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# Using a novel conjunctive MCDM approach based on DEMATEL, fuzzy ANP, and TOPSIS as an innovation support system for Taiwanese higher education

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ABSTRACT

Increasing numbers of Taiwanese higher education institutes are pursuing innovation operation. However, these institutes generally rely greatly on academic research to evaluate innovation performance. Nevertheless, the performance of innovation may be affected by numerous factors that are often beyond the scope of a single academic study. Thus, to address this concern, this paper constructs an innovation support system (ISS) for Taiwanese higher education institutes to comprehensively evaluate their innovation performance. Previous research often evaluates performance by independently considering a number of criteria. However, this assumption of independence does not model the so-called "real world"; thus, we present a novel conjunctive multiple criteria decision-making (MCDM) approach that addresses dependent relationships among each measurement criteria. As such, we utilize a decision-making trial and evaluation laboratory (DEMATEL), a fuzzy analytical network process (FANP), and a technique for order preference by similarity to an ideal solution (TOPSIS) forming order to develop an innovation support system (ISS) that considers the interdependence and the relative weights of each measurement criterion.



## 1. Introduction

Due to a recent drop in the birthrate, an increase in the number of higher educational institutions, and Taiwan's recent membership in the WTO, higher educational institutions in Taiwan will not have competitive advantages when faced with competitions from the West and Asia (Chen, 2005). Thus, the need to increase innovative operations, improve performance, and develop core competitive abilities is an urgent issue currently faced by higher educational institutions in Taiwan (Chen & Chen, 2008).

The most utilized evaluations used for innovation performance by Taiwanese higher educational institutions emerge from academic research (Chen & Chen, 2008). However, the factors that can affect innovation performance are numerous. One way to overcome the problem of evaluation performance with regard to numerous factors involves the use of multiple criteria decision-making (MCDM), which is often characterized by multiple, conflicting criteria (Hwang & Yoon, 1981; Liou, Tzeng, & Chang, 2007). Along these lines, various research studies have produced different measurement dimensions, and criteria (Chen & Chen, 2008; Chin & Pu, 2006; Lin, Wang, & Yen, 2006; Tang, 2006). Some of this research assumes independence of criteria; however, in the real world, most criteria are not mutually independent.

In this paper, a decision-making trial and evaluation laboratory (DEMATEL) method is adapted to model complex interdependent relationships and construct a relation structure using measurement criteria for innovation evaluation. A fuzzy analytic network process (FANP) is conducted to address the problem of dependence as well as feedback among each measurement criteria. A technique for order preference by similarity to an ideal solution (TOPSIS) is finally utilized to find optimal alternatives for innovation configurations. Here, we combine DEMATEL, fuzzy ANP and TOPSIS approaches to develop a novel innovation support system (ISS).

## 2. An innovation support system

Some literature has indicated that an organization must continually innovate to avoid failure (Daft, 2004; Krause, 2004). Innovation performance evaluations, involve numerous complex factors, including member innovation, administrative innovation, marketing innovation, and so on. However, an innovation criterion that follows academic research may be imperfect.

Although a large body of academic studies offers numerous insights involving innovation performance, evaluation tools developed by these studies do not evaluate innovation performance completely. Recent studies have argued that the factors influencing

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innovation in higher education are numerous (Bantel & Jackson, 1989; Damanpour, 1996; O'Sullivan, 2000; Wolfe, 1994). Thus, after summarizing relevant studies, we introduce a novel conjunctive MCDM approach that combines DEMATEL, Fuzzy ANP, and TOPSIS. In doing so, we consider increasingly complex relationships and utilize them to develop an innovation support system (ISS).

## 3. A novel conjunctive MCDM approach

Quantifying values with precision in a complex measurement system is difficult; nevertheless, such systems can be partitioned into separate subsystems to facilitate the evaluation of each partition. Here, DEMATEL is used to develop interrelations among each measurement criterion. Next, the weights of each criterion are calculated using fuzzy ANP. After that, TOPSIS is utilized to rank the alternatives. Finally, we construct an innovation support system (ISS) based on these results.

### 3.1. Illustrating interrelations among measurement criteria

All factors in a complex system may be either directly or indirectly related; therefore, it is difficult for a decision maker to evaluate a single effect from a single factor while avoiding interference from the rest of the system (Liou et al., 2007). In addition, an interdependent system may result in passive positioning; for example, a system with a clear hierarchical structure may give rise to linear activity with no dependence or feedback, which may cause problems distinct from those found in non-hierarchical systems (Tzeng, Chiang, & Li, 2007).

To avoid such problems, the Battelle Geneva Institute created DEMATEL in order to solve difficult problems that mainly involve interactive man-model techniques as well as to measure qualitative and factor-linked aspects of societal problems (Gabus & Fontela, 1972). In addition, DEMATEL has been utilized in numerous contexts, such as industrial planning, decision-making, regional environmental assessment, and even analysis of world problems (Huang, Shyu, & Tzeng, 2007); in all cases, it has confirmed interdependence among criteria and restricted the relations that reflect characteristics within an essential systemic and its developmental trends (Liou et al., 2007).

The foundation of the DEMATEL method is graph theory. It allows decision-makers to analyze as well as solve visible problems. In doing so, decision-makers can separate multiple measurement criteria into a cause and effect group to realize causal relationships much more easily. In addition, directed graphs, called digraphs, are much more helpful than directionless graphs since they depict the directed relationships among subsystems. In other words, a digraph represents a communication network or a domination relationship among entities and their groupings (Huang et al., 2007).

The steps in DEMATEL are as follows (Liou et al., 2007):

Step 1: Calculate the initial average matrix by scores.Sampled experts are asked to point the direct effect based on their perception that each element $i$ exerts on each other element $j$, as presented by $a_{ij}$, by utilizing a scale ranging from 0 to 4. No influence is represented by 0, while a very high influence is represented by 4. Based on groups of direct matrices from samples of experts, we can generate an average matrix $\boldsymbol{A}$ in which each element is the mean of the corresponding elements in the experts' direct matrices.

Step 2: Calculate the initial influence matrix.After normalizing the average matrix $\boldsymbol{A}$, the initial influence matrix $\boldsymbol{D}$,$[d_{ij}]_{n\times n}$, is calculated so that all principal diagonal elements equal zero. In accordance with $\boldsymbol{D}$, the initial effect that an element exerts and/or acquires from each other element is given. The map depicts a contextual relationship among the elements within a complex system; each matrix entry can be seen as its strength of influence. This is depicted in Fig. 1; an arrow from $d$ to $g$ represents the fact that $d$ affects $g$ with an influence score of 1. As a result, we can easily translate the relationship between the causes and effects of various measurement criteria into a comprehensible structural model of the system based on influence degree using DEMATEL.

Step 3: Develop the full direct/indirect influence matrix.The indirect effects of problems decreases as the powers of $D$ increase, e.g., to $\boldsymbol{D}^2, \boldsymbol{D}^3, \ldots, \boldsymbol{D}^\infty$, which guarantees convergent solutions to the matrix inversion. From Fig. 1, we see that the effect of $c$ on $d$ is greater than that of $c$ on $g$. Therefore, we can generate an infinite series of both direct and indirect effects. Let the $(i,j)$ element of matrix A be presented by $a_{ij}$, then the direct/indirect matrix can be acquired by following Eq. (1) through (4)

$$\boldsymbol{D} = s^{*}A, \quad s > 0 \tag{1}$$

or

$$[d_{ij}]_{n\times n} = s[a_{ij}]_{n\times n}, \quad s > 0,\ i,j \in \{1,2,\ldots,n\} \tag{2}$$

where

$$s = \mathrm{Min}\left[\frac{1}{\max\limits_{1\leqslant i\leqslant n}\sum_{j=1}^{n}|a_{ij}|}, \frac{1}{\max\limits_{1\leqslant i\leqslant n}\sum_{i=1}^{n}|a_{ij}|}\right] \tag{3}$$

and

$$\lim_{m\to\infty}\boldsymbol{D}^m = [0]_{n\times n} \text{ where } \boldsymbol{D} = [d_{ij}]_{n\times n}, \quad 0 \leqslant d_{ij} < 1. \tag{4}$$

