A QUANTITATIVE AND QUALITATIVE MULTI-CRITERIA EVALUATING APPROACH TO IDENTIFY PRIORITY FOR LOCATION DEVELOPING MULTIMODAL LOGISTIC MODES

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A QUANTITATIVE AND QUALITATIVE MULTI-CRITERIA EVALUATING APPROACH TO IDENTIFY PRIORITY FOR LOCATION DEVELOPING MULTIMODAL LOGISTIC MODES

Kuo-Liang Lee

Key words: sea-air logistic mode (M-LM), location selection, fuzzy MCQA approach.

ABSTRACT

The main purpose of this paper is to empirically study the selection for developing multimodal logistic mode (M-LM) locations in Taiwan using the quantitative and qualitative multi-criteria decision-making approach. Multinational corporations in the logistics arena were surveyed to collect factors and the priorities for location development for each type of M-LM using the fuzzy multiple criteria Q-analysis (MCQA) approach. It is suggested that each location has different competitive elements that support different types of M-LM. The findings show proposed locations for developing M-LM in Taiwan.

I. INTRODUCTION

Given the significant role of logistics in a firm’s survival and prosperity, a key management issue for multinational firms is the location and functions of consolidated distribution centers (Stenner et al., 2007; Lee et al., 2009). Hence, the decision for multinational corporations to concentrate logistics functions in particular locations is of critical importance for the economics of hub location. Many cities have made an effort to establish multimodal logistic modes (M-LM) locations in order to attract multinational corporations and logistics service providers (LSPs) to provide logistics services and distribute international commodities through the M-LM. Several studies have examined determinants affecting firms’ evaluation of specific types of operations, logistics, distribution, or transshipment centers in particular regions (Yeo and Song, 2003; Oum and Park, 2004; Lee et al., 2005; Tai and Hwang, 2005; Ding, 2010; Ding and Chou, 2012; Ding and Tseng, 2012). These papers generally selected alternatives or locations to assess the preference for a particular type of M-LM. To our knowledge there have been few empirical studies examining different types of M-LM among potentially competing locations. This paper identifies the priority for location development of different type of M-LM location development in Taiwan from the perspective of logistics service providers.

The evaluation of priorities for M-LM location development is a multiple criteria decision-making (MCDM) problem. However, the criteria of M-LM evaluation differ according to the criteria for judging subjects, circumstances, and the degree of the judge’s knowledge. Further, the degree of strength of the criteria changes as the problem is thought about in depth. By incorporating the priorities of fuzziness measurement and the fuzziness multi-criteria grade classification method (Chen and Hwang, 1992; Teng, 1997), this paper uses fuzzy multiple criteria Q-analysis (MCQA) method to improve the performance judgment of decision-makers.

II. SPECIFICATION OF MULTIMODAL LOGISTIC MODES

In this paper, the activities of the M-LM location are defined by addressing inbound, operations, and outbound logistics stages (Fig. 1). The three stages satisfy different logistics functions: (1) the supply side (international material & semi-product and production supply marketplace) provides purchasing functions for material, semi-product, and product cargos; (2) the operations side provides the storage, reprocessing, and distribution functions from the supply side to the demand side (international consumer market), relying on location’s environmental factors such as ports (air and sea) and manufacturing industries; and (3) the demand side (including international customer market) satisfies consumption and re-processing demand. By designating transshipment and reprocessing export (re-export) types of M-LM locations, M-LM types are classified by their functions and value-added. The distinctive operational features of the two types, together with their specific logistics networks, are described below:
Type 1: Transshipment type of M-LM

The transshipment type of M-LM presents a type of international goods distribution for global logistics activities. It provides several main functions in an integrated logistics mode, such as transportation, storage, consolidation, and distribution functions. To perform the transshipment function, several ports provide the transshipment service. For example, the southern-east area in China, the sea-air transshipment is the primary provide the transshipment service. For example of southern-east China, the sea-air transshipment is the primary service. For example of southern-east China, the sea-air transshipment is the primary provide the transshipment service. For example of southern-east China, the sea-air transshipment is the primary service. For example of southern-east China, the sea-air transshipment is the primary provide the transshipment service. For example of southern-east China, the sea-air transshipment is the primary service. For example of southern-east China, the sea-air transshipment is the primary service. For example of southern-east China, the sea-air transshipment is the primary service. For example of southern-east China, the sea-air transshipment is the primary service.

