Research Article

Application of a New Hybrid Fuzzy AHP Model to the Location Choice

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The purpose of this paper is to propose a new hybrid fuzzy Analytic Hierarchy Process (AHP) algorithm to deal with the decision-making problems in an uncertain and multiple-criteria environment. In this study, the proposed hybrid fuzzy AHP model is applied to the location choices of international distribution centers in international ports from the view of multiple-nation corporations. The results show that the proposed new hybrid fuzzy AHP model is an appropriate tool to solve the decision-making problems in an uncertain and multiple-criteria environment.

1. Introduction

Modern logistics service provided by the logistics provider emphasizes quick response to customer demand. However, it is difficult to fit totally customer demands in a logistics system. In particular, in a global logistics system a lot of uncertainties and complexities exist. A global logistics system includes two important roles. One is the logistics service provider, for example, shipping carriers, international ports, and international distribution centers. Another is the logistics service demander such as multinational corporations (MNCs). The international distribution center within the international port is also one important part of a global logistics system. The shipping companies and the multiple-national corporation prefer to use high-efficiency and high-service quality international logistics centers within an international port. Therefore, it is an important and complex decision-making problem for shipping companies and multinational corporations to select a high-efficiency and high-service quality international logistics center within an international port.

Due to a shift in the global center of manufacturing to Asia since 1980s, major international ports in the Asian region have been expanded rapidly. Thus, the shipping companies

and the multinational corporations focus on the location choice of international distribution centers in Asia. The major international ports in Asia include the ports of Shanghai, Singapore, Hong Kong, Shenzhen, Busan, Ningbo, Qingdao, Guangzhou, Tianjin, and Kaohsiung. In the future, the demand for cargoes in Asia will further increase. In Table 1, the container throughputs in 2010 for the world's top 20 container ports including the ports of Shanghai, Singapore, Hong Kong, Shenzhen, Busan, Ningbo, Guangzhou, Qingdao, Dubai, Rotterdam, Tianjin, Kaohsiung, Antwerp, Klang, Hamburg, Los Angeles, Tanjung Pelepas, Long Beach, Xiamen, and Laem Chabang are 29,069, 28,430, 23,611, 22,509, 14,180, 13,146, 12,545, 12,012, 11,613, 11,145, 10,086, 9,181, 8,483, 8,146, 7,900, 7,831, 6,603, 6,263, 5,824, and 5,640 thousand TEUs, respectively. The rankings and the volumes for these major international ports from 2006 to 2010 are also shown in Table 1.

Many international distribution centers at major Asian ports have been established in the recent years, such as Waigaoqiao Bond Logistics Park in the port of Shanghai, Hong Kong International Distribution Center in the port of Hong Kong, Kaohsiung Yes Logistics Zone in the port of Kaohsiung, Schwartz Logistics Hub in the port of Shenzhen, Busan Logistics Park in the port of Busan, and Keppel

TABLE 1: The container throughputs and the rankings for the world's top 20 container ports (unit: thousand TEUs).

2010	2009	2008	2007	2006	Name of port	2010	2009	2008	2007	2006
1	2	2	2	3	Shanghai	29,069	25,002	27,780	26,150	21,720
2	1	1	1	1	Singapore	28,430	25,866	29,918	27,935	24,792
3	3	3	3	2	Hong Kong	23,611	20,925	24,248	23,881	23,539
4	4	4	4	4	Shenzhen	22,509	18,250	21,400	21,090	18,468
5	5	5	5	5	Busan	14,180	11,980	13,452	13,261	12,038
6	8	8	11	13	Ningbo	13,146	10,502	10,933	9,360	7,140
7	6	7	12	15	Guangzhou	12,545	11,190	11,001	9,200	6,656
8	9	10	10	11	Qingdao	12,012	10,260	10,020	9,462	7,702
9	7	6	6	8	Dubai	11,613	11,150	11,830	11,000	8,923
10	10	9	7	7	Rotterdam	11,145	9,800	10,784	10,791	9,690
11	11	14	17	17	Tianjin	10,086	8,700	8,500	7,102	5,950
12	12	12	8	6	Kaohsiung	9,181	8,581	9,676	10,256	9,774
13	13	13	14	14	Antwerp	8,483	7,309	8,663	8,176	7,018
14	14	15	16	16	Klang	8,146	7,300	7,973	7,118	6,326
15	15	11	9	9	Hamburg	7,900	7,010	9,737	9,890	8,861
16	16	16	13	10	Los Angeles	7,831	6,748	7,849	8,355	8,469
17	17	18	18	19	Tanjung Pelepas	6,603	6,000	5,600	5,500	4,770
18	18	17	15	12	Long Beach	6,263	5,067	6,487	7,312	7,289
19	19	22	22	22	Xiamen	5,824	4,680	5,034	4,627	4,018
20	20	21	21	21	Laem Chabang	5,640	4,640	5,130	4,640	4,123

Source: Chou et al. [1].

Distripark in the port of Singapore. Therefore, it is very important for the shipping companies and the multinational corporations to evaluate the environment among these major international logistics centers in different nations, in order to design and implement an appropriate global logistics system. It is also a complex multiple-criteria decision-making (MCDM) problem under uncertain environment. AHP is an appropriate approach to solve complex multiple-criteria decision-making problem. Fuzzy sets theory method has been widely applied to the uncertain decision-making problem in the real world. Thus, this paper combines AHP and fuzzy sets theory and then proposes a new hybrid fuzzy AHP model for the location choice of international logistics centers within the international ports from the perspective of multinational corporations.

