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Full Length Research Paper

Hub location selection of third-party logistics service on multiple countries consolidations for ocean freight forwarders by using fuzzy multiple criteria decision-making (MCDM) approach

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Since a good location will effectively help expand agglomeration economy effects and increase competitive advantages, there is a need to proceed with a study on effects from various perspectives and evaluate proper location objectively. Hence, the main purpose of this paper is to use a fuzzy multiple criteria decision-making (MCDM) approach to select a hub location of third-party logistics service on multiple countries consolidations for ocean freight forwarders. At first, some concepts and methods used to develop a fuzzy MCDM algorithm are briefly introduced. Secondly, a step-by-step fuzzy MCDM algorithm is proposed. Finally, a numerical example with a hierarchy structure of seven criteria, forty-two sub-criteria, and three alternatives is illustrated by using the proposed fuzzy MCDM approach. Furthermore, this paper with its methods can be employed as a practical tool for business application, as well as the market players can modify this algorithm to evaluate hub location selection in the future. The proposed model not only releases the limitation of crisp values, but also facilitates its implementation as a computer-based decision support system in a fuzzy environment.

Key words: Hub location selection, multiple countries consolidation, third-party logistics service provider, fuzzy multiple criteria decision-making (MCDM).

INTRODUCTION

With incessant technological progress and rapid change in economic environment, the situation that today's enterprises faced is more complicated and extensive than before. Besides, competitors and market segmentation of foreign trade based countries turn globalized, which has caused lead time compression and a need to speed up understanding of customer and response to requests. Facing the coming e-commerce era, a severe change in consumer behavior is then caused with multiple factors to interplay in a global market with acute competition. The enterprises have to instantaneously respond to customer needs to ensure repeat purchase of existing customers and consumption of new customers. In order to react to the need of such time effectiveness, a concept of 'outsourcing' accepted by enterprises has become a trend, in which enterprises expect to reduce cost and increase efficiency via this, and as a result, logistics service that features time effectiveness and convenience has then risen accordingly.

As far as both buyers and sellers are concerned, a professional logistics company plays a role of third party, which is different from first the consignor and the second

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party consignee. It mainly provides outsourcing services (commonly seen in transportation and warehousing in particular). Therefore, these professional logistics companies are normally called third-party logistics service providers (hereinafter called the 3PL) (Su, 2007). Many professional logistics companies in early times only pay attention to various logistics services and yet emphasize on long-term, mutual beneficial partnership. However, the 3PL provides more customized services including many diverse service functions; reporting a long-term relationship of mutual benefits more (Murphy and Poist, 2000).

Members of container shipping communities (Martin and Thomas, 2001) include shipping line, terminal operator, feeder operator, ocean freight forwarder (hereinafter called the OFF), road hauler and rail operator, in which these groups interplay and interdepend with one another, and report a close interaction between various container shipping communities. Beside, a change in demand on various activities has led to a need to consider re-deployment and reallocation of resources of container logistics operation for container shipping communities. Therefore, the relationship in an age of container transport is a shipping line based community while other community members become 3PLs that support shipping line and cooperate with one another. Looking at container shipping communities, there are many market players involved, in which the OFF plays a role of logistics service provider who is considerably important to the entire ocean logistics chain, it also plays a role of fourth party logistics provider normally to provide total solution and acts as a coordinator to provide efficient supply chain management for consignors (Lin and Chang, 2009).Thus it can see that the OFF indeed plays an important role in international container logistics chain.

The OFF is in a position of guiding and providing consultation service, arranging and dealing with matters (Ding and Lu, 2007; Yang et al., 2010) during transportation process, with scope of business to cover general warehousing operation, cargo loading/discharge /consolidation as well as international cargo agency business etc., and reservation/arrangement with regard to container space, processing of customs clearance procedure of freight service in terms of freight forwarder operations. Besides, freight forwarders need to complete cargo delivery, customs clearance and storage activities, and even manage cargo for consignors who need to contact shipping companies, clients or customs brokers, and same line of business, arrange shipping date and cargo stuffing. Therefore, a strong support is needed for the OFFs to provide clients with diverse services including e-document processing; international cargo tracking services no matter internally or externally, that is, to achieve a goal of at consignors' service, the OFFs all expect to provide a better total delivery service.

There are branch offices opened in multiple ports and cities of one country for traditional OFFs, where the cargos of each branch office will be centralized in container yard of one local consolidation hub port through transshipment, to proceed with consolidation on cargos of the same destination port and deliver to the destination ports of other countries. However, in order to consolidate international transportation, local/abroad logistics distribution, warehousing management, logistics processing and other logistics services including services for multiple countries consolidations (hereinafter called MCCs) and multiple countries distributions (hereinafter called MCDs), the OFF has turned into a comprehensive international ocean logistics company (Ding and Tu, 2006), in which a large OFF has expanded its single-country consolidation of forwarding agent in various regions from one country to overseas markets, with branch offices by foreign investment established overseas or to cooperate with abroad agent. The OFF has turned into operation of multiple countries, a model of centralized consolidation operation in multiple countries is then developed.

The MCC development has become a trend for international OFF development. However, there are plenty of factors (Chou, 2010a, b, c; Kung, 2007; Lin, 2009) for the OFF to consider while deciding to develop more value-added services; including source of goods, backland, cost, operation efficiency, time, risk, supply chain relationship, quality, distribution, service standard, location choice and other related factors, in which location choice is the primitive decision for them to make. Due to the fact that a good location will effectively help expand agglomeration economy effects and increase competitive advantages of the OFFs, allowing the OFFs to swiftly ship products in an economical way under lower cost and to attain customer satisfaction. The OFFs will invest considerable sources for software/hardware facilities subsequently once the location is decided; in which its planning, design, construction and operation will be also time consuming. In order to satisfy the needs of the OFF and its customers, there is a need to proceed with a study on effects from various perspectives and evaluate proper location objectively.