Type 2: Reprocessing export type of M-LM

(re-export type)

This type is integrated in an effort to create an even higher value added service for material and semi-product cargos. By providing this type of logistic service, local hi-tech MC (such as science based industrial parks, hi-tech industrial parks), DC, and both sea/air ports can be integrated into the function activities of transportation, warehousing, hi-tech reprocessing, and distribution. In central Taiwan, Taichung international port (airport and seaport), the Taichung science-based industrial park, and the Taichung precision machinery park focus on re-export M-LM services for the high tech mechanical industries. Seeking to understand patterns of thought rather than the number of people that think in a particular way (Brown, 1980; Stenner et al., 2007; Donner, 2011; Watts and Stenner, 2012). Q-method is thus an exploratory approach that combines qualitative and quantitative techniques and contains unique terminology that requires some explanation (David, 2013; McKeown and Thomas, 2013; Vivica et al., 2014; Jane and Karen, 2015).

By incorporating the performance fuzziness measurement and fuzziness multi-criteria grade classification method developed by Teng (Teng, 1997), this paper uses MCQA to improve the performance judgment of decision-makers for better availability of MCQA.

1. Fuzzy Measurement of Location Performance

Assuming there are found \( n \) alternatives \( A = \{A_i\} i = 1, 2, ..., n \}, \( n \geq 1 \) under \( m \) evaluation criteria \( C = \{C_j\} j = 1, 2, ..., m \}, \( m \geq 2 \), if the performance value measured by each evaluation criteria is classified into \( p \) grades \( R = \{R_{ik} | k = 1, 2, ..., p \}, (p \geq 2 \), grade \( R_{ik} \) of subjective judgment of responders toward the \( A_i \) location under \( C_j \) criteria is represented below:

\[
R_{ik} = \left\{ R_j | k = 1, 2, \ldots, p \right\}, \forall i, j
\]

where, \( R_{ij} \) is represented by a higher degree of satisfaction of subjective judgment made by responders upon \( A_i \) alternative under \( C_j \) criteria, \( R_{ij} \) is represented by a next higher degree of satisfaction, and \( R_{ij} \) by rather dissatisfaction, and so on.

Under each evaluation criteria, the linguistic variables, such as “very satisfactory”, “satisfactory”, “ordinarily acceptable”, “dissatisfactory” and “rather dissatisfactory”, are fuzzy linguistics that can be represented by fuzzy numbers. Formerly, many scholars took the position that “linguistic variables” could be converted into scale fuzzy numbers, but gave no detailed description of how to determine scale fuzzy numbers. Saaty (1980) showed that five grade scales are a basic judgment method for the human beings. Thus, during the evaluation of alternatives, the satisfaction grade of the performance value under various criteria can be classified into “very good”, “good”, “medium”, “poor”, and “very poor”, and represented by \( R = \{R_1, R_2, R_3, R_4, R_5\} \). Meanwhile, the performance values of five grades can be represented by triangular fuzzy numbers, i.e. \( R_k (k = 1, 2, \ldots, 5) \) showing the fuzzy performance value of \( k \) grade for the alternatives. The fuzzy performance value of \( k \) grade is measured as \([0, 100]\), and the rating interval of \( R_k \) is represented by the following formula:

\[
\tilde{R}_k = (x_{k1}, x_{k2}, x_{k3})
\]

where, \( x_{ki}, x_{k2}, x_{k3} \) are optional values within \([0, 100]\), and meet the condition of \( x_{k1} \geq x_{k2} \geq x_{k3} \). This fuzzy number shows that, from the perspective of the responder, the performance value of \( R_k \) grade is between \( x_{k1} \sim x_{k3} \), and the crisp performance value
is \( x_{ib} \). The membership function \( u_{ik}(x) \) of the fuzzy performance value \( \tilde{R}_i \) of \( R_k \) grade can be expressed by the following formula:

\[
u_{ik}(x) = \begin{cases} 
0 & , x < x_{ia} \\
\frac{x - x_{ia}}{x_{ib} - x_{ia}} & , x_{ia} \leq x < x_{ib} \\
1 & , x = x_{ib} \\
\frac{x_{ib} - x}{x_{ib} - x_{ia}} & , x_{ib} < x \leq x_{ic} \\
0 & , x > x_{ic}
\end{cases} \tag{3}
\]

According to Saaty (1980), people will find it difficult to clearly judge adjacent scales, but easy to distinguish separated grades. For example, it is difficult to distinguish the satisfaction grades of “very good” and “good”, but easy to distinguish “very good” and “medium”. In other words, there is a fuzzy interval between adjacent grades other than separated grades.

For this reason, this paper has defined five satisfaction grades of fuzzy performance values.

