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AN EMPIRICAL STUDY ON ASSESSING OPTIMAL TYPE OF DISTRIBUTION PARK: APPLYING FUZZY MULTICRITERIA Q-ANALYSIS METHOD

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Abstract: In this paper, through an empirical study it is explored how respondents viewed suitable modes on locations for developing a distribution park. A fuzzy multiple criteria Q-analysis (MCQA) method is used to empirically evaluate location development for suitable types of international distribution park. The fuzzy MCQA method integrates MCQA, a fuzzy measure method and a fuzzy grade classification method. This improves the constraints evaluated by decision-makers, resulting in an explicit result value for each criterion to be evaluated, greatly decreasing the complexity of the evaluation process and preserving the advantages of the traditional MCQA method.

Keywords: International distribution park, evaluation criteria, fuzzy MCQA method, grade classification method.

MSC: 90-06

1. INTRODUCTION

In timely response to customer demands for modern commercial distribution, firms focus on the storage of many basic materials in a few strategic logistics bases, thus contributing to differentiation in logistics services. To develop a distribution park, government needs to craft polices that attract firms [18, 12]. From the perspective of firms, a distribution park provides a place for firms to achieve a number of functional activities, including transportation, storage, consolidation, assembly, inspection, labeling, packaging, financing, information, and R&D services for varying periods of time [8, 12]. Several logistics parks have been established at major Asian port cities, including Shanghai Waigaoqiao Bond Distribution park (Shanghai), Hong Kong International Distribution center (Hong Kong), and Kepple Distripark (Singapore).

Given the significant role of distribution parks in the survival and prosperity of firms, issues such as the location of distribution centers and their degree of consolidation remain a tremendous challenge for managers of firms operating in globalized industries [10, 19]. However, though the distribution centers vary by location, there is a common realization that markets should be segmented based on customer attribution requirements [5, 6, 20]. It is important for a location (city) to provide suitable sites, with competitive abilities, that offer a variety of potential logistic services functions.

The preference evaluation for distribution parks is the Multiple Criteria Decision-Making (MCDM) problem. As the evaluative criteria of MCDM problems mix quantitative and qualitative values and the values for qualitative criteria, they are often imprecisely defined. Fuzzy set theory was developed based on the premise that the key elements in human thinking are not numbers, but linguistic terms or labels of fuzzy sets [1, 22]. Hence, a fuzzy decision-making method under multiple criteria considerations is needed to integrate various linguistic assessments and weights to evaluate location suitability and determine the best selection [2].

The multiple criteria Q-analysis (MCQA) method, an extended branch of Q-Analysis method, is used to address multiple criteria and multiple aspect decision making problems. Incorporating the performance fuzziness measurement and the fuzziness multicriteria grade classification method of Teng [16], this paper uses fuzzy MCQA methods to improve the performance judgments of decision-makers.

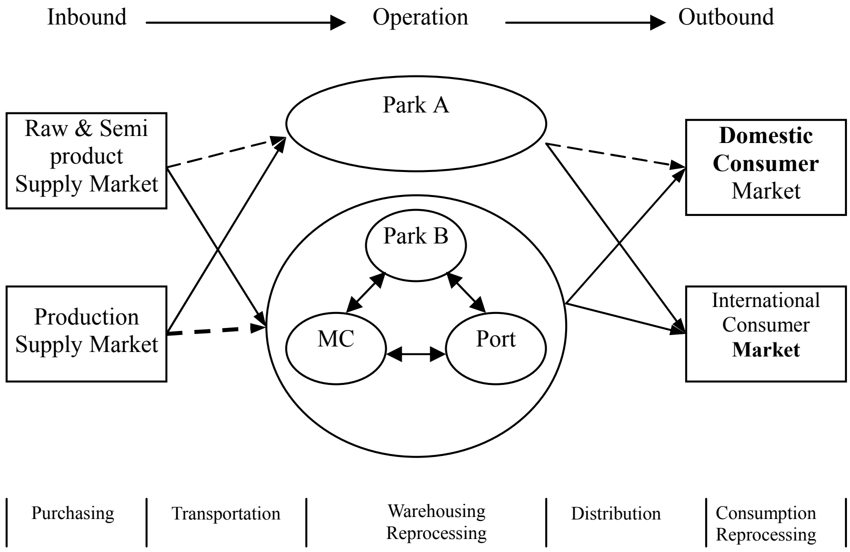
Previous studies examined determinants affecting firms' evaluation of operations, logistics, distribution, and transshipment centers in particular regions [9, 14, 21, 7]. To our knowledge, there have been few empirical studies examining different types of distribution parks among potentially competing locations. Therefore, this paper aims to evaluate the preference relations for locations developing different types of distribution parks in central Taiwan from the perspective of firms in Taiwan.