The total-influence matrix $\boldsymbol{T}$ can be acquired by utilizing Eq. (5). Here, $\boldsymbol{I}$ is the identity matrix

$$\boldsymbol{T} = \boldsymbol{D} + \boldsymbol{D}^2 + \cdots + \boldsymbol{D}^m = \boldsymbol{D}(\boldsymbol{I} - \boldsymbol{D})^{-1} \text{ when } m \to \infty. \tag{5}$$

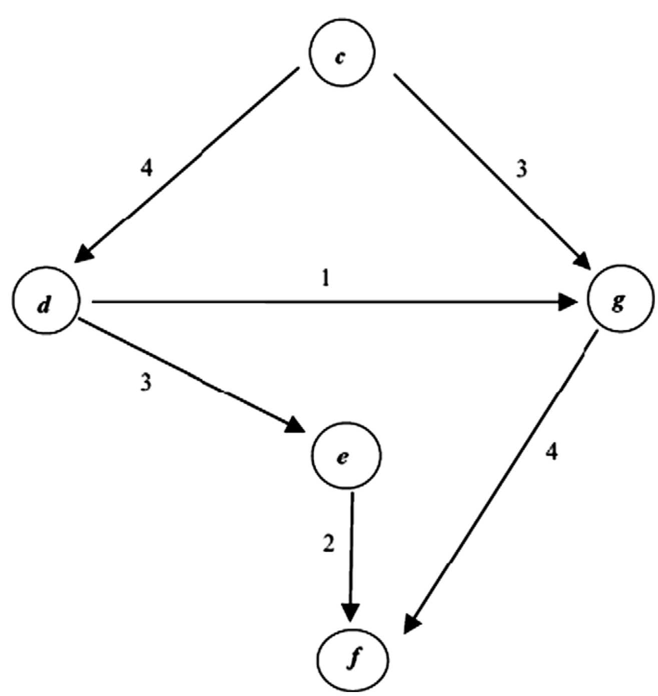


**Fig. 1.** An influential map.

If the sum of rows and the sum of columns is represented as vector $r$ and $c$, *respectively*, in the total influence matrix $\boldsymbol{T}$, then

$$\boldsymbol{T} = [t_{ij}], \quad i,j = 1,2,\ldots,n, \tag{6}$$

$$\boldsymbol{r} = [r_i]_{n\times1} = \left(\sum_{j=1}^{n} t_{ij}\right)_{n\times1} \tag{7}$$

$$\boldsymbol{c} = [c_j]'_{1\times n} = \left(\sum_{i=1}^{n} t_{ij}\right)_{1\times n} \tag{8}$$

where the superscript apostrophe denotes transposition.

If $r_i$ represents the sum of the $i$th row of matrix $\boldsymbol{T}$, then $r_i$ presents the sum of both direct and indirect effects of factor $i$ on all other criteria. In addition, if $c_j$ represents the sum of the $j$th column of matrix T, then $c_j$ presents the sum of both direct and indirect effects that all other factors have on $j$. Moreover, note that $j = i(r_i + c_i)$ demonstrates the degree to which factor $i$ affects or is affected by $j$. Note that if $(r_i - c_i)$ is positive, then factor $i$ affects other factors, and if it is negative, then factor $i$ is affected by others (Liou et al., 2007; Tzeng et al., 2007).

Step 4: Set the threshold value and generate the impact relations map.

Last, we must develop a threshold value. This value is generated by taking into account the sampled experts' opinions in order to filter minor effects presented in matrix $\boldsymbol{T}$ elements. This is needed to isolate the relation structure of the most relevant factors. In accordance with the matrix $\boldsymbol{T}$, each factor $t_{ij}$ provides information about how factor $i$ affects $j$. In order to decrease the complexity of the impact relations-map, the decision-maker determines a threshold value for the influence degree of each factor. If the influence level of an element in matrix $\boldsymbol{T}$ is higher than the threshold value, which we denote as $p$, then this element is included in the final impact relations map (IRM) (Liou et al., 2007).

### 3.2. Fuzzy ANP

#### 3.2.1. Fuzzy set theory

Fuzzy set theory was first developed in 1965 by Zadeh; he was attempting to solve fuzzy phenomenon problems, including problems with uncertain, incomplete, unspecific, or fuzzy situations. Fuzzy set theory is more advantageous than traditional set theory when describing set concepts in human language. It allows us to address unspecific and fuzzy characteristics by using a membership function that partitions a fuzzy set into subsets of members that "incompletely belong to" or "incompletely do not belong to" a given subset.

#### 3.2.2. Fuzzy numbers

We order the Universe of Discourse such that $U$ is a collection of targets, where each target in the Universe of Discourse is called an element. Fuzzy number $\widetilde{A}$ is mapped onto $U$ such that a random $x \to U$ is appointed a real number, $\mu_{\widetilde{A}}(x) \to [0,1]$. If another element in U is greater than x, we call that element *under A*.

The universe of real numbers $R$ is a triangular fuzzy number (TFN) $\widetilde{A}$, which means that for $x \in R$, $\mu_{\widetilde{A}}(x) \in [0,1]$, and

$$\mu_{\widetilde{A}}(x) = \begin{cases} (x-L)/(M-L), & L \leqslant x \leqslant M, \\ (U-x)/(U-M), & M \leqslant x \leqslant U, \\ 0, & \text{otherwise}, \end{cases}$$

Note that $\widetilde{A} = (L, M, U)$, where $L$ and $U$ represent fuzzy probability between the lower and upper boundaries, respectively, as in Fig. 2. Assume two fuzzy numbers $\widetilde{A}_1 = (L_1, M_1, U_1)$ and $\widetilde{A}_2 = (L_2, M_2, U_2)$; then,

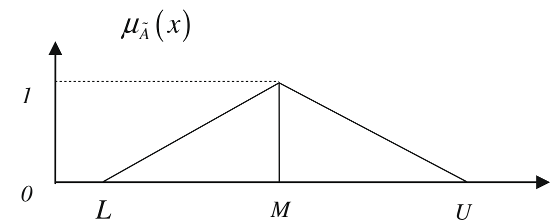


**Fig. 2.** Triangular fuzzy number.

$$(1)\ \widetilde{A}_1 \oplus \widetilde{A}_2 = (L_1, M_1, U_1) \oplus (L_2, M_2, U_2) = (L_1 + L_2, M_1 + M_2, U_1 + U_2)$$

$$(2)\ \widetilde{A}_1 \otimes \widetilde{A}_2 = (L_1, M_1, U_1) \otimes (L_2, M_2, U_2) = (L_1 L_2, M_1 M_2, U_1 U_2), L_i > 0, M_i > 0, U_i > 0$$

$$(3)\ \widetilde{A}_1 - \widetilde{A}_2 = (L_1, M_1, U_1) - (L_2, M_2, U_2) = (L_1 - L_2, M_1 - M_2, U_1 - U_2)$$

$$(4)\ \widetilde{A}_1 \div \widetilde{A}_2 = (L_1, M_1, U_1) \div (L_2, M_2, U_2) = (L_1/U_2, M_1/M_2, U_1/L_2). L_i > 0, M_i > 0, U_i > 0$$

$$\widetilde{A}_1^{-1} = (L_1, M_1, U_1)^{-1} = (1/U_1, 1/M_1, 1/L_1), L_i > 0, M_i > 0, U_i > 0$$

#### 3.2.3. Fuzzy linguistic variables

The fuzzy linguistic variable is a variable that reflects different aspects of human language. Its value represents the range from natural to artificial language. When the values or meanings of a linguistic factor are being reflected, the resulting variable must also reflect appropriate modes of change for that linguistic factor. Moreover, variables describing a human word or sentence can be divided into numerous linguistic criteria, such as equally important, moderately important, strongly important, very strongly important, and extremely important, as shown in Fig. 3; definitions and descriptions are shown in Table 1. For the purposes of the present study, the 5-point scale (equally important, moderately important, strongly important, very strongly important and extremely important) is used.