In an environment facing acute competition, an OFF company takes many evaluation criteria into consideration while facing uncertainties environmentally. Due to the characteristics of multiple criteria decision-making (MCDM) during the evaluation process of hub location and a change in various criteria upon group decision environment, the importance weights between various criteria also reports characteristics of ambiguity and alteration. An OFF company expects to deal with ambiguity of criteria weights and to express inaccuracy of decision information transmission itself via a manner of traditional decision making. It seems that the decision makers (hereinafter called DMs) of the OFFs failed to express information that various evaluation options and various decision-making criteria implicitly contain. Furthermore, in order to moderately integrate the opinons of decision-making groups (or named committee) composed of related decision-making units and to seek for optimal option upon scoring and sorting for various alternatives accordingly. Therefore, the main purpose of this article applies the fuzzy set theory (Zadeh, 1965) that combined with MCDM method to establish an evaluation model of hub location for an OFF company to make selection on optimal option in an ambiguous environment.

RESEARCH METHODS

Here, some concepts and methods used to develop a fuzzy MCDM algorithm are introduced.

Fuzzy set theory

The fuzzy set theory (Zadeh, 1965) is designed to deal with the extraction of the primary possible outcome from a multiplicity of information that is expressed in vague and imprecise terms. Fuzzy set theory treats vague data as possibility distributions in terms of set memberships. Once determined and defined, the sets of memberships in possibility distributions can be effectively used in logical reasoning.

Trapezoidal fuzzy numbers

In a universe of discourse X, a fuzzy subset A of X is defined by a membership function $f_A(x)$, which maps each element x in X to a real number in the interval $[0, 1]$. The function value $f_A(x)$ represents the grade of membership of x in A. A fuzzy number A (Dubois and Prade, 1978) in real line $\Re$ is a trapezoidal fuzzy number if its membership function $f_A : \Re \rightarrow [0, 1]$ is

$$f_A(x) = \begin{cases} (x-c)/(a-c), & c \le x \le a \\ 1, & a \le x \le b \\ (x-d)/(b-d), & b \le x \le d \\ 0, & otherwise \end{cases} \quad (1)$$

with $-\infty < c \le a \le b \le d < \infty$. The trapezoidal fuzzy number can be denoted by (c, a, b, d).

The algebraic operations of fuzzy numbers

According to extension principle (Zadeh, 1965), let $A_1 = (c_1, a_1, b_1, d_1)$ and $A_2 = (c_2, a_2, b_2, d_2)$ be fuzzy numbers, the algebraic operations of any two fuzzy A_1 and A_2 can be expressed as

(1) Fuzzy addition, $\oplus$:

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

(2) Fuzzy subtraction, $\ominus$:

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

(3) Fuzzy multiplication, $\otimes$:

$$k \otimes A_2 = (kc_2, ka_2, kb_2, kd_2),\ k \in \Re,\ k \ge 0,$$

$$A_1 \otimes A_2 \cong (c_1c_2, a_1a_2, b_1b_2, d_1d_2),\ c_1 \ge 0,\ c_2 \ge 0,$$

(4) Fuzzy division, $\varnothing$:

$$(A_1)^{-1} = (c_1, a_1, b_1, d_1)^{-1} \cong (1/d_1, 1/b_1, 1/a_1, 1/c_1),\ c_1 > 0,$$

$$A_1 \varnothing A_2 \cong (c_1/d_2, a_1/b_2, b_1/a_2, d_1/c_2),\ c_1 \ge 0, \text{ and } c_2 > 0.$$

Linguistic values

In fuzzy decision environments, two preference ratings can be used. They are fuzzy numbers and linguistic values characterized by fuzzy numbers (Zadeh, 1975, 1976). Depending on practical needs, DMs may apply one or both of them.

In this paper, the weighting set and rating set are used to analytically express the linguistic value and describe how important and good of the involved criteria, sub-criteria and alternatives against various sub-criteria above the alternative level are. The weighting set is defined as $W = \{VL, L, M, H, VH\}$ and the rating set as $S = \{VP, P, F, G, VG\}$; where *VL* = very low, *L* = low, *M* = medium, *H* = high, *VH* = very high, *VP* = very poor, *P* = poor, *F* = fair, *G* = good, and *VG* = very good. Here, we define the linguistic values of *VL* = *VP* = (0, 0, 0.2, 0.3), *L* = *P* = (0.2, 0.3, 0.4, 0.5), *M* = *F* = (0.4, 0.5, 0.6, 0.7), *H* = *G* = (0.6, 0.7, 0.8, 0.9), and *VH* = *VG* = (0.8, 0.9, 1, 1), respectively. These trapezoidal fuzzy numbers can be referred to in Ghyym (1999).

Ranking fuzzy numbers with the maximizing and minimizing sets

In order to obtain a ranking method to implement easily and powerfully, a method is proposed and developed by the author with the combination of the methods proposed by Chen (1985), Kim and Park (1990) and Chang and Chen (1994).

