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RESEARCH ARTICLE

A Hybrid Fuzzy Approach of Similarity-Influence-Network and DEMATEL: Visualization and Analysis

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Abstract The Social Influence Group Decision Making (SIGDM) entails intricate intra and interpersonal exchanges among a group of experts as they endeavor to persuade others toward reaching a mutually agreed-upon solution. However, prevailing SIGDM approaches often overlook the critical aspect of visualizing criteria interdependencies. This visual representation becomes crucial as it provides supplementary insights into analyzing the significance of criteria and their impacts within decision-making processes. In order to address the oversight of neglecting criteria interdependent relationships, we extend the similarity-influence-network algorithm by integrating a cause-effect visualization procedure inspired by the DEMATEL approach. Additionally, we introduce several supplementary steps to enhance the efficacy of existing methodologies. The proposed model not only fills a gap in the current methodology but also provides accuracy of influence representation by incorporating influence-based collective preferences. This hybrid approach stands as a valuable alternative decision-making tool, providing a comparative analysis of the related existing approaches.

Keywords: Similarity of preferences, Social Influence Network, DEMATEL, importance of criteria, criteria interdependency.

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Introduction

Decision-making is an essential process of our everyday existence, whether undertaken by a single individual or a collective group of decision-makers. These decision-makers also referred to as experts, articulate their preferences towards a range of choices or criteria, allowing discussions on how to reach a mutually agreed solution from each individual's viewpoint.

Recent studies on decision-making models are initialized, where the influence element is introduced and named as Social Influence Group Decision Making (SIGDM). SIGDM entails both personal and interpersonal exchanges among individuals with varying levels of influence, aimed at amending, sharing, or persuading others to reach a final, unanimous decision [3]. Several promising ideas and new methodologies on SIGDM can be found in Li and Wei [11], Zhang *et al*. [18], Yao and Gu [17], Gong *et al*. [5] and many more.

In visualization of criteria interdependencies, the DEMATEL method is one of the powerful procedures in group decision making (GDM). This approach enables to present the connections between criteria, provide the degree of impacts and ranking the importance of criteria based on the relation types [13]. Many studies on utilization of DEMATEL method in solving real-life decision-making problems have been introduced, such as in maritime transportation [14, 9], supplier selection, [4], health and medicine [15], risk assessment [19] and waste management [2].

The integration of DEMATEL with other approaches can provide meaningful knowledge contributions in decision making perspectives. Therefore, this study extends the SIGDM based methodology by Kamis *et al*. [8], incorporating parts of DEMATEL procedure in visualization of criteria interdependencies. This visual representation is not provided previously. This improved work enables to analyze the structural correlation of criteria by generating cause-effect diagram and can be utilized as an alternative decision making tools.

In the part that follows, we examine recent research on SIGDM and DEMATEL as well as the suggested technique. The Methodology section elaborates on the framework of the proposed model and the two main phases. The next part presents the implementation and results. The analysis of methods is then elaborated and the final portion concludes with a discussion of future directions for the field.

The Proposed Methodology

This section initiates with an overview of the proposed model's framework, followed by an elaboration of its initial phase: the Similarity-Influence-Network Group Decision Making Model. It then progresses to discuss the subsequent phase: Visualization of Interdependent Relationships of Criteria utilizing the DEMATEL approach.

Framework of the Proposed Model

In this study, we present two (2) main phases, incorporating the SIGDM [8] model with cause-effect diagram procedure, inspired by the DEMATEL. The first phase elaborates on the group decision making algorithm based on the similarity-influence-network and the second one is related to the interdependent relationship of criteria and its visualization using DEMATEL.