#### 3.2.4. Analytic network process (ANP)

The purpose of the ANP approach is to solve problems involving interdependence and feedback among criteria or alternative

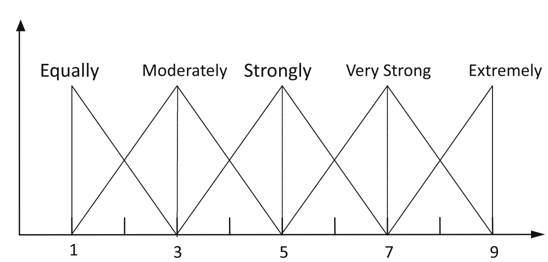


**Fig. 3.** A fuzzy membership function for linguistic variable attributes.

**Table 1**
Definition and membership function of fuzzy number.

| Fuzzy number | Linguistic variable | Triangular fuzzy number |
|---|---|---|
| $\tilde{9}$ | Extremely important/preferred | (7,9,9) |
| $\tilde{7}$ | Very strongly important/preferred | (5,7,9) |
| $\tilde{5}$ | Strongly important/preferred | (3,5,7) |
| $\tilde{3}$ | Moderately important/preferred | (1,3,5) |
| $\tilde{1}$ | Equally important/preferred | (1,1,3) |

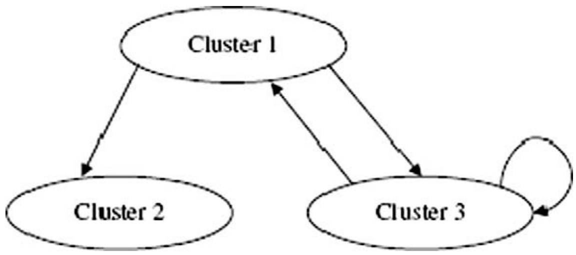


**Fig. 4.** Case 1 structure.

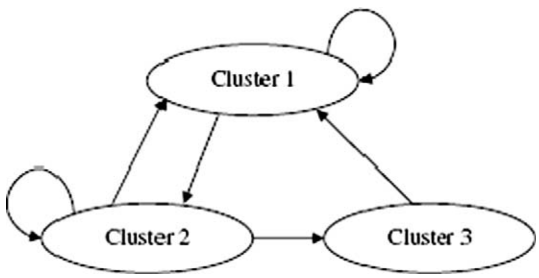


**Fig. 5.** Case 2 structure.

solutions. ANP is the general form of the analytic hierarchy process (AHP), which has been used in multi-criteria decision-making (MCDM) in order to consider non-hierarchical structures. MCDM has been applied to project selection, product planning, and so forth (Ong, Huang, & Tzeng, 2004).

The first phase of ANP compares the measuring criteria in the overall system to form a super matrix. This can be accomplished using pair-wise comparisons. The relative importance-values of pair-wise comparisons can be categorized from 1 to 9 in order to represent pairs of equal importance (1) to extreme inequality in importance (9) (Saaty, 1980). The following is the general form of the super matrix (Liou et al., 2007):

$$
W = \begin{array}{c c} & \begin{array}{cccc} C_1 & C_2 & \cdots & C_m \\ e_{11} \cdots e_{1n_1} & e_{21} \cdots e_{2n_2} & \cdots & e_{m1} \cdots e_{mn_m} \end{array} \\ \begin{array}{c c} C_1 & \begin{array}{c} e_{11} \\ e_{12} \\ \vdots \\ e_{1n_1} \end{array} \\ C_2 & \begin{array}{c} e_{21} \\ e_{22} \\ \vdots \\ e_{2n_2} \end{array} \\ \vdots & \vdots \\ C_m & \begin{array}{c} e_{m1} \\ e_{m2} \\ \vdots \\ e_{mn_m} \end{array} \end{array} & \begin{bmatrix} W_{11} & W_{12} & \cdots & W_{1m} \\ W_{21} & W_{22} & \cdots & W_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ W_{m1} & W_{m2} & \cdots & W_{mm} \end{bmatrix} \end{array}
$$

where $c_m$ denotes the $m$th cluster, $e_{mn}$ denotes the $m$th element in the $m$th cluster, and $\boldsymbol{W}_{ij}$ is the principal eigenvector of the influence of the elements compared in the $j$th cluster to the $i$th cluster. In addition, if the $j$th cluster has no influence to the $j$th cluster, then $\boldsymbol{W}_{ij} = 0$.

Thus, the form of the super matrix relies on the variety of its structure. There are several structures that were proposed by Saaty including hierarchy, holarchy, suparchy, and so on (Ong et al., 2004). In order to demonstrate how the structure is affected by the super matrix, Ong et al. (2004) offer two simple cases that both involve three clusters to show how to form the super matrix in accordance with different structures (see Fig. 4).

Based on Fig. 4, the super matrix can be formed as:

$$
W = \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \end{array} \begin{array}{c} \begin{array}{ccc} C_1 & C_2 & C_3 \end{array} \\ \begin{bmatrix} 0 & 0 & W_{13} \\ W_{21} & 0 & 0 \\ W_{31} & 0 & W_{33} \end{bmatrix} \end{array}
$$

In Fig. 5, a case more complex than that depicted in Fig. 4 is shown.

Based on Fig. 5, the super matrix can be formed as:

**Table 2**
The original innovation support system for Taiwanese higher education.

| Goal | Evaluating dimensions | Evaluating criteria |
|---|---|---|
| The original innovation support system for Taiwanese higher education | Academic Research (D1) | Research Patents (C1) |
| | | International Academic Interaction (C2) |
| | | Number of R&D Members (C3) |
| | | Financial Support of National Science Council (C4) |
| | | Journals accepted and published (C5) |
| | | Government Tender Planning (C6) |
| | Administrative process (D2) | Operation Electrification (C7) |
| | | Outsourcing (C8) |
| | | Affair Rotation (C9) |
| | Faculty and Staff (D3) | Information Study Camp (C10) |
| | | Refresher Classes (C11) |
| | | Go Abroad for Further Education (C12) |
| | Market Development (D4) | Number of Conferences (C13) |
| | | Number of International Students in School (C14) |
| | | Number of Chair Professors (C15) |
| | Organizational Structure (D5) | Learning Organization (C16) |
| | | Specialization Organization (C17) |
| | | Matrix Organization (C18) |
| | Organizational Culture (D6) | Result-Oriented (C19) |
| | | Employee-Oriented (C20) |
| | | Parochial-Oriented (C21) |
| | | Open-Oriented (C22) |
| | | Loosely Control-Oriented (C23) |
| | Leadership Style (D7) | Transformational Leadership (C24) |
| | | Transactional Leadership (C25) |

**Table 3**
The average initial direct-relation 7 × 7 matrix ***A***.

| | D1 | D2 | D3 | D4 | D5 | D6 | D7 |
|---|---|---|---|---|---|---|---|
| D1 | 0 | 0.12 | 1.35 | 1.62 | 0.27 | 0.33 | 0.03 |
| D2 | 1.24 | 0 | 2.33 | 0.57 | 1.13 | 0.06 | 0.71 |
| D3 | 3.91 | 3.76 | 0 | 2.97 | 1.19 | 0.23 | 0.04 |
| D4 | 3.29 | 0.24 | 0.26 | 0 | 0.30 | 1.75 | 1.22 |
| D5 | 1.07 | 2.93 | 3.35 | 1.10 | 0 | 3.63 | 1.32 |
| D6 | 3.01 | 1.25 | 2.63 | 2.77 | 1.29 | 0 | 1.10 |
| D7 | 2.98 | 3.03 | 3.42 | 2.20 | 3.78 | 3.89 | 0 |