2. Literature Review

2.1. Environmental Evaluation Approaches. Environment evaluation approaches including the resource-based view (RBV), traditional strength-weakness-opportunity-threat (SWOT), and quantitative SWOT such as the external factor evaluation matrix (EFE), internal factor evaluation matrix (IFE), and competitive profile matrix (CPM) have been widely used. The traditional SWOT analytical method is commonly applied to marketing strategy analysis [2–4]. The SWOT analytical method is able to help the decision maker of the enterprises evaluate qualitatively their competitiveness and can be used as a foundation of the development of strategies [5]. The quantitative SWOT such as external factor evaluation matrix (EFE), internal factor evaluation matrix (IFE), and competitive profile matrix (CPM) aim

at analyzing statistical data, differing from the traditional SWOT analytical method [3, 6]. The disadvantage of the above approaches is that they cannot evaluate the qualitative and quantitative criteria simultaneously. Therefore, this paper proposes a new hybrid approach which integrates AHP method to carry out a complete evaluation of qualitative and quantitative criteria simultaneously and to evaluate the competitive environmental relationships between the several international distribution center locations within the ports in the asian region.

Erol and Ferrell Jr. [7] use fuzzy Quality Function Deployment (QFD) to convert qualitative information into quantitative parameters and then combine this data with other quantitative data to multiobjective mathematical programming model. Mikhailov and Tsvetinov [8] propose a fuzzy AHP approach for tackling the uncertainty and imprecision of the service evaluation process. Ronza et al. [9] present a quantitative risk analysis approach to port hydrocarbon logistics. Because risk is an uncertain criterion, it is not easy for a decision maker to measure exactly the value of risk. Chang and Huang [4] present a quantitative strength/weakness/opportunity/threat (SWOT) analysis method for assessing the competing strengths of major ports in East Asia. Yong [10] uses a fuzzy TOPSIS model to solve the problem of plant location choice. Önüt and Soner [11] propose an AHP/TOPSIS approach for solving transshipment site selection problem under fuzzy environment. Tahera et al. [12] develop a fuzzy logic approach for dealing with qualitative quality characteristics of a process. Chen et al. [13] combine fuzzy AHP with Multidimension Scaling (MDS) in identifying the preference similarity of alternatives. Chou et al. [14] present a new fuzzy multiple

FIGURE 1: Trapezoidal fuzzy number $A_1 = (c_1, a_1, b_1, d_1)$.

attributes decision-making (MADM) approach for solving facility location selection problem by using objective and subjective attributes. Lee and Lin [15] use a fuzzy quantitative SWOT procedure for environment evaluation of international distribution centers in Pacific Asian region. Lee et al. [16] introduce a fuzzy AHP and Balanced Score Card (BSC) approach for evaluating performance of IT department in the manufacturing industry in Taiwan. Chou [17] uses fuzzy MCDM approach for dealing with quantitative and qualitative criteria in a process of location choice. Chou [18] deals with objective data and subjective ratings by fuzzy logic. Chou [19] analyzes the competitive relationship between the ports of Hong Kong, Shanghai, and Kaohsiung by the sensitivity analysis.

In the past, although many researchers proposed a lot of fuzzy approaches, for example, fuzzy QFD, MADM, AHP, TOPSIS, BSC, SWOT, and MCDM, few presented a hybrid qualitative/quantitative fuzzy AHP model for dealing with both objective data and subjective criteria simultaneously in the decision-making process.

2.2. Fuzzy AHP. Despite of its wide application to various decision-making problems, the conventional AHP approach may not fully reflect a style of human thinking. Thus, the fuzzy AHP approach is proposed to overcome the disadvantage of the conventional AHP. The fuzzy AHP approach is a systematic method for the alternative choice and justification problems that combines the concept of fuzzy sets theory [20] and the hierarchical structure analysis [21].

Fuzzy AHP approach has been widely applied to many decision-making problems. For example, Chang [22] developed a fuzzy extent analysis for AHP and the approach is relatively easier in computational procedure than the other fuzzy AHP approaches. Kuo et al. [23] presented a fuzzy AHP method for the location choice of a convenience store. Kurttila et al. [5] combined AHP with SWOT to provide a new hybrid method for a forest certification case. Stewart et al. [24] combined AHP method with SWOT to present a new approach for improving the usability of AHP in strategic management. Kahraman et al. [25] applied fuzzy AHP to select the location of facility. Zhang et al. [26] combined fuzzy AHP with MCDM to deal with an MCDM decision-making problem. The results show that the proposed hybrid method was a useful way to deal with MCDM decision-making problems. Erensal et al. [27] determined key capabilities

in technology management by using fuzzy AHP. Chan and Kumar [28] proposed a model for global supplier development considering risk factors by using fuzzy AHP. Bozbura and Beskese [29] determined the priorities of organizational capital measurement indicators by using fuzzy AHP. Bozbura et al. [30] used fuzzy AHP method to determine the priorities of human capital measurement indicators. Lee and Lin [15] developed a fuzzy quantified SWOT procedure that integrates MCDM concept and fuzzy AHP method for the location choice of international distribution centers.