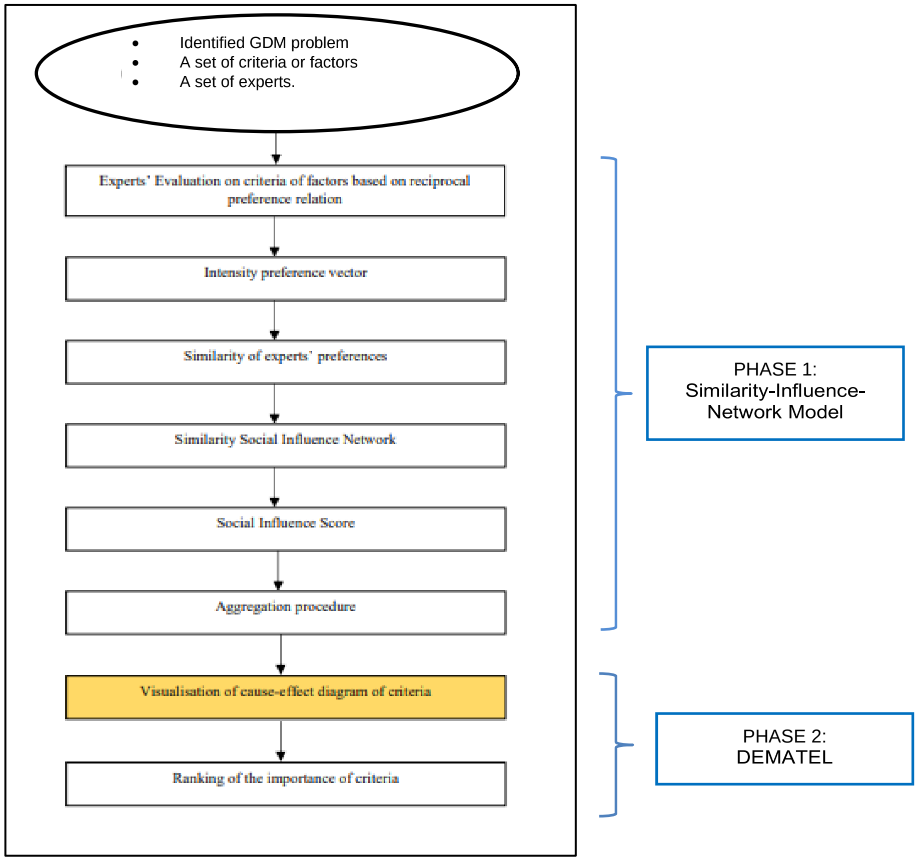

Figure 1. Framework of a hybrid fuzzy approach of Similarity-Influence-Network and DEMATEL

As illustrated in Figure 1, the GDM problem is identified, concerning a set of criteria or factors. A number of experts is involved in this decision-making process. In Phase 1, experts assess the criteria or factors through reciprocal fuzzy preference relations (RFPR). These matrices are transformed into intensity preference vectors (IPVs), reducing computation in this step. The similarity of experts' preferences is determined to measure the closeness of expert opinions on criteria, and a social influence network is subsequently constructed. An influence index of each expert is calculated to identify the most influential expert in the network, and these values are then utilized as order inducing variables in the IOWA-based aggregation operato. All individual preferences are fused into a collective one, which is further employed in the integration step in DEMATEL. New steps are introduced in this hybrid process, where the primary objective is to visualize the interrelation of criteria or factors based on a cause-effect diagram. Finally, the final ranking of the importance of criteria or factors is determined.

The Similarity-Influence-Network Group Decision Making Model

In group decision making, a set of experts $E=\left\{e^1, e^2, ..., e^m\right\}$ are allowed to express their preferences over a set of criteria or factors, $\mathrm{C}=\left\{C_1, C_2, ..., C_n\right\}$ $\left(n>2\right)$ in any types of preference representation formats.

In this study, experts express their preferences over criteria in the form of reciprocal fuzzy preference relation (RFPR). The RFPR of criteria, C can be written as $P=\left(p_{ij}\right)$ with $n \times n$ dimension. The definition of RFPR is given as:

Definition 1. *A fuzzy binary relation* $m_p : \mathrm{C}\times\mathrm{C}\rightarrow\left[0, 1\right]$ *for a pair of criteria* $\left(C_i, C_j\right)$ *is a value of*

$m_p\left(C_i, C_j\right)=p_{ij}$, *where reciprocity condition is verified as:* $p_{ij}+p_{ji}=1\left(\forall\ i,\ j\right)$. *This condition comprehends:*

(i) $p_{ij}=0.5$ *if* c_i *are indifference to* C_j,

(ii) $p_{ij} \in (0.5, 1)$ *if* c_i *is slightly preferred to* C_j,

(iii) $p_{ij}=1$ *if* c_i *is absolutely preferred to* C_j.

