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A Novel Hybrid MCDM Model Combined with DEMATEL and ANP with Applications

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Abstract —In multiple criteria decision making (MCDM) methods, the analytic network process (ANP) is used to overcome the problems of interdependence and feedback between criteria or alternatives. The ANP method currently deals with normalization in the supermatrix by assuming each cluster has equal weight. Although the method to normalize the supermatrix is easy, it ignores the different effects among clusters. Therefore, we propose a novel hybrid MCDM model combined with DEMATEL and ANP to solve the dependence and feedback problems to suit the real world. In addition, we also give an example to illustrate the proposed method with applications thereof. The results show the proposed method is more suitable in real world applications than the traditional ones.

Keywords —Analytic network process (ANP), DEMATEL, Multiple criteria decision making (MCDM)

1. INTRODUCTION

The analytic hierarchy process (AHP) was proposed by Saaty (1980). It has been widely used in multiple criteria decision making (MCDM) to evaluate/select alternatives for many years. However, using the AHP must assume that the information sources involved are non-interactive/ independent. This assumption is not realistic in many real-world applications. In order to solve this problem, Saaty (1996) proposed a new MCDM method, the ANP, to overcome the problems of interdependence and of feedback between criteria and alternatives in the real world. The ANP is an extension of the AHP; indeed, it is the general form of the AHP. The ANP handles dependence within a cluster (inner dependence) and among different clusters (outer dependence). The ANP is a nonlinear structure, while the AHP is hierarchical and linear with the goal at the top and the alternatives at lower levels (Saaty (1999)). The ANP has been applied successfully in many practical decision-making problems, such as project selection, product planning, green supply chain management, and optimal scheduling problems (Meade and Presley (2002), Lee and Kim (2000), Karsak et al. (2002), Sarkis (2003), Momoh and Zhu (2003)).

In ANP procedures, the initial step is to compare the criteria in the whole system to form an unweighted supermatrix by pairwise comparisons. Then the weighted supermatrix is derived by transforming each column to sum exactly to unity (1.00). Each element in a column is divided by the number of clusters so each column will sum to unity exactly. Using this normalization method implies each cluster has the same weight. However, using the assumption of equal weight for each cluster to obtain the weighted supermatrix seems to be irrational because there are different degrees of influence among the criteria. Thus, the purpose of this paper is to establish a model to overcome the problems of interdependence and feedback between criteria and alternatives in the real world. This study adopts the DEMATEL (Decision Making Trial and Evaluation Laboratory) method to determine the degrees of influence of these criteria and applies these to normalize the unweighted supermatrix in the ANP. In practice, the DEMATEL method (Fontela and Gabus (1974, 1976); Warfield (1976)) is applied to illustrate the interrelations among criteria and to find the central criteria to represent the effectiveness of factors/aspects. It has also been successfully applied in many situations, such as marketing strategies, control systems, safety problems, developing the competencies of global managers and group decision-making (Chiu et al. (2006), Hori and Shimizu (1999), Liou et al. (2007), Wu and Lee (2007), Lin and Wu (2008)). Furthermore, a hybrid model combining the two methods has been widely used in various fields, for example, e-learning evaluation (Tzeng et al. (2007)), airline safety measurement (Liou et al. (2007)), and innovation policy portfolios for Taiwan's SIP Mall (Huang and Tzeng (2007)).

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Therefore, in this paper we use DEMATEL not only to detect complex relationships and build an impact-relation map (IRM) of the criteria, but also to obtain the influence levels of each element over others; we then adopt these influence level values as the basis of the normalization supermatrix for determining ANP weights to obtain the relative importance.

In conclusion, the contribution of this study is to propose a novel method which combines the DEMATEL and ANP procedures to deal with the problems of criteria interdependence and feedback. We also illustrate a numerical example to show the steps of the proposed method with applications thereof. The results show this method not only deals with the problems of interdependence and feedback but also improves the normalized supermatrix to suit the real world.

The remainder of this paper is organized as follows. Section 2 describes the hybrid model. A numerical example with applications is illustrated in Section 3. Discussions and conclusions are presented in Section 4 and Section 5, respectively.

2. A HYBRID MCDM MODEL

According to above descriptions, a hybrid MCDM model combined with DEMATEL and ANP for evaluating and improving problems is more suitable in the real world than the previously available methods. The procedures of this hybrid MCDM model, a combination of the DEMATEL and ANP procedures, are shown and explained briefly as follows (Figure 1).

