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A performance evaluation model by integrating fuzzy AHP and fuzzy TOPSIS methods

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ABSTRACT

Multiple criteria decision-making (MCDM) research has developed rapidly and has become a main area of research for dealing with complex decision problems. The purpose of the paper is to explore the performance evaluation model. This paper develops an evaluation model based on the fuzzy analytic hierarchy process and the technique for order performance by similarity to ideal solution, fuzzy TOPSIS, to help the industrial practitioners for the performance evaluation in a fuzzy environment where the vagueness and subjectivity are handled with linguistic values parameterized by triangular fuzzy numbers. The proposed method enables decision analysts to better understand the complete evaluation process and provide a more accurate, effective, and systematic decision support tool.

1. Introduction

In order to compete in today's competitive environment, many organizations have recognized benchmarking as being of strategic important in the drive for better performance and commitment to achieve a competitive advantage (Gleich, Motwani, & Wald, 2008; Neely, Gregory, & Platts, 1995). There are many studies that investigated the method about performance evaluation (Chalasani & Sounderpandian, 2004; Gleich et al., 2008; Maiga & Jacobs, 2004; Wynn-Williams, 2005). Some literatures identified the different key performance indicators, including tangible and intangible aspect (Chin, Pun, Lau, & Lau, 2001; Himes, 2007; Jones & Kaluarachchi, 2008; Mukherjee, Nath, & Pal, 2002; Robson & Prabhu, 2001; Wainwright, Green, Mitchell, & Yarrow, 2005; Welch & Mann, 2001). It is essential for the application of performance measurement that a company's tangible and intangible targets are defined in a way that is more appropriate to the requirements and objects of this targets and that its strategy is more extensively operationalized, quantified, and linked in a mutually supplementing way.

In the literature, there is few fuzzy logic methods aimed at evaluating the relative performance by multidimensions. The main purpose of this paper is to provide practitioners with a fuzzy point of view to traditional performance research for dealing with imprecision and at obtaining the prioritization and the best performance of measurement dimensions. Moreover, we attempt to assist government representatives or industrial analyst in accessing the relative performance. We take the global top four notebook computer ODM companies for pursuing our case purposes. This research invites 10 experts that evaluate the performance of global top four notebook computer ODM companies via the proposed fuzzy AHP and fuzzy TOPSIS techniques with MCDM. The fuzzy AHP is used to determine the preference weights of evaluation. Then, this research adopts the fuzzy TOPSIS to improve the gaps of alternatives between real performance values and pursuing aspired levels in each dimension and criterion and find out the best alternatives for achieving the aspired/desired levels based on four proposed companies. This research looks forward to provide Taiwan industries and government with some strategic recommendations.

The reminder of this paper is organized as follows. Sections 2 and 3 present how we adopt the methodology, fuzzy AHP and fuzzy TOPSIS in real world. Section 4 displays our empirical results along with some discussions relating to managerial implications. Finally, conclusions and remarks are then given in Section 5.

2. Fuzzy analytic hierarchy process method

Analytic hierarchy process (AHP) is a powerful method to solve complex decision problems. Any complex problem can be decomposed into several sub-problems using AHP in terms of hierarchical levels where each level represents a set of criteria or attributes relative to each sub-problem. The AHP method is a multicriteria method of analysis based on an additive weighting process, in which several relevant attributes are represented through their relative importance. AHP has been extensively applied by academics and professionals, mainly in engineering applications involving financial decisions associated to non-financial attributes (Saaty,

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1996). Through AHP, the importance of several attributes is obtained from a process of paired comparison, in which the relevance of the attributes or categories of drivers of intangible assets are matched two-on-two in a hierarchic structure.

However, the pure AHP model has some shortcomings (Yang & Chen, 2004). They pointed out that the AHP method is mainly used in nearly crisp-information decision applications; the AHP method creates and deals with a very unbalanced scale of judgment; the AHP method does not take into account the uncertainty associated with the mapping of human judgment to a number by natural language; the ranking of the AHP method is rather imprecise; and the subjective judgment by perception, evaluation, improvement and selection based on preference of decision-makers have great influence on the AHP results. To overcome these problems, several researchers integrate fuzzy theory with AHP to improve the uncertainty. Hence, Buckley (1985) used the evolutionary algorithm to calculate the weights with the trapezoidal fuzzy numbers. The fuzzy AHP based on the fuzzy interval arithmetic with triangular fuzzy numbers and confidence index α with interval mean approach to determine the weights for evaluative elements.

2.1. Building the evaluation hierarchy systems for evaluating the performance of global top four notebook computer companies

This research tries to evaluate the performance of global top four notebook computer ODM companies. After reviewing the related literature, we set criteria that building the evaluation hierarchy systems. Based on the evaluation criteria, this research lists the four notebook companies for improving the competitive advantage.

2.2. Determining the evaluation dimensions weights

This research employs fuzzy AHP to fuzzify hierarchical analysis by allowing fuzzy numbers for the pairwise comparisons and find the fuzzy preference weights. In this section, we briefly review concepts for fuzzy hierarchical evaluation. Then, the following sections will introduce the computational process about fuzzy AHP in detail.

2.2.1. Establishing fuzzy number

Fuzzy sets are sets whose elements have degrees of membership. Fuzzy sets have been introduced by Zadeh (1965) as an extension of the classical notion of set. In classical set theory, the membership of elements in a set is assessed in binary terms according to a bivalent condition – an element either belongs or does not belong to the set (Liou, Yen, & Tzeng, 2007; Wu & Lee, 2007). The mathematics concept borrowed from Hsieh, Lu, and Tzeng (2004) and Liou et al. (2007).

A fuzzy number $\widetilde{A}$ on $\mathbb{R}$ to be a *TFN* if its membership function $\mu_{\widetilde{A}}(x):\mathbb{R}\to[0,1]$ is equal to following Eq. (1):

$$\mu_{\widetilde{A}}(x)=\begin{cases}(x-l)/(m-l), & l\leqslant x\leqslant m\\ (u-x)/(u-m), & m\leqslant x\leqslant u\\ 0, & \text{otherwise}\end{cases} \tag{1}$$

From Eq. (1), l and u mean the lower and upper bounds of the fuzzy number $\widetilde{A}$, and m is the modal value for $\widetilde{A}$ (as Fig. 1). The *TFN* can be denoted by $\widetilde{A}=(l,m,u)$. The operational laws of *TFN* $\widetilde{A}_1=(l_1,m_1,u_1)$ and $\widetilde{A}_2=(l_2,m_2,u_2)$ are displayed as following Eqs. (2)–(6).

Addition of the fuzzy number $\oplus$

$$\begin{aligned}\widetilde{A}_1\oplus\widetilde{A}_2&=(l_1,m_1,u_1)\oplus(l_2,m_2,u_2)\\ &=(l_1+l_2,m_1+m_2,u_1+u_2)\end{aligned} \tag{2}$$

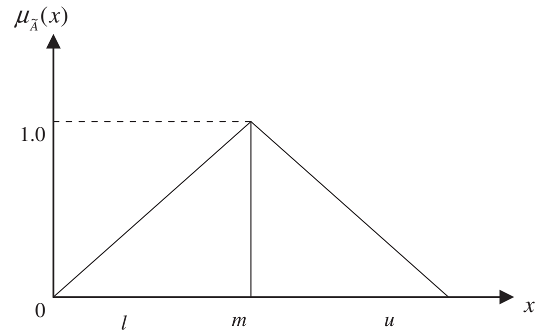

Fig. 1. The membership functions of the triangular fuzzy number.

