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An integrated MCDM technique combined with DEMATEL for a novel cluster-weighted with ANP method

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A R T I C L E   I N F O

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A B S T R A C T

Traditionally, most importance-assessing methods used to demonstrate the importance among criteria by preference weightings are based on the assumptions of additivity and independence. In fact, people have found that using such an additive model is not always feasible because of the dependence and feedback among the criteria to somewhat different degrees. To solve the issue the analytic network process (ANP) method is proposed by Saaty. The general method is easy and useful for solving the above-mentioned problem. However in ANP procedures, using average method (equal cluster-weighted) to obtain the weighted supermatrix seems to be irrational because there are different degrees of influence among the criteria. Therefore, we intended to propose an integrated multiple criteria decision making (MCDM) techniques which combined with the decision making trial and evaluation laboratory (DEMATEL) and a novel cluster-weighted with ANP method in this paper, in which the DEMATEL method is used to visualize the structure of complicated causal relationships between criteria of a system and obtain the influence level of these criteria. And, then adopt these influence level values as the base of normalization supermatrix for calculating ANP weights to obtain the relative importance. Additionally, an empirical study is illustrated to demonstrate that the proposed method is more suitable and reasonable. By the concept of ideal point, some important conclusions drawn from a practical application can be referred by practitioners.

1. Introduction

Over the past two decades, numerous studies have been made on multiple criteria decision making (MCDM) analysis in various fields. Basically, the multiple criteria decision issue focuses mainly on distinguishing the evaluation criteria and on the determining the preference structure (i.e., weights). Since the results of evaluating and comparing alternatives are based on decision-makers' preference, the determination of preference structures is very important during the decision making process. If the criterion importance can be captured properly, the quality of decision making will be enhanced correspondingly. Conventionally, when importance-assessing methods are used to demonstrate the criterion importance, the manner of multi-criteria decision analysis is often based on the assumptions of additivity and independency. However, people have found that using such traditional methods (i.e., additive model) is not always proper because of the dependence and feedback among the criteria to somewhat different degrees in real world (Leung, Hui, & Zheng, 2003; Shee, Tzeng, & Tang, 2003). To solve this issue, analytic network process (ANP) was proposed in Saaty (Saaty, 1996, 2004; Saaty & Vargas, 1998) to overcome the problem of dependence and feedback among criteria or alternatives. The ANP is the general form of the analytic hierarchy process (AHP) (Saaty, 1980), which has been used for MCDM, to release the restriction of hierarchical structure, and has been applied to project selection (Lee & Kim, 2000; Meade & Presley, 2002), product planning, strategic decision (Karsak, Sozer, & Alptekin, 2003; Lin, Chiu, & Tsai, 2008; Sarkis, 2003), optimal scheduling (Momoh & Zhu, 2003) and strategic decision (Leung, Lam, & Cao, 2006; Wu & Lee, 2007a, 2007b). Lee and Kim (2000, 2001) used ANP to facilitate an information system project selection problem but made it more complicated due to the need to consider the interdependencies among criteria and candidate projects. ANP was also used successfully for the selection of various project alternatives in an agile manufacturing process.

However, in ANP procedures, the first phase of the ANP is to compare the criteria in whole system to form the unweighted supermatrix. The decision-maker is asked to answer the question like "How much importance does a criterion have compared to

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another criterion with respect to our interests or preferences?" After forming the supermatrix, the weighted supermatrix is derived by transforming all columns sum to unity exactly (i.e., using average method). Next, the weighted supermatrix is raised to limiting powers to get the global priorities or called weights. It seems to be irrational while the weighted supermatrix is obtained by using average method. Because there are have different influence levels among criteria based on network relationship map (NRM). If we utilize the average method (equal cluster-weighted) to calculate the final global priorities, the results of the assessed weights would be higher or lower than the real situation. To this end, the decision making trial and evaluation laboratory (DEMATEL) method (Fontela & Gabus, 1976) is introduced to build the structure of relationship map for clarifying the interrelations among sub-criteria of a criterion, as well as to visualize the causal relationship of sub-systems through a causal diagram. The original DEMATEL was aim at searching the fragmented and antagonistic phenomena of world societies for integrated solutions. In recent years, the DEMATEL method has become very popular in Japan because it is especially pragmatic to visualize the structure of complicated causal relationships. The diagraph portrays a basic concept of contextual relation among the criteria of the system, in which the numeral represents the strength of influence. The method has been successfully applied to various circumstances, for example, developing global managers' competencies (Wu & Lee, 2007a, 2007b), evaluating intertwined effects in e-learning programs (Tzeng, Chiang, & Li, 2007), airline safely measurement (Liou, Tzeng, & Chang, 2007), innovation Policy Portfolios for SIP mall industry (Huang & Tzeng, 2007), choice of knowledge management strategy (Wu, 2008), causal analytic method for group decision making (Lin & Wu, 2008), and selection management systems of SMEs (Tsai & Chou, 2009).

