gamma - \sum_{\gamma=1}^{\beta} \bar{Z}_{qs}^\gamma}{\beta})
\end{bmatrix}
\]

(3)

Then, the lower and upper bounds of each element area integrated by:

\[
\frac{\sum_{\gamma=1}^{\beta} Z_{qs}^\gamma}{\beta} + \bar{Z}_{qs}^\gamma - \frac{\sum_{\gamma=1}^{\beta} \bar{Z}_{qs}^\gamma}{\beta}
\]

(4)

**Step 3-3.** The final value of the weight of experts is computed as follows:

\[
\varphi^\gamma = \sum_{s=1}^{S} \sum_{q=1}^{Q} \Theta_{qs}^\gamma \\
\quad \forall \gamma = 1, \ldots, \beta
\]

(5)

**Step 3-4.** The final weight of experts is determined by:
\[ \xi^\gamma = \frac{\Theta^\gamma}{\sum_{\gamma=1}^{\beta} \Theta^\gamma} \quad \forall \gamma = 1,\ldots,\beta \]  

**Step 4.** All decision matrices are aggregated by using the weight of experts as follows:

\[
\left[ \Theta_{q,s} \right]_{Q \times S} = \frac{\sum_{\gamma=1}^{\beta} \xi^\gamma \times \left[ (Z_{11}, \tilde{Z}_{11}^\gamma) \ldots (Z_{1s}, \tilde{Z}_{1s}^\gamma) \right] \ldots \left[ (Z_{q1}, \tilde{Z}_{q1}^\gamma) \ldots (Z_{qs}, \tilde{Z}_{qs}^\gamma) \right]}{\sum_{\gamma=1}^{\beta} \xi^\gamma}
\]

**Step 5.** The aggregated decision matrix is normalized by:

\[
\left[ H_{q,s} \right]_{Q \times S} = \left[ (H_{11}, \tilde{H}_{11}) \ldots (H_{1s}, \tilde{H}_{1s}) \right] 
\]

where,

\[
(H_{q,s}, \tilde{H}_{q,s}) = \left( \frac{\Theta_{q,s} - \Theta_{q,s}}{\overline{\Theta}_{+} - \Theta_{q,s}}, \frac{\Theta_{q,s} - \overline{\Theta}_{-}}{\Theta_{q,s} - \overline{\Theta}_{-}} \right) \text{ for the benefit criteria}
\]

\[
(H_{q,s}, \tilde{H}_{q,s}) = \left( \frac{\Theta_{q,s} - \Theta_{q,s}}{\overline{\Theta}_{+} - \Theta_{q,s}}, \frac{\Theta_{q,s} - \overline{\Theta}_{-}}{\Theta_{q,s} - \overline{\Theta}_{-}} \right) \text{ for the cost criteria}
\]

Notably, \( \overline{\Theta}_{+} = \max_{1 \leq q \leq Q} \left\{ \Theta_{q,s} \right\} \) and \( \overline{\Theta}_{-} = \max_{1 \leq q \leq Q} \left\{ \Theta_{q,s} \right\} \).

**Step 6.** The normalized decision matrices are multiplied in the weight of the criteria gathered from experts by:

\[
\left[ U_{q,s} \right]_{Q \times S} = \alpha_s \times \left[ H_{q,s} \right]_{Q \times S} = \left[ (\alpha_s \times H_{11}, \alpha_s \times \tilde{H}_{11}) \ldots (\alpha_s \times H_{1s}, \alpha_s \times \tilde{H}_{1s}) \right] 
\]

**Step 7.** The PANIS are specified as follows:

\[
(U_{q,s}^+, U_{q,s}^-) = \left[ (\max_{1 \leq q \leq Q} U_{q,s}^1, \max_{1 \leq q \leq Q} \tilde{U}_{q,s}^1), (\max_{1 \leq q \leq Q} U_{q,s}^2, \max_{1 \leq q \leq Q} \tilde{U}_{q,s}^2), \ldots, (\max_{1 \leq q \leq Q} U_{q,s}^S, \max_{1 \leq q \leq Q} \tilde{U}_{q,s}^S) \right]
\]

\[
(U_{q,s}^+, U_{q,s}^-) = \left[ (\min_{1 \leq q \leq Q} U_{q,s}^1, \min_{1 \leq q \leq Q} \tilde{U}_{q,s}^1), (\min_{1 \leq q \leq Q} U_{q,s}^2, \min_{1 \leq q \leq Q} \tilde{U}_{q,s}^2), \ldots, (\min_{1 \leq q \leq Q} U_{q,s}^S, \min_{1 \leq q \leq Q} \tilde{U}_{q,s}^S) \right]
\]