Let A_i, $i = 1, 2, \ldots, n$, be fuzzy numbers with membership functions f_{A_i} respectively. Define the maximizing set $M = \{(x, f_M(x)) \mid x \in R\}$ with

$$f_M(x) = \begin{cases} (x - x_1)/(x_2 - x_1), & x \in [x_1, x_2], \\ 0, & otherwise \end{cases},$$

and the minimizing set $G = \{(x, f_G(x)) \mid x \in R\}$ with

$$f_G(x) = \begin{cases} (x - x_2)/(x_1 - x_2), & x \in [x_1, x_2], \\ 0, & otherwise \end{cases},$$

where $x_1 = \inf D$, $x_2 = \sup D$, $D = \bigcup_{i=1}^{n} D_i$ and $D_i = \{x \mid f_{A_i}(x) > 0\},\ i = 1, 2, \ldots, n.$

Define the optimistic ranking value (that is, the optimistic utility) $U_M(A_i)$ and the pessimistic ranking value (that is, the pessimistic utility) $U_G(A_i)$ of the fuzzy numbers A_i as

$$U_M(A_i) = \sup_x \left(f_{A_i}(x) \wedge f_M(x)\right) \quad (2)$$

and

$$U_G(A_i) = \sup_x \left(f_{A_i}(x) \wedge f_G(x) \right) \quad (3)$$

where $\wedge$ means the minimum operation and $i = 1, 2, \ldots, n.$

Then, define the ranking value $U_T(A_i)$ of fuzzy numbers A_i is defined as

$$U_T(A_i) = \alpha U_M(A_i) + (1-\alpha) U_G(A_i),\ 0 \le \alpha \le 1. \quad (4)$$

The value α can be referred to as the total risk attitude index of DMs. A larger α indicates a larger degree of optimism. If $\alpha > 0.5$, it implies that the total risk attitude of DMs is optimistic. When $\alpha = 1$, it shows the absolutely optimistic attitude. If $\alpha = 0.5$, the total risk attitude of DMs is neutral (moderate). When $\alpha < 0.5$, and $\alpha = 0$, they reflects the attitudes of DMs are pessimistic and absolutely pessimistic, respectively.

The value α can be determined by two procedures. First way is that DMs give the value α at the data output stage (Kim and Park, 1990), e.g., α = 0.3, 0.45, 0.85. However, it is difficult to apply this procedure directly in multiple DMs problem. Hence, Chang and Chen (1994) suggested a reasonable way to evaluate α through the evaluation data conveyed by the DMs at the data input stage. A comparison of measures for characterizing DM's attitudes toward risk has been proposed by Ghyym (1999). In this paper, the method developed by Chang and Chen (1994) is cited to find the total risk attitude index α.

Define the ranking of the trapezoidal fuzzy numbers A_i and A_j based on the following rules:

(1) $A_i > A_j \Leftrightarrow U_T(A_i) > U_T(A_j)$,

(2) $A_i < A_j \Leftrightarrow U_T(A_i) < U_T(A_j)$,

(3) $A_i = A_j \Leftrightarrow U_T(A_i) = U_T(A_j)$

Let $A_i = (c_i, a_i, b_i, d_i)$, $i = 1, 2, \ldots, n,$ be n trapezoidal fuzzy numbers. By using Equations (1) to (4), the ranking value $U_T(A_i)$ of the trapezoidal fuzzy number A_i can be obtained

$$U_T(A_i) = \alpha \left[\frac{d_i - x_1}{x_2 - x_1 - b_i + d_i} \right] + (1-\alpha) \left[1 - \frac{x_2 - c_i}{x_2 - x_1 + a_i - c_i} \right] \quad (5)$$

where $x_1 = \min\{c_1, c_2, \ldots, c_n\}$, $x_2 = \max\{d_1, d_2, \ldots, d_n\}$, and $0 \le \alpha \le 1.$

Then, based on the ranking rules described previously, the ranking of the n trapezoidal fuzzy numbers can be effectively determined.

THE FUZZY MCDM ALGORITHM

A stepwise description of the fuzzy MCDM algorithm for selecting hub location for OFFs is proposed in the following.

Step 1: Developing a hierarchical structure

A hierarchy structure is the framework of system structure. Figure 1 shows the complete hierarchical structure of selecting hub location with k criteria, $n_1 + \cdots + n_t + \cdots + n_k$ sub-criteria and m alternatives. As regards to the evaluation criteria and sub-criteria, the authors referred some literature, which are made known in academic and management publications (Chou, 2009; Chou et al., 2010a; b; c; Ding and Liang, 2003; Ding and Lu, 2007; Ding and Tu, 2006; Giunipero et al., 2005; Harison and Boonstra, 2009; Kung, 2007; Lee, 2007; Lee and Lin, 2008; Lee et al., 2009a; 2009b; Liao and Jeng, 2005; Lin, 2009; Lin and Chang, 2009; Murphy and Poist, 2000; Özgen and Tanyas, 2011; Su, 2007; Teng et al., 2007; Yang et al., 2010). Then, the criteria and sub-criteria are preliminarily discussed with scholars and some senior managers of OFFs by the authors. Finally, seven criteria and forty-two sub-criteria are suggested and their codes are shown in parentheses.

Basic requirements of location competitiveness (C_1)

This criterion includes seven sub-criteria, that is, cargo source and economic productivity (C_{11}), level of potential in location expansion (C_{12}), level of difficulty staff employment (C_{13}), level of freedom on financial environment (C_{14}), level of stability in financial environment (C_{15}), level of extension for strategic partner (C_{16}), and level of cargo agglomeration (C_{17}), respectively.

Port hardware (facility aspect) (C_2)

This criterion includes seven sub-criteria, that is, quay and berth sufficiency (C_{21}), number of routes and frequency density (C_{22}), port operation efficiency (C_{23}), degree of cargo damage rate (C_{24}), machinery loading/discharge sufficiency (C_{25}), degree of potential in harbor district development in the future (C_{26}), and sufficiency of terminal capacity (C_{27}), respectively.

Port software (management aspect) (C_3)

This criterion includes seven sub-criteria, that is, level of harbor freedom (C_{31}), port information integration ability (C_{32}), harbor administration efficiency (C_{33}), level of personnel's attitude in harbor district (C_{34}), handling ability in compensation (C_{35}), handling ability in particular and bulky cargos (C_{36}), and cargo tracking (C_{37}), respectively.

