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A hybrid fuzzy integral decision-making model for locating manufacturing centers in China: A case study

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ABSTRACT

This study presents a hybrid fuzzy integral decision-making model that integrates factor analysis, interpretive structural modeling, Markov chain, fuzzy integral and the simple additive weighted method for selecting locations of high-tech manufacturing centers in China. The analytical results of this case study demonstrate the feasibility of the proposed model for solving fuzzy multiple attribute decision-making problems, especially when criteria are interdependent. Further, the empirical study brings out some properties that are crucial for high-tech manufacturing centers to invest in China.

1. Introduction

Over the past decade, many Taiwanese manufacturing enterprises have modified the processes and activities of their supply chains to enhance competitiveness in an increasingly globalized economy. Global competition has also imposed tremendous pressure on manufacturing enterprises to transform and adjust their supply chain operations. Meanwhile, countries with considerably low worker salaries have attracted enterprises to relocate manufacturing activities (Bock, 2008). Based on this trend, many Taiwanese enterprises have relocated their supply chain activities and have advanced into Mainland China to capture comparative advantages in production costs.

When configuring global supply chains, the manufacturing processes of a product are often distributed across multinational borders. Complicating factors therefore arise, such as duties, trade blocks, exchange rates, transfer prices, taxes and production import/export quotas (Vidal and Goetschalckx, 2001; Goetschalckx et al., 2002; Lakhal et al., 2005; Leung et al., 2007). Moreover, agglomerated economies usually drive the location decisions of enterprises. Figueiredo et al. (2002) indicated that overseas location choices are strongly governed by agglomeration economies and proximity to major urban centers, possibly replicating prior location decisions to economize on search costs. Blonigen et al. (2005) also demonstrated that the location decisions of enterprises are affected by membership in either vertical or horizontal keiretsu. Other important location factors include labor climate, land costs and utilities, proximity to markets and customers, industrial development incentives and quality of life (Sarkis and Sundarraj, 2002; Coyle et al., 2003).

Aside from the above factors, it should be noted that, in China, most logistics activities are administered or controlled by the government (Luk, 1998). Sheu (2003) further pointed out several critical issues of the facility location problem in China such as the diversity of local governmental regulations in logistics, cultural differences, etc.

Additionally, model formulations and solution algorithms for the location problem have been proposed and extensively developed over the past several decades. Herein, some studies synthesize an extensive array of past research concerning the evolution of location literature. For example, ReVelle and Eiselt (2005) reviewed many facets of location analysis by referencing both seminal works and current reviews. Further details can be found elsewhere (Vidal and Goetschalckx, 1997; Min et al., 1998; Owen and Daskin, 1998; Goetschalckx et al., 2002; Díaz-Báñez et al., 2004; Klose and Drexl, 2005; Alumur and Kara, 2008). However, the above methods are hard to deal with some qualitative factors regarding this problem.

In real-world systems, manufacturing center location decisions may involve conflicts between the above factors. However, most criteria are interdependent or interactive, so they cannot be evaluated by conventional additive measures. Further, the values of the qualitative criteria are often imprecisely defined by decision

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makers under many situations. Considering many different criteria to evaluate facility location candidates may yield a vast body of data that are often inaccurate or uncertain. Doukas et al. (2007) indicated that using crisp values in the decision-making problem may oversimplify the imprecision and subjectivity of related information. Sheu (2008) also mentioned that most decision-making approaches, *e.g.*, analytic hierarchy process (AHP), appear inadequate for imprecise and vague comparisons of qualitative criteria.

The purpose of this research is therefore to develop a hybrid fuzzy integral decision-making model for locating manufacturing centers in China which combines factor analysis, interpretive structural modeling (ISM), Markov chain, fuzzy integral and the simple additive weighted (SAW) method. Real-world case studies show that the proposed model is a suitable method for solving the location decision problem, particularly when the criteria are not independent. Moreover, the empirical data reveal some properties that are critical for high-tech manufacturing centers investing in China.

The rest of this paper is organized as follows. Section 2 presents the architecture of the proposed hybrid fuzzy integral decision-making model and its primary procedures. Section 3 describes a case study to demonstrate the feasibility of the proposed method and to further analyze the case study findings. Finally, Section 4 summarizes the conclusions of the study.

2. Methodology

Appropriate locations were identified using a hybrid fuzzy integral decision-making method. The proposed approach involves five procedures. Fuzzy set theory is also applied to weight criteria as well as the performance values of alternatives. Fig. 1 presents the framework of the proposed hybrid fuzzy integral decision-making model, and the main details are presented in the following subsections.

2.1. Extracting common factors by factor analysis

Since the decision criteria are not completely independent, factor analysis can be introduced to extract common factors where the factors are mutually independent.

Hence, factor analysis can reveal latent structures (dimensions) of a set of variables and reduce attribute space from a larger number of variables to a smaller number of factors. For example, from Fig. 1 the set of $\{x_1^F, x_2^F\}$ is in the same aspect and the set of $\{x_3^F, x_4^F, x_5^F, x_6^F\}$ is in the other aspect through factor analysis, where superscript F is termed a form of factor analysis.

2.2. Structuring the criteria relationship by ISM

Traditional pairwise comparison matrices assumed that the relationship of the criterion x_i^F affected by the criterion x_j^F is analogous to how criterion x_j^F is affected by the criterion x_i^F. However, the relationship between x_i^F and x_j^F may have different effects. Therefore, ISM technology was used to cope with the above problem.

ISM (Warfield, 1974a,b, 1976; Huang et al., 2005) is a computer-assisted methodology to construct and understand the fundamental of the relationships of the criteria in complicated situations or systems. The theory of ISM is based on discrete mathematics, group decision-making, graph theory, computer assistance, and social sciences (Huang et al., 2005). The ISM procedures were implemented through individual or group mental models to calculate binary matrices, also called relation matrices, to present the relations of the criteria (Huang et al., 2005). A relation matrix can be formed by asking a question (Huang et al., 2005) such as "Does criterion x_i^F affect criterion x_j^F? "If the answer is "Yes" then $\pi_{ij} = 1$; otherwise, $\pi_{ij} = 0$. From Fig. 1, the first aspect of the relation matrix can be presented as follows:

$$R = \begin{array}{c} \\ x_1^F \\ x_2^F \end{array} \begin{array}{c} \begin{array}{cc} x_1^F & x_2^F \end{array} \\ \begin{bmatrix} 0 & \pi_{12} \\ \pi_{21} & 0 \end{bmatrix} \end{array}, \tag{1}$$

where x_1^F is the *1*th criterion, π_{12} denotes the relation between *1*th and *2*th criteria, R is the relation matrix.

After constructing the relation matrix, the reachability matrix can be calculated using the following equations:

$$E = R + I, \tag{2}$$

$$E^* = E^k = E^{k+1}, \quad k > 1, \tag{3}$$

where I is the unit matrix, k denotes the powers, and E^* is the reachability matrix. Thereafter, the original pairwise comparison matrix is transferred to ISM pairwise comparison matrix based on the reachability matrix E^*. Restated, ISM pairwise comparison matrix creates zeros according to the corresponding position in the reach-

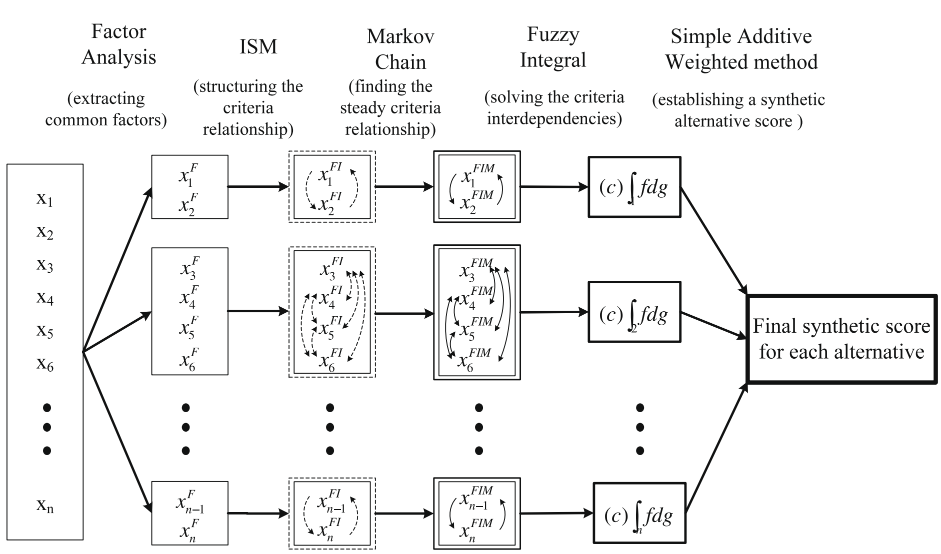


Fig. 1. Framework of the proposed method.