2. SPECIFICATION OF GLOBAL DISTRIBUTION PARK

Figure 1 shows the competitive scenario of locations developing distribution parks by addressing the inbound, operations, and outbound logistics stages [8]. In analyzing the location competition for distribution parks, it is important to evaluate the logistics activities in various locations. The managerial decision depends on the competitive conditions of a given location's environment. Distribution parks are distinguished by the viewpoints of value-added and location competition. The distinctive operational features of the four types of distribution parks are described below.

Type 1: Import-Export (IM/EX) type of distribution park

This type of distribution park moves Origin/Destination (O/D) cargos from the product supply marketplace to the domestic consumer marketplace. Another type moves cargos from the domestic manufacturing marketplace to the international consumer marketplace. The type of distribution park provides the services encompassing transportation within national borders, warehousing, consolidation, and distribution functions. Participating firms might include shipping or airline carriers, freight forwarders, and customs brokers. In this type of distribution park, the port plays a key role in providing the circumstances of the logistics functions.



MC: Manufacturing Center
Port: sea/air port

Figure 1: The activities of a distribution park

Type 2: Transshipment type of distribution park

The transshipment distribution park carries out international goods distribution for global logistics activities. It provides several main functions in an integrated logistics system, including transportation, storage, consolidation, and distribution functions. Several ports have been provided by the transshipment distribution parks, or distribution center facilities such as Kepple Distri-park (Singapore) and Hong Kong International Distribution Center (Hong Kong).

Type 3: Reprocessing import (Re-import) type of distribution park

This type supports cargo flow from the marketplace, importing raw materials or semi-finished products, to the domestic consumer marketplace after cargo reprocessing by firms supporting the domestic manufacturing marketplace. Functions provided include transportation, warehousing, hi-tech reprocessing, consolidation, and distribution functions of participants such as shipping and airline carriers, hi-tech firms, freight forwarders, and custom brokers. In this type of distribution park, local manufacturing industries and ports are the key shapers of the circumstances of the logistics functions.

Type 4: Reprocessing export (re-export) type of distribution park

The functions were provided by the participants of shipping or airline carriers, freight forwarders, hi-tech firms and customs brokers. For this type of park, a hi-tech industrial environment and port conditions are the key determinants. In response to the rapid development of global logistics activities, many locations were transformed, from the role of transshipment to a re-export service [8]. For example, in Taiwan, a large number of foreign multinational corporations (MNCs) order information technology commodities from local Original Equipment Manufacturers (OEM) [4].

Considering the key factors of four types of distribution parks, the major criteria for location decisions include transportation convenience, rental cost, land, distance from consumer markets, distance from industrial zones, distance from air/sea ports, and distance from export processing zones. These criteria were viewed as relevant by 21 logistics executives, and accepted as possessing content validity. Based on the literature review of criteria considered important to firms when making decisions on locations for distribution parks, 7 indicators (Table 1) were selected for inclusion in the present study's questionnaire.

Table 1: Evaluation criteria of four types of distribution park

Criteria	IM/EX	Re-import	Transship.	Re-export
Transportation convenience (C_1)	※	※	※	※
Rental cost (C_2)	※	※	※	※
Nature environment (C_3)	※	※	※	※
Distance from main consumer market (C_4)	※	※		
Distance from industrial zone (C_5)		※		
Distance from airport/seaport (C_6)	※		※	※
Distance from export processing zone (C_7)				※

3. METHODOLOGY

Incorporating the performance fuzziness measurement and fuzziness multi-criteria grade classification method of Teng [16], this paper uses fuzzy MCQA to improve the performance of distribution park evaluation decisions.