2.1. Dematel

The DEMATEL method is used to construct the interrelations between criteria to build an IRM. The method can be summarized as:

Step 1: *Calculate the initial average matrix by scores*. In this step, respondents are asked to indicate the degree of direct influence each factor/element i exerts on each factor/element j, which is denoted by α_{ij}. We assume that the scales 0, 1, 2, 3 and 4 represent the range from "no influence" to "very high influence". Each respondent would produce a direct matrix, and an average matrix A is then derived through the mean of the same factors/elements in the various direct matrices of the respondents. The average matrix A is represented as following equation:

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1j} & \cdots & a_{1n} \\ \vdots & & \vdots & & \vdots \\ a_{i1} & \cdots & a_{ij} & \cdots & a_{in} \\ \vdots & & \vdots & & \vdots \\ a_{n1} & \cdots & a_{nj} & \cdots & a_{nn} \end{bmatrix} \quad (1)$$

Step 2: *Calculate the initial influence matrix*. The initial direct influence matrix X ($X = [x_{ij}]_{n \times n}$) can be obtained by normalizing the average matrix A. Specifically, the matrix X can be obtained through Eq. (2) and (3), in which all principal diagonal elements are equal to zero.

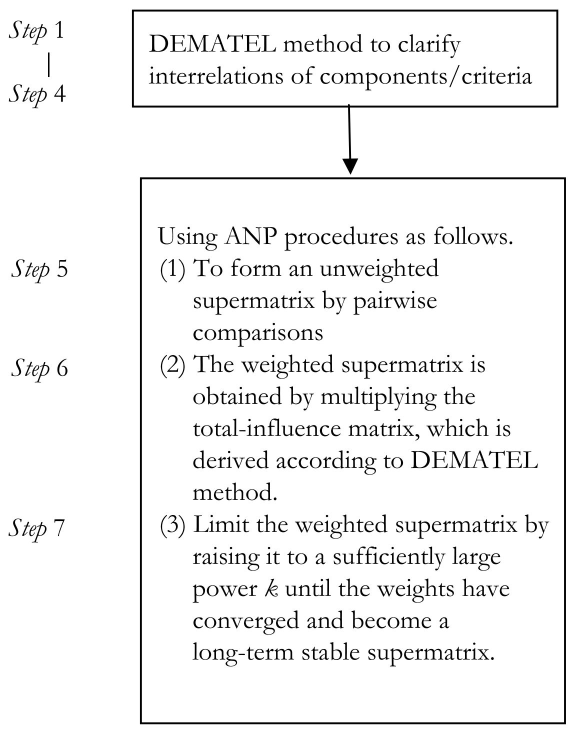

Figure 1. Hybrid MCDM model procedures.

$$X = s \times A \quad (2)$$

$$s = \min\left[\frac{1}{\max_{i}\sum_{j=1}^{n}|a_{ij}|}, \frac{1}{\max_{j}\sum_{i=1}^{n}|a_{ij}|}\right] \quad (3)$$

Step 3: *Derive the full direct/indirect influence matrix.* A continuous decrease of the indirect effects of problems along the powers of X e.g., X^2, X^3, ..., X^k and $\lim_{k\to\infty} X^k = [0]_{n\times n}$, where $X = [x_{ij}]_{n\times n}$, $0 \le x_{ij} < 1$ and $0 \le \sum_i x_{ij}$ or $\sum_j x_{ij} < 1$ only one column or one row sum equals 1. The total-influence matrix is listed as follows.

$$\begin{aligned} T &= X + X^2 + \cdots + X^k \\ &= X\left(I + X + X^2 + \cdots + X^{k-1}\right)(I-X)(I-X)^{-1} \\ &= X(I - X^k)(I-X)^{-1}, \end{aligned}$$

then $T = X(I-X)^{-1}$ when

$$\lim_{k\to\infty} X^k = [0]_{n\times n} \quad (4)$$

where $T = [t_{ij}]_{n\times n}$, $i, j = 1, 2, ..., n$. In addition, the method presents each row sum and column sum of matrix ***T***.