### 2. Adaptive Equalization

It is assumed that there are \( N \) responders expressed by \( E = \{E_h \mid h = 1, 2, \ldots, N\} \). The fuzzy performance values of \( A_i \) location under \( C_j \) criteria are represented by \( \tilde{R}_i \) \((i = 1, 2, \ldots, n; j = 1, 2, \ldots, m) \). Thus, it is possible to measure the percentage of each grade given by the responders among gross numbers as detailed below:

\[
\tilde{R}_i = \sum_{k=1}^{5} \left( \frac{N_{ijk}}{N_{ij}} \right) \tilde{R}_k, \quad \forall i, j \tag{4}
\]

\[
N_{ij} = \sum_{k=1}^{5} N_{ijk}, \quad \forall i \tag{5}
\]

where, \( N_{ijk} \) is represented by the number of responders who judge the performance value of \( A_i \) location as \( R_k \) grade under \( C_j \) criteria, and \( N_{ij} \) by the total responders. In case every responder makes a judgment, \( N = N_{ij} \). In case some responders cannot make a judgment, \( N_{ij} < N_{0j} \). \( \sum \) indicates fuzzy summation and symbol \( \otimes \) indicates fuzzy multiplication. Once the responders have finished the evaluation of alternative locations, the preference structure matrix \( \tilde{P} \) can be obtained as follows:

\[
\tilde{P} = [\tilde{R}_i]_{ij}, \quad \forall i, j \tag{6}
\]

As \( N_{ijk} \) and \( N_{ij} \) are constants, the fuzzy value \( \tilde{R}_i \) still belongs to triangular fuzzy numbers (Kaufmann and Gupta (1985)). It is required to compare \( \tilde{R}_i \) and \( \tilde{R}_j \) fuzzy numbers to determine which grade \( \tilde{R}_i \) belongs to. In other words, it is possible to judge based upon the percentage of the area of \( \tilde{R}_i \) fuzzy numbers in the area of \( \tilde{R}_j \) fuzzy numbers, i.e. obtaining the value \( \alpha_{ij} \) of \( R_i \) grade as shown in Fig. 3. The area of \( \tilde{R}_i \) in \( \tilde{R}_j \) is represented by the oblique shadow. After obtaining the area of the oblique shadow among \( \tilde{R}_i \) grade (i.e. percentage of triangle ABC), it is possible to gain the grade value \( \alpha_{ij} \), which can be shown by the ratio between two ordinary integrals of membership functions as follows:

\[
\alpha_{ij} = \frac{\int_{x_{ia}}^{x_{ib}} u_{ijr}(y)dy}{\int_{x_{ia}}^{x_{ib}} u_{ijk}(x)dx}, \quad \forall i, j, k \tag{7}
\]

where, \( u_{ijr}(y) \) is the membership function of fuzzy number \( \tilde{R}_i \) and \( u_{ijk}(x) \) is the membership function of grade fuzzy number \( \tilde{R}_k \) with overlapped fuzzy interval as \( D_k = [x_{ia}, x_c] \).

In order to identify \( p \) grades, \((p - 1)\) evaluation grade groups comprising every two adjacent grades is created:

\[
\tilde{R}_i' = \{R_1, R_2, \ldots, R_p\} \\
\tilde{R}_i' = \{R_2, R_3, \ldots, R_p\} \\
\vdots \\
\tilde{R}_i' = \{R_p\}
\]

The fuzzy value \( \tilde{R}_i \) may be evaluated according to \( \tilde{R}_i' \), \( \tilde{R}_i'' \), \ldots, \( \tilde{R}_i'\) grades, and the corresponding membership grade \( \beta_1, \beta_2, \ldots, \beta_p \) can be obtained with the grades classified by the following rule:

1. \( \beta_1 \geq M \) then \( \tilde{R}_i \in R_1 \); otherwise
2. \( \beta_2 \geq M \) then \( \tilde{R}_i \in R_2 \); otherwise
3. \( \beta_{p-1} \geq M \) then \( \tilde{R}_i \in R_{p-1} \); otherwise \( \tilde{R}_i \in R_p \)

where \( M \) represents the threshold value of the membership grade of grade \( R_1, R_2, \ldots, R_{p\times} \).

For example, there are only two grades \( R = \{R_1, R_2\} \), when the membership grade of grade \( R_1 \) reaches the threshold value \( M \), the fuzzy value \( \tilde{R}_i \) under \( C_j \) criteria belongs to grade \( R_1 \), or otherwise to grade \( R_2 \). When the \( M \) value exceeds one half or two-thirds in principle, the \( M \) value is often 0.5 or 0.7. Assuming \( \beta_1 \) and \( \beta_2 \) respectively represent the membership grade of \( \tilde{R}_i \in R_1 \) and \( \tilde{R}_i \in R_2 \), and \( \beta_1 + \beta_2 = 1 \), the following three cases will be found:
when the grade is classified into three variables: \( R = \{ R_1, R_2, R_3 \} \), the grade classification of fuzzy value \( \tilde{r}_{ij} \) may be evaluated by per two grade classification modes, i.e. \( R'_1 \{ R_1, R_2 \} R'_2 = \{ R_2, R_3 \} \). Meanwhile, it is possible to search for the respective membership grade \( \beta_1, \beta_2 \), \( \beta_1 + \beta_2 = 1 \). Thus, the grade classification can be further implemented based on \( \beta_1 \) and \( \beta_2 \) as detailed below:

1. \( \beta_1 \geq M \), then \( \tilde{r}_{ij} \in R_1 \)
2. \( \beta_2 \geq M \), then \( \tilde{r}_{ij} \in R_2 \) or \( \tilde{r}_{ij} \in R_3 \), depend on \( \beta_2 \)
   (1) \( \beta_2 \geq M \), then \( \tilde{r}_{ij} \in R_2 \)
   (2) \( \beta_2 \geq M \), then \( \tilde{r}_{ij} \in R_3 \)

Under the precondition that the membership grade of \( p \) grades summation is 1 according to various grade levels \( \alpha_{ijk} \), the membership grade of various grades \( \beta_{ijk} \) \((i = 1, 2, \ldots, n; j = 1, 2, \ldots, m; k = 1, 2, \ldots, p) \) can be obtained from the following formula:

\[
\begin{align*}
\beta_{ij} &= \sum_{k=1}^{n} \alpha_{ijk} / \sum_{k=1}^{n} \alpha_{ijk} \\
\beta_{ij} &= \sum_{k=1}^{n} \alpha_{ijk} / \sum_{k=1}^{n} \alpha_{ijk} \\
\vdots \\
\beta_{op} &= 1 \\
\end{align*}
\]

3. Fuzzy Weight

It was hard to clearly judge adjacent scales, but easy to distinguish separated grades, as Zadeh (Zadeh, 1965) found. For example, it is difficult to distinguish the satisfaction grades of “very good” and “good”, but easy to distinguish “very good” and “medium” clearly. That is to say, there is a fuzzy interval between adjacent grades, but not separated grades. Therefore, the five satisfaction grades of fuzzy performance values were defined as shown in Fig. 2. In addition, the evaluation scale \([0, 100] \) can be converted into \([0, 1] \) to facilitate the calculation. As noted earlier, there is a fuzzy interval between adjacent grades, but not between non-adjacent grades. Fig. 3 presents the satisfaction grades of fuzzy performance values. The evaluation scale \([0, 100] \), can be converted into \([0, 1] \) to facilitate calculation.

In this paper, the importance level of the evaluation criteria is classified into five grades: “absolute importance”, “demonstrated importance”, “essential importance”, “weak importance” and “importance”. They may all be represented by triangular fuzzy numbers within \([0, 100] \), and meet the condition of fuzzy linguistic. The triangular fuzzy numbers \( \tilde{V} = \{ \tilde{V}_i \} \) are adopted to represent the scores of five grades, with the corresponding fuzzy numbers shown in Fig. 3, wherein only \( \tilde{R}_i \) is converted into \( \tilde{V}_i \). With the introduction of \([0, 100] \) measurement scale, the fuzzy weight of the grade can be represented by \( \tilde{V}_i = (x_{la}, x_{lb}, x_{lc}) \), of which \( x_{la}, x_{lb}, x_{lc} \) are optional values within \([0, 100] \), and meet the condition of \( x_{lb} \geq x_{la} \).

It is assumed that 5 logistics professionals judge the importance level of evaluation criteria as \( V_i \) \((i = 1, 2, \ldots, 5) \) grades, which is represented by \( Y_{jh} \) below:

\[
Y_{jh} = V_j, j = 1, 2, \ldots, m; h = 1, 2, \ldots, N; i = 1, 2, \ldots, 5
\]

The grade judgment matrix of 5 logistics professionals can be represented by \( Y \) below:

\[
Y = [Y_{jh}]_{N \times m}
\]

It is possible to obtain the grade of consensus weight for each evaluation criteria in accordance with the grade matrix \( Y \)
of importance level and majority rule. Take \( Z[V_j] \) as the number from \( N \) logistics professionals who judge the importance under \( C_j \) criteria as grade \( V_j \), and take \( Z[\sum V_j] \) as the number of professionals with their judgment grade \( V_i \) summed to grade \( V_j \), namely:

\[
Z[\sum V_j] = \sum_{g=1}^{1} Z[V_g], \quad \forall j
\]  