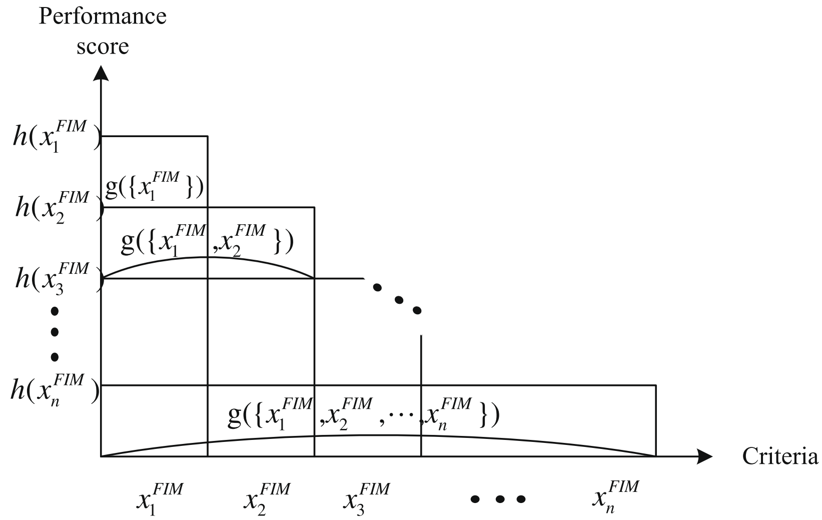


Fig. 2. The basic concept for fuzzy integral.

ability matrix instead of numbers in the same position of the original pairwise comparison matrix. Consequently, the criteria relationship can be structured by ISM, *e.g.* $x_1^{FI}, x_2^{FI}, \ldots, x_n^{FI}$ from Fig. 1, where superscript *I* is termed a form of ISM. Notable, the reachability matrix is under the operators of the Boolean multiplication and addition (*i.e.*, $1 \times 1 = 1$ and $1 + 1 = 1$). For example,

$$E = \begin{pmatrix} 1 & 0 \\ 1 & 1 \end{pmatrix}, \quad E^2 = \begin{pmatrix} 1 & 0 \\ 1 & 1 \end{pmatrix}.$$

2.3. Finding the steady-status criteria relationship with the Markov chain

Since locating manufacturing centers is a long-term investment problem, the Markov chain method was applied to find steady-status criteria relationships. The Markov chain has been frequently used to find reliability models in many real-world problems (Zhang and Yin, 1997; Prowell and Poore, 2004). The analytic network process (ANP) proposed by Saaty (1996) uses the Markov chain

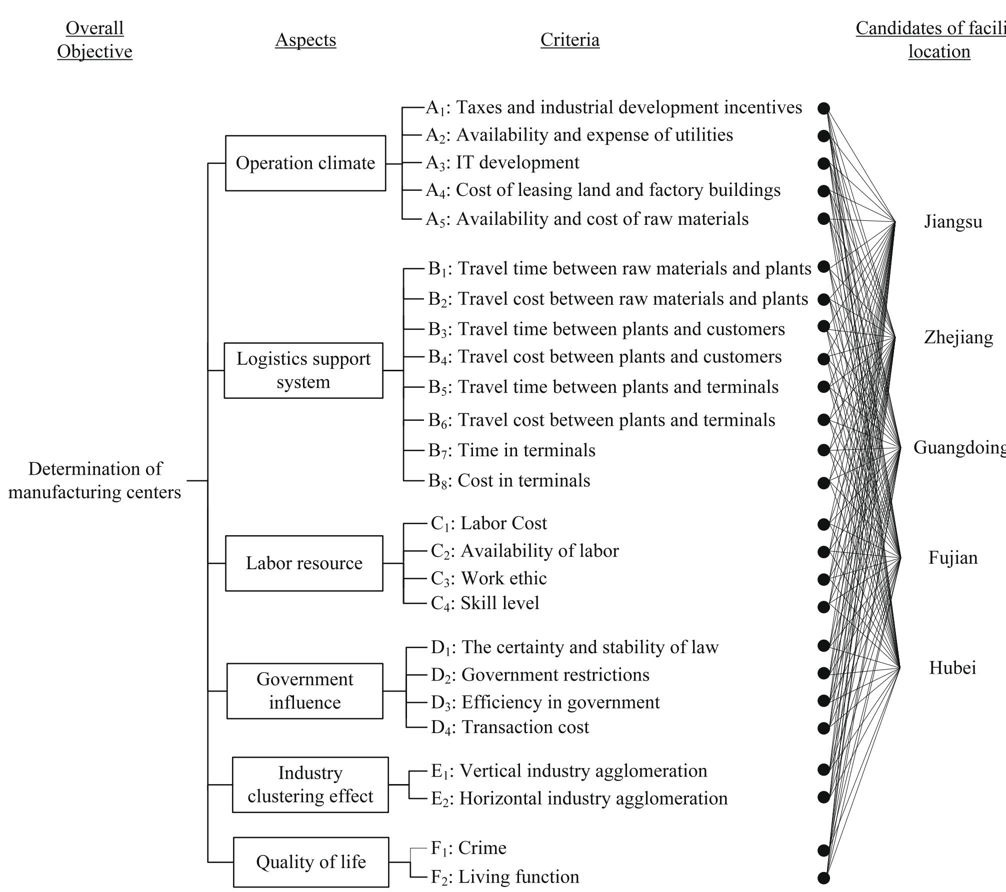
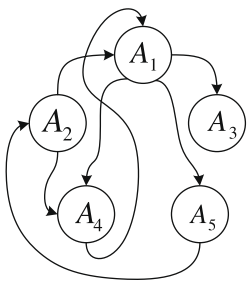


Fig. 3. The hierarchic framework of manufacturing center location.



$$R = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \\ A_5 \end{array} \begin{array}{c} \begin{array}{ccccc} A_1 & A_2 & A_3 & A_4 & A_5 \end{array} \\ \begin{bmatrix} 0 & 0 & 1 & 1 & 1 \\ 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \end{bmatrix} \end{array}$$

Fig. 4. The relationships of the criteria of operation climate.

concept to find stable weights. Nevertheless, Sarkis (2003) noted that a major limitation of the ANP approach is that additional interdependency relationships increase geometrically the number of pairwise comparison matrices and pairwise comparison questions required for an evaluation. Furthermore, logically assessing how other clusters impact a cluster is another problematic issue that respondents must face. Supporting arguments can also be found elsewhere (Wolfslehner et al., 2005). Therefore, based on the above reasons, Markov chain is incorporated into our proposed model instead of directly using ANP.

The Markov chain method (Lay, 2003) is the key to understanding the steady-status behavior, or evolution, of a dynamic system. A vector with non-negative entries that add up to 1 is termed a probability vector (Lay, 2003). A stochastic matrix is a square matrix in which columns are probability vectors (Lay, 2003). Moreover, the sum of these probabilities for all states must equal 1 before performing step 3 of the proposed method. Accordingly, ISM pairwise comparison matrix must be transformed into a normalization matrix.

The steady-status criteria relationship can be determined by the following theorem (Lay, 2003): If P is an $n \times n$ regular stochastic matrix, then P has a unique steady-state vector q. Further, if P^0 is any initial state, then the Markov chain P^k converges to q as $k \to \infty$. Restated, the stochastic matrix is raised to limiting powers such as Eq. (4) to obtain the steady-status criteria relationship, *e.g.* $x_1^{FIM}, x_2^{FIM}, \ldots, x_n^{FIM}$ from Fig. 1, where superscript M is termed a form of Markov chain:

$$\lim_{k\to\infty} p^k = q. \tag{4}$$

Table 1
Score and fuzzy integral with respect to criteria of operation climate of Jiangsu.