3. Methodology

3.1. Fuzzy Sets Theory. Fuzzy sets theory is initially introduced by Zadeh [20]. A fuzzy number is defined as follows. Suppose $A_1 = (c_1, a_1, b_1, d_1)$ is a trapezoidal fuzzy number in Figure 1. The membership function of A_1 and the fuzzy arithmetic operations on fuzzy numbers are shown as follows:

$$f_{A_1}(x) = \begin{cases} \frac{(x - c_1)}{(a_1 - c_1)}, & c_1 \leq x \leq a_1 \\ 1, & a_1 \leq x \leq b_1 \\ \frac{(x - d_1)}{(b_1 - d_1)}, & b_1 \leq x \leq d_1 \\ 0, & \text{otherwise.} \end{cases} \quad (1)$$

Suppose $A_1 = (c_1, a_1, b_1, d_1)$ and $A_2 = (c_2, a_2, b_2, d_2)$ are two trapezoidal fuzzy numbers.

(a) Addition operation on A_1 and A_2

$$A_1 \oplus A_2 = (c_1 + c_2, a_1 + a_2, b_1 + b_2, d_1 + d_2). \quad (2)$$

(b) Subtraction operation on A_1 and A_2

$$A_1 \ominus A_2 = (c_1 - d_2, a_1 - b_2, b_1 - a_2, d_1 - c_2). \quad (3)$$

(c) Multiplication operation on A_1 and r

$$r \otimes A_1 = (rc_1, ra_1, rb_1, rd_1). \quad (4)$$

(d) Division operation on A_1 and r

$$\frac{A_1}{r} = \left(\frac{c_1}{r}, \frac{a_1}{r}, \frac{b_1}{r}, \frac{d_1}{r} \right). \quad (5)$$

Chou [31] proposed the canonical representation of a triangular fuzzy number $Y = (c, a, b)$:

$$P(Y) = \frac{1}{6} (c + 4a + b). \quad (6)$$

3.2. AHP Theory. Saaty [21] initially proposed the Analytic Hierarchy Process (AHP), which is a multiple-attribute decision-making tool for solving complex multiple-criteria decision-making problems. AHP methodology has some advantages. One of the most important advantages of the AHP is based on the pairwise comparison. Another is that

the AHP calculates the inconsistency index, which is the ratio of the decision maker's inconsistency on the criteria. The computational procedures for AHP are listed as follows.

Let us consider the criteria $C_1, \dots, C_i, \dots, C_j, \dots, C_n$, someone level in the hierarchy. One wishes to find their weights of importance, $W_1, \dots, W_i, \dots, W_j, \dots, W_n$, on some elements in the next level. Allow a_{ij} , $i, j = 1, 2, \dots, n$, to be the importance strength of C_i when compared with C_j . In generally we can represent the comparative importance scale of criteria as shown in Table 2. The matrix of these numbers a_{ij} is denoted by B :

$$B = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1j} & \cdots & a_{1n} \\ \vdots & \vdots & & \vdots & & \vdots \\ a_{i1} & a_{i2} & \cdots & a_{ij} & \cdots & a_{in} \\ \vdots & \vdots & & \vdots & & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nj} & \cdots & a_{nn} \end{bmatrix}_{n \times n}, \quad (7)$$

where $a_{ji} = 1/a_{ij}$; that is, B is reciprocal. If one's judgment is perfect in all comparisons, then $a_{ik} = a_{ij} \cdot a_{jk}$ for all i, j, k and one calls the matrix B consistent. An obvious case of a consistent matrix B is its elements

$$a_{ij} = \frac{w_i}{w_j}, \quad i, j = 1, 2, \dots, n. \quad (8)$$

Thus, when the matrix B is multiplied by the vector formed by each weighting $w = (w_1, w_2, \dots, w_n)^T$, one gets

$$Bw = \begin{bmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_j} & \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \cdots & \frac{w_2}{w_j} & \cdots & \frac{w_2}{w_n} \\ \vdots & \vdots & & \vdots & & \vdots \\ \frac{w_i}{w_1} & \frac{w_i}{w_2} & \cdots & \frac{w_i}{w_j} & \cdots & \frac{w_i}{w_n} \\ \vdots & \vdots & & \vdots & & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots & \frac{w_n}{w_j} & \cdots & \frac{w_n}{w_n} \end{bmatrix}_{n \times n} \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_j \\ \vdots \\ w_n \end{bmatrix}_{n \times 1} \quad (9)$$

$$= n \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_j \\ \vdots \\ w_n \end{bmatrix} = nw.$$

Because a_{ij} is the subjective ratings given by the decision maker, there must be a distance between it and the actual values w_i/w_j . Thus, $Bw = nw$ cannot be calculated directly. Therefore Saaty suggested using the maximum eigenvalue, $\lambda_{\max} = (1/n)(w'_1/w_1 + w'_2/w_2 + \cdots + w'_n/w_n)$, of the solution of matrix B to replace n ; then

$$Bw = \lambda_{\max} w. \quad (10)$$

By this method, one can obtain the characteristic vector, referred to as the priority vector. Besides Saaty suggested the consistency index ($C.I = (\lambda_{\max} - n)/(n - 1)$) and the consistency rate ($C.R = C.I/R.I$) to test the consistency of the intuitive judgment. In general, it is satisfactory and accepted if the value of $C.I$ is about 0.1 and the value of $C.R$ is less than 0.1.