Suppose the importance level of consensus judgment under \( C_j \) evaluation criteria is judged as grade \( V_1 \). This shows that the importance level under \( C_j \) evaluation criteria meets grades from \( V_2 \) to \( V_v \). That is to say, the grade \( V_1 \) includes grades \( V_2 \) to \( V_v \). If the importance level of common understanding under \( C_j \) evaluation criteria meets the grades from \( V_j \) to \( V_v \), hence the grade \( V_j \) implies grades \( V_2 \) to \( V_v \)

\[
\sum_{l=2}^{V_v} \text{if } Z[V_l] \geq M \quad (12)
\]

where, the \( M \) value can be jointly agreed upon by \( N \) logistics professionals. The \( M \) value can be determined by the following formula with the introduction of a majority rule [19]:

\[
M = \begin{cases} 
(N/2)+1 & , \text{N is even number} \\
((N-1)/2)+1 & , \text{N is odd number}
\end{cases}
\]

Depending upon the level of consensus, the majority rule can also incorporate those over two-thirds or three-fourths. Further, it is possible to obtain grade \( V_u \) of the consensus for the importance level of \( C_j \) criteria in accordance with the analysis of the majority rule, and convert it into a fuzzy weight under this criteria, i.e. \( \tilde{w}_j \):

\[
\tilde{w}_j = V_u, \quad V_u \in V, \quad u = 1, 2, \ldots, 5
\]

4. Fuzzy MCQA Model

Assuming the grade \( R_k \), grade \( R_{jk} \) within preference structure matrix \( PR \) can be represented by \( 1 \), otherwise, represented by \( 0 \). Then, the preference structure matrix within formula (14) can be converted into the following \( p \) 0-1 type incidence matrix \( B_{jk} \) \((k = 1, 2, \ldots, p)\):

\[
B_{jk} = [b_{ij}]_{i,j} \quad \forall i, j, k
\]

\[
b_{ij} = \begin{cases} 
0, & \text{if } \tilde{R}_{ij} < \tilde{R}_{ik} \\
1, & \text{if } \tilde{R}_{ij} \geq \tilde{R}_{ik}
\end{cases}
\]

Depending upon the incidence matrix of each grade, it is possible to obtain and meet the criteria number matrix of this grade via \( q \)-connectivity, i.e. obtaining the following \( q \)-connectivity matrix \( S^{\delta_k} \) \((k = 1, 2, \ldots, p)\):

\[
S^{\delta_k} = B_{\delta_k} \left[ B_{\delta_k} \right]^T - e^T e
\]

where, \( S^{\delta_k} \): under \( R_k \) grade \( q \)-connectivity matrix \( \left[ B_{\delta_k} \right]^T \):

the transfer matrix of incidence matrix.

In accordance with the \( q \)-connectivity matrix, preference matrix structure and fuzzy weight, it is possible to obtain the fuzzy project satisfaction index \( PS_i \) and the fuzzy project comparison index \( PC_i \) for various locations, each of which is defined below:

\[
PS_i = \sum_k \tilde{R}_{ij} \otimes \tilde{T}_{ij}, \quad \forall i
\]

\[
\tilde{T}_{ij} = \sum_j b_{ij} \otimes \tilde{w}_j, \quad \forall i, k
\]

\[
PC_i = \sum_k [\tilde{q}_{jk} - q^{*}_{jk}] , \quad \forall i
\]

\[
q^{*}_{jk} = \text{maximum}_{i' \neq i} S^{\delta_k}(i, i')
\]

\[
\tilde{q}_{jk} = S^{\delta_k}(i, i)
\]

where \( q^{*}_{jk} = S^{\delta_k}(i, i') \) is represented by the dimension of \( A_i \) alternative under grade \( R_k \) and \( q^{*}_{jk} = \text{maximum}_{i' \neq i} S^{\delta_k}(i, i') \) is presented by the maximum dimension of all alternatives under grade \( R_k \).

The fuzzy project satisfaction index indicates the comprehensive satisfaction of logistics professionals toward \( A_i \). The larger the criteria, the better the performance is. It is required to obtain the fuzzy comparison index so as to compare the alternatives, as the fuzzy project satisfaction index can only measure the absolute satisfaction of various alternatives rather than the relative satisfaction. However, a pairwise comparison method will complicate the calculation. In an effort to simplify the mathematical operation, it is often assumed that preference transitivity will occur (Starr and Zeleny, 1997). Because the fuzzy MCQA method is used in this paper, it is also assumed that preference transitivity will occur. Hence, when obtaining the value of \( PC_i \), it is only required to determine maximum \( q^{*}_{jk} \) for comparison with \( \tilde{q}_{jk} \). A complex
pairwise comparison is unnecessary.