Therefore, in this paper an integrated MCDM technique combined DEMATEL and ANP methods is proposed to solve this problem for overcoming the problem of interdependence and feedback between criteria and alternatives. Also, this study uses the DEMATEL method to obtain the influence degree of these criteria, and it would be regarded as the based of normalization supermatrix for calculating ANP weights to obtain the relative importance. In addition, an empirical study is illustrated to demonstrate that the proposed method is more suitable. Furthermore, we employ the concept of ideal-point by setting aspired/desired levels to represent the gaps between the performance of the appropriate vendor and the aspired/desired levels of each criterion.

The remainder of this paper is organized as follows. In Section 2, we describe the concepts of DEMATEL and ANP methods in the proposed method. An empirical study is illustrated to demonstrate the proposed method is useful and suitable, and the results are addressed in Section 3. Discussions are presented in Section 4, and conclusions are presented in the last section.

2. Integrated methods combined DEMATEL and ANP

In this section, an integrated method, combined DEMATEL method, and a novel cluster-weighted ANP method is developed. The procedures that are used in the proposed method are described as follows.

2.1. The DEMATEL method

The DEMATEL method is based upon graph theory, enabling us to plan and solve problems visually, so that we may divide multiple criteria into a cause-and-effect group, to better understand causal relationships to plot a network relationship map. Directed graphs (also called digraphs) are more useful than directionless graphs, because digraphs will demonstrate the directed relationships of sub-systems. A digraph may typically represent a communication network, or some domination relationships between individuals. The methodology can confirm interdependence among variables/criteria and restrict the relations that reflect characteristics within an essential systemic and developmental trend (Chiu, Chen, Tzeng, & Shyu, 2006; Hori & Shimizu, 1999; Tamura, Nagata, & Akazawa, 2002). The end product of the DEMATEL process is a visual representation by which the respondent organizes his or her action in the world (Tzeng et al., 2007), e-learning evaluation (Tzeng et al., 2007), airline safety measurement (Liou et al., 2007), and innovation policy portfolios for Taiwan's SIP Mall (Huang & Tzeng, 2007).

The DEMATEL method can be summarized in the following steps:

Step 1: Find the average matrix. Suppose we have H experts in this study and n criteria to consider. Each expert is asked to indicate the degree which represents he or she believes a criterion i affects criterion j. These pairwise comparisons between any two criteria are denoted by a_{ij} and are given an integer score ranging from 0, 1, 2, 3, and 4, representing 'No influence (0),' 'Low influence (1),' 'Medium influence (2),' 'High influence (3),' and 'Very high influence (4),' respectively. The scores by each expert will give us a $n \times n$ non-negative answer matrix $\boldsymbol{X}^k = [x_{ij}^k]_{n\times n}$, with $1 \leqslant k \leqslant H$. Thus, $\boldsymbol{X}^1, \boldsymbol{X}^2, \ldots, \boldsymbol{X}^H$ are the answer matrices for each of the H experts, and each element of $\boldsymbol{X}^k$ is an integer denoted by x_{ij}^k. The diagonal elements of each answer matrix $\boldsymbol{X}^k$ are all set to zero. We can then compute the $n \times n$ average matrix $\boldsymbol{A}$ for all expert opinions by averaging the H experts' scores as follows:

$$[a_{ij}]_{n\times n} = \frac{1}{H}\sum_{k=1}^{H}[x_{ij}^k]_{n\times n} \tag{1}$$

The average matrix $\boldsymbol{A} = [a_{ij}]_{n\times n}$ is also called the initial direct relation matrix. $\boldsymbol{A}$ shows the initial direct effects that a criterion exerts on and receives from other criteria. Furthermore, we can map out the causal effect between each pair of criteria in a system by drawing an influence map (if $a_{ij} \leqslant 1$ for $\forall i, j$, we can identify among all criteria are independent; otherwise, we can identify all criteria are non-independent). Fig. 1 below is an example of such a network influence map. Each letter represents a criterion in the system. An arrow from c to d shows the effect that c has on d, and the strength of its effect is 4. DEMATEL can convert the structural relations among the criteria of a system into an intelligible map of the system.

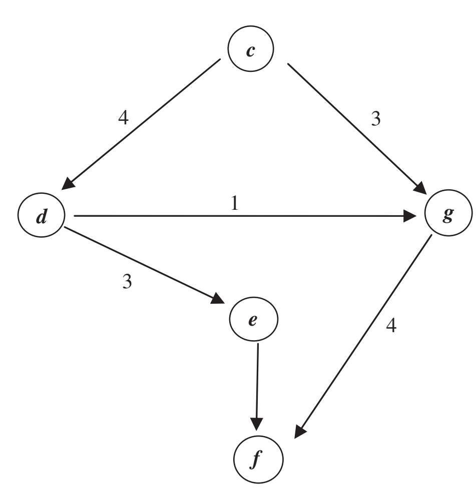

Fig. 1. Example of an influence map.

