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

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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:
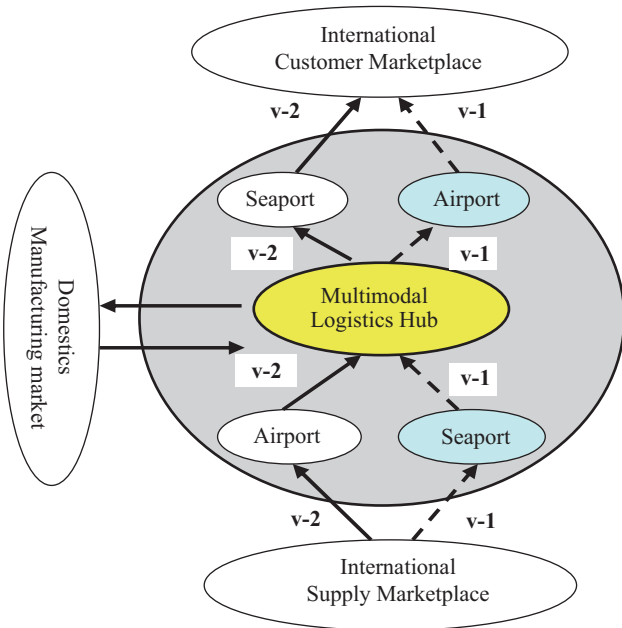
Fig. 1. Activities of multimodal logistics system.

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 of southern-east area in China, the sea-air transshipment is the primary mode for China firms, which invested by Taiwan enterprise. The delivery time is just within two days from Xiamen seaport to the specific destination via Kaohsiung seaport and transfer to Kaohsiung airport, than at least seven days from Xiamen seaport to specific destination via Hong Kong port (Feng, 2006).

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.

III. METHODOLOGY

Q-methodology is a research approach that investigates subjectivity. Researchers typically use this approach when 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 etal., 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 $A = \{A_i \mid i = 1, 2, ..., n\}$, $(n \geq 1)$ under m evaluation criteria $C = \{C_j \mid j = 1, 2, ..., m\}$, $(m \geq 2)$, if the performance value measured by each evaluation criteria is classified into p grades $R = \{R_k \mid k = 1, 2, ..., p\}$, $(p \geq 2)$, grade R_{ijk} of subjective judgment of responders toward the A_i location under C_j criteria is represented below:

$$R_{ijk} = \left\{ R_k \mid k = 1, 2, ..., p \right\}, \forall \, i, j \qquad (1)$$

where, R_{ij1} is represented by a higher degree of satisfaction of subjective judgment made by responders upon A_i alternative under C_j criteria, R_{ij2} is represented by a next higher degree of satisfaction, and R_{ijp} 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. $\tilde{R}_k$ $(k = 1, 2, ..., 5)$ 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 $\tilde{R}_k$ is represented by the following formula:

$$\tilde{R}_k = \left(x_{ka}, x_{kb}, x_{kc} \right) \qquad (2)$$

where, x_{ka}, x_{kb}, x_{kc} are optional values within [0, 100], and meet the condition of $x_{kc} \geq x_{kb} \geq x_{ka}$. This fuzzy number shows that, from the perspective of the responder, the performance value of R_k grade is between $x_{ka} \sim x_k$, and the crisp performance value

is x_{kb}. The membership function $u_{\tilde{R}_k}(x)$ of the fuzzy performance value $\tilde{R}_k$ of R_k grade can be expressed by the following formula:

$$u_{\tilde{R}_k}(x) = \begin{cases} 0 & , \quad x < x_{ka} \\ \dfrac{x - x_{ka}}{x_{kb} - x_{ka}} & , \quad x_{ka} \leq x < x_{kb} \\ 1 & , \quad x = x_{kb} \\ \dfrac{x_{kc} - x}{x_{kc} - x_{kb}} & , \quad x_{kb} < x \leq x_{kc} \\ 0 & , \quad x > x_{kc} \end{cases} \tag{3}$$

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

$$\tilde{r}_{ij} = \overset{5}{\underset{k=1}{\tilde{\sum}}} \left(\frac{N_{ijk}}{N_{ij}} \right) \otimes \tilde{R}_k \quad , \quad \forall i, j \tag{4}$$