Criteria	Performance score	Fuzzy integral
A_3	73.46	61.76[a]
A_1	72.70	
A_4	59.90	
A_5	59.40	
A_2	53.66	

[a] Global evaluation = (73.46 − 72.70) × 0 + (72.70 − 59.90) × 0.29 + (59.90 − 59.40) × 0.51 + (59.40 − 53.66) × 0.72 + (53.66 − 0) × 1 = 61.76.

Table 2
The final synthetic score of Jiangsu.

Aspects	Fuzzy integral	Final synthetic score
Operation climate	61.76	63.74[a]
Logistics support system	63.24	
Labor resource	62.30	
Government influence	60.31	
Industry clustering effect	66.40	
Quality of life	68.44	

[a] Global evaluation = 61.76 × 1/6 + 63.24 × 1/6 + 62.30 × 1/6 + 60.31 × 1/6 + 66.40 × 1/6 + 68.44 × 1/6 = 63.74.

2.4. Solving the criteria interdependencies by fuzzy integral

Fourthly, the non-additive fuzzy integral was used to solve the criteria interdependencies within each common factor. The concept of fuzzy measure and fuzzy integral are briefly narrated as follows (Sugeno, 1974, 1977; Grabisch, 1995; Narukawa et al., 2000; Chen and Tzeng, 2001; Chen and Wang, 2001; Chen et al., 2002; Angilella et al., 2004; Tzeng et al., 2005; Chiou et al., 2005; Grabisch et al., 2008).

2.4.1. Fuzzy measure

A fuzzy measure is a measure for representing the membership degree of an object in candidate sets. It assigns a value to each crisp set of the universal set and signifies the degree of evidence or belief of the membership of the element in the set (Banon, 1981; Tseng and Yu, 2005). Let $X = \{x_1, x_2, \ldots, x_n\}$ be the set of criteria, and let $P(X)$ denote the power set of X or set of all subsets of X.

Definition 1. A fuzzy measure on the set X of criteria is a set function g: $p(x) \to [0,1]$ satisfying the following equation:

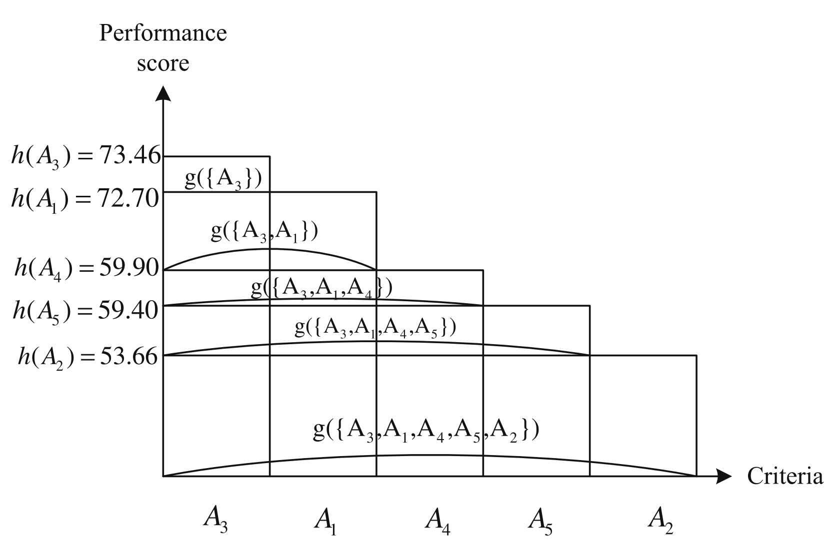


Fig. 5. The fuzzy integral of operation climate of Jiangsu.

Table 3
Compare the results of the proposed model with fuzzy AHP.

Candidates	The proposed model		Fuzzy AHP		Current investment location[a]
	Synthetic scores	Ranking	Synthetic scores	Ranking	Ranking
Jiangsu	63.74	1	61.95	2	1
Zhejiang	61.68	2	62.88	1	2
Guangdoing	59.71	3	55.54	5	3
Fujian	57.30	4	58.84	3	4
Hubei	52.69	5	56.06	4	5

[a] Current investment location represents the statistical analysis of our questionnaire for current major investment locations in China.

$$g(\phi) = 0, \quad g(X) = 1 \quad \text{(boundary conditions)},$$
$$A \subset B \subset X \text{ implies } g(A) \leqslant g(B) \quad \text{(monotonicity)}. \tag{5}$$

A λ fuzzy measure, g_λ, is a special kind of fuzzy measure defined on $P(X)$ of a finite set X and satisfying the finite λ-rule (Sugeno, 1974). If the universal set is infinite, the extra equation of continuity is required (Klir and Folger, 1988). Sugeno (1977) introduced the λ fuzzy measure satisfying Eq. (6). Thus, the λ fuzzy measure is also called a Sugeno measure:

$$\forall A, B \in P(X), \quad A \cap B = \phi,$$
$$g_\lambda(A \cup B) = g_\lambda(A) + g_\lambda(B) + \lambda g_\lambda(A) g_\lambda(B), \quad \text{where } \lambda \in (-1, \infty). \tag{6}$$

Let X be a finite criterion set, $X = \{x_1, x_2, \ldots, x_n\}$, and $P(X)$ be a class of all the subsets of X. It should be noted that $g_\lambda(\{x_i\})$ for a subset with a single element x_i is called a fuzzy density, and can be denoted as $g_i = g_\lambda(\{x_i\})$. The fuzzy measure $g_\lambda(X) = g_\lambda(\{x_1, x_2, \ldots, x_n\})$ can be formulated as the following equation (Leszczynski et al., 1985):

$$g_\lambda(\{x_1, x_2, \ldots, x_n\}) = \sum_{i=1}^{n} g_i + \lambda \sum_{i_1=1}^{n-1} \sum_{i_2=i_1+1}^{n} g_{i_1} \cdot g_{i_2} + \cdots + \lambda^{n-1} g_1 \cdot g_2 \cdots g_n$$
$$= \frac{1}{\lambda} \left| \prod_{i=1}^{n} (1 + \lambda \cdot g_i) - 1 \right| \quad \text{for } -1 < \lambda < \infty. \tag{7}$$

Based on Eq. (7), since the boundary conditions, $g_\lambda(X) = 1$, the parameter λ can be uniquely determined by the following equation:

$$\lambda + 1 = \prod_{i=1}^{n} (1 + \lambda \cdot g_i). \tag{8}$$

Table 4
The comparison of the various type of enterprise.

Candidates	Large enterprise	Small/medium enterprise	Domestic sale	Export sale	The whole samples
Jiangsu	1	2	1	1	1
Zhejiang	2	1	2	2	2
Guangdoing	3	4	3	3	3
Fujian	4	3	4	4	4
Hubei	5	5	5	5	5

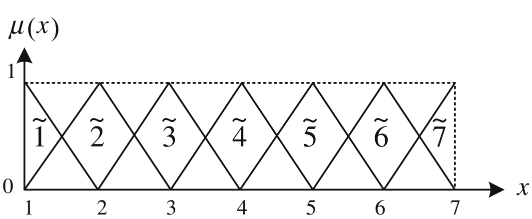


Fig. A.1. Interval of each triangular fuzzy number for degree of importance.

2.4.2. Fuzzy integrals

Two definitions of fuzzy integrals are explained as follows (Sugeno, 1974; Sugeno, 1977; Ishii and Sugeno, 1985; Grabisch, 1996):

Definition 2. Let g be a fuzzy measure on X. The Sugeno integral of a function h: $X \to [0, 1]$ with respect to g is defined by

$$S_u(h(x_1), \ldots, h(x_n)) := \vee_{i=1}^{n} (h(x_{(i)}) \wedge g(A_{(i)})), \tag{9}$$

where suffix $\cdot_{(i)}$ indicates that the indices have been permuted so that $0 \leqslant h(x_{(1)}) \leqslant \cdots \leqslant h(x_{(n)}) \leqslant 1$ and $A_{(i)}$: = $\{x_{(i)}, \ldots, x_{(n)}\}$.