Step 2: Calculate the normalized initial direct-relation matrix. The normalized initial direct-relation matrix $\boldsymbol{D}$ is obtained by normalizing the average matrix $\boldsymbol{A}$ in the following way:

$$\text{Let } s = \max\left(\max_{1\le i\le n}\sum_{j=1}^{n}a_{ij}, \max_{1\le j\le n}\sum_{i=1}^{n}a_{ij}\right), \tag{2}$$

$$\text{then } \boldsymbol{D} = \frac{\boldsymbol{A}}{s} \tag{3}$$

Since the sum of each row i of matrix $\boldsymbol{A}$ represents the total direct effects that criterion i gives to the other criteria, $\max_{1\leqslant i\leqslant n}\sum_{j=1}^{n}a_{ij}$ represents the total direct effects of the criterion with the most direct effects on others. Likewise, since the sum of each column j of matrix $\boldsymbol{A}$ represents the total direct effects received to other criteria by criterion i, $\max_{1\leqslant j\leqslant n}\sum_{i=1}^{n}a_{ij}$ represents the total direct effects that the criterion j receives the most direct effects from other criteria. The positive scalar s takes the smaller of the two as the upper bound, and the matrix $\boldsymbol{D}$ is obtained by dividing each element of $\boldsymbol{A}$ by the scalar s. Note that each element d_{ij} of matrix $\boldsymbol{D}$ is between zero and less than 1.

Step 3: Compute the total relation matrix. A continuous decrease of the indirect effects of problems along the powers of matrix $\boldsymbol{D}$, e.g. $\boldsymbol{D}^2, \boldsymbol{D}^3, \ldots, \boldsymbol{D}^\infty$, guarantees convergent solutions to the matrix inverse similar to an absorbing Markov chain matrix. Note that $\lim_{m\to\infty}\boldsymbol{D}^m = [0]_{n\times n}$ and $\lim_{m\to\infty}(\boldsymbol{I}+\boldsymbol{D}+\boldsymbol{D}^2+\boldsymbol{D}^3+\cdots+\boldsymbol{D}^m) = (\boldsymbol{I}-\boldsymbol{D})^{-1}$, where 0 is the $n\times n$ null matrix and $\boldsymbol{I}$ is the $n\times n$ identity matrix. The total relation matrix $\boldsymbol{T}$ is an $n\times n$ matrix and is defined as follow:

$$\boldsymbol{T} = [t_{ij}], \quad i,j = 1,2,\ldots,n \tag{4}$$

where
$\boldsymbol{T} = \boldsymbol{D} + \boldsymbol{D}^2 + \cdots + \boldsymbol{D}^m = \boldsymbol{D}(\boldsymbol{I} + \boldsymbol{D} + \boldsymbol{D}^2 + \cdots + \boldsymbol{D}^{m-1}) = \boldsymbol{D}[(\boldsymbol{I} + \boldsymbol{D} + \boldsymbol{D}^2 + \cdots + \boldsymbol{D}^{m-1})(1-\boldsymbol{D})](1-\boldsymbol{D})^{-1} = \boldsymbol{D}(\boldsymbol{I}-\boldsymbol{D})^{-1}$, as $m\to\infty$ and $[(\boldsymbol{I} + \boldsymbol{D} + \boldsymbol{D}^2 + \cdots + \boldsymbol{D}^{m-1})(1-\boldsymbol{D})] = \boldsymbol{I} - \boldsymbol{D}^m$

We also define $\boldsymbol{r}$ and $\boldsymbol{c}$ as $n\times 1$ vectors representing the sum of rows and sum of columns of the total relation matrix $\boldsymbol{T}$ as follows:

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

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

where superscript $'$ denotes transpose.

Let $r_i = \sum_{j=1}^{n}t_{ij}$ be the sum of ith row in matrix $\boldsymbol{T}$. Then r_i shows the total effects, both direct and indirect, given by criterion i to the other criteria $j = 1,2,\ldots,n$. Let $c_j = \sum_{i=1}^{n}t_{ij}$ denotes the sum of jth column in matrix $\boldsymbol{T}$. Then c_j shows the total effects, both direct and indirect, received by criterion j from the other criteria $i = 1,2,\ldots,n$. Thus when $j = i$, the sum $(r_i + c_i)$ gives us an index representing the total effects both given and received by criterion i. In other words, $(r_i + c_i)$ shows the degree of importance (total sum of effects given and received) that criterion i plays in the system. In addition, the difference $(r_i - c_i)$ shows the net effect that criterion i contributes to the system. When $(r_i - c_i)$ is positive, criterion i is a net causer, and when $(r_i - c_i)$ is negative, criterion i is a net receiver (Tamura et al., 2002; Tzeng et al. 2007).

Step 4: Set a threshold value and obtain the network relationship map (NRM). In order to explain the structural relation among the criteria and keep the complexity of the system to a manageable level at the same time, it is necessary to set a threshold value p to filter out some negligible effects in matrix $\boldsymbol{T}$. Only some criteria, whose effect in matrix $\boldsymbol{T}$ is greater than the threshold value, should be chosen and shown in a network relationship map (NRM) for influence (Tzeng et al., 2007).