$$r = (r_i)_{n\times 1} = \left[\sum_{j=1}^{n} t_{ij}\right]_{n\times 1} \quad (5)$$

$$c = (c_j)_{n\times 1} = (c_j)'_{1\times n} = \left[\sum_{i=1}^{n} t_{ij}\right]'_{1\times n} \quad (6)$$

where r_i denotes the row sum of the i th row of matrix T and shows the sum of direct and indirect effects of factor/element i on the other factors/elements. Similarly, c_j denotes the column sum of the j th column of matrix T and shows the sum of direct and indirect effects that factor/element j has received from the other factors/criteria. In addition, when $i = j$ (i.e., the sum of the row and column aggregates) $(r_i + c_i)$ provides an index of the strength of influences given and received, that is, $(r_i + c_i)$ shows the degree of the central role that factor i plays in the problem. If $(r_i + c_i)$ is positive, then factor i is affecting other factors, and if $(r_i + c_i)$ is negative, then factor i is being influenced by other factors (Tamura et al. (2002), Tzeng et al. (2007)).

Step 4: *Set a threshold value and obtain the IRM.* Setting a threshold value α, to filter the minor effects denoted by the factors of matrix T is necessary to isolate the relation structure of the factors. Based on the matrix T, each factor t_{ij} of matrix T provides information about how factor i affects factor j. In practice, if all the information from matrix T converts to the IRM, the map would be too complex to show the necessary information for decision making. In order to reduce the complexity of the IRM, the decision-maker sets a threshold value for the influence level: only factors whose influence value in matrix T is higher than the threshold value can be chosen and converted into the IRM. The threshold value can be decided through the brainstorming of experts. When the threshold value and relative IRM have been decided, the IRM can be shown.

In order to illustrate clearly the procedures of the DEMATEL method, this study proposes a case (Case 1). We assume Case 1 has 3 factors, Cluster 1, Cluster 2 and Cluster 3 (here, "factor" could be "element", "cluster" or "criterion"; however, in order to illustrate the following steps in the ANP procedures, we replace "factors" with "clusters"). First, we operate from *Step* 1 to *Step* 4 above to derive the total-influence matrix T; then we set a threshold value α, to filter the minor effects in the elements of matrix T, as in Eq. (7). If the circled parts are higher than the value of α in the following equation, then their IRM can be shown, as in Figure 2.

$$T = \begin{array}{c} \\ c_1 \\ c_2 \\ c_3 \end{array}\!\!\begin{array}{c} \begin{array}{ccc} c_1 & c_2 & c_3 \end{array} \\ \begin{bmatrix} t_{11} & t_{12} & t_{13} \\ t_{21} & t_{22} & t_{23} \\ t_{31} & t_{32} & t_{33} \end{bmatrix} \end{array} \quad (7)$$

We will use the following steps of the ANP method to overcome the problem of interdependence and feedback between criteria.

2.2. The ANP

The ANP is the general form of the analytic hierarchy process (AHP) (Saaty (1980)) which has been used in multicriteria decision making (MCDM) to release the restriction of hierarchical structure. The method can be described in the following steps.

Step 5: *Compare the criteria in the whole system to form the supermatrix.* The original supermatrix of column eigenvectors is obtained from pairwise comparison matrices of elements. This is done through pairwise comparisons by asking "How much importance/influence does a criterion have compared to another criterion with respect to our interests or preferences?" The relative importance value can be determined using a scale of 1 to 9 to represent equal importance to extreme importance (Saaty (1980 and 1996)). The general form of the supermatrix can be described as follows:

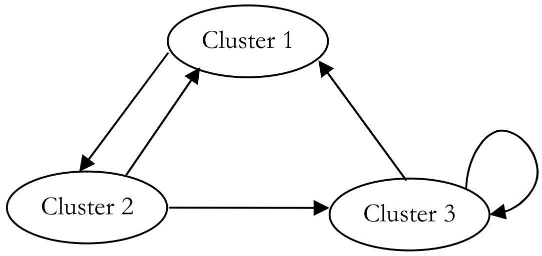

Figure 2. The structure of Case 1.