Multiplication of the fuzzy number $\otimes$

$$\begin{aligned}\widetilde{A}_1\otimes\widetilde{A}_2&=(l_1,m_1,u_1)\otimes(l_2,m_2,u_2)\\ &=(l_1l_2,m_1m_2,u_1u_2)\quad \text{for } l_1,l_2>0;\ m_1,m_2>0;\\ &\quad u_1,u_2>0\end{aligned} \tag{3}$$

Subtraction of the fuzzy number $\ominus$

$$\begin{aligned}\widetilde{A}_1\ominus\widetilde{A}_2&=(l_1,m_1,u_1)\ominus(l_2,m_2,u_2)\\ &=(l_1-u_2,m_1-m_2,u_1-l_2)\end{aligned} \tag{4}$$

Division of a fuzzy number ø

$$\begin{aligned}\widetilde{A}_1\,ø\,\widetilde{A}_2&=(l_1,m_1,u_1)\,ø\,(l_2,m_2,u_2)\\ &=(l_1/u_2,m_1/m_2,u_1/l_2)\quad \text{for } l_1,l_2>0;\ m_1,m_2>0;\\ &\quad u_1,u_2>0\end{aligned} \tag{5}$$

Reciprocal of the fuzzy number

$$\begin{aligned}&\widetilde{A}^{-1}=(l_1,m_1,u_1)^{-1}=(1/u_1,1/m_1,1/l_1)\\ &\text{for } l_1,l_2>0;\ m_1,m_2>0;\ u_1,u_2>0\end{aligned} \tag{6}$$

2.2.2. Determining the linguistic variables

Linguistic variables take on values defined in its term set: its set of linguistic terms. Linguistic terms are subjective categories for the linguistic variable. A linguistic variable is a variable whose values are words or sentences in a natural or artificial language. Here, we use this kind of expression to compare two building Notebook Computer Companies evaluation dimension by nine basic linguistic terms, as "Perfect," "Absolute," "Very good," "Fairly good," "Good," "Preferable," "Not Bad," "Weak advantage" and "Equal" with respect to a fuzzy nine level scale. In this paper, the computational technique is based on the following fuzzy numbers defined by Gumus (2009) in Table 1. Here, each membership function (scale of fuzzy number) is defined by three parameters of the symmetric triangular fuzzy number, the left point, middle point, and right point of the range over which the function is defined.

Table 1
Membership function of linguistic scale (example).

Fuzzy number	Linguistic	Scale of fuzzy number
9	Perfect	(8,9,10)
8	Absolute	(7,8,9)
7	Very good	(6,7,8)
6	Fairly good	(5,6,7)
5	Good	(4,5,6)
4	Preferable	(3,4,5)
3	Not bad	(2,3,4)
2	Weak advantage	(1,2,3)
1	Equal	(1,1,1)

2.2.3. Fuzzy AHP

Then, we will briefly introduce that how to carry out the fuzzy AHP in the following sections.

Step1: Construct pairwise comparison matrices among all the elements/criteria in the dimensions of the hierarchy system. Assign linguistic terms to the pairwise comparisons by asking which is the more important of each two dimensions, as following matrix $\widetilde{\boldsymbol{A}}$

$$\widetilde{\boldsymbol{A}} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n\mathbf{1}} & \tilde{a}_{n2} & \cdots & 1 \end{bmatrix} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{\mathbf{1}n} \\ 1/\tilde{a}_{12} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/\tilde{a}_{1n} & 1/\tilde{a}_{2n} & \cdots & 1 \end{bmatrix} \tag{7}$$

where

$$\tilde{a}_{ij} = \begin{cases} \tilde{9}^{-1}, \tilde{8}^{-1}, \tilde{7}^{-1}, \tilde{6}^{-1}, \tilde{5}^{-1}, \tilde{4}^{-1}, \tilde{3}^{-1}, \tilde{2}^{-1}, \tilde{1}^{-1}, \tilde{1}, \tilde{2}, \tilde{3}, \tilde{4}, \tilde{5}, \tilde{6}, \tilde{7}, \tilde{8}, \tilde{9}, & 1, i \neq j \\ 1 & i = j \end{cases}$$

Step 2: To use geometric mean technique to define the fuzzy geometric mean and fuzzy weights of each criterion by Hsieh et al. (2004)

$$\begin{aligned} \tilde{r}_i &= (\tilde{a}_{i1} \otimes \cdots \otimes \tilde{a}_{ij} \otimes \cdots \otimes \tilde{a}_{in})^{1/n} \\ \tilde{w}_i &= \tilde{r}_i \otimes [\tilde{r}_1 \oplus \cdots \oplus \tilde{r}_i \oplus \cdots \oplus \tilde{r}_n]^{-1} \end{aligned} \tag{8}$$

where $\tilde{a}_{ij}$ is fuzzy comparison value of dimension i to criterion j, thus, $\tilde{r}_i$ is a geometric mean of fuzzy comparison value of criterion i to each criterion, $\tilde{w}_i$ is the fuzzy weight of the ith criterion, can be indicated by a *TFN*, $\tilde{w}_i = (lw_i, mw_i, uw_i)$. The lw_i, mw_i and uw_i stand for the lower, middle, and upper values of the fuzzy weight of the ith dimension.

There are numerous studies that apply fuzzy AHP method to solve different managerial problems. Huang, Chu, and Chiang (2008) adopt a fuzzy analytic hierarchy process method and utilize crisp judgment matrix to evaluate subjective expert judgments made by perception. Pan (2008) applied fuzzy AHP model for selecting the suitable bridge construction method. Cakir and Canbolat (2008) propose an inventory classification system based on the fuzzy analytic hierarchy process. Wang and Chen (2008) applied fuzzy linguistic preference relations to construct a pairwise comparison matrix with additive reciprocal property and consistency. Sambasivan and Fei (2008) evaluate the factors and sub-factors critical to the successful implementation of ISO 14001-based environmental management system and benefits. Sharma, Moon, and Bae (2008) used AHP method to optimize the selection of delivery network design followed by relevant choices for decision-making of Home plus distribution center. Costa and Vansnick (2008) discussed the meaning of the priority vector derived from the principal eigenvalue method used in AHP. Firouzabadi, Henson, and Barnes (2008) presented a decision support methodology for strategic selection decisions used a combination of analytic hierarchy process and zero-one goal programming to address the selection problem from the point of view of an individual stakeholder. Wang, Luo, and Hua (2008) showed by examples that the priority vectors determined by the analytic hierarchy process method. Kuo, Tzeng, and Huang (2007) proposed group decision-making based on concepts of TOPIS technique for location section in fuzzy environment. Gumus (2009) evaluates hazardous waste transportation firms containing the methods of fuzzy AHP and TOPSIS. Armillotta (2008) described a computer-based tool for the selection of techniques used in the manufacture of prototypes and limited production runs of industrial products. The underlying decision model based on the AHP methodology, Dagdeviren and Yuksel (2008) presented fuzzy AHP approach to determine the level of faulty behavior risk in work systems. Chen, Tzeng, and Ding (2008) used fuzzy analytic hierarchy process to determine the weighting of subjective/perceptive judgments for each criterion and to derive fuzzy synthetic utility values of alternatives in a fuzzy multicriteria decision-making environment. Lin, Wang, Chen, and Chang (2008) proposed a framework that integrates the analytical hierarchy process and the technique for order preference by similarity to ideal solution to assist designers in identifying customer needs/requirements and design characteristics and help achieve an effective evaluation of the final design solution for achieving the aspired/desired levels.