**Table 4**
Total influence matrix ***T***.

| | D1 | D2 | D3 | D4 | D5 | D6 | D7 |
|---|---|---|---|---|---|---|---|
| D1 | 0.05 | 0.04 | 0.09 | 0.11 | 0.03 | 0.04 | 0.01 |
| D2 | 0.14 | 0.06 | 0.17 | 0.09 | 0.09 | 0.04 | 0.05 |
| D3 | 0.29 | 0.24 | 0.09 | 0.22 | 0.10 | 0.06 | 0.04 |
| D4 | 0.24 | 0.06 | 0.08 | 0.06 | 0.05 | 0.13 | 0.08 |
| D5 | 0.22 | 0.26 | 0.29 | 0.18 | 0.08 | 0.25 | 0.11 |
| D6 | 0.28 | 0.15 | 0.22 | 0.23 | 0.12 | 0.07 | 0.90 |
| D7 | 0.36 | 0.30 | 0.34 | 0.27 | 0.28 | 0.30 | 0.07 |

**Table 5**
The sum of influences on measurement dimensions.

| Measurement dimensions | $r_i + c_i$ | $r_i - c_i$ |
|---|---|---|
| D1 | 1.95 | -1.21 |
| D2 | 1.74 | -0.46 |
| D3 | 2.32 | -0.24 |
| D4 | 1.87 | -0.47 |
| D5 | 2.13 | 0.64 |
| D6 | 2.88 | 1.09 |
| D7 | 3.19 | 0.66 |

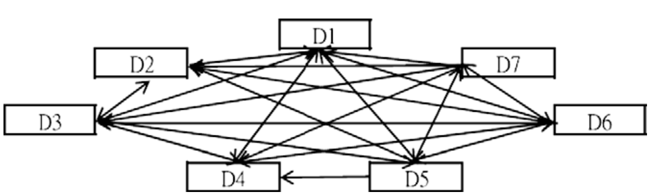


**Fig. 6.** The impact relations map of this study.

$$\mathbf{W} = \begin{matrix} & C_1 & C_2 & C_3 \\ C_1 & W_{11} & W_{12} & W_{13} \\ C_2 & W_{21} & W_{22} & 0 \\ C_3 & 0 & W_{32} & 0 \end{matrix}$$

After forming the super matrix, the weighted super matrix is generated by transforming all column sums to unity (Ong et al., 2004). Then, we use the weighted super matrix to generate a limiting super matrix by using Eq. (9) to calculate global weights.

$$\lim_{k\to\infty} \mathbf{W}^k \tag{9}$$

In this step, if the super matrix shows signs of cyclicity, then there exists more than one limiting super matrix. That is, there are two or more limiting super matrices, and the Cesaro sum must be calculated to obtain the priority among these matrices. The Cesaro sum is calculated using Eq. (10).

$$\lim_{k\to\infty} \left(\frac{1}{N}\right) \sum_{k=1}^{N} \mathbf{W}^k \tag{10}$$

Eq. (10) calculates the average effect of a limiting super matrix; otherwise, the super matrix can be raised to a large power to generate the priority weights.

The steps of the fuzzy ANP calculation are provided as follow:

Step 1: Confirm both dimensions and criteria of the model.
Step 2: Develop the ANP model hierarchically using the dimensions, and criteria.
Step 3: Determine the local weights of both dimensions and criteria by utilizing pair-wise comparison matrices. Assume that there is no dependence between each. The relative importance-values of pair-wise comparisons is provided in Table 1.
Step 4: Determine the inner dependence matrix of each dimension with respect to other dimensions. In Step 3, the dependence of local weights in the inner matrix was calculated, such that this step is intended to calculate the interdependent weights of the dimensions.
Step 5: Calculate the global weights for the sub-factors. This can be done by multiplying the local weight of each sub-factor with the interdependent weights associated with dimensions where it belongs.

### 3.3. TOPSIS

The technique for order preference by similarity to an ideal solution (TOPSIS) was first proposed by Hwang and Yoon in 1981 and expanded developments by Chen and Hwang in 1992. The foundational principle is that, in a graph, any chosen alternative should have the shortest distance from the ideal solution and the farthest distance from the negative-ideal solution (Opricovic & Tzeng, 2004).

TOPSIS is conducted as follows (Opricovic & Tzeng, 2004):

Step 1: Calculate the normalized decision matrix. The normalized value $r_{ij}$ is and is calculated as:

$$r_{ij} = f_{ij} / \sqrt{\sum_{j=1}^{J} f_{ij}^2}, \quad j = 1, \ldots, J; \; i = 1, \ldots, n, \tag{11}$$

Step 2: Calculate the weighted normalized decision matrix. The weighted normalized value is $v_{ij}$ and is calculated as:

$$v_{ij} = w_i r_{ij}, \quad j = 1, \ldots, J; \; i = 1, \ldots, n \tag{12}$$

where $w_i$ is the weight of the $i$th criterion, and $\sum_{j=1}^{n} w_i = 1$.
Step 3: Determine the ideal and negative-ideal solutions using Eqs. (13) and (14).

**Table 6**
The illustration of the local weight of criteria 13 through 15 under the effect of criterion 1.

| Measurement Criteria | C13 | | | C14 | | | C15 | | | Local Weight |
|---|---|---|---|---|---|---|---|---|---|---|
| C13 | 1.00 | 1.00 | 3.00 | 1.91 | 3.31 | 4.27 | 0.14 | 0.18 | 0.31 | 0.22 |
| C14 | 0.23 | 0.30 | 0.52 | 1.00 | 1.00 | 3.00 | 0.19 | 0.28 | 0.49 | 0.12 |
| C15 | 3.18 | 5.66 | 7.10 | 2.02 | 3.60 | 5.13 | 1.00 | 1.00 | 3.00 | 0.66 |