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

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, $N_{ij} < N_0$. $\tilde{\sum}$ 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:

$$\tilde{P} = \left[\tilde{r}_{ij} \right]_{i \times j} \quad , \quad \forall i, j \tag{6}$$

As N_{ijk} and N_{ij} are constants, the fuzzy value $\tilde{r}_{ij}$ still belongs to triangular fuzzy numbers (Kaufmann and Gupta (1985)). It

is required to compare $\tilde{r}_{ij}$ and $\tilde{R}_k$ fuzzy numbers to determine which grade $\tilde{r}_{ij}$ belongs to. In other words, it is possible to judge based upon the percentage of the area of $\tilde{r}_{ij}$ fuzzy numbers in the area of $\tilde{R}_k$ fuzzy numbers, i.e. obtaining the value α_{ijk} of R_k grade as shown in Fig. 3. The area of $\tilde{r}_{ij}$ in $\tilde{R}_k$ is represented by the oblique shadow. After obtaining the area of the oblique shadow among $\tilde{R}_k$ grade (i.e. percentage of triangle ABC), it is possible to gain the grade value α_{ijk}, which can be shown by the ratio between two ordinary integrals of membership functions as follows:

$$\alpha_{ijk} = \frac{\int_{y \in D_k} u_{\tilde{r}_{ij}}(y) dy}{\int_{x \in D_k} u_{\tilde{R}_k}(x) dx}, \quad \forall i, j, k \tag{7}$$

where, $u_{\tilde{r}_{ij}}(y)$ is the membership function of fuzzy number $\tilde{r}_{ij}$ and $u_{\tilde{R}_k}(x)$ is the membership function of grade fuzzy number $\tilde{R}_k$ with overlapped fuzzy interval as $D_k = [x_{ka}, y_c]$.

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

$$R_1' = \{R_1, R_2 \text{ or } R_3 \text{ or} ... \text{ or } R_p\}$$
$$R_2' = \{R_2, R_3 \text{ or } R_4 \text{ or} ... \text{ or } R_p\}$$
$$\vdots$$
$$R_{p-1}' = \{R_{p-1}, R_p\}$$

The fuzzy value $\tilde{r}_{ij}$ may be evaluated according to R_1', R_2', ..., R_{p-1}' grades, and the corresponding membership grade $\beta_1, \beta_2, ..., \beta_{p-1}$ can be obtained with the grades classified by the following rule:

1. $\beta_1 \geq M \quad then \quad \tilde{r}_{ij} \in R_1$; $otherwise$

2. $\beta_2 \geq M \quad then \quad \tilde{r}_{ij} \in R_2$; $otherwise$

$$\vdots$$

$(p-1). \quad \beta_{p-1} \geq M \quad then \quad \tilde{r}_{ij} \in R_{p-1}$; $otherwise \quad \tilde{r}_{ij} \in R_p$

where M represents the threshold value of the membership grade of grade $R_1', R_2', ..., R_{p-1}'$.

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 $\tilde{r}_{ij}$ 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 β_1 and β_2 respectively represent the membership grade of $\tilde{r}_{ij} \in R_1$ and $\tilde{r}_{ij} \in R_2$, and $\beta_1 + \beta_2 = 1$, the following three cases will be found:

1. $\beta_1 > M$, then $\tilde{r}_{ij} \in R_1$
2. $\beta_1 = M$, then $\tilde{r}_{ij} \in R_1$ or $\tilde{r}_{ij} \in R_2$
3. $\beta_2 > M$, then $\tilde{r}_{ij} \in R_2$

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. $R'_1 \{R_1, R_2$ or $R_3\}$ $R'_2 = \{R_2$ or $R_3\}$. Meanwhile, it is possible to search for the respective membership grade ($\beta_1, \bar{\beta}_1$), ($\beta_2, \bar{\beta}_2$), and $\beta_1 + \bar{\beta}_1 = 1$, $\beta_2 + \bar{\beta}_2 = 1$. Thus, the grade classification can be further implemented based on β_1 and β_2 as detailed below:

1. $\beta_1 \geq M$, then $\tilde{r}_{ij} \in R_1$

2. $\bar{\beta}_1 \geq M$, then $\tilde{r}_{ij} \in R_2$ or $\tilde{r}_{ij} \in R_3$, depond on β_2

   (1) $\beta_2 \geq M$, *then* $\tilde{r}_{ij} \in R_2$

   (2) $\bar{\beta}_2 \geq M$, *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 α_{ijk}, the membership grade of various grades β_{ijk} ($i = 1, 2, \ldots, n$; $j = 1, 2, \ldots, m$; $k = 1, 2, \ldots, p$) can be obtained from the following formula:

$$\beta_{ij1} = \sum_{k=1}^{1} \alpha_{ijk} \bigg/ \sum_{k=1}^{p} \alpha_{ijk}$$
$$\beta_{ij2} = \sum_{k=1}^{2} \alpha_{ijk} \bigg/ \sum_{k=1}^{p} \alpha_{ijk}$$
$$\vdots \qquad\qquad (8)$$
$$\beta_{ij(p-1)} = \sum_{k=1}^{p-1} \alpha_{ijk} \bigg/ \sum_{k=1}^{p} \alpha_{ijk}$$
$$\beta_{ijp} = 1$$

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.
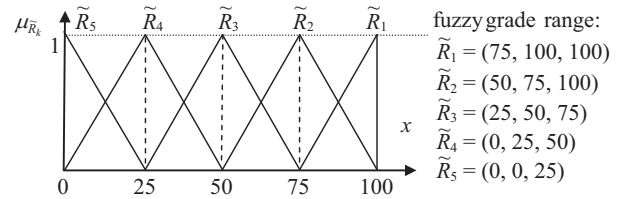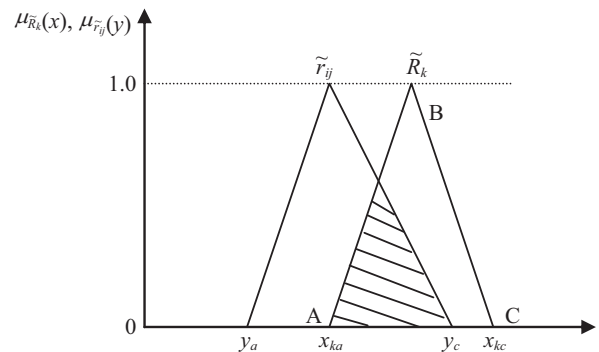

Fig. 2. grade fuzzy number $\tilde{R}_k$.

Fig. 3. grade fuzzy number $\tilde{R}_k$.

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 $V = \{V_l | l = 1, 2, \ldots, 5\}$, where, V_1 indicates "absolute importance", V_2 "demonstrated importance" and so on. As "absolute importance", "demonstrated importance", "essential importance", "weak importance" and "importance" are remain fuzzy linguistics. The triangular fuzzy numbers $\tilde{V} = \{\tilde{V}_l | l = 1, 2, \ldots, 5\}$ are adopted to represent the scores of five grades, with the corresponding fuzzy numbers shown in Fig. 3, wherein only $\tilde{R}_k$ is converted into $\tilde{V}_l$. With the introduction of [0, 100] measurement scale, the fuzzy weight of the l grade can be represented by $\tilde{V}_l = (x_{la}, x_{lb}, x_{lc})$, of which x_{la}, x_{lb}, x_{lc} are optional values within [0, 100], and meet the condition of $x_{lc} \geq x_{lb} \geq x_{la}$.

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

$$Y_{hj} = V_l, j = 1, 2, \ldots, m; h = 1, 2, \ldots, N; l = 1, 2, \ldots, 5 \qquad (9)$$