Definition 3. Let h be a measurable function from X to $[0, 1]$ and g be a fuzzy measure on X. Assuming that $h(x_1) \geqslant h(x_2) \geqslant \cdots \geqslant h(x_n)$, then the fuzzy integral is defined as following equation:

$$(c) \int h\,dg = h(x_n) g(H_n) + [h(x_{n-1}) - h(x_n)] g(H_{n-1}) + \cdots + [h(x_1) - h(x_2)] g(H_1)$$
$$= h(x_n)[g(H_n) - g(H_{n-1})] + h(x_{n-1})[g(H_{n-1}) - g(H_{n-2})] + \cdots + h(x_1) g(H_1) \tag{10}$$

where $H_1 = \{x_1\}, H_2 = \{x_1, x_2\}, \ldots, H_n = \{x_1, x_2, \ldots, x_n\} = X$. The fuzzy integral defined by $(c) \int h\,dg$ is termed a Choquet integral. The Choquet integral can be used instead of the max–min integral (Wang and Klir, 1992; Ishii and Sugeno, 1985; Murofushi and Sugeno, 1989). In practice, h can be considered the performance of a partic-

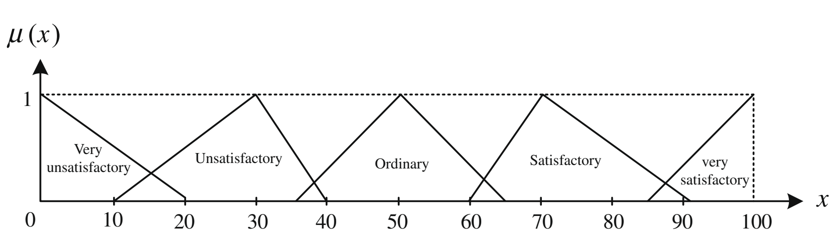


Fig. A.2. Interval of each triangular fuzzy number for degree of satisfaction.

ular attribute for the alternatives while g stands for the grade of subjective importance of each attribute. A fuzzy integral of h with respect to g gives the overall evaluation for each alternative. The application of fuzzy integrals in multiple attribute decision-making (MADM) have been studied extensively in the literature, see for example, Grabisch (1996), Chen and Chiou (1999), Wang and Keller (1999), Chen and Tzeng (2001), Chen et al. (2002), Tseng and Yu (2005), Tzeng et al. (2005), and Chiou et al. (2005). Relying on Eq. (10), the basic idea of fuzzy integral can be illustrated in Fig. 2.

2.5. Establishing a synthetic alternative score with the simple additive weighted method

Finally, the simple additive weighted method is used to aggregate the final synthetic score with respect to each alternative. Decision makers can then determine the appropriate facility locations based on the final score.

Apart from the five primary procedures of the hybrid fuzzy integral decision-making model, the defuzzification procedure has been found to derive the best non-fuzzy performance (BNP) value as fuzziness in the data. Since utilizing the Centroid method (COA, center of area) to determine the BNP is a practical measure and introducing the preferences of evaluators is unnecessary (Yager and Filev, 1994; Tsaur et al., 1997; Tang et al., 1999), this method is adopted herein and should be used before step 2 of the proposed method. The BNP value of the triangular fuzzy number (l_i, m_i, u_i) can be obtained by Eq. (11). Each candidate of the facility location can then be evaluated. The order of importance of each criterion can also be ranked according to the value of the derived BNP:

$$BNP_i = [(u_i - l_i) + (m_i - l_i)]/3 + l_i \quad \forall i. \tag{11}$$

3. Applications

This section describes an empirical study which demonstrates the feasibility of the proposed model in determining the appropriate locations for high-tech manufacturing centers in China. This section is divided into two subsections: (1) assessing the impact of location on key factors; (2) discussion.

3.1. Assessing the impact of location on key factors

Besides two experienced professors, five senior managers coming from different manufacturing enterprises participated in this project. Bi-weekly meetings were held regularly during the first 2 months of this project. Initially, five managers were asked to describe their experience in making location decisions for the high-tech manufacturing centers in China. Then, critical location factors were discussed, along with their definitions through reference to both experiences and literature reviews. Finally, each member needed to fill out the questionnaire regarding which factors should be taken into account when locating manufacturing centers in China (Appendix A). A series of meetings was subsequently held to ensure all factors deemed necessary were certainly included. Furthermore, when a consensus could not be reached, members shared their experiences to reflect personal concerns. Based on information mutually received members made inferences about the others' opinions and adjusted their perspectives accordingly. Several iterations were necessary to reach satisfaction-compromised solutions across all members in the group. Subsequently, five primary procedures of a hybrid fuzzy integral decision-making model are employed as follows:

Step 1: Factor analysis

First of all, since the evaluated criteria are not quite mutually independent in actual MADM problems, factor analysis was applied to extract the criteria in six mutually unrelated aspects (operation climate, logistics support system, labor resource, government influence, industry clustering effect and quality of life). Herein, the 25 criteria were regrouped into the above six aspects through factor analysis. The top five facility location candidates (Jiangsu, Zhejiang, Guangdoing, Fujian and Hubei) were also determined according to statistical data for trans-border investment locations of high-tech Taiwan enterprises investing in China in 2004 (MOEA, 2004), as shown in Fig. 3.

Based on the above hierarchy framework, 1000 questionnaires were fully administered via mail in the beginning. Nevertheless, only seven questionnaires were returned, while two of these questionnaires could not be adopted. Therefore, our sampling strategy had to be adjusted accordingly. We consulted with the Global Logistics Council of Taiwan for their assistance in the questionnaire survey. First, the Council targets the enterprises that were both locating their manufacturing centers to China over 3 years and also willing to answer survey questions involving the 30 large enterprises and 30 small/medium enterprises (capital ⩽*NT*\$80 million) from their members. Six well-trained postgraduates then held face-to-face surveys. Therefore, a total of 65 questionnaires were returned; such a response rate is rather valuable with respect to expert questionnaire. Besides, the above sampling process also reveals that mailed questionnaires achieve a lower response rate than face-to-face surveys do. Additionally, except for the parts of ISM, the questionnaire in our project is similar to the conventionally adopted fuzzy AHP questionnaire. Appendix A provides illustrative patterns of the questionnaire attempting to determine the high-tech manufacturing centers in China.

Thereafter, Eq. (11) was used to derive the final fuzzy weights and non-fuzzy BNP values, including the criteria weights for evaluating suitable manufacturing centers, the fuzzy performance scores of suitable manufacturing centers and the BNP values of the fuzzy performance scores with respect to the criteria, as shown in Appendices B–D, respectively.

Step 2: ISM

Secondly, ISM was performed to further clarify the relationships between criteria in each aspect. The analysis of operation climate illustrates the ISM procedure. This aspect consists of taxes and industrial development incentives (A_1), availability and expense of utilities (A_2), IT development (A_3), cost of leasing land and factory buildings (A_4) and availability and cost of raw materials (A_5). The relationships of the criteria of operation climate can be expressed in Fig. 4.

The relation matrix, R, was then converted into Eq. (12) through Eq. (2):

$$E = R + I = \begin{bmatrix} 1 & 0 & 1 & 1 & 1 \\ 1 & 1 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 & 1 \end{bmatrix}. \tag{12}$$

Further, the reachability matrix are obtained by powering the matrix, E, to satisfy Eq. (3):

$$E^* = \begin{bmatrix} 1 & 1^* & 1 & 1 & 1 \\ 1 & 1 & 1^* & 1 & 1^* \\ 0 & 0 & 1 & 0 & 0 \\ 1 & 1^* & 1^* & 1 & 1^* \\ 1^* & 1 & 1^* & 1^* & 1 \end{bmatrix}, \tag{13}$$

where the star (*) indicates the derivative relation which does not emerge in the original relation matrix.