**Table 7**
The unweighted matrix of measurement criteria.

| | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 | C10 | C11 | C12 | C13 | C14 | C15 | C16 | C17 | C18 | C19 | C20 | C21 | C22 | C23 | C24 | C25 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C1 | 0 | 0 | 0 | 0 | 0 | 0 | 0.13 | 0.1 | 0.1 | 0.06 | 0.12 | 0.08 | 0.1 | 0.11 | 0.08 | 0.06 | 0.03 | 0.06 | 0.08 | 0.1 | 0.05 | 0.04 | 0.1 | 0.03 | 0.06 |
| C2 | 0 | 0 | 0 | 0 | 0 | 0 | 0.26 | 0.41 | 0.33 | 0.19 | 0.16 | 0.23 | 0.26 | 0.21 | 0.26 | 0.13 | 0.2 | 0.13 | 0.18 | 0.15 | 0.17 | 0.21 | 0.19 | 0.14 | 0.13 |
| C3 | 0 | 0 | 0 | 0 | 0 | 0 | 0.04 | 0.06 | 0.05 | 0.05 | 0.06 | 0.04 | 0.05 | 0.07 | 0.06 | 0.03 | 0.02 | 0.05 | 0.03 | 0.03 | 0.05 | 0.04 | 0.03 | 0.03 | 0.05 |
| C4 | 0 | 0 | 0 | 0 | 0 | 0 | 0.12 | 0.13 | 0.15 | 0.1 | 0.13 | 0.11 | 0.09 | 0.12 | 0.12 | 0.08 | 0.06 | 0.08 | 0.09 | 0.13 | 0.13 | 0.09 | 0.09 | 0.11 | 0.06 |
| C5 | 0 | 0 | 0 | 0 | 0 | 0 | 0.21 | 0.18 | 0.24 | 0.14 | 0.15 | 0.18 | 0.19 | 0.19 | 0.21 | 0.12 | 0.16 | 0.12 | 0.15 | 0.13 | 0.14 | 0.19 | 0.16 | 0.07 | 0.06 |
| C6 | 0 | 0 | 0 | 0 | 0 | 0 | 0.11 | 0.04 | 0.06 | 0.05 | 0.05 | 0.05 | 0.07 | 0.05 | 0.06 | 0.05 | 0.04 | 0.03 | 0.1 | 0.05 | 0.1 | 0.04 | 0.08 | 0.12 | 0.07 |
| C7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.003 | 0.006 | 0.008 | 0 | 0 | 0 | 0.0002 | 0.001 | 0.003 | 0.006 | 0.004 | 0.002 | 0.005 | 0.005 | 0.004 | 0.006 |
| C8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.002 | 0.004 | 0.001 | 0 | 0 | 0 | 0.003 | 0.003 | 0.001 | 0.003 | 0.002 | 0.004 | 0.004 | 0.006 | 0.001 | 0.002 |
| C9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.03 | 0.02 | 0.007 | 0 | 0 | 0 | 0.002 | 0.002 | 0.002 | 0.001 | 0.003 | 0.005 | 0.001 | 0.003 | 0.002 | 0.003 |
| C10 | 0 | 0 | 0 | 0 | 0 | 0 | 0.06 | 0.02 | 0.02 | 0 | 0 | 0 | 0 | 0 | 0 | 0.002 | 0.003 | 0.001 | 0.001 | 0.005 | 0.001 | 0.003 | 0.001 | 0.003 | 0.002 |
| C11 | 0 | 0 | 0 | 0 | 0 | 0 | 0.03 | 0.03 | 0.01 | 0 | 0 | 0 | 0 | 0 | 0 | 0.04 | 0.03 | 0.04 | 0.01 | 0.03 | 0.04 | 0.02 | 0.02 | 0.02 | 0.03 |
| C12 | 0 | 0 | 0 | 0 | 0 | 0 | 0.04 | 0.03 | 0.04 | 0 | 0 | 0 | 0 | 0 | 0 | 0.03 | 0.02 | 0.04 | 0.02 | 0.02 | 0.04 | 0.03 | 0.03 | 0.03 | 0.04 |
| C13 | 0.22 | 0.21 | 0.27 | 0.31 | 0.18 | 0.33 | 0 | 0 | 0 | 0.12 | 0.11 | 0.12 | 0 | 0 | 0 | 0.11 | 0.06 | 0.05 | 0.09 | 0.11 | 0.05 | 0.13 | 0.06 | 0.06 | 0.08 |
| C14 | 0.12 | 0.03 | 0.14 | 0.16 | 0.12 | 0.12 | 0 | 0 | 0 | 0.04 | 0.07 | 0.01 | 0 | 0 | 0 | 0.03 | 0.02 | 0.04 | 0.06 | 0.03 | 0.05 | 0.04 | 0.03 | 0.02 | 0.06 |
| C15 | 0.66 | 0.76 | 0.59 | 0.53 | 0.7 | 0.55 | 0 | 0 | 0 | 0.17 | 0.09 | 0.13 | 0 | 0 | 0 | 0.12 | 0.12 | 0.11 | 0.12 | 0.14 | 0.12 | 0.11 | 0.14 | 0.13 | 0.12 |
| C16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.04 | 0.02 | 0.03 | 0 | 0 | 0 | 0 | 0 | 0 | 0.03 | 0.03 | 0.002 | 0.03 | 0.03 | 0.04 | 0.04 |
| C17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.001 | 0.004 | 0.003 | 0 | 0 | 0 | 0 | 0 | 0 | 0.002 | 0.004 | 0.007 | 0.001 | 0.003 | 0.002 | 3E-04 |
| C18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.004 | 0.006 | 0.001 | 0 | 0 | 0 | 0 | 0 | 0 | 0.004 | 0.008 | 0.006 | 0.004 | 0.007 | 0.004 | 0.003 |
| C19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.13 | 0.13 | 0.13 | 0.12 | 0.14 | 0.12 | 0 | 0 | 0 | 0 | 0 | 0.12 | 0.09 |
| C20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.08 | 0.08 | 0.05 | 0.03 | 0.06 | 0.05 | 0 | 0 | 0 | 0 | 0 | 0.05 | 0.07 |
| C21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.006 | 0.008 | 0.006 | 0.001 | 0.003 | 0.001 | 0 | 0 | 0 | 0 | 0 | 0.001 | 0.003 |
| C22 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.02 | 0.03 | 0.02 | 0.02 | 0.01 | 0.02 | 0 | 0 | 0 | 0 | 0 | 0.01 | 0.02 |
| C23 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.004 | 0.002 | 0.004 | 0.0008 | 0.006 | 0.001 | 0 | 0 | 0 | 0 | 0 | 0.003 | 7E-04 |
| C24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.02 | 0.01 | 0.05 | 0.02 | 0.02 | 0.03 | 0.01 | 0.01 | 0 | 0 |
| C25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.001 | 0.002 | 0.001 | 0.003 | 0.004 | 0.003 | 0.002 | 0.005 | 0 | 0 |