The grade judgment matrix of N logistics professionals can be represented by Y below:

$$Y = [Y_{hj}]_{N \times m} \qquad (10)$$

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 $Z[V_l]_j$ as the number from N logistics professionals who judge the importance under C_j criteria as grade V_l, and take $Z[\sum V_l]_j$ as the number of professionals with their judgment grade V_1 summed to grade V_l, namely:

$$Z[\sum V_l]_j = \sum_{g=1}^{l} Z[V_g]_j \quad , \quad \forall \, j \tag{11}$$

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 $V_2 \sim V_v$. If the importance level of common understanding under C_j evaluation criteria is judged as grade V_2, it shows that the importance level under C_j evaluation criteria meets the grades from V_3 to V_v apart from grade V_1. Namely, the grade V_2 implies grades $V_3 \sim V_v$, but does not include grade V_1. $Z[\sum V_l]_j$ must exceed a certain majority value M in accordance with the majority rule, namely

$$Z[\sum V_l]_j \geq M \tag{12}$$

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]:

$$M = \begin{cases} (N/2) + 1 & , \; N \; is \; even \; number \\ \left[(N-1)/2\right] + 1 & , \; N \; is \; odd \; number \end{cases} \tag{13}$$

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. $\tilde{w}_j$:

$$\tilde{w}_j = V_u, \quad V_u \in V, \quad u = 1, 2, \ldots, 5 \tag{14}$$

4. Fuzzy MCQA Model

Assuming the grade R_k, grade R_{ijk} within preference structure matrix $\tilde{PR}$ 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_{R_k} $(k = 1, 2, \ldots, p)$:

$$B_{R_k} = [b_{ij}]_{i \times j} \quad \forall \, i, j, k \tag{15}$$

$$b_{ij} = \begin{cases} 0, & if \;\; \tilde{R}_{ijk} < \tilde{R}_k \\ 1, & if \;\; \tilde{R}_{ijk} \geq \tilde{R}_k \end{cases} \tag{16}$$

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^{R_k} $(k = 1, 2, \ldots, p)$:

$$S^{R_k} = B_{R_k} \left[B_{R_k} \right]^T - e^T e \tag{17}$$

where, S^{R_k}: under R_k grade q-connectivity matrix $\left[B_{R_k} \right]^T$: the transfer matrix of incidence matrix.

In accordance with the q-connectivity matrix, preference structure matrix and fuzzy weight, it is possible to obtain the fuzzy project satisfaction index $\tilde{PS}_i$ and the fuzzy project comparison index $\tilde{PC}_i$ for various locations, each of which is defined below:

$$\tilde{PS}_i = \sum_k \tilde{R}_k \otimes \tilde{T}_{ik} \quad , \quad \forall \, i \tag{18}$$

$$\tilde{T}_{ik} = \sum_j \tilde{b}_{ij}^k \otimes \tilde{w}_j \quad , \quad \forall \, i, k \tag{19}$$

$$\tilde{PC}_i = \sum_k \tilde{R}_k [\hat{q}_{iR_k} - q_{iR_k}^*] \quad , \quad \forall \, i \tag{20}$$

$$q_{iR_k}^* = \underset{\substack{i'=1,2,\ldots,n \\ i \neq i'}}{\text{maximum}} S^{R_k}(i, i') \tag{21}$$

$$\hat{q}_{iR_k} = S^{R_k}(i, i) \tag{22}$$

where $\hat{q}_{iR_k} = S^{R_k}(i, i)$ is represented by the dimension of A_i alternative under grade R_k and $q_{iR_k}^* = \underset{\substack{i'=1,2,\ldots,n \\ i \neq i'}}{\text{maximum}} S^{R_k}(i, i')$ 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 $\tilde{PC}_i$, it is only required to determine maximum $q_{iR_k}^*$ for comparison with $\hat{q}_{iR_k}$. A complex

pairwise comparison is unnecessary.

Since both $\tilde{PS_i}$ and $\tilde{PC_i}$ 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 $\tilde{PS_i}$ and $\tilde{PC_i}$ into real numbers based upon the ranking method of fuzzy numbers of Kim-Park as modified by Teng and Tzeng (1996). Take $\tilde{PH_i}$ as the general expression of $\tilde{PS_i}$ and $\tilde{PC_i}$ as shown below:

$$\tilde{PH_i} = \left(LH_i, MH_i, RH_i \right), \quad i = 1, 2, \ldots, n \quad (23)$$

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' $\tilde{PH_i}$ 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 α_i value between $[0, 1]$ as the optimistic attitude of experts toward alternatives whereas $(1-\alpha_i)$ shows represents a pessimistic attitude. Assuming that $u_o(\tilde{PH_i})$ represents the optimistic membership grade of the fuzzy satisfaction index in A_i, and $u_p(\tilde{PH_i})$ represents the pessimistic membership grade, $u_T(\tilde{PH_i})$ value can be obtained from the following formula.