3.1. Fuzzy measurement of location performance

Assuming that there are found *n* alternatives $A = \left\{ A_i \left| i = 1, 2, ..., n \right. \right\}, (n \ge 1)$ under *m* evaluation criteria $C = \left\{ C_j \left| j = 1, 2, ..., m \right. \right\}, (m \ge 2)$, if the performance value measured by each evaluation criterion is classified into *p* grades $R = \left\{ R_k \left| k = 1, 2, ..., p \right. \right\}, (p \ge 2)$, grade R_{ijk} of the subjective judgment of responders upon A_i location under C_j criteria is represented below:

$$R_{ijk} = \{R_k \,|\, k = 1, 2, ..., p\}, \forall i, j \tag{1}$$

Where, R_{ijl} denotes an element performance value of a higher degree of satisfaction of subjective judgment made by responders evaluating A_i alternative under C_j criteria, R_{ij2} represents another element performance value of the another next higher degree of satisfaction and R_{ijp} by dissatisfaction, and so on. Under each evaluation criterion, the linguistic variables, such as "very satisfactory", "satisfactory", "ordinarily acceptable", "dissatisfactory" and "rather dissatisfactory", are fuzzy linguistics that may 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 [2]. Saaty [11] showed that five scales are a basic judgment method for 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 the five grades can be represented by triangular fuzzy numbers, i.e. $\tilde{R}_k (k = 1, 2, ..., 5)$ showed the fuzzy performance value of k grade for each of the alternatives. The fuzzy performance value of k grade is measured as [0, 100], the rating interval of $\tilde{R}_k$ is represented by the following formula:

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

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} □ x_k , and the crisp performance value is x_{kb} . The membership function $u_{\tilde{R}_k}(x)$ for each of the alternatives, denoted 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 [11], humans will find it difficult to clearly judge adjacent scales, but find it easy to distinguish separated scales. For example, it is difficult to distinguish between 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. For this reason, this paper has defined five satisfaction grades of fuzzy performance values as shown in Figure 2.

3.2. Fuzzy grade classification method

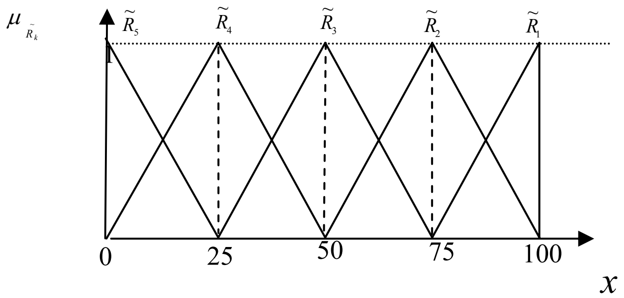
Assuming that there are *N* responders expressed by $E = \{E_h \mid h = 1, 2, ..., N\}$, the fuzzy performance values for each of locations A_i under criteria C_j are represented by $\tilde{r}_{ij} (i = 1, 2, ..., n; j = 1, 2, ..., m)$. Thus, it is possible to measure the percentage of every grade of responders amongst the gross number as detailed below:

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

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

Where, N_{ijk} denotes the performance value judged by the k^{th} responder of A_i location as R_k grade under C_j criteria, and N_{ij} by the total number of responders. In the case in which every responder makes judgment, $N = N_{ij}$; otherwise, $N_{ij} < N_0$. $\tilde{\Sigma}$ indicates fuzzy summation, and symbol $\otimes$ indicates fuzzy multiplication. Once the responders finish the evaluation of the alternative locations, the fuzzy preference structure matrix $\tilde{P}$ of A_i location under C_j criteria can be obtained:

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



fuzzy grade range：

$\tilde{R}_1 = (75, 100, 100)$

$\tilde{R}_2 = (50, 75, 100)$

$\tilde{R}_3 = (25, 50, 75)$

$\tilde{R}_4 = (0, 25, 50)$

$\tilde{R}_5 = (0, 0, 25)$

Figure 2. Grade fuzzy number $\tilde{R}_k$

Since N_{ijk} and N_{ij} are constants, the fuzzy value $\tilde{r}_{ij}$ is a triangular fuzzy number [18]. $\tilde{r}_{ij}$ and $\tilde{R}_k$ fuzzy numbers thus must be compared to determine which grade

$\tilde{r}_{ij}$ they belong to. In other words, it is possible to make judgment based on the percentage of the area of $\tilde{r}_{ij}$ fuzzy numbers among the area of $\tilde{R}_k$ fuzzy numbers, i.e. obtaining the value α_{ijk} of R_k grade as shown in Figure 3. The area of $\tilde{r}_{ij}$ among $\tilde{R}_k$ is represented by the oblique shadow. After obtaining the area of oblique shadow among $\tilde{R}_k$ grade (i.e. percentage of triangle ABC), it is possible to gain the various grade values α_{ijk} , which can be shown by the ratio between two ordinary integrals of membership functions as below:

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

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

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

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

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

$$1.\ \beta_1 \geq M \quad then\ \ \tilde{r}_{ij} \in R_1\ ; otherwise$$
$$2.\ \beta_2 \geq M \quad then\ \ \tilde{r}_{ij} \in R_2\ ; otherwise$$
$$\vdots$$
$$(p-1).\ \beta_{p-1} \geq M \quad then.\ \ \tilde{r}_{ij} \in R_{p-1}; otherwise\ \ \tilde{r}_{ij} \in R_p$$

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 ; otherwise to grade R_2 . Since, in principle, the M value exceeds one half or two-thirds, the M value is often 0.5 or 0.7. Assuming β_1 and β_2 respectively represent the membership grades of $\tilde{r}_{ij} \in R_1$ and $\tilde{r}_{ij} \in R_2$, and $\beta_1 + \beta_2 = 1$, the following three cases are 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 $\tilde{r}_{ij} \in R_2$

Further, when the grade is classified into three variables: $R = \{R_1, R_2, R_3\}$, the grade classification of the fuzzy value $\tilde{r}_{ij}$ may be evaluated as per two grade classification modes, i.e. $R_1' = \{R_1, R_2 \text{ or } R_3\}$, $R_2' = \{R_2 \text{ or } R_3\}$. Meanwhile, it is possible to search the respective membership grade ($\beta_1, \overline{\beta}_1$), ($\beta_2, \overline{\beta}_2$), and $\beta_1 + \overline{\beta}_1 = 1$, $\beta_2 + \overline{\beta}_2 = 1$. Thus, the grade classification can be further implemented, based upon β_1 and β_2, as detailed below:

1. $\beta_1 \geq M$, then $\tilde{r}_{ij} \in R_1$
2. $\overline{\beta}_1 \geq M$, 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) $\overline{\beta}_2 \geq M$, *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 αijk, the membership grade of various grades $\beta_{ijk} \, (i = 1,2,...,n; j = 1,2,...,m; k = 1,2,..., p)$ can be obtained from the following formula:

$$\begin{aligned}
\beta_{ij1} &= \sum_{k=1}^{1} \alpha_{ijk} \Big/ \sum_{k=1}^{p} \alpha_{ijk} \\
\beta_{ij2} &= \sum_{k=1}^{2} \alpha_{ijk} \Big/ \sum_{k=1}^{p} \alpha_{ijk} \\
&\vdots \\
\beta_{ij(p-1)} &= \sum_{k=1}^{p-1} \alpha_{ijk} \Big/ \sum_{k=1}^{p} \alpha_{ijk} \\
\beta_{ijp} &= 1
\end{aligned} \tag{8}$$

3.3. Fuzzy weight

In this paper, we classify the importance level of evaluation criteria into five grades, i.e. “absolute importance”, “demonstrated importance”, “essential importance”, “weak importance” and “importance”. These may all be represented as $V = \{V_l \mid l = 1,2,\ldots,5\}$, 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 still fuzzy linguistics, we adopted triangular fuzzy numbers $\tilde{V} = \{\tilde{V}_l \mid l = 1,2,\ldots,5\}$ to represent the scores of the five grades, with the corresponding fuzzy numbers shown in Figure 3, in which only $\tilde{R}_k$ is converted into $\tilde{V}_l$. With the introduction of a [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 $x_{lc} \geq x_{lb} \geq x_{la}$.

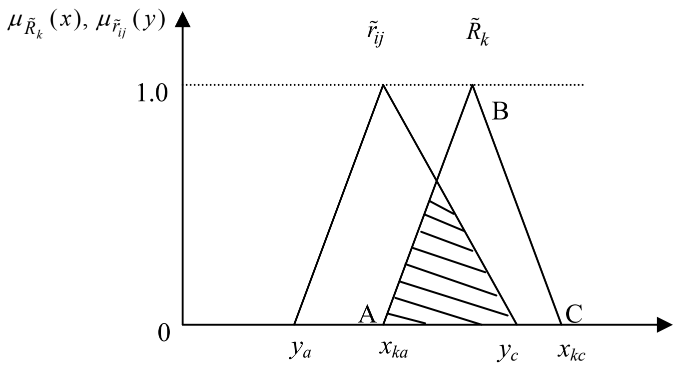


Figure 3: R_k grade attribution

If N logistics professionals judge the importance level of evaluation criteria as $V_l (l = 1, 2, ..., 5)$ grades, than Y_{hj}:

$$Y_{hj} = V_l \quad , j = 1,2,..,m \,; h = 1,2,..,N \,; l = 1,2,..,5 \tag{9}$$

The grade judgment matrix of N logistics professionals may then be represented by Y:

$$Y = [Y_{hj}]_{N \times m} \tag{10}$$

According to the grade matrix Y of importance level and majority rule, it is possible to obtain the grade of consensus weight under each evaluation criterion. Taking $Z[V1]j$ as the number of N logistics professionals who judge the importance under Cj criteria as grade Vl, and $Z\left[\Sigma^{V_l}\right]j$ as the number of professionals who grade Vl summated to grade Vl, namely:

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

If the importance level of consensus judgment under C_j evaluation criteria is judged as grade V_1, it shows that the importance level under C_j evaluation criteria meets the grades from V_2 to V_5, namely, grade V_1 includes grades V_2 ~V_5. 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_5 apart from grade V_1, namely, grade V_2 implies grades V_3 ~V_5 apart from grade V_1. According to the majority rule, $Z\left[V1\right]j$ must exceed a certain majority value M, 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 majority rule [15, 17]:

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

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

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

3.4. Fuzzy MCQA approach

In the case of grade R_k, grade R_{ijk} within preference structure matrix $\tilde{PR}$ can be represented by 1, otherwise, it is represented by 0. Therefore, the preference structure matrix within formula (10) can be converted into the following p 0-1 type incidence matrix B_{R_k} $\left(k = 1,2,\ldots,p\right)$:

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

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

Further, for the incidence matrix of every 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 - connectivi ty matrix

$\left[B_{R_k}\right]^T$: the transfer matrix of the incidence matrix

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

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

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

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

$$q^*_{iR_k} = \underset{\substack{i'=1,2,\ldots,n \\ i\neq i'}}{\max imum}\, S^{R_k}(i\,,i') \tag{21}$$

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

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 upon A_i. The bigger the criteria, the better the performance is. As the fuzzy project satisfaction index can only measure the absolute satisfaction with various alternatives rather than the relative satisfaction, the fuzzy comparison index must be obtained in order to compare the alternatives. However, pairwise comparison methods will complicate the calculation. In an effort to simplify the mathematical operation, it is often assumed that preference transitivity will occur [13]. In this paper, it is also assumed that preference transitivity will take place. Therefore, when obtaining the value of $\tilde{PC}_i$, only the maximum $q^*_{iR_k}$ for comparison with $\hat{q}_{iR_k}$ is necessary, without consideration of complex pairwise comparison methods.

As both $\tilde{PS}_i$ and $\tilde{PC}_i$ are fuzzy numbers, it is unlikely that they may be compared directly as crisp values, so a defuzzier is required. Based upon the ranking method of fuzzy numbers for Kim-Park as modified by Teng and Tzeng [15], we convert the fuzzy numbers of $\tilde{PS}_i$ and $\tilde{PC}_i$ into real numbers. Take $\tilde{PH}_i$ as the general expression of $\tilde{PS}_i$ and $\tilde{PC}_i$ as shown below:

$$\tilde{PH}_i = (LH_i, MH_i, RH_i)\,, \quad i = 1,2,\ldots,n \tag{23}$$

Take S as the range of all alternative' $\tilde{PH}_i$ measurement values as well as a universe of discourse, of which s is an element of the set S showing an optional value within the range of S. Take α_i value between〔0, 1〕as the optimistic attitude of experts upon alternatives, whereas (1-α_i) shows a pessimistic attitude. If $u_o(\tilde{PH}_i)$ 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.