$$W = \begin{array}{c} \\ \\ C_1 \begin{array}{c} e_{11} \\ e_{12} \\ \vdots \\ e_{1m_1} \end{array} \\ C_2 \begin{array}{c} e_{21} \\ e_{22} \\ \vdots \\ e_{2m_2} \end{array} \\ \vdots \\ C_n \begin{array}{c} e_{n1} \\ e_{n2} \\ \vdots \\ e_{nm_n} \end{array} \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & & C_n \\ e_{11}\ldots e_{1m_1} & e_{21}\ldots e_{2m_2} & \ldots\ldots & e_{n1}\ldots e_{nm_n} \end{array} \\ \begin{bmatrix} W_{11} & W_{12} & \cdots & W_{1n} \\ W_{12} & W_{22} & \cdots & W_{2n} \\ \vdots & \vdots & \vdots\vdots\vdots & \vdots \\ W_{n1} & W_{n2} & \cdots & W_{nn} \end{bmatrix} \end{array} \tag{8}$$

where C_n denotes the *n*th cluster, e_{nm} denotes the *m*th element in the *n*th cluster, and W_{ij} is the principal eigenvector of the influence of the elements in the *j*th cluster compared to the *i*th cluster. In addition, if the *j*th cluster has no influence on the *i*th cluster, then $W_{ij} = [0]$.

Step 6: *Obtain the weighted supermatrix by multiplying the normalized matrix*, which is derived according to the DEMATEL method. The traditional method is used to derive the weighted supermatrix by transforming each column to sum exactly to unity. Each element in a column is divided by the number of clusters so each column will sum to unity exactly. Using this normalization method implies each cluster has the same weight. However, we know the effect of each cluster on the other clusters may be different, as described in Section 2.1. Therefore, using the assumption of equal weight for each cluster to obtain the weighted supermatrix is irrational. This study adopts the DEMATEL method to solve this problem. First, we use the DEMATEL method (Section 2.1) to derive the IRM. Next, this study uses the total-influence matrix T and a threshold value α to generate a new matrix. The values of the clusters in matrix T are reset to zero if their values are less than α, i.e., they have a lower influence on the clusters if their values are less than α, the value of which is decided by decision-makers or experts. The new matrix with α-cut is called the α-cut total-influence matrix T_α, as Eq. (9).

$$T_\alpha = \begin{bmatrix} t_{11}^\alpha & \cdots & t_{1j}^\alpha & \cdots & t_{1n}^\alpha \\ \vdots & & \vdots & & \vdots \\ t_{i1}^\alpha & \cdots & t_{ij}^\alpha & \cdots & t_{in}^\alpha \\ \vdots & & \vdots & & \vdots \\ t_{n1}^\alpha & \cdots & t_{nj}^\alpha & \cdots & t_{nn}^\alpha \end{bmatrix} \quad \longrightarrow \quad d_1 = \sum_{j=1}^{n} t_{1j}^\alpha \tag{9}$$

where if $t_{ij} < \alpha$, then $t_{ij}^\alpha = 0$ else $t_{ij}^\alpha = t_{ij}$, and t_{ij} is in the total-influence matrix T. The α-cut total-influence matrix T_α needs to be normalized by dividing by the following formula.

$$d_i = \sum_{j=1}^{n} t_{ij}^\alpha \tag{10}$$

Therefore, we could normalize the α-cut total-influence matrix and represent it as T_s.

$$T_s = \begin{bmatrix} t_{11}^\alpha / d_1 & \cdots & t_{1j}^\alpha / d_1 & \cdots & t_{1n}^\alpha / d_1 \\ \vdots & & \vdots & & \vdots \\ t_{i1}^\alpha / d_i & \cdots & t_{ij}^\alpha / d_i & \cdots & t_{in}^\alpha / d_i \\ \vdots & & \vdots & & \vdots \\ t_{n1}^\alpha / d_3 & \cdots & t_{nj}^\alpha / d_3 & \cdots & t_{nn}^\alpha / d_3 \end{bmatrix} = \begin{bmatrix} t_{11}^s & \cdots & t_{1j}^s & \cdots & t_{1n}^s \\ \vdots & & \vdots & & \vdots \\ t_{i1}^s & \cdots & t_{ij}^s & \cdots & t_{in}^s \\ \vdots & & \vdots & & \vdots \\ t_{n1}^s & \cdots & t_{nj}^s & \cdots & t_{nn}^s \end{bmatrix} \tag{11}$$

where $t_{ij}^s = t_{ij}^\alpha / d_i$. This study adopts the normalized α-cut total- influence matrix T_s (hereafter abbreviated to "the normalized matrix") and the unweighted supermatrix W using Eq. (12) to calculate the weighted supermatrix W_w. Eq. (12) shows these influence level values as the basis of the normalization for determining the weighted supermatrix.