Since both \( PS_i \) and \( PC_i \) are fuzzy numbers a defuzzier shall be required. It is unlikely that it will be necessary to compare them directly as crisp values. This paper converts the fuzzy numbers of \( PS_i \) and \( PC_i \) into real numbers based upon the ranking method of fuzzy numbers of Kim-Park as modified by Teng and Tzeng (1996). Take \( PH_i \) as the general expression of \( PS_i \) and \( PC_i \) as shown below:

\[
PH_i = (LH_i, MH_i, RH_i), \quad i = 1, 2, \ldots, n
\]  \hspace{1cm} (23)

where the greater the interval of \( LH_i, MH_i \) is the greater the negative assessment of location \( A_i \), and the greater the interval of \( MH_i, RH_i \) is the higher the positive assessment of location \( A_i \).

Let \( S \) be the range of all alternative's \( PH_i \) measurement values as well as a universe of discourse, of which \( s \) is an element of set \( S \) showing an optional value within the range of \( S \). Take \( \alpha_i \) value between \([0, 1]\) as the optimistic attitude of experts toward alternatives whereas \((1-\alpha_i)\) shows a pessimistic attitude. Assuming that \( u_\alpha(PH_i) \) represents the optimistic membership grade of the fuzzy satisfaction index in \( A_i \), and \( u_\alpha(PH_i) \) represents the pessimistic membership grade, \( u_\alpha(PH_i) \) value can be obtained from the following formula.

\[
\mu_\alpha(PH_i) = \alpha_i \mu_\alpha(PH_i) + (1-\alpha_i) \mu_\alpha(PH_i), \quad i = 1, 2, \ldots, n
\]  \hspace{1cm} (24)

\[
\alpha_i = \frac{(RH_i - MH_i)}{(RH_i - LH_i)}, \quad \forall i
\]  \hspace{1cm} (25)

\[
\mu_\alpha(PH_i) = \frac{(s_{z_i} - s_{\min})}{(s_{\max} - s_{\min})}, \quad \forall i
\]  \hspace{1cm} (26)

\[
\mu_\alpha(PH_i) = 1 - \left[ \frac{(s_{z_i} - s_{\min})}{(s_{\max} - s_{\min})} \right], \quad \forall i
\]  \hspace{1cm} (27)

\[
s_{z_i} = \frac{s_{\max}RH_i - s_{\min}MH_i}{(RH_i - MH_i)} + (s_{\max} - s_{\min})
\]  \hspace{1cm} (28)

\[
s_{z_i} = \frac{s_{\max}MH_i - s_{\min}LH_i}{(MH_i - LH_i)} + (s_{\max} - s_{\min})
\]  \hspace{1cm} (29)

\[
s_{\max} = \sup S
\]  \hspace{1cm} (30)

\[
s_{\min} = \inf S
\]  \hspace{1cm} (31)

\[
S = \bigcup_{i=1}^{n} PH_i
\]  \hspace{1cm} (32)

where \( s_i \) is an element of set \( S \) showing an optional value within the range of \( MH_i, RH_i \) and \( s_i \) is an element of set \( S \) showing an optional value within the range of \( LH_i, MH_i \).

As for the fuzzy MCQA model in this paper, the author attempts to obtain the evaluation ranking of alternatives via MCQA concept based on the defuzzier value of \( PS_i \) and \( PC_i \). \( A_i \) project rating index \( PRI_i \) can be obtained from the following formula:

\[
PRI_i = \left[ \left( 1 - u_\alpha(PS_i) \right)^r + \left( 1 - u_\alpha(PC_i) \right)^r \right]^{1/r}, \quad \forall i
\]  \hspace{1cm} (33)

The smaller the \( PRI_i \) value, the closer the distance between the alternative’s vector and the ideal vector, i.e. the better the alternative is; otherwise, the worse the alternative is. When the concept of Euclidean distance is applied to formula (32), the \( r \) value is often determined to be 2.

IV. EMPIRICAL STUDY

M-LM location development in Taipei \( (A_1) \), Taichung \( (A_2) \), and Kaohsiung \( (A_3) \) in Taiwan are evaluated by comparing respondents’ satisfaction with the ability of each location to meet each evaluation criteria.

1. Critical Factors

The critical criteria of activities of multimodal logistics systems for the two types of M-LM location include the major measurement of distance from the main international raw and semi-product supply market, distance between airport and seaport, efficiency of air/seaports, transshipment cost of sea-air multimodal transportation, re-export cost of the domestic manufacturing market reprocessing quality of the domestic M-market, distance between seaport/airport and the M-market, and distance to main international consumer market. The criteria were viewed as relevant by 25 logistics service providers and accepted as possessing content validity. Based on the literature reviews of criteria considered important to firms when making decisions on location selecting from the perspective of logistics service providers (Lee and Lin, 2008; Chou, 2010a; Chou, 2010b; Ding, 2010; Lin and Lee, 2010), the 8 criteria (Table 1) were used for inclusion in the present study’s questionnaire survey.