For the purpose of having the inputs in pairwise comparison data, the RFPR is then transformed in terms of the intensity preference vector (IPV) [6] format. The definition of IPV is presented below:

Definition 2. *The intensity preference vector (IPV),* $U \in \Re^{\frac{n(n-1)}{2}}$ *is represented as:*

$$U=\left(p_{12},\ p_{13},\ \ldots,\ p_{1n},\ p_{23},\ \ldots,\ p_{2n},\ \ldots,\ p_{(n-1)n}\right)=\left(u_1,\ u_2,\ \ldots,\ u_r,\ \ldots,\ u_{\frac{n(n-1)}{2}}\right).$$

Then, the collection of experts' preferences with regard to IPVs for the set of criteria, C can be denoted as $U=\left\{U^1,\ U^2,\ \ldots,\ U^m\right\}$.

Measurement of experts' preference similarities are taken into account by utilization of Definition 3 and Definition 4 [7]. All S^{kl} are collected and represented as a similarity matrix, S.

Definition 3. *Let U be the IPVs of a set of experts over a set of criteria* C*. The similarity measure of a pair of experts' preferences is a fuzzy subset of* $U \times U$*, with* $S:\ U \times U \rightarrow \left[0,1\right]$*. This representation verifies the reflexivity,* $S\left(U^k, U^l\right)=1$ *and symmetricity,* $S\left(U^k, U^l\right)=S\left(U^l, U^k\right)$.

Definition 4. *The cosine preference similarity index of pair of experts,* e^k *and* e^l *is:*

$$S^{kl}=S\left(U^k, U^l\right)=\frac{\sum_{i=1}^{\frac{n(n-1)}{2}}\left(u_i^k \cdot u_i^l\right)}{\sqrt{\sum_{i=1}^{\frac{n(n-1)}{2}}\left(u_i^k\right)^2} \cdot \sqrt{\sum_{i=1}^{\frac{n(n-1)}{2}}\left(u_i^l\right)^2}}.$$

From the similarity of preferences, the influence index of each expert can be determined. The influence index serves as an indicator of an expert's impact, designating the expert with the greatest degree as the most influential figure within the group, and conversely for the expert with the lowest degree. The influence index, Y [8] can be defined as:

Definition 5. *Given* S_h *as a set of row normalized preference similarity matrix, S, σ be the relative weightage of internal network connections (endogenous) with respect to the external effects (exogenous), and* $Z=(z)_{m\times 1}$ *be the value of external effect (exogenous) of each expert. The influence index of each expert, denoted as* σ *- centrality,* E, $Y=\left(y^1,\ \ldots,\ y^m\right)$ *is defined as:*

$$Y=\left(I-\sigma S_h^T\right)^{-1}Z.$$

Z *represents a unity vector, a vector in which all components are set to 1, when there is no external effect involves.*

The influence indexes are ranked in descending order. Expert with higher influence index has more power in controlling the aggregation stage and directly affects the decision making process. These indices are employed as the variable that determines the order of experts' preference evaluations, $\left\{p_{ij}^{1}, \ldots, p_{ij}^{m}\right\}$ in the IOWA-based aggregation [16] process. The definition of s - *IOWA* operator is given as follows:

Definition 6. *With expert's influence indices in the network, $Y = \left(y^{1}, \ldots, y^{m}\right)$ as the order inducing variable, the aggregation of individual expert's preferences is expressed as Φ_{W}^{s}, the s - IOWA operator of dimension m.*

As a result, individual experts' preferences are aggregated and collectively presented as an influence based collective preference matrix, P^{c}.

Visualization of Interdependent Relationships of Criteria using DEMATEL Approach

In this section, only parts of the DEMATEL approach are utilized. Some modifications are considered in this stage in order to visualize the inter-relations of criteria from the influence-based collective preferences. These works improved the drawbacks of Kamis *et al*. [8] work, where the visualization of interdependent relationship between criteria is not provided.

The initial direct-relation matrix, X is constructed by utilizing the collective preference matrix, P^{c} using this new equation:

$$X = P^{c} - I, \tag{1}$$

where I is the identity matrix.

The normalization step needs to be considered, thus the initial direct-relational entries are mapped from x_{ij} to $[0, 1]$. The normalization formula is given as:

$$N = X \times M \text{ where } M = \frac{1}{\max_{i}\left(\sum_{j=1}^{n} x_{ij}\right)}. \tag{2}$$

From DEMATEL approach, the total relation matrix, T can be presented by:

$$T = N\left(I - N\right)^{-1}, \tag{3}$$

where I is the identity matrix.