In this paper, the threshold value has been decided by experts through discussions. After the threshold value is decided, the final influence result of criteria can be shown in a NRM. To clearly represent the procedures of the DEMATEL method, a simple example is developed to show how the NRM can be obtained and as well as how the relationships of criteria discussed above can be determined. For example, suppose a system contains three criteria C_1, C_2 and C_3, the total-influence matrix $\boldsymbol{T}$ can be derived by running from step1 to step 4. Next, based on the threshold value p, we can filter the minor effects in the elements of matrix $\boldsymbol{T}$. The values of elements in matrix $\boldsymbol{T}$ are zero if their values less than p. That is, there are lower influences with other criteria when their values are less than p. Thus, a new total-influence matrix $\boldsymbol{T}_p$ can be obtained and the NRM can also be shown as Fig. 2 below.

$$\boldsymbol{T}_p = \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \end{array}\begin{array}{c} \begin{array}{ccc} C_1 & C_2 & C_3 \end{array} \\ \begin{bmatrix} 0 & t_{12}^p & t_{13}^p \\ t_{21}^p & 0 & t_{23}^p \\ 0 & 0 & t_{33}^p \end{bmatrix} \end{array}$$

2.2. The ANP method

The ANP is an extension of AHP, and it is the general form of analytic hierarchy process (AHP). The ANP handles dependence within a criterion (inner dependence) and among different criteria (outer dependence). AHP models a decision making framework using a unidirectional hierarchical relationship among criteria, but ANP allows more complex interrelationships among criteria. A major difference between the two techniques is the existence of a feedback relationship among criteria within this framework.

The method of the ANP can be described as follows. The first step of the ANP is to compare the criteria in whole system to form the supermatrix. 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 1–9 to represent equal importance to extreme importance (Saaty, 1980, 1996). The general form of the supermatrix can be described as follows:

$$\boldsymbol{W} = \begin{array}{cc} & \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \\ e_{11}\ldots e_{1m_1} & e_{21}\ldots e_{2m_2} & \cdots & e_{n1}\ldots e_{nm_n} \end{array} \\ \begin{array}{cc} C_1 & \begin{array}{c} e_{11} \\ e_{12} \\ \vdots \\ e_{1m_1} \end{array} \\ C_2 & \begin{array}{c} e_{21} \\ e_{22} \\ \vdots \\ e_{2m_2} \end{array} \\ \vdots & \vdots \\ C_n & \begin{array}{c} e_{n1} \\ e_{n2} \\ \vdots \\ e_{nm_n} \end{array} \end{array} & \begin{bmatrix} \boldsymbol{W}_{11} & \boldsymbol{W}_{12} & \cdots & \boldsymbol{W}_{1n} \\ \boldsymbol{W}_{21} & \boldsymbol{W}_{22} & \cdots & \boldsymbol{W}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{W}_{n1} & \boldsymbol{W}_{n2} & \cdots & \boldsymbol{W}_{n2} \end{bmatrix} \end{array} \tag{7}$$

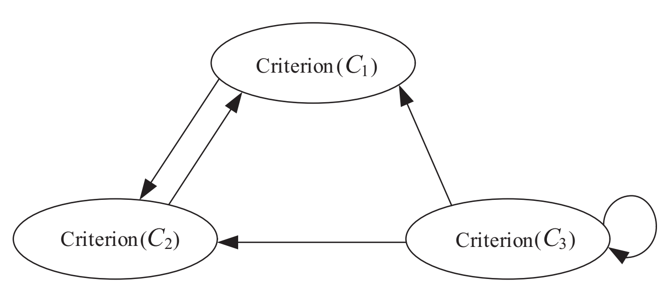

Fig. 2. The NRM of the system.

where C_n denotes the nth cluster, e_{nm} denotes the mth element in nth cluster, and $\boldsymbol{W}_{ij}$ is the principal eigenvector of the influence of the elements compared in the jth cluster to the ith cluster. In addition, if the jth cluster has no influence to the ith cluster, then $\boldsymbol{W}_{ij} = [0]$.

After, the weighted supermatrix is obtained by multiplying the total-influence matrix, which is derived according to DEMATEL method. Traditional, the weighted supermatrix is derived by transforming all columns sum to unity exactly. This step is much similar to the concept of Markov chain which ensures the sum of these probabilities of all states equals to 1. However, we know each criterion's affect the other criteria may be different according to the results of the DEMATEL method. If the influence degrees of these criteria are regarded as equal, that is, using average method to obtain the weighted supermatrix. The results of the assessed weights would be higher or lower than the real situation. It would be irrational and unsuitable in real situation. For this reason, we intend adopt the DEMATEL method to overcome the shortcomings, and suppose that the total-influence matrix $\boldsymbol{T}_p$ has been determined according to the DEMATEL method result. Because the influence degrees between criteria in the total-influence matrix $\boldsymbol{T}_p$ are different, all criteria of the total-influence matrix $\boldsymbol{T}_p$ should be normalized. The normalized elements of the total-influence matrix $\boldsymbol{T}_p$ are $t_{ij}^z = \frac{t_{ij}^p}{\sum_{i=1}^n t_{ij}^p}$ and the normalized total-influence matrix $\boldsymbol{T}_z$ is represented as follows:

$$\boldsymbol{T}_z = \begin{bmatrix} t_{11}^z & \cdots & t_{1j}^z & \cdots & t_{1n}^z \\ \vdots & & \vdots & & \vdots \\ t_{i1}^z & \cdots & t_{ij}^z & \cdots & t_{in}^z \\ \vdots & & \vdots & & \vdots \\ t_{n1}^z & \cdots & t_{nj}^z & \cdots & t_{nn}^z \end{bmatrix} \tag{8}$$