$$W_w = \begin{bmatrix} t_{11}^s \times W_{11} & t_{21}^s \times W_{12} & \cdots & \cdots & t_{n1}^s \times W_{1n} \\ t_{12}^s \times W_{21} & t_{22}^s \times W_{22} & \vdots & & \vdots \\ \vdots & \cdots & t_{ji}^s \times W_{ij} & \cdots & t_{ni}^s \times W_{in} \\ \vdots & & \vdots & & \vdots \\ t_{1n}^s \times W_{n1} & t_{2n}^s W_{n2} & \cdots & \cdots & t_{nn}^s \times W_{nn} \end{bmatrix} \tag{12}$$

Step 7: *Limit the weighted supermatrix by raising it to a sufficiently large power k*, as Eq. (13), until the supermatrix has converged and become a long-term stable supermatrix to get the global priority vectors or called weights.

$$\lim_{k\to\infty} W_w^k \tag{13}$$

If the limiting supermatrix is not the only one, such as if there are N supermatrices, the average of the values is obtained by adding the N supermatrices and dividing by N.

This study demonstrates an example to illustrate the above steps. We continue to use the structure in Figure 2. to demonstrate *Step* 5 to *Step* 7. First, if the unweighted supermatrix is described by the following equation

$$W = \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \end{array} \begin{array}{c} \begin{array}{ccc} C_1 & C_2 & C_3 \end{array} \\ \begin{bmatrix} 0 & W_{12} & W_{13} \\ W_{21} & 0 & 0 \\ 0 & W_{32} & W_{33} \end{bmatrix} \end{array} \tag{14}$$

then the α-cut total-influence matrix T_α, as in Eq. (9), is

$$T_\alpha = \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \end{array} \begin{array}{c} \begin{array}{ccc} C_1 & C_2 & C_3 \end{array} \\ \begin{bmatrix} 0 & t_{12} & 0 \\ t_{21} & 0 & t_{23} \\ t_{31} & 0 & t_{33} \end{bmatrix} \end{array} \begin{array}{c} \\ \rightarrow d_1 \\ \rightarrow d_2 \\ \rightarrow d_3 \end{array} \tag{15}$$

Then $d_i = \sum_{j=1}^{3} t_{ij}$ is used to divide its rows, as in the following matrix T_s.

$$T_s = \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \end{array} \begin{array}{c} \begin{array}{ccc} C_1 & C_2 & C_3 \end{array} \\ \begin{bmatrix} 0 & 1 & 0 \\ t_{21}/d_2 & 0 & t_{23}/d_2 \\ t_{31}/d_3 & 0 & t_{33}/d_3 \end{bmatrix} \end{array} = \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \end{array} \begin{array}{c} \begin{array}{ccc} C_1 & C_2 & C_3 \end{array} \\ \begin{bmatrix} 0 & 1 & 0 \\ t_{21}^s & 0 & t_{23}^s \\ t_{31}^s & 0 & t_{33}^s \end{bmatrix} \end{array}$$

(The normalized matrix T_s)

Next, we adopt the normalized matrix T_s and the unweighted supermatrix W and use Eq. (12) to calculate the weighted supermatrix W_w, as Eq. (16)

$$W_w = \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \end{array} \begin{array}{c} \begin{array}{ccc} C_1 & C_2 & C_3 \end{array} \\ \begin{bmatrix} 0 & t_{21}^s W_{12} & t_{31}^s W_{13} \\ W_{21} & 0 & 0 \\ 0 & t_{23}^s W_{32} & t_{33}^s W_{33} \end{bmatrix} \end{array} \tag{16}$$

Finally, the weighted supermatrix W_w is limited until it has converged and become a long-term stable supermatrix, as in Eq. (13). In addition, if the limiting supermatrix is not the only one, for example if $N = 3$ and $\lim_{k\to\infty} W_w^k = \{W^1,\ W^2,\ W^3\}$, the final weighted limiting supermatrix is presented as the following matrix:

$$W_f = \frac{1}{3}W^1 + \frac{1}{3}W^2 + \frac{1}{3}W^3 \tag{17}$$

In short, a stable limiting supermatrix can be derived using the above steps. The overall priorities are also obtained. This aim of this paper is to propose a feasible model which combines the DEMATEL and ANP procedures to deal with the problem of interdependence and feedback among the subsystems/criteria; the proposed model described above is more suitable and rational in real world applications than the traditional method.