The reachability matrix, Eq. (13), was then used to transform the original matrix, Eq. (14), into the ISM matrix, Eq. (15):

$$\text{Original matrix} = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \\ A_5 \end{array} \begin{array}{c} \begin{array}{ccccc} A_1 & A_2 & A_3 & A_4 & A_5 \end{array} \\ \begin{bmatrix} 1 & 1.05 & 1.54 & 1.31 & 1.38 \\ 0.96 & 1 & 1.48 & 1.25 & 1.32 \\ 0.65 & 0.68 & 1 & 0.85 & 0.90 \\ 0.76 & 0.80 & 1.18 & 1 & 1.06 \\ 0.72 & 0.76 & 1.12 & 0.95 & 1 \end{bmatrix} \end{array}, \quad (14)$$

$$\text{ISM matrix} = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \\ A_5 \end{array} \begin{array}{c} \begin{array}{ccccc} A_1 & A_2 & A_3 & A_4 & A_5 \end{array} \\ \begin{bmatrix} 1 & 1.05 & 1.54 & 1.31 & 1.38 \\ 0.96 & 1 & 1.48 & 1.25 & 1.32 \\ 0 & 0 & 1 & 0 & 0 \\ 0.76 & 0.80 & 1.18 & 1 & 1.06 \\ 0.72 & 0.76 & 1.12 & 0.95 & 1 \end{bmatrix} \end{array}. \quad (15)$$

Step 3: Markov chain

Thirdly, the operation climate aspect was continually analyzed as an example to show the steps of Markov chain. First, the sum of probabilities in each column must equal 1. Therefore, ISM pairwise comparison matrix must be transformed into a normalization matrix as follows:

$$\text{Normalization matrix} = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \\ A_5 \end{array} \begin{array}{c} \begin{array}{ccccc} A_1 & A_2 & A_3 & A_4 & A_5 \end{array} \\ \begin{bmatrix} 0.29 & 0.29 & 0.24 & 0.29 & 0.29 \\ 0.28 & 0.28 & 0.23 & 0.28 & 0.28 \\ 0 & 0 & 0.16 & 0 & 0 \\ 0.22 & 0.22 & 0.19 & 0.22 & 0.22 \\ 0.21 & 0.21 & 0.18 & 0.21 & 0.21 \end{bmatrix} \end{array}. \quad (16)$$

The normalization matrix was then raised to limiting powers such as Eq. (4) to obtain the steady-state matrix as follows:

$$\text{Steady-status matrix} = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \\ A_5 \end{array} \begin{array}{c} \begin{array}{ccccc} A_1 & A_2 & A_3 & A_4 & A_5 \end{array} \\ \begin{bmatrix} 0.29 & 0.29 & 0.29 & 0.29 & 0.29 \\ 0.28 & 0.28 & 0.28 & 0.28 & 0.28 \\ 0 & 0 & 0 & 0 & 0 \\ 0.22 & 0.22 & 0.22 & 0.22 & 0.22 \\ 0.21 & 0.21 & 0.21 & 0.21 & 0.21 \end{bmatrix} \end{array}. \quad (17)$$

Step 4: Fuzzy integral

Fourthly, fuzzy integral was used to solve the criteria interdependencies within each aspect. Considering the aspect of operation climate of Jiangsu, the λ fuzzy measure was calculated using Eq. (8), and then gaining the fuzzy measures of criteria: $g(\{A_3\}) = 0$, $g(\{A_3,A_1\}) = 0.29$, $g(\{A_3,A_1,A_4\}) = 0.51$, $g(\{A_3,A_1,A_4,A_5\}) = 0.72$ and $g(\{A_3,A_1,A_4,A_5,A_2\}) = 1$. Thereafter, as Fig. 5 shows, the fuzzy integral was obtained through Eq. (10). Table 1 shows the performance score and fuzzy integral with respect to criteria of operation climate of Jiangsu.

Step 5: Simple additive weighted method.

Finally, the simple additive weighted method was used to aggregate the final synthetic score with respect to each candidate facility location. Table 2 shows the final synthetic score obtained for Jiangsu.

3.2. Results and discussions

From Appendix B, the five most important criteria in determining the appropriate locations for the high-tech manufacturing centers in China are vertical industry agglomeration (E_1), efficiency in government (D_3), taxes and industrial development incentives (A_1), government restrictions (D_2) and availability and expense of utilities (A_2). If decision makers want to make this kind of location decision, they should pay much attention to the above key criteria.

Based on the procedure of the proposed method mentioned above, the final synthetic score with respect to each candidate of facility location are summarized in Table 3. The synthetic scores for facility location candidates were also ranked as follows: Jiangsu $\succ$ Zhejiang $\succ$ Guangdoing $\succ$ Fujian $\succ$ Hubei, in which Jiangsu $\succ$ Zhejiang indicating that Jiangsu is preferred to Zhejiang. However, the ranking order is Zhejiang $\succ$ Jiangsu $\succ$ Fujian $\succ$ Hubei $\succ$ Guangdoing as the fuzzy AHP method was further employed. Notably, ranking order differed when the two methods were used to obtain overall scores. The ranking derived by using the proposed model appears reasonable since the ranking correlated with the statistical analysis of our questionnaire for current major investment locations in China. The main reason for these statistical results may be that the fuzzy AHP method assumes that criteria are mutually independent while the proposed method does not.

After verifying the proposed method, the ranking effects of large enterprise, small/medium enterprise, domestic sales and export sales were further investigated. Table 4 indicates that the location rankings of large enterprise, domestic sale and export sale are equivalent to the whole samples. Nevertheless, the ranking of small/medium enterprises clearly differed from the others. Moreover, Spearman's test (Zuwaylif, 1979) was conducted to analyze the ranking results of both large and small/medium enterprises. According to results of Spearman's test, low correlation could be found between large enterprises and small/medium enterprises ($P > 0.05$). Restated, the rankings of the facilities differ with respect to industry-level differences. To explain this finding, managers of Taiwan manufacturing enterprises (including large and small/medium enterprises) operating in Mainland China were interviewed. Most interviewed managers agreed that small/medium enterprises often lack sufficient capital to locate in the best sites, such as Jiangsu, and tend to choose the second best location adjacent to the best (main) location. For example, because Jiangsu is close to Zhejiang, small/medium enterprises may choose Zhejiang instead of Jiangsu. The same reason could be applied to the location of Guangdoing and Fujian. Additionally, domestic and export sales have similar effects when selecting locations for manufacturing centers.

The key findings of the extended analysis can be summarized as follows. First, the traditional method (*i.e.*, fuzzy AHP) ignores the problem of preference independence and cannot perform rational decision-making in practice. To address this problem, the hybrid fuzzy integral decision-making model is proposed to overcome the non-additive problem among criteria. Applying the proposed approach to an actual case study indicates that the method is both operational and rational. Second, vertical industry agglomeration is the crucial factor when selecting locations for high-tech manufacturing centers in China, which indicates that enterprises investing in China should take into account the effects of agglomeration economics. Third, government of China has a powerful influence on the location of manufacturing centers. The formation and development of good social networks in government is essential for success. Finally, small/medium enterprises should carefully

Table A.1
An example of the relative importance degree and the relationships of the criteria.

Former criterion affects latter criterion	Former	Relative importance of the criteria with respect to operation climate													Latter	Latter criterion affects former criterion
		7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7		
○	A_1	✓													A_2	×
×	A_1			✓											A_3	○
○	A_1						✓								A_4	○
×	A_1					✓									A_5	○
×	A_2			✓											A_3	×
×	A_2				✓										A_4	○
○	A_2					✓									A_5	×
×	A_3									✓					A_4	×
×	A_3							✓							A_5	×
×	A_4								✓						A_5	×

Note: A_1 – taxes and industrial development incentives; A_2 – availability and expense of utilities; A_3 – IT development; A_4 – cost of leasing land and factory buildings; A_5 – availability and cost of raw materials.

Table A.2
Example of the degree of satisfaction of the candidates of facility location.

Criteria	Degree of satisfaction	Candidates				
		Jiangsu	Zhejiang	Guangdoing	Fujian	Hubei
Availability and cost of raw materials	Very satisfactory	✓				
	Satisfactory		✓		✓	
	Ordinary			✓		
	Unsatisfactory					
	Very unsatisfactory					✓

Table A.3
Example of the degree of importance of the factor.