Furthermore, the weighted supermatrix $\boldsymbol{W}_w$ such as Eq. (9) can be calculated by multiplying the unweighted supermatrix $\boldsymbol{W}$ and the normalized total-influence matrix $\boldsymbol{T}_z$. That is

$$\boldsymbol{W}_w = \boldsymbol{T}_z \times \boldsymbol{W} \tag{9}$$

Finally, we raise the weighted supermatrix to limiting powers l such as Eq. (10) until the supermatrix converged to get the global priority vectors or weights.

$$\lim_{l\to\infty} \boldsymbol{W}_w^l \tag{10}$$

In addition, if the limiting supermatrix is not the only one, it would be calculated to get the final weighted limiting supermatrix $\boldsymbol{W}_f$ (i.e., the average priority weights) as

$$\lim_{k\to\infty} \left(\frac{1}{N}\right) \sum_{j=1}^{N} \boldsymbol{W}_j^k \tag{11}$$

where $\boldsymbol{W}_j$ denoted the jth limiting supermatrix.

3. An illustrative example for the best vendor selection

The selection of competent vendors has long been regarded as one of the most important functions to be performed by a purchasing department in real world. Selection of a wrong vendor or source could be enough to upset the company's financial and operational position. Due to the fact, various criteria must be considered and the criteria are usually interdependent on each other in the decision making process. An empirical example for the best vendor selection is illustrated to demonstrate the proposed method to be more rational and suitable in this section, which is divided into three Subsections: (1) problem descriptions, (2) determining the relationships among criteria, and (3) calculating the weights of criteria.

3.1. Problems descriptions

The case company is a well-known 3C component manufacturer in Taiwan. Its products mainly include PC enclosures, communications equipment, and consumer electronic products. In 2004, the consolidated revenues were US$13 billion dollars, and the company has over 100,000 employees around the world. Its main customer groups include a lot of global enterprises, such as Intel, IBM, Dell, HP, Motorola, and Sony. For this case company, decision maker has only considered several important criteria for selecting an appropriate vendor in a purchase project. But in real situations, the appropriate vendor may find that the performances on specific criteria are poor in procurement manager's mind. To find out the central criteria for improving the performance of an appropriate and best vendor in the complex system, an effective vendor selection model based on the relations map among criteria is needed. According to the purchasing request (e.g., 10,000 pieces/week) of heat sinks based on scenario writings and brainstorming for notebook personnel computer in a consumer electronic business division, we will evaluate and improve these five candidate vendors (V_1, V_2, V_3, V_4, and V_5). Those vendors who successfully passed the screening processes were eligible for procurement. Also, choosing the possible evaluation criteria for the vendor improvement and selection involves a decision making team, which includes managers from different functional divisions of the case company (i.e., purchasing director, purchasing manager, quality manager, product manager and production manager). The criteria and sub-criteria involved in the vendor selection have been chosen according to the experts of professional knowledge and managers' experiences. These major influencing criteria and sub-criteria involved in vendor selection are given in Table 1. Then, a purchasing committee with five experts $E_1, E_2, \ldots, E_5$ is constituted to determine the network relationships and weights among criteria. And give the performance scores for each candidate vendor in terms of all criteria in the evaluation hierarchical structure respectively. The following shows how the case company utilized our proposed method to evaluate and select the best vendor when these criteria with interdependence on each other.

3.2. Determining the network relationships among criteria

The aim of the phase is to determine the network relationships among criteria in influence each other. A questionnaire was used to find out influential relations from each expert for ranking each criterion on the appropriate vendor with a four-point scale ranging

Table 1
Criteria and sub-criteria for the vendor selection.

Criteria	Sub-criteria
Quality (C_1)	Quality performance (C_{11}) Quality containment & VDCS feedback (C_{12})
Price & Terms (C_2)	Price (C_{21}) Terms (C_{22}) Responsiveness (C_{23}) Lead time (C_{24}) VMI/VOI hub set up cost (C_{25})
Supply chain support (C_3)	Purchase order reactiveness (C_{31}) Capacity support & flexibility(C_{32}) Delivery/VMI operation (C_{33})
Technology (C_4)	Technical support (C_{41}) Design involvement (C_{42}) ECN/PCN process (C_{43})

from 0 to 4, representing from 'No influence (0),' to 'Very high influence (4),' respectively. Meanwhile, the participants are also asked to respond to a questionnaire through a series of pairwise comparisons with Saaty's nine-point scale. This questionnaire was developed based on the pairwise comparison, in which each question consisted of a pairwise comparison of two criteria. For each pairwise comparison, the participants have to determine the intensity of the relative importance between two criteria. At first, the average initial direct matrix $\boldsymbol{A}$ is obtained based on Eq. (1) as Table 2. By using Eqs. (2) and (3), the normalized initial direct-relation matrix $\boldsymbol{D}$ is calculated. Sequentially, the total relation matrix $\boldsymbol{T}$ is also derived utilizing Eq. (4) shown in Table 3. Total sum of effects given and received by each criterion is seen in Table 4 using Eqs. (5) and (6). To obtain an appropriate network relationship map (NRM), a threshold value of 0.7 was chosen by experts. Thus the NRM of DEMATEL method result was obtained and shown in Fig. 3.