$$\mu_T\left(\tilde{PH_i} \right) = \alpha_i \mu_o\left(\tilde{PH_i} \right) + \left(1 - \alpha_i \right) \mu_p\left(\tilde{PH_i} \right), i = 1, 2, \ldots, n \quad (24)$$

$$\alpha_i = \left(RH_i - MH_i \right) / \left(RH_i - LH_i \right), \quad \forall i \quad (25)$$

$$\mu_o\left(\tilde{PH_i} \right) = \left(s_{2_i} - s_{\min} \right) / \left(s_{\max} - s_{\min} \right), \quad \forall i \quad (26)$$

$$\mu_p\left(\tilde{PH_i} \right) = 1 - \left[\left(s_{\max} - s_{2_i} \right) / \left(s_{\max} - s_{\min} \right) \right], \quad \forall i \quad (27)$$

$$s_{1_i} = \frac{s_{\max} RH_i - s_{\min} MH_i}{\left(RH_i - MH_i \right) + \left(s_{\max} - s_{\min} \right)} \quad (28)$$

$$s_{2_i} = \frac{s_{\max} MH_i - s_{\min} LH_i}{\left(MH_i - LH_i \right) + \left(s_{\max} - s_{\min} \right)} \quad (29)$$

$$s_{\max} = \sup S \quad (30)$$

$$s_{\min} = \inf S \quad (31)$$

$$S = \bigcup_{i \in A} \tilde{PH_i} \quad (32)$$

where s_{1_i} is an element of set S showing an optional value within the range of MH_i, RH_i, and s_{2_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 $\tilde{PS_i}$ and $\tilde{PC_i}$. A_i project rating index PRI_i, can be obtained from the following formula:

$$PRI_i = \left[\left(1 - u_T\left(\tilde{PS_i} \right) \right)^r + \left(1 - u_T\left(\tilde{PC_i} \right) \right)^r \right]^{1/r}, \quad \forall i \quad (33)$$

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.
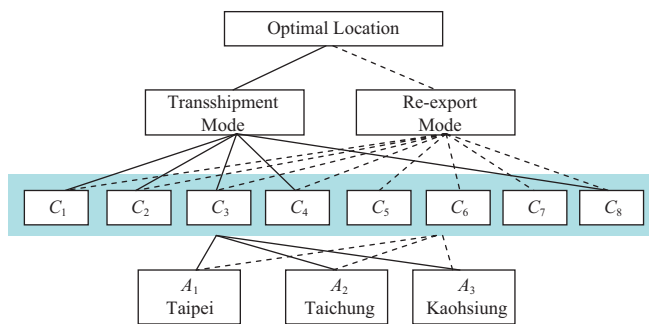
1. Critical Factors

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/sea ports, 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 literatures review 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/sea port (C_3), transshipment cost of sea-air multimodal (C_4), and efficiency to main international consumer

Table 1. Evaluation criteria of the two types of M-LM.

Modes	Criteria
Transshipment	Efficiency from main Int. raw & semi-product supply market (C_1)
	Efficiency between airport and seaport (C_2)
	Efficiency of air/sea port (C_3)
	Efficiency to main Int. consumer market (C_8)
Re-export	Efficiency from main Int. raw & semi-product supply market (C_1)
	Efficiency between airport and seaport (C_2)
	Efficiency of air/sea port (C_3)
	Transshipment cost of sea-air multimodal (C_4)
	Reprocessing cost of domestic M-market (C_5)
	Reprocessing quality of domestic M-market (C_6)
	Efficiency between sea/air ports and M-market (C_7)
	Efficiency to main Int. consumer market (C_8)

Fig. 4. Grade fuzzy number $\tilde{R}_k$.

Table 2. Sample firms.