3. NUMERICAL EXAMPLE WITH APPLICATION

In this section, we provide a numerical example with application to demonstrate the proposed method. We construct the network structure using the DEMATEL procedures, i.e., from *Step* 1 to *Step* 4. Next, we calculate the limited supermatrix using *Step* 5 to *Step* 7 to obtain the weights of the features in the network structure of the ANP.

We assume a simple example (Case 2) for DEMATEL *Step* 1 to *Step* 3 to obtain the total-influence matrix T, as Table 1. Using *Step* 4, if a threshold value of 0.1 is chosen, then the IRM of the relations is as listed in Figure 3.

Table 1. The total-influence matrix T of Case 2

	Cluster 1	Cluster 2
Cluster 1	0.1	3
Cluster 2	0.4	0.1

We know the degrees of influence of Cluster 1 and Cluster 2 on each other are different from Table 1. Therefore, using the traditional normalized method is irrational. In this research, we combine the DEMATEL method, which is used to obtain the normalized matrix T_s, and the ANP method to solve this problem. In this case, we first normalize the total-influence matrix T, as in Table 2.

Table 2. The normalized matrix T_s of Case 2

	Cluster 1	Cluster 2
Cluster 1	0.032	0.968
Cluster 2	0.800	0.200

According to the IRM of relations obtained above (Figure 3), we assume Cluster 1 has 3 elements/criteria, *C*, *R* and *D*, and Cluster 2 has *A*, *E*, *J*. They are shown in Figure 4.

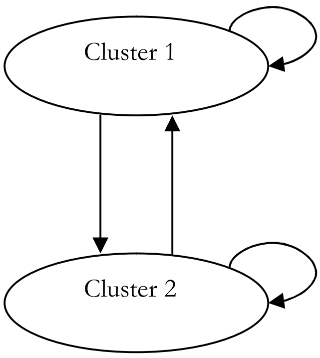

Figure 3. The IRM of relations in Case 2.

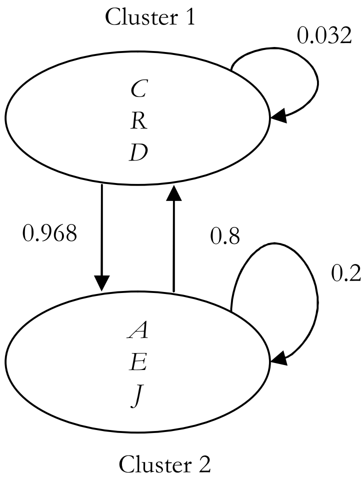

Figure 4. The structure of Case 2.

Then, using the structure of Case 2 as in Figure 4, we can obtain the unweighted supermatrix (here, we assume a loop for the element/criterion by simply connecting each element/criterion to itself on Cluster 1 and Cluster 2) as follows.

$$
\begin{array}{cc|ccc|ccc|c}
 & & C & R & D & A & E & J & \\
\hline
 & C & 1 & 0 & 0 & 0.634 & 0.25 & 0.4 & \\
W_{11} & R & 0 & 1 & 0 & 0.192 & 0.25 & 0.2 & W_{12} \\
 & D & 0 & 0 & 1 & 0.174 & 0.5 & 0.4 & \\
\hline
 & A & 0.637 & 0.582 & 0.105 & 1 & 0 & 0 & \\
W_{21} & E & 0.105 & 0.109 & 0.637 & 0 & 1 & 0 & W_{22} \\
 & J & 0.259 & 0.309 & 0.258 & 0 & 0 & 1 & \\
\end{array}
$$

Next, the weighted supermatrix is obtained by Eq. (12), as below.

$$
W_w = \begin{array}{c} \\ C \\ R \\ D \\ A \\ E \\ J \end{array}
\begin{array}{c}
\begin{array}{cccccc} C & R & D & A & E & J \end{array} \\
\begin{bmatrix}
0.032 & 0.000 & 0.000 & 0.507 & 0.200 & 0.320 \\
0.000 & 0.032 & 0.000 & 0.154 & 0.200 & 0.160 \\
0.000 & 0.000 & 0.032 & 0.139 & 0.400 & 0.320 \\
0.616 & 0.563 & 0.102 & 0.200 & 0.000 & 0.000 \\
0.102 & 0.106 & 0.616 & 0.000 & 0.200 & 0.000 \\
0.250 & 0.299 & 0.250 & 0.000 & 0.000 & 0.200
\end{bmatrix}
\end{array} \tag{18}
$$

Finally, using Eq. (13) to obtain the limiting supermatrix W_f, the weights are as follows.