Factors	Degree of importance				
	Very unimportant	Unimportant	Ordinary	Important	Very important
Availability and cost of raw materials					✓

observe how large enterprises are deployed prior to investing in China.

4. Conclusion

This study presents a hybrid fuzzy integral decision-making model for locating manufacturing centers, especially when most criteria have interdependent or interactive characteristics and a vast body of data that are often inaccurate or uncertain. The proposed method involves five major components: (1) factor analysis, (2) ISM, (3) Markov Chain, (4) fuzzy integral and (5) simple additive weighted method. A case study of a series of methods provides academics and managers a macro view of the strategies for implementing location decisions.

To demonstrate the applicability of the proposed methodology, this research designed and conducted a questionnaire survey as well as in-depth interviews to examine the location problem of Taiwan enterprises in China. The results from the empirical study revealed some crucial properties as follows. First, enterprises investing in China should consider the effect of agglomeration economics. Second, the formation and development of good social networks in China government can help foreign enterprises operate in the unique business environment in China. Finally, small/medium enterprises should carefully observe the activities of large enterprises before investing in China. Further, managers conferred that these findings would be useful when selecting locations for manufacturing centers in China. This survey is significant in practice due to the growing trend among enterprises to locate manufacturing centers in Mainland China.

Our study differs from previous MADM problems in several respects. First, since the evaluated criteria are not quite mutually independent in actual MADM problems, factor analysis was used to extract the criteria in several mutually unrelated aspects. Sec-

Table B.1
The criteria weights for evaluating suitable manufacturing centers.

Aspects and criteria	Local weights	Overall weights	BNP	Ranking
Operation climate	(0.183, 0.286, 0.892)			
A_1	(0.206, 0.379, 0.829)	(0.038, 0.109, 0.740)	0.295	3
A_2	(0.210, 0.342, 0.796)	(0.039, 0.098, 0.710)	0.282	5
A_3	(0.187, 0.290, 0.511)	(0.034, 0.083, 0.456)	0.191	15
A_4	(0.212, 0.334, 0.608)	(0.039, 0.096, 0.543)	0.225	10
A_5	(0.170, 0.316, 0.580)	(0.031, 0.091, 0.518)	0.213	12
Logistics support system	(0.169, 0.270, 0.781)			
B_1	(0.129, 0.130, 0.632)	(0.022, 0.035, 0.493)	0.183	16
B_2	(0.128, 0.129, 0.630)	(0.022, 0.035, 0.491)	0.182	17
B_3	(0.124, 0.125, 0.525)	(0.021, 0.034, 0.410)	0.154	22
B_4	(0.128, 0.129, 0.530)	(0.022, 0.035, 0.413)	0.156	20
B_5	(0.129, 0.129, 0.530)	(0.022, 0.035, 0.414)	0.157	19
B_6	(0.126, 0.127, 0.527)	(0.021, 0.034, 0.411)	0.155	21
B_7	(0.114, 0.116, 0.518)	(0.019, 0.031, 0.405)	0.152	23
B_8	(0.113, 0.115, 0.517)	(0.019, 0.031, 0.403)	0.151	24
Labor resource	(0.171, 0.272, 0.872)			
C_1	(0.258, 0.359, 0.761)	(0.044, 0.098, 0.664)	0.268	6
C_2	(0.231, 0.335, 0.737)	(0.040, 0.091, 0.643)	0.258	8
C_3	(0.155, 0.256, 0.557)	(0.027, 0.070, 0.486)	0.194	14
C_4	(0.250, 0.350, 0.750)	(0.043, 0.095, 0.654)	0.264	7
Government influence	(0.173, 0.275, 0.876)			
D_1	(0.276, 0.280, 0.589)	(0.048, 0.077, 0.516)	0.214	11
D_2	(0.251, 0.351, 0.851)	(0.043, 0.096, 0.746)	0.295	4
D_3	(0.251, 0.371, 0.851)	(0.043, 0.102, 0.746)	0.297	2
D_4	(0.209, 0.317, 0.722)	(0.036, 0.087, 0.633)	0.252	9
Industry clustering effect	(0.159, 0.297, 0.992)			
E_1	(0.288, 0.564, 0.879)	(0.046, 0.168, 0.873)	0.362	1
E_2	(0.221, 0.436, 0.445)	(0.035, 0.130, 0.442)	0.202	13
Quality of life	(0.129, 0.136, 0.640)			
F_1	(0.232, 0.437, 0.646)	(0.030, 0.059, 0.414)	0.167	18
F_2	(0.214, 0.363, 0.468)	(0.028, 0.049, 0.299)	0.125	25

ond, ISM was employed to clarify the relationships of the criteria in each aspect. Third, Markov chain was used to find stable weights. Fourth, the non-additive fuzzy integral was used to cope with interdependencies existing among criteria. Finally, the simple additive weighted method was used to establish the final synthetic score of each alternative regarding the independence among aspects. The methodology presented in this research may stimulate research in the related fields of decision-making and may help address issues regarding the non-independent criteria case.

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Appendix A. Illustrative patterns of the questionnaire for selecting important factors, identifying critical factors and selecting a suitable location

Part 1: Interval of each triangular fuzzy number

Fig. A.1 illustrates the interval of each triangular fuzzy number for degree of importance. The meaning of each fuzzy number is expressed as follows:

$\tilde{1}$: equally important;
$\tilde{3}$:weakly more important;
$\tilde{5}$:strongly more important;
$\tilde{7}$:absolutely more important;
$\tilde{2}, \tilde{4}, \tilde{6}$:intermediate value.

A triangular fuzzy number is denoted simply as (l, m, u). The parameters l, m, and u indicate the smallest possible value, the most promising value, and the largest possible value, respectively. Please fill in the blanks with subjective determinations of each triangular fuzzy number for degree of importance. For example, $\tilde{1} = (1, 1, 2)$; $\tilde{2} = (1, 2, 3)$; $\tilde{3} = (2, 3, 4)$; $\tilde{4} = (3, 4, 5)$; $\tilde{5} = (4, 5, 6)$; $\tilde{6} = (5, 6, 7)$; $\tilde{7} = (6, 7, 7)$.

Fig. A.2 illustrates the interval of each triangular fuzzy number for degree of satisfaction. Please fill in the blanks with subjective determinations of each triangular fuzzy number for degree of satisfaction. For example, Very unsatisfactory = (0,0,20); Unsatisfactory = (10,30,40); Ordinary = (36,50,65); Satisfactory = (60,72,91); Very satisfactory = (85,100,100). Moreover, the questionnaire items regarding the interval of each triangular fuzzy number for degree of importance for selecting important factors was similar to degree of satisfaction.

Part 2: Relative importance degree and the relationships of the criteria

Please place a check "✓"on the pairwise comparison matrix for the degree of importance of the criteria. Also, answer "○" (denoting "Yes") or "×" (denoting "No") on the first and last column for the relationships of the criteria. Table A.1 displays an example of the relative importance degree and the relationships of the criteria. Herein, for the relationship between A_1 and A_2, placing "○"on the first column means that A_1 affects A_2 and placing "×"on the last column means that A_2 does not affect A_1.

Table C.1
The fuzzy performance scores of suitable manufacturing centers.