**Table 8**
The weighted matrix of measurement criteria.

| | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 | C10 | C11 | C12 | C13 | C14 | C15 | C16 | C17 | C18 | C19 | C20 | C21 | C22 | C23 | C24 | C25 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C1 | 0.0495 | 0.0495 | 0.0495 | 0.0495 | 0.0495 | 0.0495 | 0.0495 | 0.0495 | 0.0495 | 0.0495 | 0.0495 | 0.0495 | 0.0495 | 0.0495 | 0.0495 | 0.0495 | 0.0495 | 0.0495 | 0.0495 | 0.0495 | 0.0495 | 0.0495 | 0.0495 | 0.0495 | 0.0495 |
| C2 | 0.1368 | 0.1368 | 0.1368 | 0.1368 | 0.1368 | 0.1368 | 0.1368 | 0.1368 | 0.1368 | 0.1368 | 0.1368 | 0.1368 | 0.1368 | 0.1368 | 0.1368 | 0.1368 | 0.1368 | 0.1368 | 0.1368 | 0.1368 | 0.1368 | 0.1368 | 0.1368 | 0.1368 | 0.1368 |
| C3 | 0.0306 | 0.0306 | 0.0306 | 0.0306 | 0.0306 | 0.0306 | 0.0306 | 0.0306 | 0.0306 | 0.0306 | 0.0306 | 0.0306 | 0.0306 | 0.0306 | 0.0306 | 0.0306 | 0.0306 | 0.0306 | 0.0306 | 0.0306 | 0.0306 | 0.0306 | 0.0306 | 0.0306 | 0.0306 |
| C4 | 0.0634 | 0.0634 | 0.0634 | 0.0634 | 0.0634 | 0.0634 | 0.0634 | 0.0634 | 0.0634 | 0.0634 | 0.0634 | 0.0634 | 0.0634 | 0.0634 | 0.0634 | 0.0634 | 0.0634 | 0.0634 | 0.0634 | 0.0634 | 0.0634 | 0.0634 | 0.0634 | 0.0634 | 0.0634 |
| C5 | 0.1099 | 0.1099 | 0.1099 | 0.1099 | 0.1099 | 0.1099 | 0.1099 | 0.1099 | 0.1099 | 0.1099 | 0.1099 | 0.1099 | 0.1099 | 0.1099 | 0.1099 | 0.1099 | 0.1099 | 0.1099 | 0.1099 | 0.1099 | 0.1099 | 0.1099 | 0.1099 | 0.1099 | 0.1099 |
| C6 | 0.0371 | 0.0371 | 0.0371 | 0.0371 | 0.0371 | 0.0371 | 0.0371 | 0.0371 | 0.0371 | 0.0371 | 0.0371 | 0.0371 | 0.0371 | 0.0371 | 0.0371 | 0.0371 | 0.0371 | 0.0371 | 0.0371 | 0.0371 | 0.0371 | 0.0371 | 0.0371 | 0.0371 | 0.0371 |
| C7 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0006 |
| C8 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 |
| C9 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 |
| C10 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 |
| C11 | 0.0020 | 0.0020 | 0.0020 | 0.0020 | 0.0020 | 0.0020 | 0.0020 | 0.0020 | 0.0020 | 0.0020 | 0.0020 | 0.0020 | 0.0020 | 0.0020 | 0.0020 | 0.0020 | 0.0020 | 0.0020 | 0.0020 | 0.0020 | 0.0020 | 0.0020 | 0.0020 | 0.0020 | 0.0020 |
| C12 | 0.0025 | 0.0025 | 0.0025 | 0.0025 | 0.0025 | 0.0025 | 0.0025 | 0.0025 | 0.0025 | 0.0025 | 0.0025 | 0.0025 | 0.0025 | 0.0025 | 0.0025 | 0.0025 | 0.0025 | 0.0025 | 0.0025 | 0.0025 | 0.0025 | 0.0025 | 0.0025 | 0.0025 | 0.0025 |
| C13 | 0.1107 | 0.1107 | 0.1107 | 0.1107 | 0.1107 | 0.1107 | 0.1107 | 0.1107 | 0.1107 | 0.1107 | 0.1107 | 0.1107 | 0.1107 | 0.1107 | 0.1107 | 0.1107 | 0.1107 | 0.1107 | 0.1107 | 0.1107 | 0.1107 | 0.1107 | 0.1107 | 0.1107 | 0.1107 |
| C14 | 0.0475 | 0.0475 | 0.0475 | 0.0475 | 0.0475 | 0.0475 | 0.0475 | 0.0475 | 0.0475 | 0.0475 | 0.0475 | 0.0475 | 0.0475 | 0.0475 | 0.0475 | 0.0475 | 0.0475 | 0.0475 | 0.0475 | 0.0475 | 0.0475 | 0.0475 | 0.0475 | 0.0475 | 0.0475 |
| C15 | 0.2997 | 0.2997 | 0.2997 | 0.2997 | 0.2997 | 0.2997 | 0.2997 | 0.2997 | 0.2997 | 0.2997 | 0.2997 | 0.2997 | 0.2997 | 0.2997 | 0.2997 | 0.2997 | 0.2997 | 0.2997 | 0.2997 | 0.2997 | 0.2997 | 0.2997 | 0.2997 | 0.2997 | 0.2997 |
| C16 | 0.0032 | 0.0032 | 0.0032 | 0.0032 | 0.0032 | 0.0032 | 0.0032 | 0.0032 | 0.0032 | 0.0032 | 0.0032 | 0.0032 | 0.0032 | 0.0032 | 0.0032 | 0.0032 | 0.0032 | 0.0032 | 0.0032 | 0.0032 | 0.0032 | 0.0032 | 0.0032 | 0.0032 | 0.0032 |
| C17 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 |
| C18 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0006 | 0.0006 |
| C19 | 0.0603 | 0.0603 | 0.0603 | 0.0603 | 0.0603 | 0.0603 | 0.0603 | 0.0603 | 0.0603 | 0.0603 | 0.0603 | 0.0603 | 0.0603 | 0.0603 | 0.0603 | 0.0603 | 0.0603 | 0.0603 | 0.0603 | 0.0603 | 0.0603 | 0.0603 | 0.0603 | 0.0603 | 0.0603 |
| C20 | 0.0279 | 0.0279 | 0.0279 | 0.0279 | 0.0279 | 0.0279 | 0.0279 | 0.0279 | 0.0279 | 0.0279 | 0.0279 | 0.0279 | 0.0279 | 0.0279 | 0.0279 | 0.0279 | 0.0279 | 0.0279 | 0.0279 | 0.0279 | 0.0279 | 0.0279 | 0.0279 | 0.0279 | 0.0279 |
| C21 | 0.0028 | 0.0028 | 0.0028 | 0.0028 | 0.0028 | 0.0028 | 0.0028 | 0.0028 | 0.0028 | 0.0028 | 0.0028 | 0.0028 | 0.0028 | 0.0028 | 0.0028 | 0.0028 | 0.0028 | 0.0028 | 0.0028 | 0.0028 | 0.0028 | 0.0028 | 0.0028 | 0.0028 | 0.0028 |
| C22 | 0.0097 | 0.0097 | 0.0097 | 0.0097 | 0.0097 | 0.0097 | 0.0097 | 0.0097 | 0.0097 | 0.0097 | 0.0097 | 0.0097 | 0.0097 | 0.0097 | 0.0097 | 0.0097 | 0.0097 | 0.0097 | 0.0097 | 0.0097 | 0.0097 | 0.0097 | 0.0097 | 0.0097 | 0.0097 |
| C23 | 0.0017 | 0.0017 | 0.0017 | 0.0017 | 0.0017 | 0.0017 | 0.0017 | 0.0017 | 0.0017 | 0.0017 | 0.0017 | 0.0017 | 0.0017 | 0.0017 | 0.0017 | 0.0017 | 0.0017 | 0.0017 | 0.0017 | 0.0017 | 0.0017 | 0.0017 | 0.0017 | 0.0017 | 0.0017 |
| C24 | 0.0021 | 0.0021 | 0.0021 | 0.0021 | 0.0021 | 0.0021 | 0.0021 | 0.0021 | 0.0021 | 0.0021 | 0.0021 | 0.0021 | 0.0021 | 0.0021 | 0.0021 | 0.0021 | 0.0021 | 0.0021 | 0.0021 | 0.0021 | 0.0021 | 0.0021 | 0.0021 | 0.0021 | 0.0021 |
| C25 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 |

$$A^* = \{v_1^*, \ldots, v_n^*\} = \left\{ (\max_j v_{ij} | i \in I'), (\min_j v_{ij} | i \in I'') \right\} \quad (13)$$

$$A^- = \{v_1^-, \ldots, v_n^-\} = \left\{ (\min_j v_{ij} | i \in I'), (\max_j v_{ij} | i \in I'') \right\} \quad (14)$$

where $\boldsymbol{I}'$ is associated with benefit criteria, and $\boldsymbol{I}''$ is associated with cost criteria.

Step 4: Calculate the separation measures using the $n$-dimensional Euclidean distance. The separation of each alternative from the ideal solution is:

$$D_j^* = \sqrt{\sum_{i=1}^{n} (v_{ij} v_i^-)^2}, \quad j = 1, \ldots, J \quad (15)$$

Similarly, the separation from the negative-ideal solution is:

$$D_j^- = \sqrt{\sum_{i=1}^{n} (v_{ij} v_i^-)^2}, \quad j = 1, \ldots, J \quad (16)$$

Step 5: Calculate the relative closeness to the ideal solution. The relative closeness of alternative $a_j$ with respect to $A^*$ is defined as:

$$C_j^* = D_j^- \Big/ \left(D_j^* + D_j^-\right), \quad j = 1, \ldots, J. \quad (17)$$

Step 6: Rank the preference order.

## 4. An empirical study of an innovation support system (ISS)

Owing to increasing domestic and international pressures due to joining the WTO and the drop in the birthrate, universities in Taiwan are innovating in order to gain a sustainable competitive advantage. They evaluate innovation performance mainly by drawing on previous academic research, and some studies address this need by specifically searching out measurement criteria for innovation performance. Most criteria have been assumed to be independent of each other; however, in the real world, they may be interdependent. In addition, when applying such research to Taiwanese higher education, we must keep in mind that higher educational institutions fall into three categories, namely, research-intensive universities, teaching-intensive universities, and professional-intensive universities (Li, 2007). The focus of innovation improvement and evaluation are different among each of these different types of universities. Thus, in order to construct a novel innovation support system (ISS) for Taiwan higher education, we consider the interrelationships for each criterion as well as these different types of universities.

### 4.1. Developing the original innovation support system

Developing an innovation support system for higher education is complicated, as it contains member, environmental, administrative and other factors. It is obvious that the components of an innovation support system should be both interdependent as well as being in accordance with real practice. Thus, twenty-five higher educational experts were consulted, including ten from research-intensive universities, seven from professional-intensive universities, and eight from teaching-intensive universities. In addition, the National Science Council (2008), and the R&D departments of thirty universities were consulted to construct a seven-dimensional innovation support system based on Academic Research (D1), Administrative Process (D2), Faculty and Staff (D3), Market Development (D4), Organizational Structure (D5), Organizational Culture (D6), and Leadership Style (D7). Each dimension has three to six measurement criteria (Table 2). A questionnaire was given to sixty-six experts, including thirty-six from research-intensive universities, eleven from teaching-intensive universities, and nineteen from professional-intensive universities. Their ranking of each measurement innovation criterion was ascertained by adapting a 5-point scale, as shown in Table 3, with respect to the innovation performance of each type of university. Experts were asked to rank their perceptions of innovative performance based on a scale ranging from 100 (the best) to 0 (the worst).