Fees collection and customs clearance (C_4)

This criterion includes seven sub-criteria, that is, level of

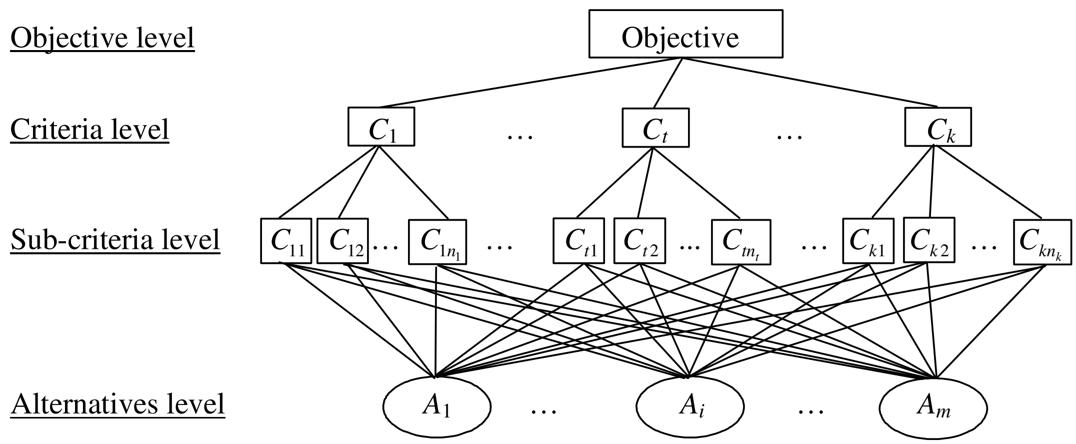

Figure 1. Hierarchy structure of selecting hub location.

use of harbor facility and service fee (C_{41}), level of vessel sailing cost (C_{42}), level of convenience in customs clearance/cargo collection (C_{43}), level of ocean freight price (C_{44}), level of warehousing operation fee (C_{45}), level of application fee and overhead (C_{46}), and random customs inspection ratio (C_{47}), respectively.

Level of inland transport service (C_5)

This criterion includes six sub-criteria, that is, level of convenience in access transportation of harbor district (C_{51}), distance between consolidation location and port (C_{52}), total distance between consolidation location and cargo source (C_{52}), fluency of transport network planning for the location (C_{54}), trailer delivery service efficiency (C_{55}), and inland transport costs for cargos (C_{56}), respectively.

Compliance of policy and rule (C_6)

This criterion includes five sub-criteria, that is, level of effects of national maritime development policy (C_{61}), level of effects of overall urban planning and development (C_{62}), level of expansion in external economic relations (C_{63}), level of integration in related laws (C_{64}), and overall national logistics standard (C_{65}), respectively.

Effects of location's social environment (C_7)

This criterion includes three sub-criteria, that is, opinions of local government and residents (C_{71}), effects on quality of local life (C_{72}), economic and cultural effects of local society (C_{73}), respectively.

Step 2: Calculating the fuzzy weights of all criteria and sub-criteria

The arithmetic mean method is used to obtain the average weights of all criteria and sub-criteria. The linguistic values of the weighting set are assisted in obtaining the fuzzy weights. Let $w_t^h = (c_t^h, a_t^h, b_t^h, d_t^h)$, $0 \le c_t^h \le a_t^h \le b_t^h \le d_t^h \le 1$, $t = 1, 2, \ldots, k$; $h = 1, 2, \ldots, n$, be the weight given to criterion C_t by the h^{th} DM on the criteria level. Then, the weight of C_t can be represented as $W_t = (c_t, a_t, b_t, d_t)$, where $c_t = \frac{1}{n}\sum_{h=1}^{n} c_t^h$, $a_t = \frac{1}{n}\sum_{h=1}^{n} a_t^h$, $b_t = \frac{1}{n}\sum_{h=1}^{n} b_t^h$, $d_t = \frac{1}{n}\sum_{h=1}^{n} d_t^h$.

Let $w_{tj}^h = (c_{tj}^h, a_{tj}^h, b_{tj}^h, d_{tj}^h)$, $0 \le c_{tj}^h \le a_{tj}^h \le b_{tj}^h \le d_{tj}^h \le 1$, $t = 1, 2, \ldots, k$; $j = 1, 2, \ldots, n_t$; $h = 1, 2, \ldots, n$, be the weight given to criterion C_{tj} by the expert or DM h on the sub-criteria level. Then, the weight of C_{tj} can be represented as $W_{tj} = (c_{tj}, a_{tj}, b_{tj}, d_{tj})$, where $c_{tj} = \frac{1}{n}\sum_{h=1}^{n} c_{tj}^h$, $a_{tj} = \frac{1}{n}\sum_{h=1}^{n} a_{tj}^h$, $b_{tj} = \frac{1}{n}\sum_{h=1}^{n} b_{tj}^h$, $d_{tj} = \frac{1}{n}\sum_{h=1}^{n} d_{tj}^h$.

Step 3: Estimating the fuzzy ratings of all alternatives versus all sub-criteria

The fuzzy ratings of alternatives versus all various sub-criteria can be obtained by using the arithmetic mean method. The linguistic values of the rating set are aided with obtaining the fuzzy appropriateness ratings. Let $s_{itj}^h = (c_{itj}^h, a_{itj}^h, b_{itj}^h, d_{itj}^h)$, $0 \le c_{itj}^h \le a_{itj}^h \le b_{itj}^h \le d_{itj}^h \le 1$, $i = 1, 2, \ldots, m$; $t = 1, 2, \ldots, k$; $j = 1, 2, \ldots, n_t$; $h = 1, 2, \ldots, n$, be the fuzzy appropriateness rating assigned to alternative A_i by the h^{th} DM for criterion C_{tj}. Then, the fuzzy appropriateness ratings of alternative

A_i can be represented as $S_{itj}=(c_{itj},a_{itj},b_{itj},d_{itj})$, where $c_{itj}=\frac{1}{n}\sum_{h=1}^{n}c_{itj}^{h}$, $a_{itj}=\frac{1}{n}\sum_{h=1}^{n}a_{itj}^{h}$, $b_{itj}=\frac{1}{n}\sum_{h=1}^{n}b_{itj}^{h}$, $d_{itj}=\frac{1}{n}\sum_{h=1}^{n}d_{itj}^{h}$.