3.3. Proposed Hybrid Fuzzy AHP Approach. The proposed hybrid fuzzy AHP approach to solving both quantitative data and qualitative ratings simultaneously in process of the location selection is introduced in this section. The proposed hybrid fuzzy AHP approach involves 11 steps shown as follows.

Step 1. Construct a hierarchical analysis structure in Table 3. These criteria in the hierarchical analysis structure can be divided into two categories: objective and subjective criteria. The objective criteria are defined in monetary or quantitative terms. The subjective criteria are defined in linguistic terms represented by fuzzy numbers.

Step 2. Introduce linguistic variables for importance weight of criteria. Terms of linguistic variables for importance weight of criteria could be called "equally important," "weakly important," "strongly important," "demonstrably important," "absolutely important," and so forth. These linguistic variables can be expressed in fuzzy numbers such as "equally important" = (1, 1, 1), "weakly important" = (2, 3, 4), "strongly important" = (4, 5, 6), "demonstrably important" = (6, 7, 8), and "absolutely important" = (9, 9, 9). Their reciprocals are considered as "weakly unimportant" = (1/4, 1/3, 1/2), "strongly unimportant" = (1/6, 1/5, 1/4), "demonstrably unimportant" = (1/8, 1/7, 1/6), and "absolutely unimportant" = (1/9, 1/9, 1/9).

Step 3. Introduce linguistic variables for ratings of alternative locations. Terms of linguistic variables for ratings of alternative locations could be called "very poor," "poor," "fair," "good," "very good," and so forth. These linguistic variables can be expressed in fuzzy numbers such as "very poor" = (0.0, 1.0, 2.0), "poor" = (1.0, 2.0, 3.0), "fair" = (2.0, 3.0, 4.0), "good" = (3.0, 4.0, 5.0), "very good" = (5.0, 5.0, 5.0), and so forth.

Step 4. Determine the importance weights of criteria by the decision maker. Assume there are N candidate locations ($A_1, A_2, A_n, \dots, A_N$), I evaluation criteria ($C_1, C_2, C_i, \dots, C_I$), and J subcriteria ($C_{i1}, C_{i2}, C_{ij}, \dots, C_{ij}$) under criteria i , where $1 \leq n \leq N$, $1 \leq i \leq I$, $1 \leq j \leq J$. $\tilde{W}_i = (c_i, a_i, b_i)$ and $\tilde{W}_{ij} = (c_{ij}, a_{ij}, b_{ij})$ are the fuzzy importance weights given by the decision maker to criteria C_i and subcriteria C_{ij} , respectively.

Step 5. Defuzzify the weights of criteria and subcriteria. Then calculate the normalized weights. According to (6) proposed by Chou [31], we can obtain the representation of fuzzy numbers $\tilde{W}_i$ and $\tilde{W}_{ij}$ as follows:

$$P(\tilde{W}_i) = \frac{1}{6} (c_i + 4a_i + b_i),$$

TABLE 2: Comparative importance scale of criteria.

Scale	Definition	Description
(1, 1, 1)	Equally important, EI	The importance of both comparative alternatives is equal
(1, 2, 3)	Intermediate values, IV	Need to compromise between EI and WI
(2, 3, 4)	Weakly important, WI	Experience and judgment weakly tend to prefer one alternative
(3, 4, 5)	Intermediate values, IV	Need to compromise between WI and SI
(4, 5, 6)	Strongly important, SI	Experience and judgment strongly tend to prefer one alternative
(5, 6, 7)	Intermediate values, IV	Need to compromise between SI and DI
(6, 7, 8)	Demonstrably important, DI	Experience and judgment demonstrably tend to prefer one alternative
(7, 8, 9)	Intermediate values, IV	Need to compromise between DI and AI
(9, 9, 9)	Absolutely important, AI	Experience and judgment absolutely tend to prefer one alternative

TABLE 3: A hierarchical analysis structure.

Criteria and subcriteria	Weight	Rating
Geographical condition (C_1)	0.1527	
Closeness to the import/export area (C_{11})	0.3333	(5.0, 5.0, 5.0)
Proximity of the feeder port (C_{12})	0.1111	(4.2, 4.2, 4.2)
Closeness to main navigation route (C_{13})	0.1111	(5.0, 5.0, 5.0)
Frequency of ship calls (C_{14})	0.1111	(4.6, 4.8, 5.0)
Delivery time (C_{15})	0.3333	(3.0, 4.0, 5.0)
Cost (C_2)	0.4394	
Transportation cost (C_{21})	0.3543	(2.0, 3.0, 4.0)
Operation cost (C_{22})	0.1921	(2.0, 3.0, 4.0)
Land cost (C_{23})	0.1921	(2.0, 3.0, 4.0)
Labor cost (C_{24})	0.1921	(2.0, 3.0, 4.0)
Port charge (C_{25})	0.0694	(1.0, 1.0, 1.0)
Economy (C_3)	0.0824	
Volume of import cargoes (C_{31})	0.2607	(4.4, 4.6, 4.6)
Volume of export cargoes (C_{32})	0.1720	(4.2, 4.4, 4.6)
Volume of transshipment cargoes (C_{33})	0.1976	(4.9, 4.9, 5.0)
Economic growth (C_{34})	0.1720	(5.0, 5.0, 5.0)
Trade variables (C_{35})	0.1976	(3.0, 4.0, 5.0)
Government (C_4)	0.0757	
Private ownership of enterprise (C_{41})	0.1131	(5.0, 5.0, 5.0)
Efficiency of customs (C_{42})	0.3055	(5.0, 5.0, 5.0)
Efficiency of government department (C_{43})	0.2453	(5.0, 5.0, 5.0)
Type of cooperation of enterprise and government (C_{44})	0.1226	(3.0, 4.0, 5.0)
Political stability (C_{45})	0.2135	(3.0, 4.0, 5.0)
Investment conditions (C_5)	0.0785	
Tax break and preferential treatment (C_{51})	0.2500	(2.0, 3.0, 4.0)
Law on investment restrictions (C_{52})	0.2500	(5.0, 5.0, 5.0)
Social stability (C_{53})	0.1250	(3.0, 4.0, 5.0)
Land availability and expansion possibility (C_{54})	0.2500	(0.0, 1.0, 2.0)
Labor quality (C_{55})	0.1250	(5.0, 5.0, 5.0)
Infrastructure and efficiency (C_6)	0.1714	
Port facilities (C_{61})	0.1057	(5.0, 5.0, 5.0)
Loading and discharging facilities (C_{62})	0.2164	(4.9, 4.9, 5.0)
Intermodal link (C_{63})	0.3096	(3.0, 4.0, 5.0)
Cargo handling efficiency (C_{64})	0.2043	(4.7, 4.9, 5.0)
Computer information system (C_{65})	0.1640	(3.0, 4.0, 5.0)