$$W_f = \begin{array}{c} \\ C \\ R \\ D \\ A \\ E \\ J \end{array} \begin{array}{c} \begin{array}{cccccc} C & R & D & A & E & J \end{array} \\ \begin{bmatrix} 0.212 & 0.212 & 0.212 & 0.212 & 0.212 & 0.212 \\ 0.096 & 0.096 & 0.096 & 0.096 & 0.096 & 0.096 \\ 0.149 & 0.149 & 0.149 & 0.149 & 0.149 & 0.149 \\ 0.250 & 0.250 & 0.250 & 0.250 & 0.250 & 0.250 \\ 0.154 & 0.154 & 0.154 & 0.154 & 0.154 & 0.154 \\ 0.149 & 0.149 & 0.149 & 0.149 & 0.149 & 0.149 \end{bmatrix} \end{array} \tag{19}$$

In order to compare the traditional methods and this research, we also calculate the weighted supermatrix and the limiting supermatrix using the traditional normalized method; the results are presented in Eq. (20) and (21), respectively. In Eq. (20), we find all feedback values are 0.5 (because each cluster use the same weight), which is unsuitable in a real-world situation. Therefore, our method adopts these influence level values as the basis of the normalization to adjust the weighted supermatrix to obtain a suitable weighted supermatrix, as Eq. (18).

$$W_w^{tra} = \begin{array}{c} \\ C \\ R \\ D \\ A \\ E \\ J \end{array} \begin{array}{c} \begin{array}{cccccc} C & R & D & A & E & J \end{array} \\ \begin{bmatrix} 0.500 & 0.000 & 0.000 & 0.317 & 0.125 & 0.200 \\ 0.000 & 0.500 & 0.000 & 0.096 & 0.125 & 0.100 \\ 0.000 & 0.000 & 0.500 & 0.087 & 0.250 & 0.200 \\ 0.318 & 0.291 & 0.053 & 0.500 & 0.000 & 0.000 \\ 0.052 & 0.055 & 0.319 & 0.000 & 0.500 & 0.000 \\ 0.129 & 0.155 & 0.129 & 0.000 & 0.000 & 0.500 \end{bmatrix} \end{array} \tag{20}$$

$$W_f^{tra} = \begin{array}{c} \\ C \\ R \\ D \\ A \\ E \\ J \end{array} \begin{array}{c} \begin{array}{cccccc} C & R & D & A & E & J \end{array} \\ \begin{bmatrix} 0.232 & 0.232 & 0.232 & 0.232 & 0.232 & 0.232 \\ 0.105 & 0.105 & 0.105 & 0.105 & 0.105 & 0.105 \\ 0.163 & 0.163 & 0.163 & 0.163 & 0.163 & 0.163 \\ 0.226 & 0.226 & 0.226 & 0.226 & 0.226 & 0.226 \\ 0.140 & 0.140 & 0.140 & 0.140 & 0.140 & 0.140 \\ 0.135 & 0.135 & 0.135 & 0.135 & 0.135 & 0.135 \end{bmatrix} \end{array} \tag{21}$$

According to the above two matrices, we find the ranks of weights for the two matrices are different. In the next section, we provide a detailed discussion and comparisons between the abilities of the traditional method and the proposed method to cope with normalized problems in the ANP.

4. DISCUSSIONS AND COMPARISONS

In Eq. (19), using the DEMATEL method to normalize the unweighted supermatrix (our proposed method), the ranks of weights (the limiting supermatrix) are $A > C > E > J = D > R$. On the other hand, in Eq. (21), using the traditional normalized method, the ranks of weights are $C > A > D > E > J > R$. This study further analyses the weights obtained with the two different methods and shows them in Table 3 and Figure 5, respectively.

From Table 3 and Figure 5, the weights of elements *C*, *R*, and *D* in the traditional method are higher than in the proposed method, but the elements *A*, *E*, and *J* in the traditional method are lower than in the proposed method. Table 2 and Figure 4 reveal that the effect of Cluster 1 on Cluster 2 is 0.968 and the effect of Cluster 2 on Cluster 1 is 0.8. Therefore, Cluster 1 has a higher effect on Cluster 2 than Cluster 2 does on Cluster 1, which implies Cluster 2 is affected more than Cluster 1. Cluster 2 would then be paid more attention than Cluster 1 in the real world, i.e., it should have more weight than Cluster 1. Thus, if we use the assumption of equal weight for each cluster to normalize the unweighted supermatrix to gain the weighted supermatrix, the results of the assessed weights would be higher or lower than the real situation. Figure 5 shows the elements of Cluster 2 (*A*, *E*, *J*) are under-estimated, whereas the elements of Cluster 1 (*C*, *R*, *D*) are over-estimated if we adopt the traditional method. Therefore, we use the DEMATEL method combined with the ANP to obtain better and more accurate results in real world applications.