3. The fuzzy TOPSIS method

In this study, we propose this method to evaluate the performance of global top four notebook computer ODM companies. TOPSIS views a MADM problem with m alternatives as a geometric system with m points in the n-dimensional space of criteria. The method is based on the concept that the chosen alternative should have the shortest distance from the positive-ideal solution (i.e., achieving the minimal gaps in each criterion) and the longest distance from the negative-ideal solution (i.e., achieving the maximal levels in each criterion). TOPSIS defines an index called similarity to the positive-ideal solution and the remoteness from the negative-ideal solution. Then, the method chooses an alternative with the maximum similarity to the positive-ideal solution (Hwang & Yoon, 1981; Wang & Chang, 2007). It is often difficult for a decision-maker to assign a precise performance rating to an alternative for the attributes under consideration. The merit of using a fuzzy approach is to assign the relative importance of attributes using fuzzy numbers instead of precise numbers for suiting the real world in fuzzy environment. This section extends the TOPSIS to the fuzzy environment (Kuo et al., 2007; Yang & Hung, 2007). This method is particularly suitable for solving the group decision-making problem under fuzzy environment. We briefly review the rationale of fuzzy theory before the development of fuzzy TOPSIS. The mathematics concept borrowed from Büyüközkan, Feyzioğlu, and Nebol (2007), Kuo et al. (2007) and Wang and Chang (2007).

Step 1: Determine the weighting of evaluation criteria.
This research employs fuzzy AHP to find the fuzzy preference weights.

Step 2: Construct the fuzzy performance/decision matrix and choose the appropriate linguistic variables for the alternatives with respect to criteria

$$\widetilde{\boldsymbol{D}} = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix} \end{array} \tag{9}$$

$$i = 1, 2, \ldots, \ m; j = 1, 2, \ldots, n$$

$$\tilde{x}_{ij} = \frac{1}{K}\left(\tilde{x}_{ij}^{1} \oplus \cdots \oplus \tilde{x}_{ij}^{k} \oplus \cdots \oplus \tilde{x}_{ij}^{K}\right)$$

where $\tilde{x}_{ij}^{k}$ is the performance rating of alternativeA_i with respect to criterion C_j evaluated by kth expert, and $\tilde{x}_{ij}^{k} = (l_{ij}^{k}, m_{ij}^{k}, u_{ij}^{k})$.

Step 3: Normalize the fuzzy-decision matrix.
The normalized fuzzy-decision matrix denoted by $\widetilde{\boldsymbol{R}}$ is shown as following formula:

$$\widetilde{\boldsymbol{R}} = [\tilde{r}_{ij}]_{m \times n}, \quad i = 1, 2, \ldots, m; \ j = 1, 2, \ldots, n \tag{10}$$

Then, the normalization process can be performed by following formula: $\tilde{r}_{ij} = \left(\frac{l_{ij}}{u_j^{+}}, \frac{m_{ij}}{u_j^{+}}, \frac{u_{ij}}{u_j^{+}}\right), \ u_j^{+} = \max_i\{u_{ij} | i = 1, 2, \ldots, n\}$

or we can set the best aspired level u_j^+ and $j = 1,2,\ldots,n$ is equal one; otherwise, the worst is zero.

The normalized $\tilde{r}_{ij}$ is still triangular fuzzy numbers. For trapezoidal fuzzy numbers, the normalization process can be conducted in the same way. The weighted fuzzy normalized decision matrix is shown as following matrix $\widetilde{\boldsymbol{V}}$:

$$\widetilde{\boldsymbol{V}} = [\tilde{v}_{ij}]_{n\times n}, \quad i = 1,2,\ldots,m;\ j = 1,2,\ldots,n \tag{11}$$

where $\tilde{v}_{ij} = \tilde{r}_{ij} \otimes \tilde{w}_j$.

Step 4: Determine the fuzzy positive-ideal solution (FPIS) and fuzzy negative-ideal solution (FNIS).

According to the weighted normalized fuzzy-decision matrix, we know that the elements $\tilde{v}_{ij}$ are normalized positive *TFN*and their ranges belong to the closed interval $[0,1]$. Then, we can define the FPIS A^+ (aspiration levels) and FNIS A^- (the worst levels) as following formula:

$$A^+ = (\tilde{v}_1^*,\ldots,\tilde{v}_j^*,\ldots,\tilde{v}_n^*) \tag{12}$$

$$A^- = (\tilde{v}_1^-,\ldots,\tilde{v}_j^-,\ldots,\tilde{v}_n^-) \tag{13}$$

where $\tilde{v}_j^* = (1,1,1) \otimes \tilde{w}_j = (lw_j, mw_j, uw_j)$ and $\tilde{v}_j^- = (0,0,0)$, $j = 1,2,\ldots,n$.

Step 5: Calculate the distance of each alternative from FPIS and FNIS.

The distances ($\tilde{d}_i^+$ and $\tilde{d}_i^-$) of each alternative from A^+ and A^- can be currently calculated by the area compensation method

$$\tilde{d}_i^+ = \sum_{j=1}^{n} d\left(\tilde{v}_{ij}, \tilde{v}_j^*\right), \quad i = 1,2,\ldots,m;\ j = 1,2,\ldots,n \tag{14}$$

$$\tilde{d}_i^- = \sum_{j=1}^{n} d\left(\tilde{v}_{ij}, \tilde{v}_j^-\right), \quad i = 1,2,\ldots,m;\ j = 1,2,\ldots,n \tag{15}$$

Step 6: Obtain the closeness coefficients (relative gaps-degree) and improve alternatives for achieving aspiration levels in each criterion.

Opricovic and Tzeng (2004) proposed a compromise solution by MCDM methods for comparative analysis of VIKOR and TOPSIS in EJOR; they pointed out the TOPSIS cannot be used for ranking purpose. Based on those concepts, the improved and chosen alternative should have the shortest distance from the positive-ideal solution (i.e., achieving the minimal gaps in each criterion) and the longest distance from the negative-ideal solution (i.e., achieving the maximal levels in each criterion).

Therefore, we propose the $\widetilde{CC}_i$ is defined to determine the fuzzy gaps-degree based on fuzzy closeness coefficients for improving alternatives; once the $\tilde{d}_i^+$ and $\tilde{d}_i^-$ of each alternative have been calculated. Calculate similarities to ideal solution. This step solves the similarities to an ideal solution by formula:

$$\widetilde{CC}_i = \frac{\tilde{d}_i^-}{\tilde{d}_i^+ + \tilde{d}_i^-} = 1 - \frac{\tilde{d}_i^+}{\tilde{d}_i^+ + \tilde{d}_i^-}, \quad i = 1,2,\ldots,m \tag{16}$$

where we define $\frac{\tilde{d}_i^-}{\tilde{d}_i^+ + \tilde{d}_i^-}$ as fuzzy satisfaction degree in ith alternative and $\frac{\tilde{d}_i^+}{\tilde{d}_i^+ + \tilde{d}_i^-}$ as fuzzy gap degree in ith alternative. We can know which and how fuzzy gaps should be improved for achieving aspiration levels and getting the best win–win strategy from among a fuzzy set of feasible alternatives.