For the purpose of obtaining the structural correlation analysis, the sum of rows and columns in T are computed as:

$$R_{i} = \sum_{j=1}^{n} t_{ij} \; \left(i = 1, 2, \ldots, n\right), \tag{4}$$

$$D_{j} = \sum_{i=1}^{n} t_{ij} \; \left(j = 1, 2, \ldots, n\right). \tag{5}$$

The value of R_{i} represents both direct and indirect effects given by criteria i to the other criteria.

Otherwise, the value of D_j summarizes direct and indirect effects by criteria j from the other criteria.

The cause-effect diagram, which represents the interdependencies of criteria can be constructed by mapping the data set of $\left(D_j + R_i, D_j - R_i\right)$.

Let R_i be $n \times 1$ vector of sum of rows and D_j be $1 \times n$ vector of sum of columns from matrix *T*. The $\left(D_j + R_i\right)$ values represent the total effects given and received by criteria i, while $\left(D_j - R_i\right)$ shows the net effect that criteria i contributes to the system. When $\left(D_j - R_i\right)$ is positive, criteria i is a net cause. On the contrary, criteria i is a net receiver if value of $\left(D_j - R_i\right)$ is negative [10], [12].

From the diagram, the importance of criteria can be determined by ranking of the $D_j + R_i$ values. The higher the value, the higher the rank of the criteria, the more important the criteria in the decision making process.

The proposed methodology highlights the common oversight in prevailing SIGDM approaches, which often neglects the critical aspect of visualizing criteria interdependencies. Emphasizing the significance of a visual representation, this study advocates for a more thorough consideration of criteria and their impacts within decision-making processes. This hybrid work underscores the importance of addressing criteria interdependent relationships and presents a refined algorithm with added steps for improved effectiveness in similarity-influence-network approach.

Implementation and Results

Consider a group of eight (8) experts, $E = \{e_1, e_2, ..., e_8\}$, each expressing their preferences on a set of 7 influential criteria, $C = \{C_1, C_2, ..., C_7\}$ in RFPR format. The evaluations are recorded [1] and referred as follows:

$$e_1 = \begin{bmatrix} 0.5 & 0.4 & 0.3 & 0.8 & 0.7 & 0.2 & 0.3 \\ 0.6 & 0.5 & 0.4 & 0.2 & 0.8 & 0.9 & 0.6 \\ 0.7 & 0.6 & 0.5 & 0.3 & 0.9 & 0.2 & 0.4 \\ 0.2 & 0.8 & 0.7 & 0.5 & 0.1 & 0.3 & 0.1 \\ 0.3 & 0.2 & 0.1 & 0.9 & 0.5 & 0.8 & 0.6 \\ 0.8 & 0.1 & 0.8 & 0.7 & 0.2 & 0.5 & 0.9 \\ 0.7 & 0.4 & 0.6 & 0.9 & 0.4 & 0.1 & 0.5 \end{bmatrix} \quad e_2 = \begin{bmatrix} 0.5 & 0.3 & 0.1 & 0.5 & 0.4 & 0.8 & 0.7 \\ 0.7 & 0.5 & 0.6 & 0.2 & 0.4 & 0.3 & 0.5 \\ 0.9 & 0.4 & 0.5 & 0.1 & 0.8 & 0.2 & 0.6 \\ 0.5 & 0.8 & 0.9 & 0.5 & 0.1 & 0.2 & 0.9 \\ 0.6 & 0.6 & 0.2 & 0.9 & 0.5 & 0.7 & 0.2 \\ 0.2 & 0.7 & 0.8 & 0.8 & 0.3 & 0.5 & 0.7 \\ 0.3 & 0.5 & 0.4 & 0.1 & 0.8 & 0.3 & 0.5 \end{bmatrix}$$

$$e_3 = \begin{bmatrix} 0.5 & 0.1 & 0.8 & 0.4 & 0.3 & 0.9 & 0.7 \\ 0.9 & 0.5 & 0.3 & 0.5 & 0.3 & 0.2 & 0.2 \\ 0.2 & 0.7 & 0.5 & 0.7 & 0.2 & 0.4 & 0.7 \\ 0.6 & 0.5 & 0.3 & 0.5 & 0.1 & 0.8 & 0.3 \\ 0.7 & 0.7 & 0.8 & 0.9 & 0.5 & 0.4 & 0.5 \\ 0.1 & 0.8 & 0.6 & 0.2 & 0.6 & 0.5 & 0.2 \\ 0.3 & 0.8 & 0.3 & 0.7 & 0.5 & 0.8 & 0.5 \end{bmatrix} \quad e_4 = \begin{bmatrix} 0.5 & 0.4 & 0.3 & 0.8 & 0.2 & 0.1 & 0.5 \\ 0.6 & 0.5 & 0.9 & 0.7 & 0.9 & 0.4 & 0.8 \\ 0.7 & 0.1 & 0.5 & 0.6 & 0.3 & 0.4 & 0.2 \\ 0.2 & 0.3 & 0.4 & 0.5 & 0.7 & 0.1 & 0.2 \\ 0.8 & 0.1 & 0.7 & 0.3 & 0.5 & 0.9 & 0.6 \\ 0.9 & 0.6 & 0.6 & 0.9 & 0.1 & 0.5 & 0.3 \\ 0.5 & 0.2 & 0.8 & 0.8 & 0.4 & 0.7 & 0.5 \end{bmatrix}$$