Step 4: Aggregating evaluation ratings of all alternatives

Let $W_t=(c_t,a_t,b_t,d_t)$, $t=1,2,\ldots,k$, be the weight of the criterion C_t on the criteria level. Let $W_{tj}=(c_{tj},a_{tj},b_{tj},d_{tj})$, $t=1,2,\ldots,k$; $j=1,2,\ldots,n_t$, be the weight of the j^{th} sub-criterion C_{tj} under t^{th} criterion C_t. Let $S_{itj}=(c_{itj},a_{itj},b_{itj},d_{itj})$, $i=1,2,\ldots,m$; $t=1,2,\ldots,k$; $j=1,2,\ldots,n_t$, be the appropriateness rating of the alternative A_i under the sub-criteria C_{tj} of the sub-criteria level. The aggregation appropriateness rating of alternative A_i for the n_t sub-criteria under criterion C_t $(t=1,2,\ldots,k)$ can be denoted as

$$R_{it}=\frac{1}{n_t}\otimes\left[(S_{it1}\otimes W_{t1})\oplus(S_{it2}\otimes W_{t2})\oplus\cdots\oplus(S_{itj}\otimes W_{tj})\oplus\cdots\oplus(S_{itn_t}\otimes W_{tn_t})\right]$$
$$t=1,2,\ldots,k;\ i=1,2,\ldots,m. \quad (6)$$

Because $S_{itj}=(c_{itj},a_{itj},b_{itj},d_{itj})$ and $W_{tj}=(c_{tj},a_{tj},b_{tj},d_{tj})$, we can denote $R_{it}\cong(Y_{it},Q_{it},G_{it},Z_{it})$, where $Y_{it}=\sum_{j=1}^{n_t}c_{itj}\,c_{tj}/n_t$, $Q_{it}=\sum_{j=1}^{n_t}a_{itj}\,a_{tj}/n_t$, $G_{it}=\sum_{j=1}^{n_t}b_{itj}\,b_{tj}/n_t$, $Z_{it}=\sum_{j=1}^{n_t}d_{itj}\,d_{tj}/n_t$, $i=1,2,\ldots,m$; $t=1,2,\ldots,k$.

Furthermore, the final aggregation appropriateness rating of alternative A_i can be denoted as

$$F_i=\frac{1}{k}\otimes\left[(R_{i1}\otimes W_1)\oplus(R_{i2}\otimes W_2)\oplus\cdots\oplus(R_{it}\otimes W_t)\oplus\cdots\oplus(R_{ik}\otimes W_k)\right]$$
$$i=1,2,\ldots,m. \quad (7)$$

Since $W_t=(c_t,a_t,b_t,d_t)$, $t=1,2,\ldots,k$, we can denote $F_i\cong(Y_i,Q_i,G_i,Z_i)$, where $Y_i=\sum_{t=1}^{k}Y_{it}\,c_t/k$, $Q_i=\sum_{t=1}^{k}Q_{it}\,a_t/k$, $G_i=\sum_{t=1}^{k}G_{it}\,b_t/k$, $Z_i=\sum_{t=1}^{k}Z_{it}\,d_t/k$, $i=1,2,\ldots,m$.

Step 5: Selecting the optimal alternative

Using the ranking method mentioned previously, the ranking value $U_T(F_i)$ of the final aggregation appropriateness rating of alternative A_i can be obtained by

$$U_T(F_i)=\alpha\left[\frac{Z_i-x_1}{x_2-x_1-G_i+Z_i}\right]+(1-\alpha)\left[1-\frac{x_2-Y_i}{x_2-x_1+Q_i-Y_i}\right] \quad (8)$$

where $i=1,2,\ldots,m$, $x_1=\min\{Y_1,Y_2,\ldots,Y_m\}$ and $x_2=\max\{Z_1,Z_2,\ldots,Z_m\}$.

The value α can be evaluated by the data input stage procedure (Chang and Chen, 1994). For the fuzzy MCDM algorithm presented in this paper, the total risk attitude index α of all DMs can be obtained by

$$\alpha=\frac{\alpha_1+\alpha_2+\alpha_3}{k+\sum_{t=1}^{k}n_t+m\times\sum_{t=1}^{k}n_t} \quad (9)$$

where $\alpha_1=\sum_{t=1}^{k}\left(\frac{a_t-c_t}{(d_t-b_t)+(a_t-c_t)}\right)$,

$\alpha_2=\sum_{t=1}^{k}\sum_{j=1}^{n_t}\left(\frac{a_{tj}-c_{tj}}{(d_{tj}-b_{tj})+(a_{tj}-c_{tj})}\right)$, and

$\alpha_3=\sum_{i=1}^{m}\sum_{t=1}^{k}\sum_{j=1}^{n_t}\left(\frac{a_{itj}-c_{itj}}{(d_{itj}-b_{itj})+(a_{itj}-c_{itj})}\right)$.

Finally, by Equations (8) and (9), the final ranking values $U_T(F_i)$ of the m alternatives can be obtained. Based on the ranking rules, the committee can select the optimal alternative.