$$P(\bar{W}_{ij}) = \frac{1}{6} (c_{ij} + 4a_{ij} + b_{ij}). \quad (11)$$

The normalized weights of criteria C_i and subcriteria C_{ij} are given by

$$W_i = \frac{P(\bar{W}_i)}{\sum_{i=1}^I P(\bar{W}_i)}, \quad (12)$$

$$W_{ij} = \frac{P(\bar{W}_{ij})}{\sum_{j=1}^J P(\bar{W}_{ij})},$$

where $\sum_{i=1}^I W_i = 1$, $\sum_{j=1}^J W_{ij} = 1$.

The weight vector is therefore formed as follows:

$$W = [W_1 \times W_{11}, W_1 \times W_{12}, \dots, W_1 \times W_{1j}, \dots, W_i \times W_{i1},$$

$$W_i \times W_{i2}, \dots, W_i \times W_{ij}, \dots, W_I \times W_{I1},$$

$$W_I \times W_{I2}, \dots, W_I \times W_{IJ}]$$

$$= [W_{111}, W_{112}, \dots, W_{11j}, \dots, W_{ii1}, W_{ii2}, \dots, W_{ijj}, \dots,$$

$$W_{Ii1}, W_{Ii2}, \dots, W_{Iij}]. \quad (13)$$

Step 6. Calculate the maximum eigenvalue ($\lambda_{\max}$), the consistency index (C.I), and the consistency rate (C.R) for AHP model to test the consistency of the intuitive judgment.

Step 7. The decision maker assesses alternatives under subjective criteria. Let $\bar{R}_{ijn} = (c_{ijn}, a_{ijn}, b_{ijn})$ be the fuzzy ratings given by the decision maker to alternative A_n under subjective subcriteria C_{ij} .

Step 8. Assess alternatives under objective criteria. Let $\bar{R}_{ijn}^o = (c_{ijn}^o, a_{ijn}^o, b_{ijn}^o)$ be the fuzzy quantity given to alternative A_n under objective sub-criteria C_{ij} . The objective criteria are determined in various units and must be transformed into dimensionless indices (or ratings) to ensure compatibility with the linguistic ratings of subjective criteria. The alternative with the minimum cost (or maximum benefit) should have the highest rating. By (14) and (15), we can transform fuzzy quantities for objective subcriteria into fuzzy ratings:

$$\bar{R}_{ijn} = \left\{ \frac{\bar{R}_{ijn}^o}{\max_i \{b_{ijn}^o\}} \right\} \times 5, \quad (14)$$

where $\max_i \{b_{ijn}^o\} > 0$ and $\bar{R}_{ijn}$ denotes the transformed fuzzy rating of objective fuzzy benefit $\bar{R}_{ijn}^o$. $\bar{R}_{ijn}$ becomes larger when objective fuzzy benefit $\bar{R}_{ijn}^o$ is larger:

$$\bar{R}_{ijn} = \left\{ \frac{\min_i \{c_{ijn}^o\}}{\bar{R}_{ijn}^o} \right\} \times 5, \quad (15)$$

where $\min_i \{c_{ijn}^o\} > 0$ and $\bar{R}_{ijn}$ denotes the transformed fuzzy rating of objective fuzzy cost $\bar{R}_{ijn}^o$. $\bar{R}_{ijn}$ becomes smaller when objective fuzzy cost $\bar{R}_{ijn}^o$ is larger.