Table 2
Initial direct matrix $\boldsymbol{A}$.

Criteria	Quality	Price & Terms	Supply chain support	Technology
Quality	0	0.327	0.265	0.265
Price & Terms	0.347	0	0.347	0.306
Supply-chain support	0.143	0.163	0	0.245
Technology	0.245	0.184	0.245	0

Table 3
Total influential relation matrix $\boldsymbol{T}$.

Criteria	Quality	Price & Terms	Supply chain support	Technology
Quality	0.686	0.889	0.991	0.962
Price & Terms	1.017	0.712	1.126	1.070
Supply chain support	0.589	0.571	0.527	0.705
Technology	0.744	0.672	0.824	0.605

Table 4
Sum of influences given and received on each criterion.

Criteria	$r_i + c_i$	$r_i - c_i$
Quality	6.563	0.493
Price & Terms	6.769	1.080
Supply chain support	5.860	−1.075
Technology	6.186	−0.497

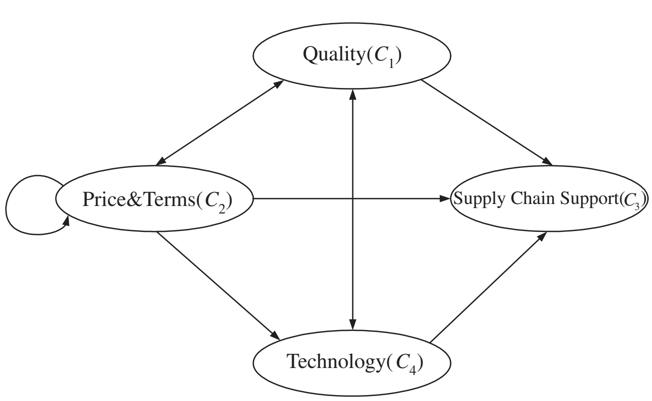

Fig. 3. Network relationship map of impacts for the best vendor selection.

Table 5
Normalized the total influence matrix $\boldsymbol{T}_z$.

	Quality	Price & Terms	Supply chain support	Technology
Quality	0	0.3101	0	0.8065
Price & Terms	0.8286	0.4919	0	0
Supply chain support	0.0873	0.1431	0	0.1935
Technology	0.0841	0.0549	1	0

3.3. Calculating the weights of criteria

From Table 3, we know the degrees of influence of criteria are different with each other. The cluster-weighted supermatrix that was obtained by using traditional average method (equal cluster-weighted) in ANP is irrational. Therefore, the normalized matrix $\boldsymbol{T}_z$, which is obtained influential cluster-weighted by DEMATEL method results, is combined to the procedure of the ANP method in this study. At first, the total influence matrix is normalized by using Eq. (8) shown as Table 5. Based on the NRM of influential relations, the importance of relationships between sub-criteria is compared. An unweighted supermatrix can be obtained by using Eq. (7) as Table 6. By applying Eq. (9), the weighted supermatrix is determined and its result is expressed in Table 7. By calculating the limiting power of the influential cluster-weighted supermatrix, Eq. (10) is applied until a steady-state condition has been achieved. Finally, the weights of each sub-criterion can be obtained. To further compare the difference of traditional ANP method and our proposed method, we calculate the limiting supermatrix with traditional average method, and the influential cluster-weighted supermatrix is derived shown in Table 8. As seen in Tables 7 and 8, the ranks of weights for each sub-criterion by two methods are different.

On the other hand, for each candidate vendor, five experts are asked to evaluate the level of satisfactions for each criterion. The normalized performance score [0, 1] for the candidate vendors is shown in Table 9. Using the performance data of each candidate vendor (Table 9), the synthesis score of the proposed method, unlike the traditional average method, conducts with normalized problem in ANP process (Table 9 below). Regardless of using the traditional average method or the proposed method, the ranking of the candidate vendors will be same. That is, the appropriate vendor is V_2. Furthermore, we employed the concept of the ideal point to represent the results of the analysis for selecting appropriate vendor with the proposed method in Fig. 4. These aspired/desired/ideal points (1 scores) represent points at which all criteria of each vendor would be optimized. It emphasizes the gaps between the appropriate vendor and the ideal points. We could find that there is still a great deal of room for these candidate vendors to drastically improve their performance.

4. Discussions

Based on the results in above Section 3, those criteria had some interrelations with each other. The direct/indirect influential relationship of criteria was figured out by using the DEMATEL method. According to the impact-direction map (Fig. 5), we can obtain valuable cues for making accurate decisions. At first, we know the influence degrees among criteria are different based on the impact-direction map. Since decision-maker can find the key criterion for improving the performances of vendors. It is clear for a purchase department to find the exact vendor's performance. For example, if the case company wanted to improve the effectiveness of a specific criterion (e.g., Supply chain support (C_3)), it would possible be necessary to pay greatly attention to the Quality (C_1) and Price &

Table 6
The unweighted supermatrix.