In the last years, some fuzzy TOPSIS methods were developed in the different applied field. Lin and Chang (2008) adopted fuzzy TOPSIS for order selection and pricing of manufacturer (supplier) with make-to-order basis when orders exceed production capacity. Chen and Tsao (2008) is to extend the TOPSIS method based on interval-valued fuzzy sets in decision analysis. Büyüközkan et al. (2007) identified the strategic main and sub-criteria of alliance partner selection that companies consider the most important through fuzzy AHP and fuzzy TOPSIS model and achieved the final partner-ranking results. Abo-Sinna, Amer, and Ibrahim (2008) focused on multiobjective large-scale non-linear programming problems with block angular structure and extended the technique for order preference by similarity ideal solution to solve them. Wang and Chang (2007) applied fuzzy TOPSIS to help the Air Force Academy in Taiwan choose optimal initial training aircraft in a fuzzy environment. Li (2007) developed a compromise ratio (CR) methodology for fuzzy multiattribute group decision-making (FMAGDM), which is an important part of decision support system. Wang and Lee (2007) generalized TOPSIS to fuzzy multiple-criteria group decision-making (FMCGDM) in a fuzzy environment. Kahraman, Sezi, Nüfer, and Gülbay (2007) proposed a fuzzy hierarchical TOPSIS model for the multicriteria evaluation of the industrial robotic systems. Benítez, Martín, and Román (2007) presented a fuzzy TOPSIS approach for evaluating dynamically the service quality of three hotels of an important corporation in Gran Canaria island via surveys. Wang and Elhag (2006) proposed a fuzzy TOPSIS method based on alpha level sets and presents a non-linear programming solution procedure. Chen, Lin, and Huang (2006) applied fuzzy TOPSIS approach to deal with the supplier selection problem in supply chain system.

4. Numerical example

The performance measurement activity has paralleled the strategy activity throughout the period of the grant. This paper applies the focus group research method to get the evaluation relative dimensions. Focus group research is based on facilitating an organized discussion with a group of individuals selected because they were believed to be representative of some class. Discussion is used to bring out insights and understandings in ways, which simple questionnaire items may not be able to tap. The interaction among focus group participants brings out differing perspectives through the language that is used by the discussants. Interaction is the key to successful focus groups. In an interactive setting, discussants draw each other out, sparking new ideas (Morgan, 1988). The reactions of each person spark ideas in others, and one person may fill in a gap left by others.

The host researcher raised a number of issues including: the relative importance of notebook computer ODM companies performance evaluation criteria as recognized by participants, industrial analysts, professors and so on. After thorough discussion, and with the aid of answers to open-ended questionnaires and recording equipment, opinions were integrated and summarized. Finally, six potential evaluation dimensions are determined through the focus group process. They are manufacturing capability, supply chain capability, innovation capability, financial capability, human resource capability, and service quality capability.

4.1. Manufacturing capability

Manufacturing capability is considered to be an important element in a firm's endeavor to improve firm performance. Manufacturing capability management strategies have reduced inventory and manufacturing cycle times, and more complete and on-time shipments of better quality products (Himes, 2007). The enterprises should focus on reducing costs; they also pay much more attention to building agility and flexibility into their manufacturing processes, seeking better market differentiation. Cost reductions remain the focus of all enterprises and many still struggle with data collection and cultural issues (Wainwright et al., 2005). The manufacturing capability includes five aspects, such as reducing manufacturing cost, shrinking manufacturing cycle time, improving schedule compliance, satisfying demand for more complete and on-time shipments (Gleich et al., 2008; Welch & Mann, 2001).

4.2. Supply chain capability

Supply chain management, analysis, and improvement are becoming increasingly important. Managers want to measure the performance of the supply chain and the results of improvement efforts across supplier, company, and customer operations. Supply chain management will affect more than costs, and managers must be able to sell the value created to senior executives, trading partners, and shareholders (Pollen & Coleman, 2005). Everyone agrees that "you can only manage what you measure," but many companies struggle with creating and using effective performance measurement systems for forecasting, purchasing, production, and distribution operations (Gupta & Selvaraju, 2006). The challenges may include lack of consistency, inability to share data, or poor buy-in, among others. This course provides a fast-paced overview of a proven approach for identifying measurement needs, developing appropriate metrics, and implementing the infrastructure to support them. The course is essential for those who want to use measures to maximize supply chain performance and improvement (Welch & Mann, 2001).

4.3. Innovation capability

It is well known that industrial enlivenment must continually cope with extremely rapid changes, which demand an innovative technological and managerial response. Such a response must redefine the firms' organizational assets in order to achieve a satisfactory degree of adaptation to the external environment. Innovation is a necessary condition, not only for increasing the firms' competitiveness, but primarily to ensure their survival (Capaldo, Iandoli, Raffa, & Zollo, 2003). Innovation is about change, about doing different things, or doing things differently. The ability to innovate is critical to the survival and growth of your business.

Innovation shows up in the quality and quantity of ideas and the efficiency and effectiveness of implementation of those ideas (Jones & Kaluarachchi, 2008). The second face of R&D is called the absorptive capacity, and it is considered to be crucial particularly for assessing the effective contribution by spillovers from others. Defined as a set of knowledge and competencies, the firm's knowledge base remains a preliminary condition in the assimilation of spillovers from R&D efforts of environment. R&D activity does not only stimulate innovation, but it also enhances the firms' ability to assimilate outside knowledge.

4.4. Financial capability

Financial capability concerns itself with the application of this discipline to the finance function. It deals with how well the finance organizations support a company's strategic objectives (Maiga & Jacobs, 2004). The majority of empirical studies have found that firm's cash flow as a measure of internal financial capability is associated with higher levels of performance. The financial capabilities include five aspects, such as liquidity, financial leverage, asset turnover, profitability, and market value.

Liquidity is particularly interesting to short-term creditors. Liquidity is the availability of credit or the ease with which institutions can borrow or take on leverage. The financial managers are working with banks and other short-term lenders, an understanding of liquidity is essential. Financial leverage takes the form of a loan or other borrowings, the proceeds of which are reinvested with the intent to earn a greater rate of return than the cost of interest. The higher a firm's financial leverage, the riskier the firm's operations are considered to be. The most typical system of determining an acceptable level of financial leverage is by comparing operations to others firms in the same industry. Asset turnover is a financial ratio that measures the efficiency of a company's use of its assets in generating sales revenue or sales income to the company. Profit generally is the making of gain in business activity for the benefit of the owners of the business. Market value is a concept distinct from market price, which is "the price at which one can transact", while market value is "the true underlying value".

4.5. Human resource capability

Successfully managing human resource capability is important for the high tech industry. Management techniques, such as recruit, train, apply, apprise and maintain combine organizational strategies and human resources plans that can effectively carry out human resources development and directly influence the Taiwanese economy's success or failure (Tai & Wang, 2006). Businesses find success when they can establish clear strategic goals and marshal all resources to achieve those objectives. Human resource performance management is a huge priority for competitive organizations. That is where superior software solutions come in. By automating much of the human resource performance management process, and adding much-needed knowledge and information access to the equation, such solutions can help to make these HR initiatives a source of success. Valued human resource development not only improves professional skills and capabilities, but also solves the problem of measuring the effect of human resources on an organization. We think that HRM as an instrument designed to enhance the labor extraction process and thus improve firm performance.

4.6. Service quality capability

SERVQUAL as the most often used approach for measuring service quality has been to compare customers' expectations before a service encounter and their perceptions of the actual service delivered. For Parasuraman, Zeithaml, and Berry (1985, 1988a), service quality is measured in 10 phases: accessibility, communication, capability, courtesy, trustworthiness, reliability, responsiveness, safety, tangibility, and understanding with customers. Parasuraman et al. (1988a), Parasuraman, Zeithaml, and Berry (1988b) also reduced the 10 to 5: tangibility, reliability, responsiveness, assurance, and empathy.