Step 9. Construct a fuzzy rating matrix based on fuzzy ratings. The fuzzy rating matrix M can be concisely expressed in matrix format:

$$M = \begin{bmatrix} \bar{R}_{111} & \bar{R}_{121} & \cdots & \bar{R}_{IJ1} \\ \bar{R}_{112} & \bar{R}_{122} & \cdots & \bar{R}_{IJ2} \\ \vdots & \vdots & \cdots & \vdots \\ \bar{R}_{11N} & \bar{R}_{12N} & \cdots & \bar{R}_{IJN} \end{bmatrix}. \quad (16)$$

Step 10. Obtain the total fuzzy rating ($\bar{R}$) based on the fuzzy rating matrix (M) and weight vector (W):

$$\bar{R} = \begin{bmatrix} \bar{R}_{111} & \bar{R}_{121} & \cdots & \bar{R}_{IJ1} \\ \bar{R}_{112} & \bar{R}_{122} & \cdots & \bar{R}_{IJ2} \\ \vdots & \vdots & \cdots & \vdots \\ \bar{R}_{11N} & \bar{R}_{12N} & \cdots & \bar{R}_{IJN} \end{bmatrix} \otimes \begin{bmatrix} W_{111} \\ W_{112} \\ \vdots \\ W_{IJN} \end{bmatrix} = \begin{bmatrix} \bar{R}_1 \\ \bar{R}_2 \\ \vdots \\ \bar{R}_N \end{bmatrix}. \quad (17)$$

Step 11. Defuzzify the total fuzzy rating by (6) and then rank alternatives according to their total crisp ratings. Finally, we can select easily the best alternative with the maximum total crisp ratings:

$$P(\bar{R}_n) = \frac{1}{6} (c_n + 4a_n + b_n). \quad (18)$$

4. A Case Study

In this section, the proposed hybrid fuzzy AHP approach is applied to the location choice of international distribution centers in the global logistics of the multinational corporation. A Taiwanese multinational corporation plans to select an appropriate location of international distribution center at the international transshipment port. After initial screening, three alternative port locations including the port A_1 , the port A_2 , and the port A_3 are selected for further evaluation. The procedures for evaluation are shown as follows.

Step 1. Constructing a hierarchical analysis structure is shown in Table 3. There are 6 criteria and 30 subcriteria in the hierarchical analysis structure summarized by Chou [19]. These criteria in the hierarchical analysis structure can be divided into two categories: objective and subjective criteria. The objective criteria include proximity of the feeder port (C_{12}), frequency of ship calls (C_{14}), port charge (C_{25}), volumes of import containers (C_{31}), volumes of export containers (C_{32}), volumes of transshipment containers (C_{33}),

TABLE 4: Survey data for fuzzy comparative weights for each criterion.

Criteria	(9,9,9) AI	(7,8,9) IV	(6,7,8) DI	(5,6,7) IV	(4,5,6) SI	(3,4,5) IV	(2,3,4) WI	(1,2,3) IV	(1,1,1) EI	(1/3,1/2,1) IV	(1/4,1/3,1/2) WUI	(1/5,1/4,1/3) IV	(1/6,1/5,1/4) SUI	(1/7,1/6,1/5) IV	(1/8,1/7,1/6) DUI	(1/9,1/8,1/7) IV	(1/9,1/9,1/9) AUI	Criteria
C ₁ : geographical												X						C ₂ : cost
C ₁ : geographical							X											C ₃ : economy
C ₁ : geographical							X	X										C ₄ : government
C ₁ : geographical										X								C ₅ : investment
C ₁ : geographical																		C ₆ : infrastructure and efficiency
C ₂ : cost						X												C ₃ : economy
C ₂ : cost				X		X												C ₄ : government
C ₂ : cost				X		X												C ₅ : investment
C ₃ : economy								X										C ₆ : infrastructure and efficiency
C ₃ : economy									X									C ₄ : government
C ₄ : government											X							C ₅ : investment
C ₄ : government									X									C ₆ : infrastructure and efficiency
C ₅ : investment									X									C ₆ : infrastructure and efficiency

TABLE 5: Survey data for fuzzy comparative weights for each subcriteria.