To sum up, the hybrid model combining the ANP and DEMATEL have been widely used in MCDM. The DEMATEL method is used to construct interrelations between criteria/factors, and the ANP can overcome the problems of dependence and feedback. However, using the assumption of equal weight in each cluster in the procedures of the ANP is irrational. This study adopts the normalized matrix of DEMATEL to improve this problem. Several examples are demonstrated to illustrate this proposed method, and the results show this method is suitable and effective.

Table 3. Comparisons of weights of each element between the traditional hybrid method and our proposed method

Elements	Traditional hybrid method	The proposed method	Difference
C	0.232	0.212	0.020
R	0.105	0.096	0.009
D	0.163	0.149	0.014
A	0.226	0.250	(0.024)*
E	0.14	0.154	(0.014)*
J	0.135	0.149	(0.014)*

*: Parentheses represent negative values.

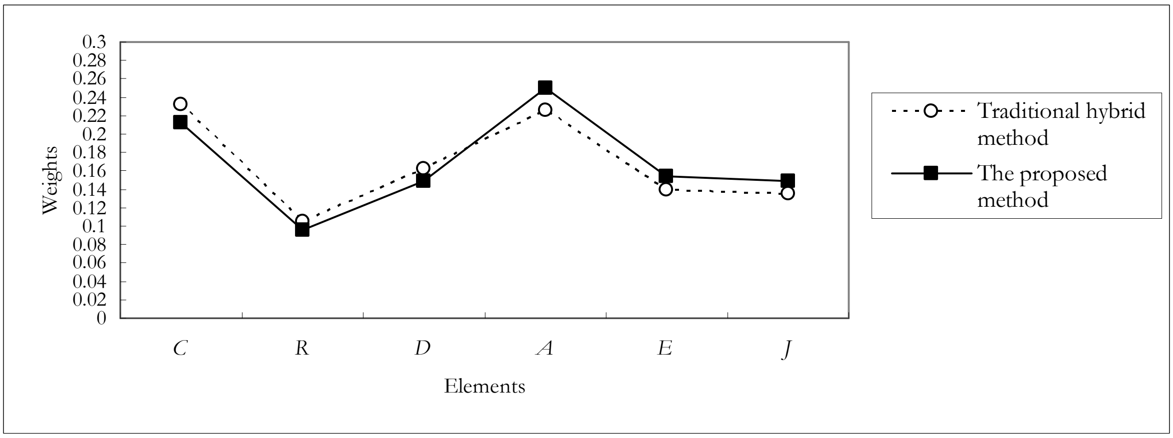

Figure 5. Comparisons of weights of each element between the traditional hybrid method and our proposed method.

5. CONCLUSIONS

Most decision-making methods assume independence between the criteria of a decision and the alternatives of that decision, or simply among the criteria or among the alternatives themselves. However, assuming independence among criteria/variables is too strict to overcome the problem of dependent criteria. Therefore, many papers have discussed ways to overcome this problem. The ANP is not limited by independent assumptions; it is used to deal with problems which have dependent criteria. On the other hand, the DEMATEL method is used to detect complex relationships and build the IRM of relations among criteria. The methodology can confirm interdependence among variables/criteria and restrict the relations that reflect characteristics within an essential systemic and developmental trend. The hybrid model of the two methods has been widely used in various fields. However, the method with the assumption of equal weight for each cluster is adopted to overcome normalization for the weighted supermatrix, which ignores the different effects among clusters. This research proposes a new concept to overcome this irrational situation. We adopt the normalized matrix, which is obtained by the DEMATEL method, to transform the unweighted supermatrix to a weighted supermatrix. The novel combined model is more suitable than the traditional method to solve problems with different degrees of effects among clusters. We also demonstrate two cases to illustrate the effectiveness and feasibility of the proposed method to suit real-world applications. Consequently, using the method proposed in this research is an appropriate approach to overcome the problem of interdependence and feedback among criteria.

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