A NUMERICAL ILLUSTRATION

Here, a numerical example of selecting hub location for an OFF company is studied to demonstrate the computational process of the proposed fuzzy MCDM algorithm, step by step, as follows.

Step 1

Assume that an OFF company needs to select a hub location of third-party logistics service on multiple countries consolidations. Three locations, that is, *X*, *Y*, and *Z*, respectively, are chosen after preliminary screening for further evaluation. The company has formed a committee of three DMs, that is, *A*, *B*, and *C*, respectively, to evaluate the best choice among three candidates. Seven criteria and forty-two sub-criteria are suggested in the step 1 of the proposed fuzzy MCDM algorithm section.

Step 2

Three DMs use linguistic values of weighting set to evaluate the importance weights of all criteria and all sub-criteria. For example, three DMs evaluate the importance of C_1 with linguistic values are *M*, *H*, and *H*, respectively. Then, according to the step 2 of the proposed fuzzy MCDM algorithm, the importance weight of C_1 can be shown as (0.533, 0.633, 0.733 and 0.833). Using this way, the results of the importance weights of all criteria and sub-criteria can be summed up as shown in Table 1. Similarly, the fuzzy appropriateness ratings of three candidates versus all sub-criteria can be obtained by the step 3 of the proposed fuzzy MCDM algorithm; the results are shown in Table 2.

Step 3

By utilizing Equation (6), the aggregation appropriateness ratings of three candidates versus all sub-criteria can be obtained, the results are shown in Table 3. Then, the final aggregation appropriateness ratings of three alternatives can be obtained by utilizing Equation (7), the results are shown in Table 4.

Step 4

By using Equation (9), we can obtain the three DMs' total risk attitude index

$$\alpha = \frac{3.504 + 22.113 + 59.392}{7 + 42 + 3 \times 42} = 0.486 .$$

Then, by utilizing Equation (8), we can obtain

$$x_1 = \min\{0.051, 0.105, 0.026\} = 0.026,$$

$$x_2 = \max\{0.358, 0.503, 0.290\} = 0.503,$$

$$U_T(F_X) = 0.3483,$$

$$U_T(F_Y) = 0.5148,$$

$$U_T(F_Z) = 0.2549.$$

The order of final ranking value of fuzzy overall evaluation for three candidates is $U_T(F_Y) > U_T(F_X) > U_T(F_Z)$.

Based on the ranking rules mention in the research method section, it is obvious that the optimal hub location is *Y*. Therefore, the committee of the OFF company can recommend that hub location Y is the most suitable location of third-party logistics service on MCC for the company.

Conclusions

The OFF indeed plays an important role in international container logistics chain. A strong support is needed for the OFFs to provide clients with diverse services to provide a better total delivery service. However, in order to expand the MCC and MCD services, many large OFFs have turned into a comprehensive international ocean logistics company in various regions from one country to overseas markets. The MCC development has become a trend for international OFF development. However, there are plenty of factors for OFFs to consider while deciding to develop more value-added services, in which location choice is the primitive decision for them to make. It is because a good location will effectively help expand agglomeration economy effects and increase competitive advantages of the OFFs, allowing OFFs to swiftly ship products in an economical way under lower cost and to attain customer satisfaction. The OFFs will invest considerable sources for software/hardware facilities subsequently once the location is decided; in which its planning, design, construction and operation will be also time consuming. In order to satisfy the needs of OFF and its customers, there is a need to proceed with a study on effects from various perspectives and evaluate proper location objectively. The evaluation process of hub location selection problem involves a multiplicity of complex considerations and poses a MCDM situation. Moreover, some evaluation criteria are faced an ambiguous and uncertain nature. Hence, the evaluation of hub location selection is confronted with a fuzzy decision-making environment. In light of this, the aim of this paper is to develop a fuzzy MCDM model to evaluate hub location selection for OFFs.

To effectively evaluate hub location selection for OFFs, a systematically fuzzy MCDM model is proposed. At first, we develop a hierarchical structure of selecting hub location with seven criteria and forty-two sub-criteria for OFFs. Then, we use the arithmetic mean operations to develop the multiple DMs' opinions on the criteria/sub-criteria importance and ratings of alternatives, as well as incorporate the risk attitude index to convey the total risk attitude of all DMs by using the estimation data obtained at the data input stage. Thirdly, we calculate the final aggregation ratings and develop a ranking method based on the maximizing and minimizing sets for the proposed fuzzy MCDM method with multiple DMs. Finally, a step by step numerical example is illustrated to study the computational process of the fuzzy MCDM model. In addition, the proposed approach has successfully accomplished our goal.

Furthermore, this paper with its methodologies developed

Table 1. The fuzzy weights of all criteria and sub-criteria.