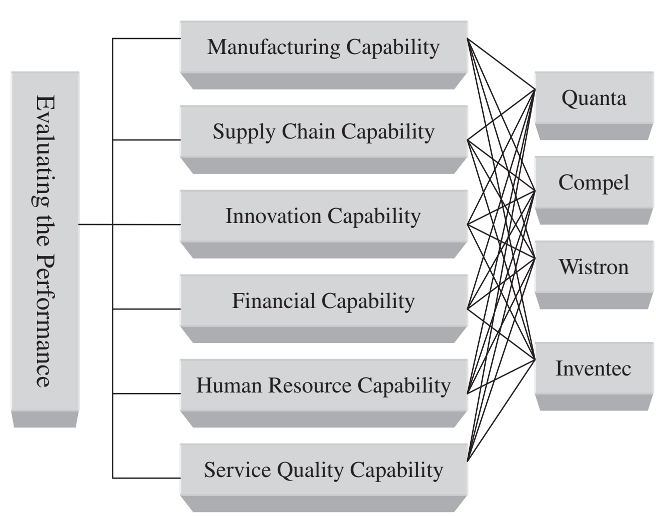

Fig. 2. Research framework.

The hierarchical structure of this research decision problem is shown in Fig. 2. The whole hierarchy of accessing the performance of global top four notebook computer ODM companies can be easily visualized from Fig. 2. After the construction of the hierarchy, the different priority weights of each criteria, attributes and alternatives are calculated using the fuzzy AHP and fuzzy TOPSIS approaches. The comparison of the importance or preference of one criterion, attribute or alternative over another can be done with the help of the questionnaire. The method of calculating priority weights of the different decision alternatives is discussed below.

Step 1: The weights of evaluation dimensions.

We adopt fuzzy AHP method to evaluate the weights of different dimensions for the performance of notebook computer ODM companies. Following the construction of fuzzy AHP model, it is extremely important that experts fill the judgment matrix.

The following section demonstrates the computational procedure of the weights of dimensions.

(1) According to the committee with ten representatives about the relative important of dimension, then the pairwise comparison matrices of dimensions will be obtained. We apply the fuzzy numbers defined in Table 1. We transfer the linguistic scales to the corresponding fuzzy numbers (as Appendix A).

(2) Computing the elements of synthetic pairwise comparison matrix by using the geometric mean method suggested by Buckley (1985) that is:

$$\tilde{a}_{ij} = \left(\tilde{a}_{ij}^1 \otimes \tilde{a}_{ij}^2 \otimes \ldots \otimes \tilde{a}_{ij}^{10}\right), \quad \text{for } \tilde{a}_{12} \text{ as the example :}$$

$$\begin{aligned}\tilde{a}_{12} &= (1,1,1) \otimes (1,1,1) \otimes \cdots \otimes (2,3,4)^{1/10} \\ &= ((1 \times 1 \times \cdots \times 2)^{1/10}, (1 \times 1 \times \cdots \times 3)^{1/10}, \\ &\quad (1 \times 1 \cdots \times 4)^{1/10}) = (0.88, 1.14, 1.37)\end{aligned}$$

It can be obtained the other matrix elements by the same computational procedure, therefore, the synthetic pairwise comparison matrices of the five representatives will be constructed as follows matrix $\boldsymbol{A}$:

$$\boldsymbol{A} = \begin{array}{c} \\ D_1 \\ D_2 \\ D_3 \\ D_4 \\ D_5 \\ D_6 \end{array} \begin{array}{c} \begin{array}{cccccc} D_1 & D_2 & D_3 & D_4 & D_5 & D_6 \end{array} \\ \begin{bmatrix} 1 & (0.88,1.14,1.37) & (1.21,1.49,1.74) & (0.87,0.98,1.07) & (2.14,2.93,3.79) & (1.06,1.28,1.55) \\ (0.73,0.88,1.14) & 1 & (1.14,1.55,1.91) & (1.76,1.94,2.09) & (2.65,3.36,3.98) & (2.14,2.70,3.19) \\ (0.58,0.67,0.83) & (0.52,0.64,0.88) & 1 & (1.40,1.63,1.93) & (1.56,2.22,2.91) & (1.67,2.13,2.56) \\ (0.93,1.02,1.15) & (0.48,0.52,0.57) & (0.52,0.61,0.71) & 1 & (1.92,2.48,2.96) & (1.64,2.24,2.75) \\ (0.26,0.34,0.47) & (0.25,0.30,0.38) & (0.34,0.45,0.69) & (0.34,0.40,0.52) & 1 & (0.95,1.12,1.25) \\ (0.65,0.78,0.95) & (0.31,0.37,0.47) & (0.39,0.47,0.60) & (0.36,0.45,0.61) & (0.80,0.90,1.06) & 1 \end{bmatrix} \end{array}$$

(3) To calculate the fuzzy weights of dimensions, the computational procedures are displayed as following parts

$$\begin{aligned}\tilde{r}_1 &= (\tilde{a}_{11} \otimes \tilde{a}_{12} \otimes \tilde{a}_{13} \otimes \tilde{a}_{14} \otimes \tilde{a}_{15} \otimes \tilde{a}_{16})^{1/6} \\ &= ((1 \times 0.88 \times \cdots \times 1.06)^{1/6}, (1 \times 1.14 \times \cdots \times 1.28)^{1/6}, \\ &\quad (1 \times 1.37 \times \cdots \times 1.55)^{1/6}) = (1.130, 1.358, 1.571)\end{aligned}$$

Similarly, we can obtain the remaining $\tilde{r}_i$, there are:

$$\tilde{r}_2 = (1.423, 1.699, 1.966)$$

$$\tilde{r}_3 = (1.017, 1.222, 1.478)$$

$$\tilde{r}_4 = (0.949, 1.101, 1.248)$$

$$\tilde{r}_5 = (0.440, 0.524, 0.655)$$

$$\tilde{r}_6 = (0.533, 0.615, 0.745)$$

For the weight of each dimension, they can be done as follows:

$$\begin{aligned}\tilde{w}_1 &= \tilde{r}_1 \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \tilde{r}_3 \oplus \tilde{r}_4 \oplus \tilde{r}_5 \oplus \tilde{r}_6)^{-1} \\ &= (1.130, 1.358, 1.571) \otimes (1/(1.571 + \cdots + 0.745), \\ &\quad 1/(1.358 + \cdots + 0.615), 1/(1.130 + \cdots + 0.533)) \\ &= (0.147, 0.208, 0.286)\end{aligned}$$

We also can calculate the remaining $\tilde{w}_i$, there are:

$$\tilde{w}_2 = (0.186, 0.261, 0.358)$$

$$\tilde{w}_3 = (0.133, 0.187, 0.269)$$

$$\tilde{w}_4 = (0.124, 0.169, 0.227)$$

$$\tilde{w}_5 = (0.057, 0.080, 0.119)$$

$$\tilde{w}_6 = (0.070, 0.094, 0.136)$$

(4). To apply the COA method to compute the *BNP* value of the fuzzy weights of each dimension: To take the *BNP* value of the weight of D_1 (manufacturing capability) as an example, the calculation process is as follows

$$\begin{aligned}BNP_{w_1} &= [(U_{w_1} - L_{w_1}) + (M_{w_1} - L_{w_1})]/3 + L_{w_1} \\ &= [(0.286 - 0.147) + (0.208 - 0.147)]/3 + 0.147 \\ &= 0.214\end{aligned}$$

Then, the weights for the remaining dimensions can be found as shown in Table 2. Table 2 shows the relative weight of six dimensions of the evaluation of notebook computer companies, which obtained by AHP method. The weights for each dimension are: manufacturing capability (0.214), supply chain capability (0.268), innovation capability (0.196), financial capability (0.173), human resource capability (0.086), and service quality capability (0.100). From the fuzzy AHP results, we can understand the first two important dimensions for the evaluation of notebook computer companies are supply chain capability (0.268) and manufacturing capability (0.214). Moreover, the less important dimension is human resource capability (0.086).

Table 2
Weights of dimensions.