$$e_5 = \begin{bmatrix} 0.5 & 0.8 & 0.6 & 0.6 & 0.5 & 0.5 & 0.9 \\ 0.2 & 0.5 & 0.4 & 0.2 & 0.3 & 0.4 & 0.8 \\ 0.4 & 0.6 & 0.5 & 0.7 & 0.9 & 0.1 & 0.7 \\ 0.4 & 0.8 & 0.3 & 0.5 & 0.1 & 0.3 & 0.2 \\ 0.5 & 0.7 & 0.1 & 0.9 & 0.5 & 0.8 & 0.6 \\ 0.5 & 0.6 & 0.9 & 0.7 & 0.2 & 0.5 & 0.1 \\ 0.1 & 0.2 & 0.3 & 0.8 & 0.4 & 0.9 & 0.5 \end{bmatrix} \quad e_6 = \begin{bmatrix} 0.5 & 0.3 & 0.4 & 0.9 & 0.7 & 0.7 & 0.6 \\ 0.7 & 0.5 & 0.4 & 0.1 & 0.2 & 0.2 & 0.8 \\ 0.6 & 0.6 & 0.5 & 0.3 & 0.8 & 0.9 & 0.2 \\ 0.1 & 0.9 & 0.7 & 0.5 & 0.6 & 0.3 & 0.3 \\ 0.3 & 0.8 & 0.2 & 0.4 & 0.5 & 0.1 & 0.4 \\ 0.3 & 0.8 & 0.1 & 0.7 & 0.9 & 0.5 & 0.2 \\ 0.4 & 0.2 & 0.8 & 0.7 & 0.6 & 0.8 & 0.5 \end{bmatrix}$$

$$e_7 = \begin{bmatrix} 0.5 & 0.3 & 0.3 & 0.7 & 0.6 & 0.2 & 0.4 \\ 0.7 & 0.5 & 0.4 & 0.2 & 0.4 & 0.8 & 0.3 \\ 0.7 & 0.6 & 0.5 & 0.1 & 0.4 & 0.6 & 0.2 \\ 0.3 & 0.8 & 0.9 & 0.5 & 0.3 & 0.7 & 0.1 \\ 0.4 & 0.6 & 0.6 & 0.7 & 0.5 & 0.6 & 0.5 \\ 0.8 & 0.2 & 0.4 & 0.3 & 0.4 & 0.5 & 0.4 \\ 0.6 & 0.7 & 0.8 & 0.9 & 0.5 & 0.6 & 0.5 \end{bmatrix} \quad e_8 = \begin{bmatrix} 0.5 & 0.3 & 0.1 & 0.4 & 0.5 & 0.6 & 0.6 \\ 0.7 & 0.5 & 0.6 & 0.4 & 0.2 & 0.3 & 0.1 \\ 0.9 & 0.4 & 0.5 & 0.8 & 0.7 & 0.5 & 0.4 \\ 0.6 & 0.6 & 0.2 & 0.5 & 0.3 & 0.8 & 0.6 \\ 0.5 & 0.8 & 0.3 & 0.7 & 0.5 & 0.7 & 0.8 \\ 0.4 & 0.7 & 0.5 & 0.2 & 0.3 & 0.5 & 0.3 \\ 0.4 & 0.9 & 0.6 & 0.4 & 0.2 & 0.7 & 0.5 \end{bmatrix}$$