Criteria / sub-criteria	Fuzzy weight
C_1	(0.533, 0.633, 0.733, 0.833)
C_{11}	(0.467, 0.567, 0.667, 0.767)
C_{12}	(0.2, 0.267, 0.4, 0.5)
C_{13}	(0.4, 0.5, 0.6, 0.7)
C_{14}	(0.667, 0.767, 0.867, 0.933)
C_{15}	(0.067, 0.1, 0.267, 0.367)
C_{16}	(0.6, 0.7, 0.8, 0.867)
C_{17}	(0.533, 0.633, 0.733, 0.833)
C_2	(0.4, 0.5, 0.6, 0.7)
C_{21}	(0.667, 0.767, 0.867, 0.933)
C_{22}	(0.4, 0.5, 0.6, 0.7)
C_{23}	(0.4, 0.5, 0.6, 0.7)
C_{24}	(0.2, 0.267, 0.4, 0.5)
C_{25}	(0.267, 0.367, 0.467, 0.567)
C_{26}	(0.333, 0.4, 0.533, 0.633)
C_{27}	(0.533, 0.633, 0.733, 0.8)
C_3	(0.4, 0.5, 0.6, 0.7)
C_{31}	(0.2, 0.267, 0.4, 0.5)
C_{32}	(0.6, 0.7, 0.8, 0.867)
C_{33}	(0.2, 0.267, 0.4, 0.5)
C_{34}	(0.667, 0.767, 0.867, 0.933)
C_{35}	(0.6, 0.7, 0.8, 0.867)
C_{36}	(0.267, 0.367, 0.467, 0.567)
C_{37}	(0.4, 0.5, 0.6, 0.7)
C_4	(0.667, 0.767, 0.867, 0.933)
C_{41}	(0.667, 0.767, 0.867, 0.933)
C_{42}	(0.667, 0.767, 0.867, 0.933)
C_{43}	(0.667, 0.767, 0.867, 0.933)
C_{44}	(0.667, 0.767, 0.867, 0.933)
C_{45}	(0.4, 0.5, 0.6, 0.7)
C_{46}	(0.333, 0.4, 0.533, 0.633)
C_{47}	(0.2, 0.267, 0.4, 0.5)
C_5	(0.4, 0.5, 0.6, 0.7)
C_{51}	(0.4, 0.5, 0.6, 0.7)
C_{52}	(0.4, 0.5, 0.6, 0.7)
C_{53}	(0.467, 0.567, 0.667, 0.767)
C_{54}	(0.467, 0.567, 0.667, 0.767)
C_{55}	(0.4, 0.5, 0.6, 0.7)
C_{56}	(0.533, 0.633, 0.733, 0.833)
C_6	(0.4, 0.5, 0.6, 0.7)
C_{61}	(0.8, 0.9, 1, 1)
C_{62}	(0.4, 0.5, 0.6, 0.7)
C_{63}	(0.467, 0.567, 0.667, 0.767)
C_{64}	(0.6, 0.7, 0.8, 0.867)
C_{65}	(0.733, 0.833, 0.933, 0.967)
C_7	(0.2, 0.267, 0.4, 0.5)
C_{71}	(0.533, 0.633, 0.733, 0.833)
C_{72}	(0.467, 0.567, 0.667, 0.767)
C_{73}	(0.533, 0.633, 0.733, 0.8)

Table 2. The appropriateness ratings of three candidates versus all sub-criteria.