Subcriteria	(9,9,9) AI	(7,8,9) IV	(6,7,8) DI	(5,6,7) IV	(4,5,6) SI	(3,4,5) IV	(2,3,4) WI	(1,2,3) IV	(1,1,1) EI	(1/3,1/2,1) IV	(1/4,1/3,1/2) WUI	(1/5,1/4,1/3) IV	(1/6,1/5,1/4) SUI	(1/7,1/6,1/5) IV	(1/8,1/7,1/6) DUI	(1/9,1/8,1/7) IV	(1/9,1/9,1/9) AUI	Subcriteria
C ₁₁ : imp/exp. area							X											C ₁₂ : feeder port
C ₁₁ : imp/exp. area							X											C ₁₃ : main route
C ₁₁ : imp/exp. area							X											C ₁₄ : frequency
C ₁₂ : feeder port									X									C ₁₅ : delivery
C ₁₂ : feeder port									X									C ₁₃ : main route
C ₁₃ : main route									X									C ₁₄ : frequency
C ₁₃ : main route									X									C ₁₅ : delivery
C ₁₄ : frequency																		C ₁₄ : frequency
C ₁₄ : frequency																		C ₁₅ : delivery
C ₂₁ : transport cost								X										C ₂₂ : operation cost
C ₂₁ : transport cost								X										C ₂₃ : land cost
C ₂₁ : transport cost								X										C ₂₄ : labor cost
C ₂₁ : transport cost																		C ₂₅ : port charge
C ₂₂ : operation cost						X												C ₂₃ : land cost
C ₂₂ : operation cost									X									C ₂₄ : labor cost
C ₂₂ : operation cost							X		X									C ₂₅ : port charge
C ₂₂ : operation cost									X									C ₂₅ : port charge
C ₂₃ : land cost							X		X									C ₃₂ : vol. of export
C ₂₃ : land cost							X											C ₃₃ : vol. of tranship
C ₂₄ : labor cost																		C ₃₄ : economy
C ₃₁ : vol. of import								X										C ₃₅ : trade variable
C ₃₁ : vol. of import								X										C ₃₃ : vol. of tranship
C ₃₁ : vol. of import									X									C ₃₄ : economy
C ₃₂ : vol. of export									X									C ₃₅ : trade variable
C ₃₂ : vol. of export								X										C ₃₄ : economy
C ₃₃ : vol. of tranship									X									C ₃₅ : trade variable
C ₃₃ : vol. of tranship										X								C ₄₂ : customs
C ₃₄ : economy																		C ₄₃ : government
C ₄₁ : private																		C ₄₄ : cooperation
C ₄₁ : private									X									C ₄₅ : political
C ₄₁ : private									X									C ₄₃ : government
C ₄₂ : customs										X								C ₄₄ : cooperation
C ₄₂ : customs									X									C ₄₅ : political
C ₄₂ : customs																		C ₄₅ : political
C ₄₃ : government								X										C ₅₂ : law
C ₄₃ : government								X										C ₅₃ : social stability
C ₄₄ : cooperation								X										C ₅₄ : expansion
C ₅₁ : tax break									X									C ₅₅ : labor quality
C ₅₁ : tax break																		C ₅₃ : social stability
C ₅₁ : tax break																		C ₅₄ : expansion
C ₅₂ : law																		C ₅₅ : labor quality
C ₅₂ : law																		C ₅₅ : labor quality
C ₅₃ : social stability																		C ₅₅ : labor quality
C ₅₃ : social stability																		C ₅₅ : labor quality
C ₅₄ : expansion																		C ₅₅ : labor quality

TABLE 5: Continued.

Subcriteria	(9,9,9) AI	(7,8,9) IV	(6,7,8) DI	(5,6,7) IV	(4,5,6) SI	(3,4,5) IV	(2,3,4) WI	(1,2,3) IV	(1,1,1) EI	(1/3,1/2,1) IV	(1/4,1/3,1/2) WUI	(1/5,1/4,1/3) IV	(1/6,1/5,1/4) SUI	(1/7,1/6,1/5) IV	(1/8,1/7,1/6) DUI	(1/9,1/8,1/7) IV	(1/9,1/9,1/9) AUI	Subcriteria
C ₆₁ : port facilities										X								C ₆₂ : load/discharge
C ₆₁ : port facilities											X							C ₆₃ : modal link
C ₆₁ : port facilities									X		X							C ₆₄ : cargo handle
C ₆₁ : port facilities									X									C ₆₅ : information
C ₆₂ : load/discharge									X									C ₆₃ : modal link
C ₆₂ : load/discharge									X									C ₆₄ : cargo handle
C ₆₂ : load/discharge									X									C ₆₅ : information
C ₆₃ : modal link																		C ₆₄ : cargo handle
C ₆₃ : modal link																		C ₆₅ : information
C ₆₄ : cargo handle									X									C ₆₅ : information

TABLE 6: Fuzzy ratings for alternatives under objective criteria.

	Objective criteria	Fuzzy quantity	Fuzzy rating
C ₁₂	Proximity of the feeder port (nautical mile)		
A ₁		(6356, 6356, 6356)	(4.2, 4.2, 4.2)
A ₂		(5401, 5401, 5401)	(5.0, 5.0, 5.0)
A ₃		(7288, 7288, 7288)	(3.7, 3.7, 3.7)
C ₁₄	Frequency of ship calls (vessel/week)		
A ₁		(415, 435, 455)	(4.6, 4.8, 5.0)
A ₂		(167, 177, 187)	(1.8, 1.9, 2.1)
A ₃		(186, 206, 226)	(2.1, 2.3, 2.5)
C ₂₅	Port charge (\$US/TEU)		
A ₁		(328, 338, 348)	(1.0, 1.0, 1.0)
A ₂		(100, 110, 120)	(2.7, 3.0, 3.3)
A ₃		(65, 70, 75)	(4.3, 4.6, 5.0)
C ₃₁	Volumes of import containers (TEU)		
A ₁		(11599000, 12041000, 12064000)	(4.4, 4.6, 4.6)
A ₂		(1887381, 1906255, 1925318)	(0.7, 0.7, 0.7)
A ₃		(9042000, 10860000, 13075000)	(3.5, 4.2, 5.0)
C ₃₂	Volumes of export containers (TEU)		
A ₁		(11002000, 11475000, 11958000)	(4.2, 4.4, 4.6)
A ₂		(2116017, 2158338, 2201505)	(0.8, 0.8, 0.8)
A ₃		(9042000, 10860000, 13075000)	(3.5, 4.2, 5.0)
C ₃₃	Volume of transshipment containers (TEU)		
A ₁		(10000000, 10150000, 10300000)	(4.9, 4.9, 5.0)
A ₂		(5406461, 5647846, 5710712)	(2.6, 2.7, 2.8)
A ₃		(300000, 400000, 5000000)	(0.1, 0.2, 0.2)
C ₆₁	Port facilities (length of wharf, m)		
A ₁		(8530, 8530, 8530)	(5.0, 5.0, 5.0)
A ₂		(7453, 7453, 7453)	(4.4, 4.4, 4.4)
A ₃		(8387, 8387, 8387)	(4.9, 4.9, 4.9)
C ₆₂	Loading and discharging facilities (crane)		
A ₁		(83, 84, 85)	(4.9, 4.9, 5.0)
A ₂		(66, 67, 68)	(3.9, 3.9, 4.0)
A ₃		(81, 82, 83)	(4.8, 4.8, 4.9)
C ₆₄	Cargo handling efficiency (move/h)		
A ₁		(33, 34, 35)	(4.7, 4.9, 5.0)
A ₂		(31, 32, 33)	(4.4, 4.6, 4.7)
A ₃		(29, 30, 31)	(4.1, 4.3, 4.4)