	C_{11}	C_{12}	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{31}	C_{32}	C_{33}	C_{41}	C_{42}	C_{43}
C_{11}	0	0	0.187	0.199	0.187	0.036	0.207	0	0	0	0.587	0.612	0.490
C_{12}	0	0	0.062	0.050	0.062	0.213	0.042	0	0	0	0.147	0.122	0.245
C_{21}	0.403	0.381	0.513	0	0	0	0	0	0	0	0	0	0
C_{22}	0.089	0.199	0	0.513	0	0	0	0	0	0	0	0	0
C_{23}	0.177	0.071	0	0	0.513	0	0	0	0	0	0	0	0
C_{24}	0.051	0.071	0	0	0	0.513	0	0	0	0	0	0	0
C_{25}	0.030	0.028	0	0	0	0	0.513	0	0	0	0	0	0
C_{31}	0.046	0.074	0.095	0.068	0.118	0.109	0.072	0	0	0	0.038	0.031	0.030
C_{32}	0.047	0.013	0.046	0.057	0.037	0.026	0.052	0	0	0	0.152	0.163	0.188
C_{33}	0.036	0.043	0.033	0.048	0.019	0.038	0.050	0	0	0	0.076	0.071	0.047
C_{41}	0.047	0.029	0.041	0.004	0.029	0.004	0.005	0.644	0.413	0.614	0	0	0
C_{42}	0.036	0.075	0.007	0.011	0.027	0.013	0.010	0.242	0.260	0.268	0	0	0
C_{43}	0.037	0.016	0.017	0.049	0.009	0.048	0.051	0.114	0.328	0.117	0	0	0

Table 7
The cluster-weighted supermatrix by proposed method (DEMATEL tool).

	C_{11}	C_{12}	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{31}	C_{32}	C_{33}	C_{41}	C_{42}	C_{43}
C_{11}	0.203	0.203	0.203	0.203	0.203	0.203	0.203	0.203	0.203	0.203	0.203	0.203	0.203
C_{12}	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069
C_{21}	0.235	0.235	0.235	0.235	0.235	0.235	0.235	0.235	0.235	0.235	0.235	0.235	0.235
C_{22}	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.069
C_{23}	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088
C_{24}	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033
C_{25}	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017
C_{31}	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049
C_{32}	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043
C_{33}	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027
C_{41}	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085
C_{42}	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044
C_{43}	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038

Table 8
The weighted supermatrix by traditional method (equal cluster-weighted).

	C_{11}	C_{12}	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{31}	C_{32}	C_{33}	C_{41}	C_{42}	C_{43}
C_{11}	0.189	0.189	0.189	0.189	0.189	0.189	0.189	0.189	0.189	0.189	0.189	0.189	0.189
C_{12}	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061
C_{21}	0.204	0.204	0.204	0.204	0.204	0.204	0.204	0.204	0.204	0.204	0.204	0.204	0.204
C_{22}	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060
C_{23}	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077
C_{24}	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028
C_{25}	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
C_{31}	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057
C_{32}	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061	0.061
C_{33}	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037
C_{41}	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106
C_{42}	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056
C_{43}	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048

Terms (C_2) criteria. This is because the Quality and Price & Terms criteria are the influencing criteria, whereas the supply chain support criterion is the influenced criterion. Then, it is easier for a company to find the performance of the appropriate vendor by using the results. Additionally, it can be provided to derive the influential cluster-weighted supermatrix to obtain the weights of criteria in ANP method. The ranking results of weights of sub-criteria between the traditional average method and the DEMATEL method which normalizing the unweighted supermatrix can be obtained shown as Fig. 6. In Fig. 6, the sub-criteria of Quality and Price & Terms in the traditional average method are lower than the proposed method, but the sub-criteria of Supply chain support and Technology in the traditional average method are higher than the proposed method. Take Price & Terms criterion for example, we can find the criterion affected by Supply chain support criterion is 0.571 and Supply chain support criterion affected by Price & Terms criterion is 1.126 (see Table 3). Obviously, Supply chain support criterion is affected by Price & Terms criterion more than Price & Terms criterion is affected by Supply chain support criterion. It represents the influence degree of Price & Terms criterion is more than that of Supply chain support criterion. The result implies that Price & Terms criterion is the central criterion for evaluating the appropriate vendor. In addition, the results show that the evaluators are most concerned about the price performance when selecting the appropriate vendor, which is consistent with the results found in a real purchase project. From Fig. 6, it can also be seen that the sub-criteria of Price & Terms criterion are underestimated, whereas the sub-criteria of Supply chain support criterion are overestimated by applying the traditional average method.

On the other hand, from the causal diagrams (see Fig. 5), we know the Price & Terms (C_2) is the most important and the most influencing criterion because it has the highest intensity of

Table 9
Performance matrix of candidate vendor for each criterion.