Candidates	Criteria				
	A_1	A_2	A_3	A_4	A_5
Jiangsu	(61.35,72.56,84.18)	(38.86,54.16,67.97)	(62.19,73.28,84.91)	(46.77,59.92,73.00)	(46.39,59.30,72.51)
Zhejiang	(56.98,68.48,80.62)	(39.05,52.63,66.27)	(55.20,67.06,79.48)	(47.79,60.53,73.62)	(49.39,61.73,74.79)
Guangdoing	(52.14,65.49,78.39)	(42.76,56.59,70.13)	(57.23,68.92,81.10)	(40.41,54.68,68.35)	(47.22,60.01,73.28)
Fujian	(50.14,62.19,75.07)	(43.24,56.40,69.81)	(46.54,59.12,72.31)	(51.71,64.31,77.28)	(49.18,61.66,74.75)
Hubei	(43.50,56.41,69.77)	(35.14,49.46,63.32)	(39.79,53.77,67.47)	(54.71,67.10,79.75)	(48.28,61.01,74.14)
	B_1	B_2	B_3	B_4	B_5
Jiangsu	(59.72,71.29,83.27)	(51.74,64.14,76.94)	(61.52,73.03,85.04)	(53.85,66.11,78.69)	(58.58,70.41,82.67)
Zhejiang	(51.67,63.93,76.72)	(52.15,64.15,76.92)	(55.87,67.47,79.85)	(50.19,62.70,75.46)	(51.47,63.73,76.53)
Guangdoing	(58.33,69.86,81.98)	(56.52,68.44,80.73)	(57.30,70.26,82.54)	(48.71,62.66,75.76)	(54.42,69.08,81.91)
Fujian	(43.82,56.62,69.95)	(47.02,59.64,72.75)	(40.22,54.31,68.02)	(44.07,58.14,71.59)	(43.07,56.79,70.30)
Hubei	(36.81,49.98,63.57)	(41.40,54.49,67.95)	(35.47,50.42,64.48)	(40.56,54.68,68.38)	(35.48,49.87,63.78)
	B_6	B_7	B_8	C_1	C_2
Jiangsu	(51.81,64.15,76.91)	(43.58,57.04,70.45)	(46.32,59.19,72.47)	(45.48,58.79,72.04)	(51.65,55.48,66.42)
Zhejiang	(47.02,59.80,72.96)	(42.21,55.21,68.57)	(46.14,58.61,71.84)	(44.34,62.98,71.32)	(49.27,65.92,75.95)
Guangdoing	(50.95,64.60,77.60)	(43.94,58.04,71.58)	(45.52,58.39,71.70)	(45.65,58.79,72.07)	(51.94,59.18,77.34)
Fujian	(41.68,55.45,69.03)	(36.64,50.73,64.60)	(42.94,55.67,69.10)	(53.92,66.12,78.77)	(55.88,67.52,79.94)
Hubei	(40.09,54.14,67.81)	(33.47,47.72,61.64)	(42.74,55.30,68.67)	(59.52,71.03,83.11)	(50.26,68.01,75.57)
	C_3	C_4	D_1	D_2	D_3
Jiangsu	(49.68,63.70,76.94)	(53.36,66.97,79.94)	(50.32,53.52,72.01)	(43.78,57.75,71.23)	(51.04,56.93,62.51)
Zhejiang	(67.70,70.84,75.16)	(50.42,63.94,77.10)	(49.23,61.02,70.20)	(45.87,59.54,71.08)	(51.84,63.22,71.65)
Guangdoing	(40.32,48.42,53.49)	(48.93,62.48,75.66)	(44.73,50.86,59.84)	(40.42,51.63,56.61)	(39.80,42.02,51.57)
Fujian	(37.01,52.72,66.93)	(40.34,55.09,68.97)	(41.92,55.99,69.64)	(40.56,54.51,68.22)	(32.64,48.41,62.76)
Hubei	(46.61,58.72,59.71)	(45.98,53.71,58.59)	(46.71,55.96,63.76)	(56.12,59.39,62.17)	(40.19,51.61,59.30)
	D_4	E_1	E_2	F_1	F_2
Jiangsu	(48.13,51.24,57.01)	(45.48,58.38,75.63)	(50.49,63.75,76.77)	(50.42,56.75,65.13)	(58.84,70.45,82.52)
Zhejiang	(40.66,63.48,68.38)	(53.89,65.90,78.49)	(48.31,68.25,76.41)	(48.61,67.14,69.48)	(54.27,66.12,78.67)
Guangdoing	(34.12,34.92,60.12)	(41.06,44.51,64.23)	(41.03,45.63,70.06)	(39.14,48.45,62.01)	(48.82,51.20,55.39)
Fujian	(35.30,50.56,64.69)	(47.56,69.22,70.21)	(45.26,67.84,71.31)	(47.73,63.17,69.84)	(50.74,62.87,75.69)
Hubei	(37.32,51.61,65.40)	(41.23,55.04,63.45)	(47.69,58.29,66.09)	(50.64,59.47,65.74)	(48.27,53.75,62.10)

Table D.1
The BNP values of the fuzzy performance scores with respect to the criteria.

Candidates	BNP values of criteria								
	A_1	A_2	A_3	A_4	A_5	B_1	B_2	B_3	B_4
Jiangsu	72.70	53.66	73.46	59.90	59.40	71.43	64.27	73.20	66.22
Zhejiang	68.69	52.65	67.25	60.65	61.97	64.11	64.41	67.73	62.78
Guangdoing	65.34	56.49	69.09	54.48	60.17	70.06	68.56	70.03	62.37
Fujian	62.47	56.48	59.33	64.43	61.86	56.80	59.80	54.18	57.94
Hubei	56.56	49.31	53.68	67.19	61.14	50.12	54.61	50.12	54.54
	B_5	B_6	B_7	B_8	C_1	C_2	C_3	C_4	D_1
Jiangsu	70.55	64.29	57.02	59.33	58.77	57.85	63.44	66.76	58.62
Zhejiang	63.91	59.93	55.33	58.86	59.54	63.71	71.23	63.82	60.15
Guangdoing	68.47	64.38	57.85	58.53	58.84	62.82	47.41	62.36	51.81
Fujian	56.72	55.39	50.66	55.90	66.27	67.78	52.22	54.80	55.85
Hubei	49.71	54.01	47.61	55.57	71.22	64.61	55.01	52.76	55.48
	D_2	D_3	D_4	E_1	E_2	F_1	F_2		
Jiangsu	57.59	56.83	52.13	59.83	63.67	57.43	70.60		
Zhejiang	58.83	62.24	57.51	66.09	64.32	61.74	66.36		
Guangdoing	49.55	44.46	43.05	49.93	52.24	49.87	51.80		
Fujian	54.43	47.94	50.19	62.33	61.47	60.25	63.10		
Hubei	59.23	50.37	51.44	53.24	57.36	58.62	54.71		

Part 3: Degree of satisfaction of the candidates of facility location

Please place a check "✓"on the degree of satisfaction table for each candidates of the facility location. Table A.2 describes an example of the degree of satisfaction of the candidates of the facility location. Similarly, Table A.3 displays an example of the degree of importance of the factor for selecting important factors.

Appendix B. The criteria weights for evaluating suitable manufacturing centers

See Table B.1.

Appendix C. The fuzzy performance scores of suitable manufacturing centers

See Table C.1.

Appendix D. The BNP values of the fuzzy performance scores with respect to the criteria

See Table D.1.

References

Alumur, S., Kara, B.Y., 2008. Network hub location problems: The state of the art. European Journal of Operational Research 190 (1), 1–21.

Angilella, S., Greco, S., Lamantia, F., Matarazzo, B., 2004. Assessing non-additive utility for multicriteria decision aid. European Journal of Operational Research 158 (3), 734–774.

Banon, G., 1981. Distinction between several subsets of fuzzy measures. Fuzzy Sets and Systems 5 (3), 291–305.

Blonigen, B.A., Ellis, C.J., Fausten, F., 2005. Industrial groupings and foreign direct investment. Journal of International Economics 65 (1), 75–91.

Bock, S., 2008. Supporting offshoring and nearshoring decisions for mass customization manufacturing processes. European Journal of Operational Research 184 (2), 490–508.

Chen, L.-H., Chiou, T.-W., 1999. A fuzzy credit-rating approach for commercial loans: A Taiwan case. Omega 27 (4), 407–419.

Chen, Y.-W., Tzeng, G.-H., 2001. Using fuzzy integral for evaluating subjectively perceived travel costs in a traffic assignment model. European Journal of Operational Research 130 (3), 653–664.

Chen, T.-Y., Wang, J.-C., 2001. Identification of λ-fuzzy measures using sampling design and genetic algorithms. Fuzzy Sets and Systems 123 (3), 321–341.

Chen, T.-Y., Chang, H.-L., Tzeng, G.-H., 2002. Using fuzzy measures and habitual domains to analyze the public attitude and apply to the gas taxi policy. European Journal of Operational Research 137 (1), 145–161.

Coyle, J.J., Bardi, E.J., Langley, C.J., 2003. Network design and facility location. In: Acuña, M. (Ed.), The Management of Business Logistics: A Supply Chain Perspective. Thomson Learning, Canada, pp. 502–539.