Dimensions	Weights	*BNP*	Rank
Manufacturing capability	(0.147, 0.208, 0.286)	0.214	2
Supply chain capability	(0.186, 0.261, 0.358)	0.268	1
Innovation capability	(0.133, 0.187, 0.269)	0.196	3
Financial capability	(0.124, 0.169, 0.227)	0.173	4
Human resource capability	(0.057, 0.080, 0.119)	0.086	6
Service quality capability	(0.070, 0.094, 0.136)	0.100	5

Table 3
Linguistic scales for the rating of each company.

Linguistic variable	Corresponding triangular fuzzy number
Very poor (VP)	(0,1,3)
Poor (P)	(1,3,5)
Fair (F)	(3,5,7)
Good (G)	(5,7,9)
Very good (VG)	(7,9,10)

Step 2: Construct the fuzzy-decision matrix and choose the appropriate linguistic variables for the alternatives with respect to criteria.

This paper focus on evaluating the performance of global top four notebook computer ODM companies; so, we assume that questionnaire has collected completely and will start with building dataset that are collected. The evaluators have their own range for the linguistic variables employed in this study according to their subjective judgments (Hsieh et al., 2004).

For each evaluator with the same importance, this study employs the method of average value to integrate the fuzzy/vague judgment values of different evaluators regarding the same evaluation dimensions. The evaluators then adopted linguistic terms (see Table 3), including "very poor", "poor", "fair", "good" and "very good " to express their opinions about the rating of every companies regarding each capability criteria, based on the technological data of the four companies listed in Table 4.

Using Eq. (9), we can normalize the fuzzy-decision matrix as Table 5.

Step 4: Establish the weighted normalized fuzzy-decision matrix.

The forth step in the analysis is to find the weighted fuzzy-decision matrix; the resulting fuzzy-weighted decision matrix is shown as Table 6.

Step 5: Determine the fuzzy positive and fuzzy negative-ideal reference points.

Then, we can define the fuzzy positive-ideal solution (FPIS) and the fuzzy negative-ideal solution (FNIS) as: A^+ and A^-. This is the fifth step of the fuzzy TOPSIS analysis

Table 4
Subjective cognition results of evaluators towards the five levels of linguistic variables.

	Quanta	Compal	Wistron	Inventec
Manufacturing capability	(5.0, 7.0, 8.9)	(4.4, 6.4, 8.4)	(4.4, 6.4, 8.3)	(2.6, 4.6, 6.6)
Supply chain capability	(5.2, 7.2, 9.0)	(4.6, 6.6, 8.6)	(3.8, 5.8, 7.7)	(2.6, 4.6, 6.6)
Innovation capability	(4.6, 6.6, 8.6)	(3.6, 5.6, 7.6)	(4.0, 6.0, 7.9)	(3.0, 5.0, 7.0)
Financial capability	(5.6, 7.6, 9.2)	(4.8, 6.8, 8.7)	(4.6, 6.6, 8.4)	(3.2, 5.2, 7.2)
Human resource capability	(4.8, 6.8, 8.7)	(4.0, 6.0, 8.0)	(3.8, 5.8, 7.8)	(2.6, 4.6, 6.6)
Service quality capability	(5.0, 7.0, 9.0)	(4.4, 6.4, 8.4)	(4.2, 6.2, 8.1)	(2.5, 4.4, 6.4)

In order to calculate the closeness coefficients of each of the alternatives d_1^+ and d_1^- calculation is used as an example as follows:

$$d_1^+ = 0.230, \quad d_1^- = 0.936$$

Once the distances from FPIS and FNIS are determined, the closeness coefficient can be obtained with Eq. (15). The index CC_1 of first alternative is calculated as:

$$\widetilde{CC}_1^- = \frac{0.936}{0.230 + 0.936} = 0.803$$
$$\widetilde{CC}_1^+ = \frac{0.230}{0.230 + 0.936} = 0.197$$

We define $\widetilde{CC}_i^-$ as satisfaction degree in ith alternative and $\widetilde{CC}_i^+$ as gap degree in ith alternative. We can know which and how gaps should be improved for achieving aspiration levels and getting the best win–win strategy from among a fuzzy set of feasible alternatives. The aspired/desired satisfaction degree of fuzzy TOPSIS is 1.00. From the results of Table 7, we can find out the satisfaction degrees and gap degrees of each company. Then, the satisfaction degree value of Quanta, Compal, Wistron and Inventec are 0.803, 0.746, 0.72, and 0.601 levels respectively; i.e., 0.197, 0.254, 0.274, and 0.399 levels should be improved, respectively. On the other hand, we also can calculate the gap degrees between the policy tools and aspired/desired level by using Eq. (15). The results of Table 7 reveal that the gap degree of Quanta and Compal is bigger than other companies. Therefore, we consider that the Quanta and Compal are similarities to aspired/desired level.

From the proposed method, fuzzy AHP and fuzzy TOPSIS, we find out the first two important dimensions for notebook computer ODM companies are supply chain capability and manufacturing capability. Moreover, the Quanta and Compel rank the first two performances for these companies.

$$\begin{aligned}
A^+ &= [(1,1,1),(1,1,1),(1,1,1),(1,1,1),(1,1,1),(1,1,1)] \otimes \tilde{w}_j \\
&= [(1,1,1),(1,1,1),(1,1,1),(1,1,1),(1,1,1),(1,1,1)] \\
&\quad \otimes [(0.147,0.208,0.286),(0.186,0.261,0.358),(0.133,0.187,0.269),(0.124,0.169,0.227),(0.057,0.080,0.119),(0.070,0.094,0.136)] \\
&= (0.147,0.208,0.286),(0.186,0.261,0.358),(0.133,0.187,0.269),(0.124,0.169,0.227),(0.057,0.080,0.119),(0.070,0.094,0.136)
\end{aligned}$$

$$A^- = [(0,0,0),(0,0,0),(0,0,0),(0,0,0),(0,0,0),(0,0,0)]$$

Step 6: Estimating the performance and ranking the alternatives.

Better manufacturing ability could predict resource capacities and competing resource requirements provides more accurate forecasts of production lead time. This ability comes from the

Table 5
Normalized fuzzy-decision matrix.

	Quanta	Compal	Wistron	Inventec
Manufacturing capability	(0.543, 0.761, 0.967)	(0.478, 0.696, 0.913)	(0.478, 0.696, 0.902)	(0.283, 0.500, 0.717)
Supply chain capability	(0.565, 0.783, 0.978)	(0.500, 0.717, 0.935)	(0.413, 0.630, 0.837)	(0.283, 0.500, 0.717)
Innovation capability	(0.500, 0.717, 0.935)	(0.391, 0.609, 0.826)	(0.435, 0.652, 0.859)	(0.326, 0.543, 0.761)
Financial capability	(0.609, 0.826, 1.000)	(0.522, 0.739, 0.946)	(0.500, 0.717, 0.913)	(0.348, 0.565, 0.783)
Human resource capability	(0.522, 0.739, 0.946)	(0.435, 0.652, 0.870)	(0.413, 0.630, 0.848)	(0.283, 0.500, 0.717)
Service quality capability	(0.543, 0.761, 0.978)	(0.478, 0.696, 0.913)	(0.457, 0.674, 0.880)	(0.272, 0.478, 0.696)

Table 6
Weighted normalized fuzzy-decision matrix.