**Step 8.** The computed distance from PANIS is obtained as below:

\[
\left[ D_{q,s} \right]_{Q \times S} = \left[ \pi_{11}^+, \ldots, \pi_{1s}^+, \ldots, \pi_{q1}^+, \ldots, \pi_{qs}^+ \right]
\]

\[
\left[ D_{q,s} \right]_{Q \times S} = \left[ \pi_{11}^-, \ldots, \pi_{1s}^-, \ldots, \pi_{q1}^-, \ldots, \pi_{qs}^- \right]
\]
where $\pi^*_{qs} = \sqrt{(U_{qs} - \max U_{qs})^2 + (U_{qs} - \max U_{qs})^2}$.

**Step 9.** The negative and positive grey relational coefficient matrix $[\rho^*_{qs}]_{Q \times S}$ is calculated by:

\[
\begin{bmatrix}
\rho^+_{11} & \cdots & \rho^+_{1S} \\
\vdots & \ddots & \vdots \\
\rho^+_{q1} & \cdots & \rho^+_{qS}
\end{bmatrix}_{Q \times S} = \left[ \min \min_{q_i} \pi^*_{qs} + \tau \min_{q_i} \pi^+_{qs} \right]_{Q \times S} \quad \rho^-_{qs} = \left[ \min \min_{q_i} \pi^-_{qs} + \tau \min_{q_i} \pi^-_{qs} \right]_{Q \times S}.
\]

**Step 10.** In the classic reference point method, the Tchebycheff’s min-max metric is used. In this paper, because the nature of data after applying the grey relational coefficient, the max-min Tchebycheff metric is implemented by:

\[
\max_q \left( \frac{\min_r \rho^+_{qs} + \min_r (1 - \rho^-_{qs})}{2} \right) \quad \forall q = 1, \ldots, Q \quad \text{and} \quad s = 1, \ldots, S
\]

Note that the higher values get the more top ranks.

### 3. Illustrative example

An example from the literature (Mousavi et al., 2014) is solved for reflecting the calculational process and strengths of PM. The best conveyor of material handling equipment must be selected in the textile manufacturing company. Four conveyors and six critical criteria are defined for this application. The applicable criteria are defined as follows: 1) Fixed cost 2) Variables cost 3) Speed of conveyor 4) Item width 5) Item weight, and 6) Flexibility.

**Step 1.** The data are gathered from a team of experts with three members and converted them based on Tables 1 and 2. The initial data are tabulated in Tables 3 and 4.

**Step 2.** Three decision matrices are formed by using employing Eq. (1).

**Step 3.** The weights of experts are computed through a new version of the MABAC method based on Eqs. (2-6). The final weight of experts is tabulated in Table 5.
Table 3. Collected data on ratings of conveyors based on the efficient criteria from experts

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Alternatives</th>
<th>Expert1</th>
<th>Expert2</th>
<th>Expert3</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>A1</td>
<td>P</td>
<td>VP</td>
<td>P</td>
</tr>
<tr>
<td></td>
<td>A2</td>
<td>F</td>
<td>F</td>
<td>F</td>
</tr>
<tr>
<td></td>
<td>A3</td>
<td>F</td>
<td>F</td>
<td>F</td>
</tr>
<tr>
<td></td>
<td>A4</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
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<tr>
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<td>F</td>
<td>F</td>
<td>MG</td>
</tr>
<tr>
<td>C3</td>
<td>A1</td>
<td>VG</td>
<td>G</td>
<td>G</td>
</tr>
<tr>
<td></td>
<td>A2</td>
<td>MG</td>
<td>MG</td>
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<td>G</td>
<td>G</td>
</tr>
<tr>
<td></td>
<td>A4</td>
<td>MP</td>
<td>MP</td>
<td>F</td>
</tr>
<tr>
<td>C4</td>
<td>A1</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
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<td>C5</td>
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<td></td>
<td>A4</td>
<td>MG</td>
<td>MG</td>
<td>F</td>
</tr>
</tbody>
</table>