### 4.2. Evaluating the relationships among each dimension

The purpose of this paper is to determine critical innovation criteria and evaluate the relationships among such criteria. Sixty-six educational experts were asked to indicate the relationships between seven measurement dimensions. Based on an average of their opinions, we formed an initial direct-relation 7 × 7 matrix $\boldsymbol{A}$ by using pair-wise comparisons (see Table 3).

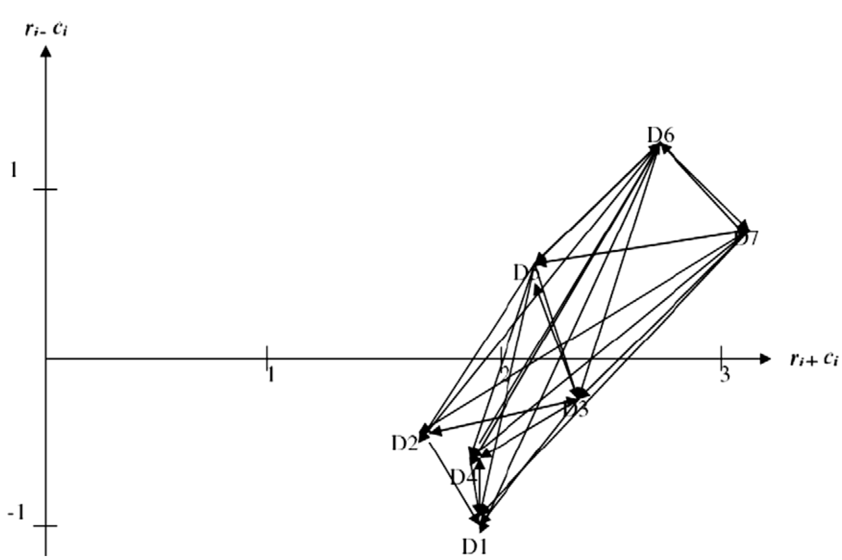


**Fig. 7.** The impact of direction map of measurement criteria.

**Table 9**
The initial value from experts for three types of universities.

| | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 | C10 | C11 | C12 | C13 | C14 | C15 | C16 | C17 | C18 | C19 | C20 | C21 | C22 | C23 | C24 | C25 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RU | 90 | 95 | 93 | 96 | 98 | 92 | 96 | 85 | 80 | 95 | 95 | 93 | 97 | 96 | 97 | 93 | 94 | 80 | 90 | 84 | 91 | 92 | 79 | 81 | 82 |
| TU | 77 | 86 | 81 | 86 | 84 | 84 | 91 | 84 | 81 | 91 | 89 | 90 | 85 | 89 | 91 | 91 | 95 | 79 | 86 | 86 | 84 | 83 | 77 | 86 | 82 |
| PU | 86 | 80 | 86 | 84 | 82 | 87 | 92 | 86 | 77 | 90 | 89 | 90 | 83 | 86 | 93 | 86 | 91 | 87 | 90 | 83 | 90 | 87 | 79 | 79 | 77 |
| W | 0.0495 | 0.1368 | 0.0306 | 0.0634 | 0.1099 | 0.0371 | 0.0006 | 0.0003 | 0.0003 | 0.0003 | 0.0020 | 0.0025 | 0.1107 | 0.0475 | 0.2997 | 0.0032 | 0.0003 | 0.0006 | 0.0603 | 0.0279 | 0.0028 | 0.0097 | 0.0017 | 0.0021 | 0.0003 |

**Table 10**
The result of universities ranking by TOPSIS.

| Wed M | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 | C10 | C11 | C12 | C13 | C14 | C15 | C16 | C17 | C18 | C19 | C20 | C21 | C22 | C23 | C24 | C25 | $D^*$ | D- | $D^* + D-$ | $C^*j$ | Ranking |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RU | 0.0300 | 0.0837 | 0.0189 | 0.0377 | 0.0669 | 0.0224 | 0.0004 | 0.00018 | 0.00018 | 0.00018 | 0.0012 | 0.0015 | 0.0700 | 0.0295 | 0.1778 | 0.0019 | 0.00018 | 0.00035 | 0.0356 | 0.0160 | 0.00170 | 0.0061 | 0.00101 | 0.00121 | 0.00018 | 0.0016 | 0.0187 | 0.0202 | 0.9231 | 1 |
| TU | 0.0275 | 0.0729 | 0.0170 | 0.0350 | 0.0603 | 0.0204 | 0.0003 | 0.00017 | 0.00017 | 0.00017 | 0.0011 | 0.0014 | 0.0584 | 0.0255 | 0.1676 | 0.0018 | 0.00017 | 0.00035 | 0.0347 | 0.0162 | 0.00162 | 0.0054 | 0.00097 | 0.00119 | 0.00017 | 0.0206 | 0.0032 | 0.0238 | 0.1357 | 3 |
| PU | 0.0282 | 0.0800 | 0.0171 | 0.0370 | 0.0630 | 0.0214 | 0.0003 | 0.00017 | 0.00017 | 0.00017 | 0.0012 | 0.0014 | 0.0627 | 0.0271 | 0.1735 | 0.0019 | 0.00017 | 0.00034 | 0.0341 | 0.0161 | 0.00153 | 0.0054 | 0.00097 | 0.00123 | 0.00017 | 0.0106 | 0.0086 | 0.0192 | 0.4464 | 2 |
| W | 0.0495 | 0.1368 | 0.0306 | 0.0634 | 0.1099 | 0.0371 | 0.0006 | 0.0003 | 0.0003 | 0.0003 | 0.002 | 0.0025 | 0.1107 | 0.0475 | 0.2997 | 0.0032 | 0.0003 | 0.0006 | 0.0603 | 0.0279 | 0.0028 | 0.0097 | 0.0017 | 0.0021 | 0.0003 | | | | | |
| $A^+$ | 0.0303 | 0.0829 | 0.0188 | 0.0377 | 0.0678 | 0.0223 | 0.0004 | 0.00018 | 0.00018 | 0.00018 | 0.0012 | 0.0015 | 0.0696 | 0.0293 | 0.1778 | 0.0019 | 0.00018 | 0.00036 | 0.0354 | 0.0168 | 0.0017 | 0.006 | 0.00102 | 0.00127 | 0.00018 | | | | | |
| $A^-$ | 0.0272 | 0.0747 | 0.017 | 0.0346 | 0.0598 | 0.0203 | 0.0003 | 0.00017 | 0.00017 | 0.00017 | 0.0011 | 0.0014 | 0.0593 | 0.0263 | 0.1698 | 0.0017 | 0.00016 | 0.00033 | 0.0345 | 0.0155 | 0.00157 | 0.0052 | 0.00095 | 0.00116 | 0.00016 | | | | | |

In accordance with Eq. (1) through (3), we next generated the normalized direct-relation matrix ***D*** from ***A***. After that, Eq. (5) is used to calculate the total influence matrix ***T***, as show in Table 4. Finally, Eqs. (7) and (8) are utilized to calculate total influences given and received along each of these measurement dimensions; the result of these calculations is given in Table 5.

For the purposes of this paper, we use a threshold value of 0.1; we only consider influence values above this threshold, otherwise our system becomes intractably complex. We adopted a threshold value of 0.1 after consultation with educational experts. The resulting impact relations map (IRM) is given in Fig. 6.

### 4.3. Calculating weights of criteria in the innovation support system

In this stage, we used fuzzy ANP to calculate the weights of measurement criteria after illustrating the relationship structure of the innovation support system. At first, the relative importance of relationships among measurement criteria resembles the impact relations map. Note again that pair-wise comparisons were conducted according to Table 4 above. Table 6 illustrates the local weight, which is acquired using the principle eigenvector of comparison between criterion 1 and criteria 13 through 15; and the results of other relationships are addressed as an unweighted super matrix in Table 7.

From the Eq. (9), we calculated the limiting power of the unweighted matrix until it reached stability; the results are provided in Table 8. The entries in the same row are the global weights of each measurement criterion. Finally, using above results, the impact-direction map that depicts the importance of each measurement criterion is shown in Fig. 7.