	Quanta	Compal	Wistron	Inventec
Manufacturing capability	(0.080, 0.159, 0.277)	(0.071, 0.145, 0.261)	(0.071, 0.145, 0.258)	(0.042, 0.104, 0.205)
Supply chain capability	(0.105, 0.204, 0.350)	(0.093, 0.187, 0.335)	(0.077, 0.164, 0.300)	(0.052, 0.130, 0.257)
Innovation capability	(0.066, 0.134, 0.252)	(0.052, 0.114, 0.222)	(0.058, 0.122, 0.231)	(0.043, 0.102, 0.205)
Financial capability	(0.075, 0.139, 0.227)	(0.065, 0.125, 0.215)	(0.062, 0.121, 0.207)	(0.043, 0.095, 0.178)
Human resource capability	(0.030, 0.059, 0.113)	(0.025, 0.052, 0.104)	(0.024, 0.051, 0.101)	(0.016, 0.040, 0.086)
Service quality capability	(0.038, 0.072, 0.133)	(0.033, 0.066, 0.124)	(0.032, 0.064, 0.119)	(0.019, 0.045, 0.094)

Table 7
Closeness coefficients to aspired level among different companies.

	d_i^+	d_i^-	Gaps degree of CC_i^+	Satisfaction degree of CC_i^-
Quanta	0.230	0.936	0.197	0.803
Compal	0.294	0.861	0.254	0.746
Wistron	0.315	0.832	0.274	0.726
Inventec	0.454	0.684	0.399	0.601

acuity gained through improved communication, scanning, and analysis. Then, greater responsiveness provides flexibility to react to schedule variations and changes. Competing in the marketplace on the basis of cost efficiency requires striving for low cost production. In order to keep manufacturing costs competitive, managers must address materials, labor, overhead, and other costs. Inventories have long been the focus of cost reduction in factories and are one of the justifications of the JIT system. Therefore, inventory and inventory-related items, such as improving vendor's quality, reducing waste of purchased materials, are considered as the indicators of the cost capability. Realizing low inventory level, decreasing labor cost, and reducing machine time are all positive factors of the cost efficiency construct.

In addition, online tool launched to help companies improve supply chain capability. The web-based information system could provide sufficient detail and richness to steer supply chain performance. Then, the enterprises should design the demand planning, manufacturing planning, and transportation and logistics planning. Demand planning can gain advanced forecasting capabilities to more accurately predict and shape customer demand while sufficiently preparing for a multitude of unforeseen changes capable of both positively and negatively affecting demand. Manufacturing planning could help ensure maximized efficiency throughout entire supply chain by streamlining each of manufacturing process to make the most of valuable assets while reducing total costs. Transportation and logistics planning could overcome the complex challenges of optimally coordinating pick-up and delivery times across multiple worldwide locations, while adhering to a growing number of international regulations to ensure customers consistently receive the right goods at the right time.

5. Conclusions and remarks

The aim of this research is to construct a fuzzy AHP and fuzzy TOPSIS model to evaluate different notebook computer ODM companies. In the performance evaluation for the notebook computer ODM companies including manufacturing capability, financial capability, innovation capability, supply chain capability, human resource capability, and service quality capability. These factors are to generate a final evaluation ranking for priority among these notebook computer ODM companies of the proposed model. The importance of the dimensions is evaluated by experts, and the uncertainty of human decision-making is taken into account through the fuzzy concept in fuzzy environment. From the proposed method, fuzzy AHP and fuzzy TOPSIS, we find out the first two important dimensions for notebook computer ODM companies are supply chain capability and manufacturing capability. On the other hand, human resource ranks last priorities among these dimensions. Moreover, the Quanta and Compel rank the first two performances for these companies.

The integrated evaluation system is designed to provide practitioners with a fuzzy point of view to traditional performance evaluation model for dealing with imprecision. The proposed method enables decision analysts to better understand the complete evaluation process. Furthermore, this approach provides a more accurate, effective, and systematic decision support tool. Furthermore, the further research can explore that how to improve the gaps in each criteria based on Network Relationship Map (NRM) and capture the complex relationships among these evaluation criteria. The NRM is not only to find out the most important criterion for the performance but also to measure the relationships among these evaluation criteria.

Appendix A. Linguistic scale of each expert

$$\begin{array}{cc} & \begin{matrix} D_1 & D_2 & D_3 & D_4 & D_5 & D_6 \end{matrix} \\ \begin{matrix} D_1 \\ D_2 \\ D_3 \\ D_4 \\ D_5 \\ D_6 \end{matrix} & \begin{bmatrix} 1 & \tilde{1} & \tilde{2} & \tilde{1} & \tilde{4} & \tilde{4} \\ \tilde{1} & 1 & \tilde{2} & \tilde{1} & \tilde{4} & \tilde{4} \\ \tilde{2}^{-1} & \tilde{2}^{-1} & 1 & \tilde{2}^{-1} & \tilde{2} & \tilde{2} \\ \tilde{1} & \tilde{1} & \tilde{2} & 1 & \tilde{4} & \tilde{4} \\ \tilde{4}^{-1} & \tilde{4}^{-1} & \tilde{2}^{-1} & \tilde{4}^{-1} & 1 & \tilde{1} \\ \tilde{4}^{-1} & \tilde{4}^{-1} & \tilde{2}^{-1} & \tilde{4}^{-1} & \tilde{1} & 1 \end{bmatrix} \end{array}, \begin{array}{cc} & \begin{matrix} D_1 & D_2 & D_3 & D_4 & D_5 & D_6 \end{matrix} \\ \begin{matrix} D_1 \\ D_2 \\ D_3 \\ D_4 \\ D_5 \\ D_6 \end{matrix} & \begin{bmatrix} 1 & \tilde{5}^{-1} & \tilde{7}^{-1} & \tilde{7}^{-1} & \tilde{2}^{-1} & \tilde{6}^{-1} \\ \tilde{5} & 1 & \tilde{7}^{-1} & \tilde{7} & \tilde{7} & \tilde{8} \\ \tilde{7} & \tilde{7} & 1 & \tilde{8} & \tilde{9} & \tilde{8} \\ \tilde{7} & \tilde{7}^{-1} & \tilde{8}^{-1} & 1 & \tilde{8} & \tilde{5} \\ \tilde{2} & \tilde{7}^{-1} & \tilde{9}^{-1} & \tilde{8}^{-1} & 1 & \tilde{6}^{-1} \\ \tilde{6} & \tilde{8}^{-1} & \tilde{8}^{-1} & \tilde{5}^{-1} & \tilde{6} & 1 \end{bmatrix} \end{array}$$

$$\begin{array}{cc} & \begin{matrix} D_1 & D_2 & D_3 & D_4 & D_5 & D_6 \end{matrix} \\ \begin{matrix} D_1 \\ D_2 \\ D_3 \\ D_4 \\ D_5 \\ D_6 \end{matrix} & \begin{bmatrix} 1 & \tilde{1} & \tilde{4} & \tilde{1} & \tilde{3} & \tilde{3} \\ \tilde{1} & 1 & \tilde{4} & \tilde{1} & \tilde{3} & \tilde{3} \\ \tilde{4}^{-1} & \tilde{4}^{-1} & 1 & \tilde{4}^{-1} & \tilde{2}^{-1} & \tilde{3}^{-1} \\ \tilde{1} & \tilde{1} & \tilde{4} & 1 & \tilde{3} & \tilde{2} \\ \tilde{3}^{-1} & \tilde{3}^{-1} & \tilde{2} & \tilde{3}^{-1} & 1 & \tilde{1} \\ \tilde{3}^{-1} & \tilde{3}^{-1} & \tilde{3} & \tilde{2}^{-1} & \tilde{1} & 1 \end{bmatrix} \end{array}, \begin{array}{cc} & \begin{matrix} D_1 & D_2 & D_3 & D_4 & D_5 & D_6 \end{matrix} \\ \begin{matrix} D_1 \\ D_2 \\ D_3 \\ D_4 \\ D_5 \\ D_6 \end{matrix} & \begin{bmatrix} 1 & \tilde{9}^{-1} & \tilde{1} & \tilde{1} & \tilde{9} & \tilde{1} \\ \tilde{9} & 1 & \tilde{1} & \tilde{9} & \tilde{9} & \tilde{9} \\ \tilde{1} & \tilde{1} & 1 & \tilde{9} & \tilde{9} & \tilde{9} \\ \tilde{1} & \tilde{9}^{-1} & \tilde{9}^{-1} & 1 & \tilde{2} & \tilde{2} \\ \tilde{9}^{-1} & \tilde{9}^{-1} & \tilde{9}^{-1} & \tilde{2}^{-1} & 1 & \tilde{1} \\ \tilde{1} & \tilde{9}^{-1} & \tilde{9}^{-1} & \tilde{2}^{-1} & \tilde{1} & 1 \end{bmatrix} \end{array}$$