Table 4. Collected data on the significance of criteria from experts

<table>
<thead>
<tr>
<th>DMs</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>C6</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM1</td>
<td>MH</td>
<td>M</td>
<td>M</td>
<td>L</td>
<td>ML</td>
<td>M</td>
</tr>
<tr>
<td>DM2</td>
<td>M</td>
<td>MH</td>
<td>MH</td>
<td>L</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>DM3</td>
<td>H</td>
<td>M</td>
<td>M</td>
<td>ML</td>
<td>ML</td>
<td>M</td>
</tr>
</tbody>
</table>

Table 5. Final weight of experts

<table>
<thead>
<tr>
<th>Experts</th>
<th>Final weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expert1</td>
<td>0.37</td>
</tr>
<tr>
<td>Expert2</td>
<td>0.43</td>
</tr>
<tr>
<td>Expert3</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Step 4. Three decision matrices are aggregated by using the weight of three experts through Eq. (7).

Step 5. The aggregated decision matrix is normalized by Eqs. (8) and (9).
Step 6. The normalized decision matrix is multiplied in the weight of criteria gathered from experts. Notably, the inferred importance of criteria from experts is aggregated and then, multiplied in the normalized matrix.

Step 7. The PANIS is computed by means of Eq. (11).

Step 8. The matrix of distanced from PANIS is calculated by using Eqs. (12) and (13).

Step 9. The negative and positive grey relational coefficient matrices are obtained by Eqs. (14) and (15).

Step 10. The final values and rankings of alternatives are computed by applying the max-min Tchebycheff metric employing Eq. (16). The final results are tabulated in Table 6.

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>Final values</th>
<th>Final rankings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conveyor 1</td>
<td>0.662407</td>
<td>1</td>
</tr>
<tr>
<td>Conveyor 2</td>
<td>0.409343</td>
<td>2</td>
</tr>
<tr>
<td>Conveyor 3</td>
<td>0.366921</td>
<td>3</td>
</tr>
<tr>
<td>Conveyor 4</td>
<td>0.166667</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 6. Final values and rankings of alternatives

Comparative analysis: In this part, the final values and ranking of alternatives derived from the PM are compared with the results of the TOPSIS method. The results are demonstrated in Table 7. The results of the TOPSIS method have confirmed the results of PM. This authentication demonstrates the validity of PM.

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>Final values</th>
<th>Final rankings</th>
<th>Final results of the TOPSIS method</th>
<th>Final rankings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conveyor 1</td>
<td>0.662407</td>
<td>1</td>
<td>0.978659</td>
<td>1</td>
</tr>
<tr>
<td>Conveyor 2</td>
<td>0.409343</td>
<td>2</td>
<td>0.690811</td>
<td>2</td>
</tr>
<tr>
<td>Conveyor 3</td>
<td>0.366921</td>
<td>3</td>
<td>0.626399</td>
<td>3</td>
</tr>
<tr>
<td>Conveyor 4</td>
<td>0.166667</td>
<td>4</td>
<td>0</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 7. Results of comparative analysis

4. Conclusion

In this paper, a new decision method has been developed. The GRA method has been extended by using the reference point approach for achieving stable and durable results. Moreover, instead of the Tchebycheff’s min-max metric, the Tchebycheff’s max-min metric has been applied. To increase the reliability of making the right decisions, the weight of experts has been added to the proposed MCDM procedure. The experts’ weight determination has been done based on the MABAC method and average ideal solutions. Also, the proposed reliable decision method has been extended under the grey numbers. Grey numbers as a powerful tool for coping with the
uncertainty has been applied. Moreover, the authentication of the proposed method has been derived by comparing it with the results of the TOPSIS method. The proposed method can be applied in conventional MCDM problems (e.g., supplier selection, robot selection, critical path determination). For future studies, the criteria’s weight determination methods can be applied to the proposed method. The data-driven MCDM approach can be added to the proposed method for determining the weight of experts or criteria.

References