Sub-criteria	Fuzzy rating		
	X	***Y***	***Z***
C_{11}	(0.4, 0.6, 0.6, 0.8)	(0.6, 0.8, 0.8, 1)	(0.4, 0.6, 0.667, 0.8)
C_{12}	(0.3, 0.5, 0.567, 0.7)	(0.6, 0.8, 0.867, 1)	(0.1, 0.3, 0.3, 0.5)
C_{13}	(0.3, 0.5, 0.5, 0.7)	(0.6, 0.8, 0.867, 1)	(0.2, 0.333, 0.467, 0.6)
C_{14}	(0.2, 0.4, 0.4, 0.6)	(0.6, 0.8, 0.8, 1)	(0, 0.067, 0.2, 0.4)
C_{15}	(0.1, 0.233, 0.3, 0.5)	(0.6, 0.8, 0.933, 1)	(0.2, 0.333, 0.4, 0.6)
C_{16}	(0.5, 0.7, 0.767, 0.9)	(0.6, 0.8, 0.8, 1)	(0, 0.067, 0.2, 0.4)
C_{17}	(0.3, 0.5, 0.5, 0.7)	(0.6, 0.8, 0.867, 1)	(0.2, 0.4, 0.4, 0.6)
C_{21}	(0.3, 0.5, 0.567, 0.7)	(0.6, 0.8, 0.867, 1)	(0.1, 0.3, 0.3, 0.5)
C_{22}	(0.3, 0.5, 0.5, 0.7)	(0.6, 0.8, 0.867, 1)	(0.2, 0.4, 0.4, 0.6)
C_{23}	(0.1, 0.233, 0.3, 0.5)	(0.4, 0.533, 0.6, 0.8)	(0, 0.067, 0.2, 0.4)
C_{24}	(0.3, 0.5, 0.5, 0.7)	(0.6, 0.8, 0.867, 1)	(0, 0.133, 0.2, 0.4)
C_{25}	(0.3, 0.5, 0.5, 0.7)	(0.6, 0.8, 0.933, 1)	(0.2, 0.4, 0.467, 0.6)
C_{26}	(0.1, 0.233, 0.3, 0.5)	(0.6, 0.8, 0.867, 1)	(0, 0.067, 0.2, 0.4)
C_{27}	(0.2, 0.4, 0.4, 0.6)	(0.6, 0.8, 0.867, 1)	(0.3, 0.5, 0.5, 0.7)
C_{31}	(0.4, 0.6, 0.667, 0.8)	(0.6, 0.8, 0.867, 1)	(0, 0.067, 0.2, 0.4)
C_{32}	(0.2, 0.4, 0.4, 0.6)	(0.6, 0.8, 0.867, 1)	(0, 0.133, 0.2, 0.4)
C_{33}	(0.2, 0.333, 0.4, 0.6)	(0.6, 0.8, 0.867, 1)	(0, 0, 0.2, 0.4)
C_{34}	(0.2, 0.4, 0.4, 0.6)	(0.4, 0.533, 0.667, 0.8)	(0.2, 0.4, 0.4, 0.6)
C_{35}	(0.3, 0.5, 0.567, 0.7)	(0.6, 0.8, 0.867, 1)	(0, 0, 0.2, 0.4)
C_{36}	(0.3, 0.5, 0.5, 0.7)	(0.5, 0.7, 0.7, 0.9)	(0.1, 0.233, 0.3, 0.5)
C_{37}	(0.2, 0.333, 0.4, 0.6)	(0.6, 0.8, 0.8, 1)	(0.1, 0.233, 0.3, 0.5)
C_{41}	(0.2, 0.4, 0.4, 0.6)	(0.5, 0.7, 0.767, 0.9)	(0.3, 0.433, 0.5, 0.7)
C_{42}	(0.3, 0.5, 0.5, 0.7)	(0.5, 0.7, 0.7, 0.9)	(0.1, 0.3, 0.3, 0.5)
C_{43}	(0.1, 0.233, 0.3, 0.5)	(0.6, 0.8, 0.867, 1)	(0, 0.067, 0.2, 0.4)
C_{44}	(0.4, 0.6, 0.667, 0.8)	(0.5, 0.7, 0.7, 0.9)	(0.3, 0.5, 0.5, 0.7)
C_{45}	(0.1, 0.233, 0.3, 0.5)	(0.5, 0.7, 0.767, 0.9)	(0, 0.133, 0.2, 0.4)
C_{46}	(0.2, 0.4, 0.4, 0.6)	(0.3, 0.433, 0.5, 0.7)	(0.2, 0.333, 0.4, 0.6)
C_{47}	(0.3, 0.5, 0.5, 0.7)	(0.4, 0.6, 0.667, 0.8)	(0.4, 0.533, 0.667, 0.8)
C_{51}	(0.2, 0.4, 0.4, 0.6)	(0.5, 0.7, 0.767, 0.9)	(0.1, 0.233, 0.3, 0.5)
C_{52}	(0.2, 0.4, 0.4, 0.6)	(0.6, 0.8, 0.867, 1)	(0.1, 0.233, 0.3, 0.5)
C_{53}	(0.1, 0.233, 0.3, 0.5)	(0.3, 0.433, 0.567, 0.7)	(0.2, 0.4, 0.4, 0.6)
C_{54}	(0.3, 0.5, 0.5, 0.7)	(0.6, 0.8, 0.8, 1)	(0.1, 0.233, 0.3, 0.5)
C_{55}	(0.2, 0.4, 0.4, 0.6)	(0.5, 0.7, 0.7, 0.9)	(0, 0.133, 0.2, 0.4)
C_{56}	(0.3, 0.5, 0.567, 0.7)	(0.3, 0.433, 0.5, 0.7)	(0.3, 0.433, 0.5, 0.7)
C_{61}	(0.2, 0.333, 0.4, 0.6)	(0.5, 0.7, 0.7, 0.9)	(0, 0.133, 0.2, 0.4)
C_{62}	(0.2, 0.4, 0.4, 0.6)	(0.5, 0.7, 0.767, 0.9)	(0, 0.067, 0.2, 0.4)
C_{63}	(0.4, 0.6, 0.6, 0.8)	(0.5, 0.7, 0.767, 0.9)	(0.2, 0.4, 0.4, 0.6)
C_{64}	(0.1, 0.233, 0.3, 0.5)	(0.5, 0.7, 0.767, 0.9)	(0, 0, 0.2, 0.4)
C_{65}	(0.3, 0.5, 0.5, 0.7)	(0.6, 0.8, 0.867, 1)	(0, 0.133, 0.2, 0.4)
C_{71}	(0.4, 0.6, 0.667, 0.8)	(0.5, 0.7, 0.767, 0.9)	(0.2, 0.267, 0.467, 0.6)
C_{72}	(0.2, 0.333, 0.4, 0.6)	(0.5, 0.7, 0.767, 0.9)	(0.2, 0.333, 0.4, 0.6)
C_{73}	(0.3, 0.5, 0.5, 0.7)	(0.3, 0.433, 0.5, 0.7)	(0.3, 0.5, 0.5, 0.7)

can be employed as a practical tool for business application. The proposed model not only releases the limitation of crisp values, but also facilitates its implementation as a computer-based decision support system in a fuzzy environment. Besides, the proposed algorithm presented in this paper can also be applied to selection problems, such as partner selection, port selection, strategy selection, and many other selections of

Table 3. The aggregation ratings of three candidates versus all sub-criteria.

R_{X1}	(0.138, 0.266, 0.333, 0.509)	R_{Y1}	(0.252, 0.404, 0.517, 0.710)	R_{Z1}	(0.058, 0.139, 0.226, 0.389)
R_{X2}	(0.091, 0.202, 0.266, 0.434)	R_{Y2}	(0.229, 0.373, 0.502, 0.670)	R_{Z2}	(0.051, 0.141, 0.199, 0.360)
R_{X3}	(0.102, 0.219, 0.289, 0.458)	R_{Y3}	(0.229, 0.373, 0.495, 0.670)	R_{Z3}	(0.029, 0.089, 0.164, 0.327)
R_{X4}	(0.119, 0.249, 0.316, 0.501)	R_{Y4}	(0.254, 0.415, 0.518, 0.704)	R_{Z4}	(0.088, 0.191, 0.272, 0.458)
R_{X5}	(0.098, 0.222, 0.278, 0.461)	R_{Y5}	(0.203, 0.346, 0.446, 0.641)	R_{Z5}	(0.063, 0.155, 0.219, 0.401)
R_{X6}	(0.141, 0.284, 0.349, 0.549)	R_{Y6}	(0.315, 0.507, 0.619, 0.794)	R_{Z6}	(0.019, 0.098, 0.187, 0.375)
R_{X7}	(0.156, 0.295, 0.374, 0.562)	R_{Y7}	(0.220, 0.371, 0.480, 0.667)	R_{Z7}	(0.120, 0.225, 0.325, 0.507)

Table 4. The final aggregation appropriateness ratings of three alternatives.

F_X	(0.051, 0.129, 0.197, 0.358)
F_Y	(0.105, 0.210, 0.322, 0.503)
F_Z	(0.026, 0.077, 0.142, 0.290)

management decision problems.

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