Characteristics	Number of respondents	Percentage of respondents
Firms		
Air /Sea carriers	9	19.1%
Hi-tech manufacturers	16	34.0%
Air/sea Freight forwarders	22	46.9%
Sex		
Male	39	82.9%
Female	8	17.1%
Educatiom		
High school	1	2.1%
Bacholor	23	49.0%
Master	21	44.7%
Doctor	2	4.2%
Ages range		
30-45	12	25.5%
46-56	27	57.5%
56-65	8	17.0%
Total	47	100%

Note: Interviews were conducted between September 2013 and February 2014.

Fig. 5. Decision making procedure of M-LM priority.

market (C_8) are both common evaluation criteria, while the other three criteria are determined based on the re-export type of M-LM.

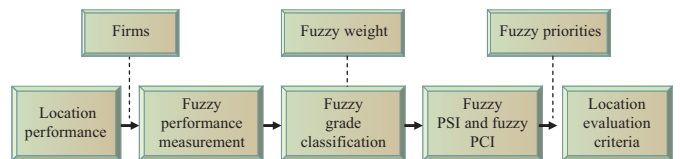## 2. Evaluating Procedure

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 A_1~A_3. 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.

Locations \ Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
A_1. Taipei	R_5	R_5	R_5	R_5	R_3	R_3	R_3	R_5
A_2. Taichung	R_2	R_3	R_3	R_3	R_4	R_4	R_4	R_3
A_3. Kaohsiung	R_4	R_4	R_4	R_3	R_3	R_3	R_3	R_3

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

Criteria	Consensus grade	Fuzzy weight	Criteria	Consensus grade	Fuzzy weight
C_1	V_2	(0.5,0.75,1.0)	C_5	V_2	(0.5,0.75,1.0)
C_2	V_1	(0.75,1.0,1.0)	C_6	V_1	(0.75,1.0,1.0)
C_3	V_1	(0.75,1.0,1.0)	C_7	V_3	(0.25,0.5,0.75)
C_4	V_2	(0.5,0.75,1.0)	C_8	V_4	(0.0,0.25,0.5)

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

Location	$\tilde{PS_i}$	$\mu_T(\tilde{PS_i})$	$\tilde{PC_i}$	$\mu_T(\tilde{PC_i})$
A_1. Taipei	(1.50, 2.25, 2.81)	0.68	(0.50, 0.75, 1.00)	0.70
A_2. Taichung	(1.13, 1.69, 2.19)	0.41	(0.00, 0.00, 0.00)	0.00
A_3. Kaohsiung	(0.88, 1.31, 1.69)	0.35	(0.50, 0.75, 1.00)	0.39

Remark: PSI: Project Satisfaction Index; PCI: Project Comparison Index.

Table 6. PSI and PCI value of re-export type of M-LM location.

Location	$\tilde{PS_i}$	$\mu_T(\tilde{PS_i})$	$\tilde{PC_i}$	$\mu_T(\tilde{PC_i})$
A_1. Taipei	(0.88, 1.31, 1.69)	0.35	(0.50, 0.75, 1.00)	0.39
A_2. Taichung	(1.13, 1.69, 2.19)	0.41	(0.00, 0.00, 0.00)	0.00
A_3. Kaohsiung	(1.13, 1.69, 2.19)	0.41	(0.00, 0.00, 0.00)	0.00

Remark: PSI: Project Satisfaction Index; PCI: Project Comparison Index.

Table 7. Priority for M-LM location development in Taiwan.

Location (A_i)	Transshipment PRI_i (priority)	Re-export PRI_i (priority)	TPRIi	priority
A_1. Taipei	0.44 (1)	0.89(1)	1.33	1
A_2. Taichung	1.28 (3)	1.16 (2)	2.44	3
A_3. Kaohsiung	0.79 (2)	1.16(2)	1.95	2

Table 8. Location priorities for a single mode of M-LM.

Locations	Transshipment type 0.5*	0.6*	0.7*	0.8*	Re-export type 0.5*	0.6*	0.7*	0.8*
A_1. Taipei	1	1	1	1	1	1	1	1
A^2. Taichung	3	3	3	3	2	2	2	2
A_3. Kaohsiung	2	2	2	2	2	2	3	3

*showed the weight variety of important degree at each type of M-LM.