Criteria and sub-criteria	Weights	Candidate vendor (V_j)				
		V_1	V_2	V_3	V_4	V_5
Quality						
– Quality performance	0.203 (0.189)	0.620	0.860	0.740	0.520	0.720
– Quality containment & VDCS feedback	0.069 (0.061)	0.720	0.740	0.620	0.620	0.580
Price & Terms						
– Price	0.235 (0.204)	0.820	0.680	0.920	0.540	0.520
– Terms	0.069 (0.060)	0.620	0.860	0.660	0.500	0.600
– Responsiveness	0.088 (0.077)	0.740	0.680	0.820	0.660	0.680
– Lead time	0.033 (0.028)	0.780	0.960	0.520	0.580	0.720
– VMI/VOI hub set-up cost	0.017 (0.015)	0.780	0.660	0.600	0.620	0.580
Supply chain support						
– Purchase order reactiveness	0.049 (0.057)	0.720	0.720	0.580	0.580	0.660
– Capacity support & flexibility	0.043 (0.061)	0.740	0.720	0.640	0.620	0.580
– Delivery/VMI operation	0.027 (0.037)	0.820	0.780	0.640	0.580	0.500
Technology						
– Technical support	0.085 (0.106)	0.620	0.740	0.700	0.440	0.600
– Design involvement	0.044 (0.056)	0.680	0.900	0.540	0.540	0.400
– ECN/PCN process	0.038 (0.048)	0.740	0.720	0.580	0.780	0.560
Synthesis scores		0.715 (0.712)	0.765* (0.764)	0.733 (0.720)	0.559 (0.559)	0.604 (0.599)

() Represents the results obtained by traditional equal cluster-weighted method (ANP).
* Represents the appropriate vendor.

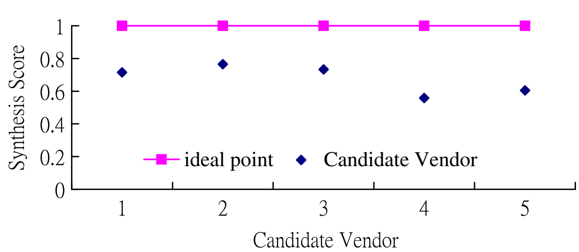

Fig. 4. Comparisons the synthesis scores between the appropriate vendor and the ideal point.

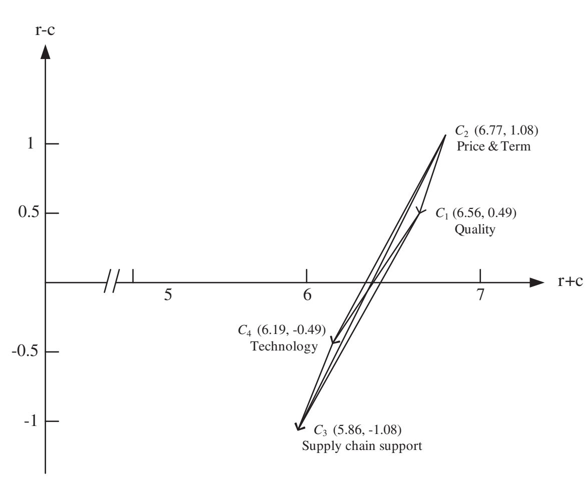

Fig. 5. The impact-direction map.

relationship to other criteria. Thus, it can be regarded as the critical criterion for evaluating and improving the appropriate vendor. To reduce the gaps between the appropriate vendor and aspired levels (Fig. 4), we can make some suggestions to improve the performances of the appropriate vendor for each criterion priorities from the results of NMR. From the abovementioned analysis, we know the Price & Terms and Quality are the two most important cause criteria. If we wanted to obtain high performances in terms of

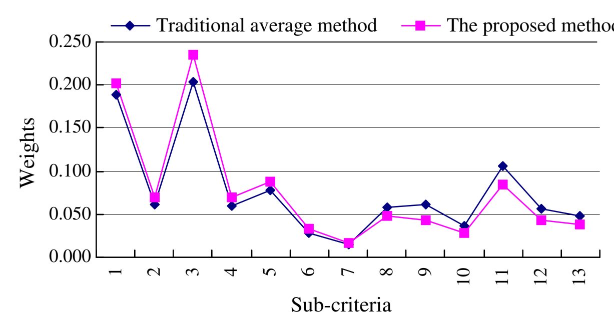

Fig. 6. Comparisons of weights between the traditional method and the proposed method.

the effect criteria (i.e., Supply chain support and Technology), the appropriate vendor would get an improved priority for the two cause criteria beforehand, so that it can successfully to be the best vendor with the approaching-ideal point.

5. Conclusions

Most importance-assessing methods used to demonstrate the importance of criteria are often based on the assumptions of additivity and independence. However, in fact, people have found that using such an additive model is not always suitable in real world because of the interdependence/interrelation among the criteria to somewhat different degrees. The ANP method is used to overcome the problems of dependence and feedback among criteria, but in the ANP method uses an average method which normalizes the cluster-weighted supermatrix. The results ignored the different influence degrees among criteria. To this end, we propose a novel concept to derive the cluster-weighted supermatrix to obtain the weights of criteria, in which the total-influence matrix is obtained and regarded as the base of normalization supermatrix for calculating ANP weights using DEMATEL method. Obviously, it is useful and feasible for solving the irrational situation. Through the causal diagram (Fig. 5), the complexity of a problem is easier to capture, so that profound decision can be made. Finally, we use an empirical applications in Taiwan is to demonstrate that the proposed method provides practitioners some important conclusions drawn from this case applications.

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