From the individual expert's evaluation, the similarity of preferences is measured and presented in the form of matrix S is as follows:

$$S = \begin{bmatrix} 1 & 0.8142 & 0.6575 & 0.7914 & 0.8318 & 0.7456 & \mathbf{0.9035} & 0.7671 \\ 0.8142 & 1 & 0.7379 & 0.7267 & 0.8220 & 0.7737 & 0.7482 & 0.8264 \\ \mathbf{0.6575} & 0.7379 & 1 & 0.6830 & 0.8102 & 0.7374 & 0.7592 & 0.8717 \\ 0.7914 & 0.7267 & 0.6830 & 1 & 0.7949 & 0.7450 & 0.8140 & 0.7681 \\ 0.8318 & 0.8220 & 0.8102 & 0.7949 & 1 & 0.8028 & 0.7949 & 0.8363 \\ 0.7456 & 0.7737 & 0.7374 & 0.7450 & 0.8028 & 1 & 0.8197 & 0.7853 \\ 0.9035 & 0.7482 & 0.7592 & 0.8140 & 0.7949 & 0.8197 & 1 & 0.8474 \\ 0.7671 & 0.8263 & 0.8717 & 0.7681 & 0.8363 & 0.7853 & 0.8474 & 1 \end{bmatrix}$$

From S matrix, it is shown that the highest similarity degree is 0.9035, falls in row 1 and column 7, meaning that Expert 1 and Expert 7 has very similar opinion to each other. While the lowest value is 0.6575, appears in row 3 and column 1. This shows that Expert 1 and Expert 3 has very different preference towards criteria.

The influence score is determined using the relative endogenous effect, with Z represented as a matrix of ones and the scalar σ set to a constant value of 0.5. Based on Definition 2.6, the value of the influence score is presented as below:

$$Y = \left(I - (0.5) \begin{bmatrix} 0.1536 & 0.1250 & 0.1010 & 0.1215 & 0.1278 & 0.1145 & 0.1388 & 0.1178 \\ 0.1263 & 0.1551 & 0.1144 & 0.1127 & 0.1275 & 0.1200 & 0.1160 & 0.1281 \\ 0.1051 & 0.1179 & 0.1598 & 0.1092 & 0.1295 & 0.1179 & 0.1213 & 0.1393 \\ 0.1252 & 0.1149 & 0.1080 & 0.1582 & 0.1257 & 0.1178 & 0.1287 & 0.1215 \\ 0.1243 & 0.1228 & 0.1211 & 0.1188 & 0.1494 & 0.1199 & 0.1188 & 0.1250 \\ 0.1163 & 0.1207 & 0.1150 & 0.1162 & 0.1253 & 0.1560 & 0.1279 & 0.1225 \\ 0.1351 & 0.1119 & 0.1135 & 0.1217 & 0.1189 & 0.1226 & 0.1495 & 0.1267 \\ 0.1145 & 0.1233 & 0.1301 & 0.1146 & 0.1248 & 0.1172 & 0.1264 & 0.1492 \end{bmatrix}^{-1} \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \end{bmatrix} \right)$$

$$= \begin{bmatrix} 2.0007 & 1.9916 & 1.9625 & 1.9725 & 2.0289 & 1.9857 & 2.0278 & 2.0303 \end{bmatrix}.$$

Here, the value of Y represents the influence index of each expert. Expert 1 has 2.0007 influence score, experts 2 has 1.9916 influence score and the values continue for the rest of the experts. It is clear that within this network, Expert 8 stands out as the most prominent figure, with an impressive influence score of 2.0303. In contrast, Expert 3 ranks as the least influential expert, with a degree of 1.9625.

The modification of DEMATEL procedure begins with the definition of initial direct-relation matrix, X (Equation 1), where collective preference matrix, P^c is utilized. The X matrix is presented as follows:

$$X = \begin{bmatrix} 0 & 0.3638 & 0.3467 & 0.6693 & 0.5274 & 0.4457 & 0.5209 \\ 0.6362 & 0 & 0.4779 & 0.2862 & 0.5424 & 0.5468 & 0.5382 \\ 0.6533 & 0.5221 & 0 & 0.3951 & 0.6953 & 0.3318 & 0.4408 \\ 0.3307 & 0.7138 & 0.6049 & 0 & 0.2202 & 0.3820 & 0.3049 \\ 0.4726 & 0.4576 & 0.3047 & 0.7798 & 0 & 0.6772 & 0.5206 \\ 0.5543 & 0.4532 & 0.6682 & 0.6180 & 0.3228 & 0 & 0.5442 \\ 0.4791 & 0.4618 & 0.5592 & 0.6951 & 0.4794 & 0.4558 & 0 \end{bmatrix}$$

From the result of collective preference relation, the matrix is used to be the initial direct relation matrix in the beginning of DEMATEL steps. The purpose of using collective preference relation as the initial direct matrix is because the value of P^c consists of all aggregated opinion on the criteria. In order to achieve the objective of this study, which is to visualize the cause and effect of criteria, therefore, the collective preference relation P^c is the best and suitable matrix to be represented as the initial direct-relation matrix, X.