4. Results Analysis

The satisfaction grade of the evaluation criteria of various potential locations can be classified into "very good (R_1)", "good (R_2)", "medium (R_3)", "poor (R_4)" and "very poor (R_5)". The logistics professionals tended 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 ($\tilde{PS_i}$), fuzzy project comparison index ($\tilde{PC_i}$), and corresponding crisp values ($\mu_T(\tilde{PS_i})$, $\mu_T(\tilde{PC_i})$) 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 $\tilde{PS_i}$ and $\tilde{PC_i}$. 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 (A_1), Kaohsiung (A_3), and Taichung (A_2).

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 (A_1), Kaohsiung (A_3), and Taichung (A_2) 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 (A_1), Kaohsiung (A_3) and Taichung (A_2) when the importance weight is 0.5*~0.6*, and the priorities are Taipei (A_1), Taichung (A_2), and Kaohsiung (A_3) 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
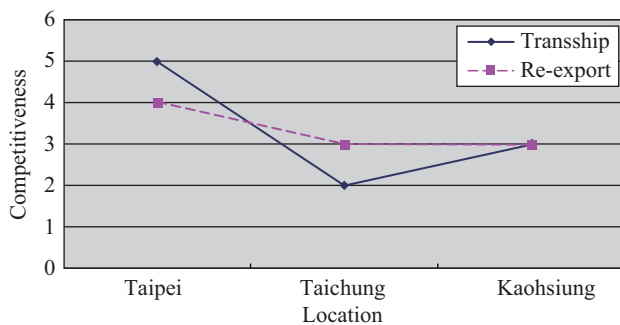
Fig. 6. Competitive relations of M-LM in Taiwan.

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 seaport 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 (C_5)', 'Reprocessing quality of domestic M-market (C_6)', and weakness in external conditions and in internal conditions of 'Transportation efficiency between airport and seaport (C_2)' and 'Efficiency of air/sea port' (C_3) as a re-export M-LM location. Kaohsiung has the advantage in internal conditions of 'Reprocessing cost of domestic M-market (C_5)' 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

Table 9. Location performance of potential M-LM locations in Taiwan.

Criteria	A_1. Taipei	A_2. Taichung	A_3. Kaohsiung
Internal environment			
Transportation efficiency between airport and seaport (C_2)	+	−	○
Efficiency of air/sea port (C_3)	+	−	○
Transshipment cost of sea-air multimodal (C_4)	+	○	○
Reprocessing cost of domestic M-market (C_5)	○	+	+
Reprocessing quality of domestic M-market (C_6)	+	+	○
Transportation efficiency between sea/air port and M-market (C_7)	−	○	−
External environment			
Transportation efficiency from main Int. raw & semi-product supply market (C_1)	+	−	○
Transportation efficiency to main Int. consumer market (C_8)	+	−	○

Remark: 1. "+" advantage, "−" disadvantage, "○" ordinary.
2. Advantages and disadvantages are determined by the fuzzy performance value of Appendix A and B.

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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REFERENCES

Brown, S. R. (1980). Political Subjectivity: Applications of Q Methodology in Political Science. Yale University Press, New Haven, CT.

Chen, S. J. and C. L. Hwang (1992). Fuzzy Multiple Attribute Decision Making: Methods and Applications. Springer-Verlag. New York.

Chou, C. C. (2010a). An Integrated Quantitative and Qualitative FMCDM Model for Location Choices. Soft Computing 14(7), 757-771.

Chou, C. C. (2010b). Application of FMCDM Model to Selecting the Hub Location in the Marine Transportation: A Case Study in Southeastern Asia. Mathematical and Computer Modelling 51(5/6), 791-801.

David, M. L. (2013). Not all baselines are created equal: A Q methodology analysis of stakeholder perspectives of additionality in a carbon forestry offset project in Costa Rica Original Research Article. Global Environmental Change 23(3), 654-663.

Ding, J. F. (2010). Critical factors influencing customer value for global shipping carrier-based logistics service providers using fuzzy AHP ap-

proach. African Journal of Business Management 4(7), 1299-1307.

Ding, J. F. and C. C. Chou (2012a). A fuzzy MCDM model to evaluate investment risk of location selection for container terminals. WSEAS Transactions on Information Science and Applications 9(10), 295-304.