$$\begin{array}{cc} & \begin{matrix} D_1 & D_2 & D_3 & D_4 & D_5 & D_6 \end{matrix} \\ \begin{matrix} D_1 \\ D_2 \\ D_3 \\ D_4 \\ D_5 \\ D_6 \end{matrix} & \begin{bmatrix} 1 & \tilde{2} & \tilde{3} & \tilde{3} & \tilde{2} & \tilde{4} \\ \tilde{2}^{-1} & 1 & \tilde{6} & \tilde{4} & 2 & \tilde{1} \\ \tilde{3}^{-1} & \tilde{6}^{-1} & 1 & \tilde{1} & \tilde{3} & \tilde{4} \\ \tilde{3}^{-1} & \tilde{4}^{-1} & \tilde{1} & 1 & \tilde{3} & \tilde{4} \\ \tilde{2}^{-1} & \tilde{2}^{-1} & \tilde{3}^{-1} & \tilde{3}^{-1} & 1 & \tilde{3} \\ \tilde{4}^{-1} & \tilde{1} & \tilde{4}^{-1} & \tilde{4}^{-1} & \tilde{3}^{-1} & 1 \end{bmatrix} \end{array}, \begin{array}{cc} & \begin{matrix} D_1 & D_2 & D_3 & D_4 & D_5 & D_6 \end{matrix} \\ \begin{matrix} D_1 \\ D_2 \\ D_3 \\ D_4 \\ D_5 \\ D_6 \end{matrix} & \begin{bmatrix} 1 & \tilde{3} & \tilde{4} & \tilde{1} & \tilde{6} & \tilde{2}^{-1} \\ \tilde{3}^{-1} & 1 & \tilde{2} & \tilde{1} & \tilde{6} & \tilde{4} \\ \tilde{4}^{-1} & \tilde{2}^{-1} & 1 & \tilde{3} & \tilde{2} & \tilde{5} \\ \tilde{1} & 1 & \tilde{3}^{-1} & 1 & \tilde{5} & \tilde{1} \\ \tilde{6}^{-1} & \tilde{6}^{-1} & \tilde{2}^{-1} & \tilde{5}^{-1} & 1 & \tilde{1} \\ \tilde{2} & \tilde{4}^{-1} & \tilde{5}^{-1} & \tilde{1} & \tilde{1} & 1 \end{bmatrix} \end{array}$$

$$\begin{array}{cc} & \begin{matrix} D_1 & D_2 & D_3 & D_4 & D_5 & D_6 \end{matrix} \\ \begin{matrix} D_1 \\ D_2 \\ D_3 \\ D_4 \\ D_5 \\ D_6 \end{matrix} & \begin{bmatrix} 1 & \tilde{3} & \tilde{4} & \tilde{1} & 6 & \tilde{1} \\ \tilde{3}^{-1} & 1 & \tilde{1} & \tilde{1} & \tilde{1} & \tilde{1} \\ \tilde{4}^{-1} & \tilde{1} & 1 & \tilde{1} & \tilde{2} & \tilde{2} \\ \tilde{1} & \tilde{1} & \tilde{1} & 1 & \tilde{1} & \tilde{1} \\ \tilde{6}^{-1} & \tilde{1} & \tilde{2}^{-1} & \tilde{1} & 1 & \tilde{2} \\ \tilde{1} & \tilde{1} & \tilde{2}^{-1} & \tilde{1} & \tilde{2}^{-1} & 1 \end{bmatrix} \end{array}, \begin{array}{cc} & \begin{matrix} D_1 & D_2 & D_3 & D_4 & D_5 & D_6 \end{matrix} \\ \begin{matrix} D_1 \\ D_2 \\ D_3 \\ D_4 \\ D_5 \\ D_6 \end{matrix} & \begin{bmatrix} 1 & \tilde{3} & \tilde{2} & \tilde{1} & \tilde{1} & \tilde{2} \\ \tilde{3}^{-1} & 1 & \tilde{4} & \tilde{5} & \tilde{1} & \tilde{3} \\ \tilde{2}^{-1} & \tilde{4}^{-1} & 1 & \tilde{5} & \tilde{3} & \tilde{1} \\ \tilde{1} & \tilde{5}^{-1} & \tilde{5}^{-1} & 1 & \tilde{2} & \tilde{1} \\ \tilde{1} & \tilde{1} & \tilde{3}^{-1} & \tilde{2}^{-1} & 1 & \tilde{3} \\ \tilde{2}^{-1} & \tilde{3}^{-1} & \tilde{1} & \tilde{1} & \tilde{3}^{-1} & 1 \end{bmatrix} \end{array}$$

$$\begin{array}{cc} & \begin{matrix} D_1 & D_2 & D_3 & D_4 & D_5 & D_6 \end{matrix} \\ \begin{matrix} D_1 \\ D_2 \\ D_3 \\ D_4 \\ D_5 \\ D_6 \end{matrix} & \begin{bmatrix} 1 & \tilde{3} & \tilde{1} & \tilde{1} & \tilde{2} & \tilde{3} \\ \tilde{3}^{-1} & 1 & \tilde{3} & \tilde{1} & \tilde{5} & \tilde{3} \\ \tilde{1} & \tilde{3}^{-1} & 1 & \tilde{1} & \tilde{3} & \tilde{1} \\ \tilde{1} & 1 & \tilde{1} & 1 & \tilde{1} & \tilde{2} \\ \tilde{2}^{-1} & \tilde{5}^{-1} & \tilde{3}^{-1} & \tilde{1} & 1 & \tilde{3} \\ \tilde{3}^{-1} & \tilde{3}^{-1} & \tilde{1} & \tilde{2}^{-1} & \tilde{3}^{-1} & 1 \end{bmatrix} \end{array}, \begin{array}{cc} & \begin{matrix} D_1 & D_2 & D_3 & D_4 & D_5 & D_6 \end{matrix} \\ \begin{matrix} D_1 \\ D_2 \\ D_3 \\ D_4 \\ D_5 \\ D_6 \end{matrix} & \begin{bmatrix} 1 & \tilde{3} & \tilde{1} & \tilde{2} & \tilde{6} & \tilde{1} \\ \tilde{3}^{-1} & 1 & \tilde{2} & \tilde{3} & \tilde{4} & \tilde{2} \\ \tilde{1} & \tilde{2}^{-1} & 1 & \tilde{5} & \tilde{1} & \tilde{1} \\ \tilde{2}^{-1} & \tilde{3}^{-1} & \tilde{5}^{-1} & 1 & \tilde{3} & \tilde{5} \\ \tilde{6}^{-1} & \tilde{4}^{-1} & \tilde{1} & \tilde{3}^{-1} & 1 & \tilde{1} \\ \tilde{1} & \tilde{2}^{-1} & \tilde{1} & \tilde{5}^{-1} & \tilde{1} & 1 \end{bmatrix} \end{array}$$

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