Amongst the evaluation criteria required to construct the two types of M-LM location, the Efficiency of transportation from the main international raw and semi-product supply market \( (C_1) \), efficiency between airport and seaport \( (C_2) \), efficiency of air/seaport \( (C_3) \), transshipment cost of sea-air multimodal \( (C_4) \), and efficiency to main international consumer
market (C₈) are both common evaluation criteria, while the other three criteria are determined based on the re-export type of M-LM.

2. Evaluating Procedure

Based on the evaluation criteria in Fig. 4, the hierarchical structure of the two types of M-LM location is constructed, and 3 alternative locations are selected for the decision making of the M-LM location and labeled A₁~A₃. This evaluation procedure in collaboration with fuzzy measurement, fuzzy grade classification, fuzzy weight, and MCQA method was used for the empirical study. It is intended to collect the actual quantification and qualification performance value of various alternative locations in order to facilitate the decision-making for the M-LM location as the evaluation criteria under research and discussion. However, because the logistics professionals had different levels of satisfaction toward the actual performance value, this evaluation is scheduled to measure their satisfaction via the fuzzy measurement method, and then classify the grade of performance value via the fuzzy grade classification method. In an effort to assess the importance level of the evaluation criteria, this study obtains the fuzzy weight via majority rule. Further, based on the fuzzy grade and fuzzy weight as well as the evaluation procedure, this evaluation acquired the fuzzy project satisfaction index and fuzzy project comparison index for the alternatives, and finally defuzzifies them via the fuzzy ranking method to obtain the Project Rating Index (PRI) for the alternatives. The framework of the decision-making for the M-LM alternatives is shown in Fig. 5.

3. Company Characterization

The data collection instruments including two modes and eight important factors (Table 1) were used to design the questionnaire. The survey was carried out from September 2013 to February 2014. The evaluation problem involves group decision-making. Robbins (Robbins, 1994) suggested that five to seven decision-makers are sufficient when dealing with group decision-making problems and that an evaluation can be generated by a group of professional experts. The survey was sent to the 200 managers of international logistics service providers (sea/air carriers and forwarders) and hi-tech firms in Taiwan. Most respondents were middle or senior managers who had been working in the field for over 10 years. The overall response rate for this study was 23 percent. Survey respondents are categorized by industry in Table 2.
Table 3. Classification contribution of alternative locations for each criterion.

<table>
<thead>
<tr>
<th>Locations</th>
<th>Criteria</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>C6</th>
<th>C7</th>
<th>C8</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1, Taipei</td>
<td>R2</td>
<td>R2</td>
<td>R2</td>
<td>R2</td>
<td>R2</td>
<td>R2</td>
<td>R2</td>
<td>R2</td>
<td>R2</td>
</tr>
<tr>
<td>A2, Taichung</td>
<td>R3</td>
<td>R3</td>
<td>R3</td>
<td>R3</td>
<td>R3</td>
<td>R3</td>
<td>R3</td>
<td>R3</td>
<td>R3</td>
</tr>
<tr>
<td>A3, Kaohsiung</td>
<td>R4</td>
<td>R4</td>
<td>R4</td>
<td>R4</td>
<td>R4</td>
<td>R4</td>
<td>R4</td>
<td>R4</td>
<td>R4</td>
</tr>
</tbody>
</table>

Table 4. Consensus grade and fuzzy weight of criteria Cj.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Consensus grade</th>
<th>Fuzzy weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>(0.5,0.75,1.0)</td>
<td></td>
</tr>
<tr>
<td>C2</td>
<td>(0.75,1.0,1.0)</td>
<td></td>
</tr>
<tr>
<td>C3</td>
<td>(0.75,1.0,1.0)</td>
<td></td>
</tr>
<tr>
<td>C4</td>
<td>(0.5,0.75,1.0)</td>
<td></td>
</tr>
</tbody>
</table>

Table 5. PSI and PCI value of transshipment t M-LM location.

<table>
<thead>
<tr>
<th>Location</th>
<th>PSi</th>
<th>μi(PSi)</th>
<th>PCi</th>
<th>μi(PCi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1, Taipei</td>
<td>1.50</td>
<td>0.68</td>
<td>0.70</td>
<td></td>
</tr>
<tr>
<td>A2, Taichung</td>
<td>1.13</td>
<td>0.41</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>A3, Kaohsiung</td>
<td>0.88</td>
<td>0.35</td>
<td>0.39</td>
<td></td>
</tr>
</tbody>
</table>

4. Results Analysis

The satisfaction grade of the evaluation criteria of various potential locations can be classified into “very good (R1)”, “good (R2)”, “medium (R3)”, “poor (R4)” and “very poor (R5)”. The logistics professionals tend to estimate the performance value and judge the satisfaction grade as one evaluation criterion particular to a suitable alternative. For the different preference of each logistics professional, the fuzzy measurement method was used to assess the preference and the fuzzy grade classification method obtained the grade of potential locations for each evaluation criteria.