Ding, J. F. and W. J. Tseng (2012b). Applying fuzzy AHP approach to evaluate key operational safety elements for exclusive container terminals of Kaohsiung port in Taiwan. WSEAS Transactions on Mathematics 11(10), 855-865.

Donner, J. C. (2011). Using q-sorts in participatory processes: an introduction to the methodology. In: Social Analysis: Selected Tools and Techniques. Social Development Papers. The World Bank, Social Development Department, Washington, DC, 24-59.

Feng, Z. W. (2006). The seaport study between Taiwan and China in example of Taichung port, Executive Master of Public Affair, Tunghai University (in Chinese).

Jane, B. P. and H. M. Karen (2015). Using Q-methodology to reveal nurse educators' perspectives about simulation design. Clinical Simulation in Nursing 11(1), 11-19.

Kaufmann, A. and M. M. Gupta (1985). Introduction to Fuzzy Arithmetic. Ban Nostrand. New York.

Lee, H. S., M. T. Chou and S. G. Kuo (2005). Evaluating port efficiency in Asia Pacific region with recursive data envelopment analysis. Journal of the Eastern Asia Society for Transportation Studies, 544-559.

Lee, K. L., W. C. Huang and J. Y. Teng (2009). Locating the competitive relationship of global logistics hub using quantitative SWOT analytical method. Quality and Quantity 43, 87-107.

Lee, K. L. and S. C. Lin (2008). A fuzzy quantified SWOT procedure for environmental evaluation of an international distribution center. Information Sciences 178, 531-549.

Lin, S. C. and K. L. Lee (2010). Fuzzy investment decision based on economic and strategic factors: A case of air logistics service provider. African Journal of Business Management 4(12), 2546-2553.

McKeown, B. F. and D. B. Thomas (2013). Q Methodology (2nd ed.). Los Angeles: Sage Publications.

Oum, T. H. and J. H. Park (2004). Multinational firms' location preference for regional distribution centers: focus on the Northeast Asian region. Trans-

portation Research Part E. 40, 101-121.

Prahalad, C. and Y. Doz (1987). The Multinational Mission: Balancing Local Demands and International Vision, N.Y.: Free press.

Robbins, S. P. (1994). Management, New York: McGraw-Hill.

Starr, M. and M. Zeleny (1997). MCDM: State and future of the arts, in Starr, M. and Zeleny, M. (eds.). Multiple Criteria Decision Making. North-Holland. Amsterdam, 179-210.

Satty, T. L. (1980). The Analytic Hierarchy Process, NY: McGraw-Hill.

Stenner, P., S. Watts and M. Worrell (2007). Q methodology. In: Willig-Stainton-Rogers. The Sage Handbook of Qualitative Research in Psychology, 215-239.

Tai, H. H. and C. C. Hwang (2005). Analysis of hub port choice for container trunk lines in East Asia. Journal of the Eastern Asia Society for Transportation Studies, 907-919.

Teng, J. Y. (1997). The Project Evaluation of Army Technical Research. Huafan University.

Teng, J. Y. and G. H. Tzeng (1996). Fuzzy multicriteria ranking of urban transportation investment alternatives. Transportation Planning and Technology 20, 15-31.

Teng, J. Y. and G. H. Tzeng (1998). Transportation investment project selection using fuzzy multiobjection programming. Fuzzy Sets and Systems 96, 259-280.

Vivica, I. K., S. Boyd, L. Mark and H. Paul (2014). A Q methodology study of stakeholders' views about accountability for promoting healthy food environments in England through the Responsibility Deal Food Network Original Research Article. Food Policy 49(1), 207-218.

Vos, B. and E. van den Berg (1996). Assessing international allocation strategies. International Journal of Logistics Management 7(2), 69-84.

Watts, S. and P. Stenner (2012). Doing Q methodological research: theory, method and interpretation. Sage Publications Ltd., Thousand Oaks, CA and London.

Yeo, K. T. and D. W. Song (2003). An evaluation of container ports in china and Korea with the analytic hierarchy process. Journal of the Eastern Asia Society for Transportation Studies 5, 726-741.

Zadeh, L. A. (1965). Fuzzy Sets. Information and Control 8, 338-353.