Then, the normalized direct-relation matrix, N and the total relation matrix, T are determined and presented as in the following matrices:

$$N = \begin{bmatrix} 0 & 0.1151 & 0.1097 & 0.2118 & 0.1669 & 0.1410 & 0.1648 \\ 0.2013 & 0 & 0.1512 & 0.0905 & 0.1716 & 0.1730 & 0.1703 \\ 0.2067 & 0.1652 & 0 & 0.1250 & 0.2200 & 0.1050 & 0.1395 \\ 0.1046 & 0.2258 & 0.1914 & 0 & 0.0697 & 0.1209 & 0.0965 \\ 0.1495 & 0.1448 & 0.0964 & 0.2467 & 0 & 0.2143 & 0.1647 \\ 0.1754 & 0.1434 & 0.2114 & 0.1955 & 0.1021 & 0 & 0.1722 \\ 0.1516 & 0.1461 & 0.1769 & 0.2199 & 0.1517 & 0.1442 & 0 \end{bmatrix}$$

$$T = \begin{bmatrix} 0 & 0.2737 & 0.2582 & 0.5770 & 0.3762 & 0.3207 & 0.3805 \\ 0.5346 & 0 & 0.3811 & 0.2529 & 0.4114 & 0.4210 & 0.4716 \\ 0.5485 & 0.4206 & 0 & 0.3516 & 0.5346 & 0.2498 & 0.3380 \\ 0.2330 & 0.5084 & 0.4226 & 0 & 0.1391 & 0.2488 & 0.1987 \\ 0.4041 & 0.3808 & 0.2482 & 0.7415 & 0 & 0.5455 & 0.4164 \\ 0.4726 & 0.3723 & 0.5555 & 0.5725 & 0.2449 & 0 & 0.4311 \\ 0.4019 & 0.3766 & 0.4561 & 0.6427 & 0.3656 & 0.3520 & 0 \end{bmatrix}$$

The formation of cause-effect diagram is beneficial in presenting the value of the influence effect and the interdependence relationship between the criteria or factors. Besides, the criteria or factors are classified as the causal or effected influence based on the analysis of the visualization of a cause-effect diagram and the visual relationship among the criteria or factors [20].

The sum of rows and columns are determined in order to present the structural correlation between criteria. The results are shown in Table 1 below.

Table 1. The Sum of Influence Cause and Effect on Seven (7) Criteria

Criteria	D	R	$D+R$	$D-R$
C_1	2.1863	2.5946	4.7809	-0.4083
C_2	2.4185	2.3324	4.7509	0.0860
C_3	2.4432	2.3217	4.7649	0.1215
C_4	1.7505	3.1383	4.8888	-1.3877
C_5	2.7366	2.0718	4.8084	0.6648
C_6	2.6489	2.1378	4.7867	0.5111
C_7	2.5949	2.1823	4.7773	0.4126

The cause-effect diagram can be constructed by utilizing values of $D+R$ as the horizontal axis (x-axis) and $D-R$ as the vertical axis (y-axis). Thus, the cause-effect diagram based on the 7 criteria is shown in Figure 2.

Based on Table 1 and Figure 2, the criteria that represent the net cause are C_2, C_3, C_5, C_6 and C_7, due to the positive values of $D-R$. While C_1 and C_4 are represented as the net effect because they have negative values in $D-R$. With value 0.6648, which is the highest value of $D-R$, C_5 becomes the most influencing criteria. Otherwise, C_4 has the lowest $D-R$ priority of −1.3877, indicates that C_4 is the most easily influenced by other criteria.