### 4.4. Ranking alternatives in order to develop a novel innovation support system (ISS)

As mentioned before, universities in Taiwan can be categorized into three main types; namely, research-intensive universities,

**Table 11**
The overall result of this study.

| Goal | Evaluating Dimensions | Evaluating Criteria (After considered interrelationships) | Global Weights | University Type | Overall Ranking |
|---|---|---|---|---|---|
| The original innovation support system for Taiwanese higher education | Academic Research (D1) | Research Patents (C1) | 0.0495 | Research- Intensive University (RU) | 1 |
| | | International Academic Interaction (C2) | 0.1368 | | |
| | | Number of R&D Members (C3) | 0.0306 | | |
| | | Financial Support of National Science Council (C4) | 0.0634 | | |
| | | Journals Accepted and Published (C5) | 0.1099 | | |
| | | Government Tender Planning (C6) | 0.0371 | | |
| | Administrative Process (D2) | Operation Electrification (C7) | 0.0006 | | |
| | | Outsourcing (C8) | 0.0003 | | |
| | | Affair Rotation (C9) | 0.0003 | Teaching- Intensive University | 3 |
| | Faculty and Staff (D3) | Information Study Camp (C10) | 0.0003 | | |
| | | Refresher Classes (C11) | 0.0020 | | |
| | | Go Abroad for Further Education (C12) | 0.0025 | | |
| | Market Development (D4) | Number of Conferences (C13) | 0.1107 | | |
| | | Number of International Students in School (C14) | 0.0475 | | |
| | | Number of Chair Professors (C15) | 0.2997 | | |
| | Organizational Structure (D5) | Learning Organization (C16) | 0.0032 | | |
| | | Specialization Organization (C17) | 0.0003 | Professional- Intensive University (PU) | 2 |
| | | Matrix Organization (C18) | 0.0006 | | |
| | Organizational Culture (D6) | Result-Oriented (C19) | 0.0603 | | |
| | | Employee-Oriented (C20) | 0.0279 | | |
| | | Parochial-Oriented (C21) | 0.0028 | | |
| | | Open-Oriented (C22) | 0.0097 | | |
| | | Loosely Control-Oriented (C23) | 0.0017 | | |
| | Leadership Style (D7) | Transformational Leadership (C24) | 0.0021 | | |
| | | Transactional Leadership (C25) | 0.0003 | | |

**Table 12**
A novel innovation support system (ISS).

| IS System | IS Dimension | IS Criteria | Optimal IS Type |
|---|---|---|---|
| A novel innovation support system (ISS) | Academic Research | International Academic Interaction | Research-Intensive University (RU) |
| | | Financial Support of NSC | |
| | | Journals Accepted and Published | |
| | External Academic Support | Number of Conferences | |
| | | Number of Chair Professors | |
| | Organizational Culture | Result-Oriented | |
| | Innovation Accelerated Force: Transformational Leadership | | |

teaching-intensive universities, and professional-intensive universities. As a result, notions of innovation improvement as well as evaluative focuses differ among these universities. Ranking these types of universities is thus useful in determining an optimal innovation system for non-optimal, existing universities. This allows us to develop a benchmark for existing universities as well as to yield insights to newly built universities so that they are better equipped to make key choices early in their development. Note that we use the insights of eight of the sixty-six educational experts who either have served in all three types of universities since entering academia or have served on an academic performance measurement committee.

Based on the responses of these eight educational experts, as shown in Table 9, and the global weights of measurement criteria, as shown in Table 8, we utilized TOPSIS to rank the three types of universities, which can be considered alternative solutions for our purposes here. Following the steps of TOPSIS, we generated values necessary to rank these types of universities, as shown in Table 10. We also present the overall results of this study in Table 11. Following the construction of innovation measurement criteria, the calculation of weights, and the generation of university rankings, we finally propose a novel innovation support system in which measurement criteria are extracted from top six weights among all criteria. The reason for this is that we believe that focusing an evaluation of innovation performance on more influential criteria is better than basing it on whole measurement criteria. In addition, the transformational leadership criterion is included due to its large influence on innovation promotion (see Table 12).

## 5. Conclusions

Given a recent drop in birthrates, an increase in the number of higher educational institutions, and a new membership in the WTO, Taiwanese higher educational institutions are facing increased competition. As such, they have recently tried to upgrade their innovation capabilities and innovation performance by using various evaluative tools. In doing so, they mainly focus on academic research. However, the factors influencing innovation in higher education are various. In accordance with the potentially numerous criteria useful in evaluating innovation performance in higher educational institutions, we have combined DEMATEL, fuzzy ANP and TOPSIS approaches to develop an innovation support system (ISS) that considers the interdependence and relative weights of each measurement criterion and different types of universities. As a result, we hope that ISS will help future innovation improvements to be more practical, efficient and efficacious.

## References


Bantel, K., & Jackson, S. (1989). Top management and innovations in banking: does the composition of the top team make a difference. *Strategic Management Journal, 10*, 107–124.

Chen, M. C. (2005). Creativity comes from living field. *Journal of Shih-Yu, 456*(5), 13–19.

Chen, J. K., & Chen, I. S. (2008). Select innovative index of higher educational institutions by FAHP. *Journal of American Academy of Business, Cambridge, 13*(1), 151–157.

Chen, S. J., & Hwang, C. L. (1992). *Fuzzy multiple attribute decision making: Methods and applications*. Berlin: Springer- Verlag.

Chin, J. M., & Pu, S. W. (2006). The concepts and implementations of school innovation management. *Journal of Educational Research and Development, 2*(3), 123–150.

Daft, R. L. (2004). *Organization theory & design*. NY: West.

Damanpour, F. (1996). Organizational complexity and innovation: Developing and testing multiple contingency models. *Management Science, 42*, 693–716.

Gabus, A., & Fontela, E (1972). World problems, an invitation to further thought within the framework of DEMATEL. Geneva, Switzerland: Battelle Geneva Research Center.

Huang, C. Y., Shyu, J. Z., & Tzeng, G. H. (2007). Reconfiguring the innovation policy portfolios for Taiwan's SIP Mall industry. *Technovation, 27*(12), 744–765.

Hwang, C. L., & Yoon, K. S. (1981). *Multiple attribute decision making: Method and applications*. NY: Springer.

Krause, D. E. (2004). Influence-based leadership as a determinant of the inclination to innovative and of innovate-related behavior: An empirical investigation. *The Leadership Quarterly, 15*, 79–102.

Li, U. C. (2007). Enter university by 2.8 point each subject. Retrieved August 18, 2007, from <http://news.msn.com.tw/print.aspx?id=210245>.

Lin, H. F., Wang, H. L., Wang C. M., & Yen, J. F. (2006). The relationship between elementary principle leadership, continuous knowledge management and innovative operation-take three cities in northern Taiwan as example. In *Education Development in Chinese Society Conference, University of Macau, China*.

Liou, J. H., Tzeng, G. H., & Chang, H. C. (2007). Airline safety measurement using a hybrid model. *Journal of Air Transport Management, 13*, 243–249.

National Science Council (2008). Fast connection. Retrieved November 23, 2008, from <http://web1.nsc.gov.tw/mp.aspx>.

Ong, C. S., Huang, J. J., & Tzeng, G. H. (2004). Multidimensional data in multidimensional scaling using the analytic network process. *Pattern Recognition Letters, 26*(6), 755–767.

Opricovic, S., & Tzeng, G. H. (2004). Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS. *European Journal of Operational Research, 156*(2004), 445–455.

O'Sullivan, M. A. (2000). *Contests for corporate control: Corporate governance and economic performance in the United States and Germany*. NY: Oxford University Press.

Saaty, T. L. (1980). *The analytic hierarchy process*. NY: McGraw-Hill.

Tang, C. M. (2006). *School building and campus planning*. Taipei: Wu-Nan Press.

Tzeng, G. H., Chiang, C. H., & Li, C. W. (2007). Evaluating intertwined effects in e-learning programs: A novel hybrid MCDM model based on factor analysis and DEMATEL. *Expert Systems with Applications, 32*, 1028–1044.

Wolfe, R. A. (1994). Organizational innovation: Review, critique and suggested research directions. *Journal of Management Studies, 3*(3), 405–430.