Chiou, H.-K., Tzeng, G.-H., Cheng, D.-C., 2005. Evaluating sustainable fishing development strategies using fuzzy MCDM approach. Omega 33 (3), 223–234.

Díaz-Báñez, J.M., Mesa, J.A., Schöbel, A., 2004. Continuous location of dimensional structures. European Journal of Operational Research 152 (1), 22–44.

Doukas, H.C., Andreas, B.M., Psarras, J.E., 2007. Multi-criteria decision aid for the formulation of sustainable technological energy priorities using linguistic variables. European Journal of Operational Research 182 (2), 844–855.

Figueiredo, O., Guimarães, P., Woodward, D., 2002. Home-field advantage: Location decisions of Portuguese entrepreneurs. Journal of Urban Economics 52 (2), 341–361.

Grabisch, M., 1995. Fuzzy integral in multicriteria decision making. Fuzzy Sets and Systems 69 (3), 279–298.

Grabisch, M., 1996. The application of fuzzy integrals in multicriteria decision making. European Journal of Operational Research 89 (3), 653–664.

Grabisch, M., Kojadinovic, I., Meyer, P., 2008. A review of methods for capacity identification in Choquet integral based multi-attribute utility theory: Applications of the Kappalab R package. European Journal of Operational Research 186 (2), 766–785.

Goetschalckx, M., Vidal, C.J., Dogan, K., 2002. Modeling and design of global logistics systems: A review of integrated strategic and tactical models and design algorithms. European Journal of Operational Research 143 (1), 1–18.

Huang, J-J., Tzeng, G.-H., Ong, C.-S., 2005. Multidimensional data in multidimensional scaling using the analytic network process. Pattern Recognition Letters 26 (6), 755–767.

Ishii, K., Sugeno, M., 1985. A model of human evaluation process using fuzzy measure. International Journal of Man–Machine Studies 22 (1), 19–38.

Investment Commission, Ministry of Economic Affairs (MOEA), Republic of China, 2004. Indirect investment in mainland China. Statistics on Overseas Chinese & Foreign Investment, Outward Investment, and Mainland Investment, Monthly Report (in Chinese).

Klir, G.J., Folger, T.A., 1988. Fuzzy Sets, Uncertainty, and Information. Prentice Hall, Englewood Cliffs, NJ.

Klose, A., Drexl, A., 2005. Facility location models for distribution system design. European Journal of Operational Research 162 (1), 4–29.

Leszczynski, K., Penczek, P., Grochulski, W., 1985. Sugeno's fuzzy measure and fuzzy clustering. Fuzzy Sets and System 15 (2), 147–158.

Leung, S.C.H., Tsang, S.O.S., Ng, W.L., Wu, Y., 2007. A robust optimization model for multi-site production planning problem in an uncertain environment. European Journal of Operational Research 181 (1), 224–238.

Luk, S.T.K., 1998. Structural changes in China's distribution system. International Journal of Physical Distribution and Logistics Management 28 (1), 44–67.

Lay, D.C., 2003. Applications to Markov chains. In: Hoffman, W. (Ed.), Linear Algebra and Its Applications. Addison-Wesley, America, pp. 288–296.

Lakhal, S.Y., H'Mida, S., Venkatadri, D., 2005. A market-driven transfer price for distributed products using mathematical programming. European Journal of Operational Research 162 (3), 690–699.

Murofushi, T., Sugeno, M., 1989. An interpretation of fuzzy measure and the Choquet integral as an integral with respect to a fuzzy measure. Fuzzy Sets and Systems 29 (2), 201–227.

Min, H., Jayaraman, V., Srivastava, R., 1998. Combined location-routing problems: A synthesis and future research direction. European Journal of Operational Research 108 (1), 1–15.

Narukawa, Y., Murofushi, T., Sugeno, M., 2000. Regular fuzzy measure and representation of comonotonically additive functional. Fuzzy Sets and Systems 112 (2), 177–186.

Owen, S.H., Daskin, M.S., 1998. Strategic facility location: A review. European Journal of Operational Research 111 (3), 423–447.

Prowell, S.J., Poore, J.H., 2004. Computing system reliability using Markov chain usage models. The Journal of Systems and Software 73 (2), 219–225.
ReVelle, C.S., Eiselt, H.A., 2005. Location analysis: A synthesis and survey. European Journal of Operational Research 165 (1), 1–19.
Sugeno, M., 1974. Theory of fuzzy integrals and its applications. Ph.D. Dissertation, Tokyo Institute of Technology, Tokyo, Japan.
Sugeno, M., 1977. Fuzzy measures and fuzzy integrals: A survey. In: Gupta, M.M., Saridis, G.N., Gaines, B.R. (Eds.), Fuzzy Automata and Decision Processes. North-Holland, Amsterdam/New York, pp. 89–102.
Saaty, T.L., 1996. Decision Making with Dependence and Feedback: The Analytic Network Process. RWS Publications, Pittsburgh.
Sarkis, J., Sundarraj, R.P., 2002. Hub location at Digital Equipment Corporation: A comprehensive analysis of qualitative and quantitative factors. European Journal of Operational Research 137 (2), 336–347.
Sarkis, J., 2003. Quantitative models for performance measurement systems – Alternate considerations. International Journal of Production Economics 86 (1), 81–90.
Sheu, J.-B., 2003. Locating manufacturing and distribution centers: An integrated supply chain-based spatial interaction approach. Transportation Research Part E 39 (5), 381–397.
Sheu, J.-B., 2008. A hybrid neuro-fuzzy analytical approach to mode choice of global logistics management. European Journal of Operational Research 189 (3), 971–986.
Tsaur, S.-H., Tzeng, G.-H., Wang, G.-C., 1997. Evaluating tourist risks from fuzzy perspectives. Annals of Tourism Research 24 (4), 796–812.
Tang, M.-T., Tzeng, G.-H., Wang, S.-W., 1999. A hierarchy fuzzy MCDM method for studying electronic marketing strategies in the information service industry. Journal of International Information Management 8 (1), 1–22.
Tseng, F.-M., Yu, C.-Y., 2005. Partitioned fuzzy integral multinomial logit model for Taiwan's internet telephony market. Omega 33 (3), 267–276.
Tzeng, G.-H., Ou Yang, Y.-P., Lin, C.-T., Chen, C.-B., 2005. Hierarchical MADM with fuzzy integral for evaluating enterprise intranet web sites. Information Sciences 169 (3-4), 409–426.
Vidal, C.J., Goetschalckx, M., 1997. Strategic production–distribution models: A critical review with emphasis on global supply chain models. European Journal of Operational Research 98 (1), 1–18.
Vidal, C.J., Goetschalckx, M., 2001. A global supply chain model with transfer pricing and transportation cost allocation. European Journal of Operational Research 129 (1), 134–158.
Warfield, J.N., 1974a. Toward interpretation of complex structural modeling. IEEE Transactions on Systems Man and Cybernetics 4 (5), 405–417.
Warfield, J.N., 1974b. Developing interconnection matrices in structural modeling. IEEE Transactions on Systems Man and Cybernetics 4 (1), 81–87.
Warfield, J.N., 1976. Societal Systems: Planning, Policy, and Complexity. Wiley–Interscience, New York.
Wang, Z., Klir, G.J., 1992. Fuzzy Measure Theory. Plenum Press, New York.
Wang, X., Keller, J.M., 1999. Human-based spatial relationship generalization through neural-fuzzy approaches. Fuzzy Sets and Systems 101 (1), 5–20.
Wolfslehner, B., Vacik, H., Lexer, M.J., 2005. Application of the analytic network process in multi-criteria analysis of sustainable forest management. Forest Ecology and Management 207 (1-2), 157–170.
Yager, R.R., Filev, D.P., 1994. Essentials of Fuzzy Modeling and Control. Wiley, New York.
Zhang, Q., Yin, G., 1997. Structural properties of Markov chains with weak and strong interactions. Stochastic Processes and their Applications 70 (2), 181–197.
Zuwaylif, F.H., 1979. Applied General Statistics, third ed. Addison-Wesley, Reading, MA.