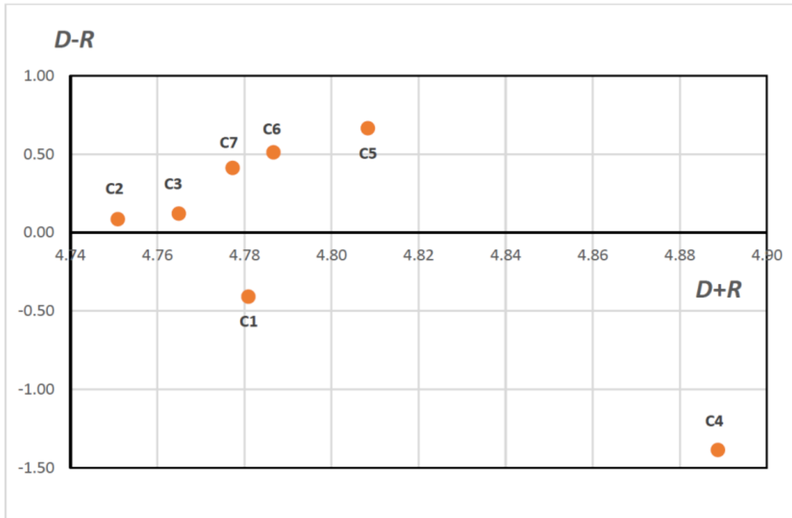

Figure 2. The cause-effect diagram of 7 criteria

The ranking of criteria can be obtained based on the values of $D+R$. The higher the value of $D+R$, the higher the ranking of importance of criteria in the decision making process. The ranking of importance of criteria is shown in Table 2 below:

Table 2. Ranking of importance of criteria

Rank	Criteria	D_i+R_j
1	C_4	4.8888
2	C_5	4.8084
3	C_6	4.7867
4	C_1	4.7809
5	C_7	4.7773
6	C_3	4.7649
7	C_2	4.7509

Based on the degree of importance in Table 2, C_4 is the most important criteria, while C_2 is the least important criteria. The ranking of all criteria in descending order is given as:

$$C_4 \succ C_5 \succ C_6 \succ C_1 \succ C_7 \succ C_3 \succ C_2.$$

Analysis of Methods

In the context of this study's scope, we present a methodology analysis that elucidates the strengths and drawbacks of the researches introduced by Kamis *et al*. [8], the DEMATEL approach, and our hybrid model, as shown in Table 3 below:

Table 3. The Analysis of Related Approaches

Methods	Drawbacks	Strengths
Similarity-Influence-Network [8]	No visualisation of criteria interdependencies	The importance of experts is determined by the influence degree.
DEMATEL	Direct evaluation of influence.	Able to visualize the structure of causal interactions or relationships of factors
Our hybrid model	Intricate steps	• The evaluation of criteria inter-relations is performed by the influence-based collective preferences. • Visualisation of criteria interdependencies are presented.

Based on the drawback in [8], the absence of visual representation of interdependencies between criteria or factors can hinder understanding and decision-making processes. Decision-makers may find it challenging to grasp the complex relationships and interactions between different criteria without a visual aid.In DEMATEL, the drawback lies in the direct evaluation, where it may overlook crucial connections between different elements, potentially leading to biased or incomplete assessments of influence.

Our hybrid model assesses criteria interrelations by synthesizing the collective preferences shaped by the insights and expertise of decision-makers. This collaborative approach ensures that relevant factor, such as influence is considered and weighed appropriately, leading to more robust decision-making outcomes. In addition, it offers the notable advantage of visually representing the interdependencies among criteria. Through graphical representations or diagrams, decision-makers gain a clear and intuitive depiction of how various criteria or factors interact with one another. This visual aid serves as a powerful tool for comprehension, allowing decision-makers to visualize intricate patterns, detect trends, and identify dependencies within the decision-making framework.

We can conclude that the proposed model has advantages in terms of accuracy of influence representation and visualizing interdependencies among criteria. However, it entails complex steps in its methodology, as anticipated for a hybridization of two approaches.

Conclusions and Future Works

In this study, we achieved the main objective, which overcomes the drawback of Kamis *et al*. [8] work. The extension of similarity-influence-network GDM methodology considers certain parts of DEMATEL procedure in visualization of the interdependent relationship of criteria. Some additional steps are introduced for the purpose of improving the existing approach. The cause-effect diagram is presented in order to analyze the structural correlation among 7 criteria involved.

The improvement proposed in this research provides an alternative procedure in Social Influence Group Decision Making (SIGDM) processes. However, this work is still possible to be further explored. Other visualization techniques can be utilized, for examples; the multi-dimensional scaling (MDS) or clustering algorithms. In addition, real-life applications can be used in implementing the proposed model.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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