Source: Hong Kong Maritime Industry Council website, <http://www.mic.gov.hk/>.

Port of Kaohsiung website, <http://www.khb.gov.tw/>.

Port of Shanghai website, <http://www.portshanghai.com.cn/>.

Containerization International Yearbook.

The Institute of Transportation, Ministry of Transportation and Communications, Taiwan.

port facilities (C₆₁), loading and unloading facilities (C₆₂), and cargo handling efficiency (C₆₄). The others are subjective criteria. The objective criteria are defined in quantitative terms (e.g., nautical mile, \$US, TEU). The subjective criteria are defined in linguistic terms represented by fuzzy numbers.

Step 2. Present the linguistic variables and fuzzy numbers for comparative importance weights of criteria.

Step 3. Present the linguistic variables and fuzzy numbers for ratings of alternatives.

Step 4. Determine the fuzzy comparative importance weights of criteria and subcriteria by the decision maker in Tables 4 and 5, respectively.

Step 5. Defuzzify the fuzzy weights of criteria and subcriteria. Then calculate the normalized weights in Table 3.

Step 6. Calculate the maximum eigenvalue ($\lambda_{\max}$), the consistency index (C.I), and the consistency rate (C.R) for AHP model to test the consistency of the intuitive judgment:

$$Aw = \begin{bmatrix} 1 & \frac{1}{4} & 3 & 3 & 2 & \frac{1}{2} \\ 4 & 1 & 4 & 5 & 4 & 4 \\ \frac{1}{3} & \frac{1}{4} & 1 & 2 & 1 & \frac{1}{3} \\ \frac{1}{3} & \frac{1}{5} & \frac{1}{2} & 1 & 1 & 1 \\ \frac{1}{2} & \frac{1}{4} & 1 & 1 & 1 & \frac{1}{3} \\ 2 & \frac{1}{4} & 3 & 1 & 3 & 1 \end{bmatrix} \begin{bmatrix} 0.1527 \\ 0.4394 \\ 0.0824 \\ 0.0757 \\ 0.0785 \\ 0.1714 \end{bmatrix} = \begin{bmatrix} 0.9793 \\ 2.7574 \\ 0.5301 \\ 0.5055 \\ 0.4799 \\ 1.1449 \end{bmatrix}, \quad (19)$$

$$\lambda_{\max} = \frac{1}{6} \left(\frac{0.9793}{0.1527} + \frac{2.7574}{0.4394} + \frac{0.5301}{0.0824} + \frac{0.5055}{0.0757} + \frac{0.4799}{0.0785} + \frac{1.1449}{0.1714} \right) = 6.4331,$$

$$C.I = \frac{\lambda_{\max} - n}{n - 1} = \frac{6.4331 - 6}{6 - 1} = 0.08,$$

$$C.R = \frac{C.I}{R.I} = \frac{0.08}{1.24} = 0.07.$$

Step 7. The decision maker assesses alternatives under subjective criteria. For example, the fuzzy ratings given by the decision maker to the port A_1 under subjective subcriteria are shown in Table 3.

Step 8. Assess alternatives under objective criteria. The fuzzy quantities given to alternative under objective subcriteria are listed in Table 6. The objective fuzzy quantities are determined in various units (e.g., nautical mile, \$US, TEU) and must be transformed into dimensionless indices (or ratings) to ensure compatibility with the linguistic ratings of subjective criteria. By (14) and (15), we can transform fuzzy quantities for objective subcriteria into fuzzy ratings in Table 6.

Step 9. Construct a fuzzy rating matrix based on fuzzy ratings.

Step 10. Obtain the total fuzzy ratings based on the fuzzy rating matrix and the weight vector.

Step 11. By (6), we can defuzzify the total fuzzy ratings and the total crisp ratings for the port A_1 , the port A_2 , and the port A_3 are 3.72, 3.88, and 4.41, respectively. Finally, the decision maker of Taiwanese multinational corporation selects easily the port A_3 with the maximum total crisp ratings as the best location for international distribution center in the global logistics system.

5. Conclusions

The paper proposes a new hybrid fuzzy AHP model for dealing with both objective and subjective criteria in process of decision making simultaneously. The proposed hybrid fuzzy AHP model is applied to solve the location choice problem of international distribution center in the global logistics of multinational corporation. The results show that the proposed new hybrid fuzzy AHP model is an appropriate and more efficient approach to deal with both objective and subjective criteria in process of decision making simultaneously. The hybrid fuzzy AHP model in this paper overcomes the disadvantages of quantitative or qualitative approaches in the previous literature. The proposed hybrid fuzzy AHP approach can not only solve the problems of location choice, but also many other decision-making problems.

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