The results are listed in Tables 3 and 4 along with the evaluation criteria for the transshipment and re-export types of M-LM location. The four groups of the fuzzy project satisfaction index (PSi), fuzzy project comparison index (PCI), and corresponding crisp values (μi(PSi), μi(PCI)) may be obtained and analyzed via the fuzzy MCQA method (Tables 5 and 6). The project rating index (PRI) of various potential locations may then be obtained from formula (32) based on the crisp value of PSi and PCI. Given the same importance of two types of M-LM, it is possible to calculate the gross project rating index of various potential locations. The smaller the value, the better the results. The ranking of the priority of various potential M-LM locations is obtained and displayed in Table 7. The satisfaction grade of 47 logistics professionals for the 3 potential M-LM locations results in a priority ranking of Taipei (A1), Kaohsiung (A3), and Taichung (A2).

5. Discussion and Analysis

In this paper, a sensitivity analysis was discussed to analyze the priority changes for potential M-LM locations in Taiwan. Based upon the various combinations, in the case of most importance for a single type of M-LM, it is assumed that the importance weight of the most important mode of M-LM is available at 0.5, 0.6, 0.7 and 0.8, while the other mode of M-LM shares the remaining weight (calculated by weight summation 1). Hence, the priority of the 3 M-LM locations can be obtained, as listed in Table 8. Respondents ranked the priorities as Taipei (A1), Kaohsiung (A3), and Taichung (A2) when the importance weight of transshipment type of M-LM is 0.5~0.8*. From the respective re-export types of M-LM, the priority relations are Taipei (A1), Kaohsiung (A3) and Taichung (A2) when the importance weight is 0.5~0.6*, and the priorities are Taipei (A1), Taichung (A2), and Kaohsiung (A3) when the importance weight is 0.7~0.8*.

Fig. 6 shows the competitive relations for each type of M-LM. There are competitive gaps for each location of the two types of M-LM. Because of their role as home bases for
the M-LM hub, with the Taoyuan International Airport and Taipei/Keelung international port, and the high tech industrial cluster around the Hsinchu Science Park, in Taiwan, Taipei shows the strongest competitiveness for the transshipment and re-export types of M-LM. Kaohsiung is second in the transshipment and re-export types of M-LM due to its excellent sea-air transportation conditions, with first international sea-port in Taiwan and airport, and a high tech industrial cluster around the Southern Taiwan Science Park outside Tainan. With its excellent high tech machinery industry and sea-air transportation conditions and the Taichung international airport/seaport, Taichung is competitive as a re-export M-LM location, but has weaknesses as a transshipment M-LM location.

Furthermore, the majority of surveys of internal and external factors (Table 9) indicate that Taipei has an absolute advantage in developing transshipment and re-export M-LM locations. Taichung has the advantage in internal conditions of ‘Reprocessing cost of domestic M-market (C5)’, ‘Reprocessing quality of domestic M-market (C6)’, and weakness in external conditions and in internal conditions of ‘Transportation efficiency between airport and seaport (C2)’ and ‘Efficiency of air/sea port’ (C3) as a re-export M-LM location. Kaohsiung has the advantage in internal conditions of ‘Reprocessing cost of domestic M-market (C5)’ and ordinary competitiveness in other internal and external conditions as a re-export M-LM location.

V. CONCLUSION

To effectively evaluate the alternatives for M-LM location development, a systematically fuzzy quantitative and qualitative multi-criteria evaluation approach is considered. A fuzzy multiple criteria Q-analysis (MCQA) approach is proposed to assess the priority of locations for M-LM location development. With the use of fuzzy MCQA in combination with fuzzy grade measurement, fuzzy grade classification, and the MCQA method, decision-makers are only required to judge the satisfaction grade of alternatives rather than granting scores, thereby making judgments in a time saving and efficient way while maintaining the advantages of the traditional MCQA method.

Two types of M-LM were identified as the foundation for assessing the priority for different types of M-LM location development in Taiwan. The three potential locations were subsequently compared using respondents’ perceptions of their ability to meet the evaluation criteria. Results show that Taipei is the respondents’ preferred location for developing the two types of M-LM locations, and Taichung and Kaohsiung were suggested for development of re-export M-LM locations based on their local industries.

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