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

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

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

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

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

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

$$s_{\max} = \sup \ \mathrm{S} \tag{30}$$

$$s_{\min} = \inf \ S \tag{31}$$

$$S = \bigcup_{i \in A} \tilde{PH}_i \tag{32}$$

As for the fuzzy MCQA model in this paper, based upon the defuzzier value of $\tilde{PS}_i$ and $\tilde{PC}_i$, we attempt to obtain the evaluation ranking of alternatives via the MCQA concept. A_i project rating index PRI_i, can be obtained from the following formula:

$$PRI_i = \left[\left(1 - u_T\left(\tilde{PS}_i\right)\right)^r + \left(1 - u_T\left(\tilde{PC}_i\right)\right)^r\right]^{1/r} , \ \forall\, i \tag{33}$$

The smaller the PRI_i value is, the closer the distance between an alternative's vector and its ideal vector, i.e. the better the alternative is; otherwise, the worse the alternative is. Since the concept of Euclidean distance is applied to formula (33), the r value is often determined to be 2.

4. EMPIRICAL STUDY

Eight candidate locations in central Taiwan are assessed for development of distribution parks: Taichung Port (L_1), Taichung Airport (L_2), the Taichung Industrial Zone (L_3), the Central Taiwan Science Park (L_4), the Taichung Export Processing Zone (L_5), the Chungkang Export Processing Zone (L_6), the Taichung Precision Machinery Technological Park (L_7), and the Changhua Coastal Industrial Park (L_8). They are evaluated by comparing respondents' satisfaction with the ability of the locations to meet each investment criterion.

4.1. Structure and procedure

For assessing distribution park locations, a hierarchical structure of the evaluation system was constructed (Figure 4) in accordance with the evaluation criteria. Figure 5 shows the framework of the decision-making of the distribution park location. This paper's fuzzy MCQA approach, which integrates the fuzzy measurement, fuzzy grade classification, fuzzy weight and MCQA method, is used to assess the location decision.

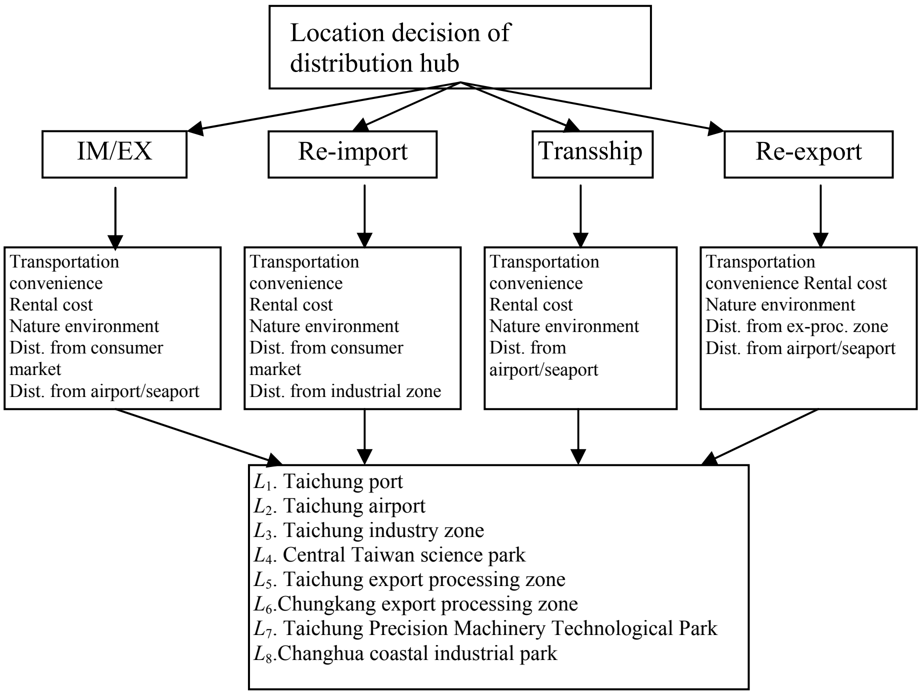


Figure 4. Multicriteria evaluative system of distribution park

This approach is intended to collect the actual quantification and qualification performance value of various locations in order to facilitate the decision-making for the location of distribution parks. However, because the satisfaction of logistics professionals with actual performance values differs, we measure their satisfaction via the fuzzy measurement method, and then classify the grade of the performance value via the fuzzy grade classification method. In an effort to assess the importance level of evaluation criteria, we tried to obtain the fuzzy weight via majority rule. Further, based upon the fuzzy grade and fuzzy weight as well as the MCQA method, the various locations' fuzzy project satisfaction index and fuzzy project comparison index are acquired, and finally defuzzified via the fuzzy ranking method to obtain the Project Rating Index (PRI) of each location.

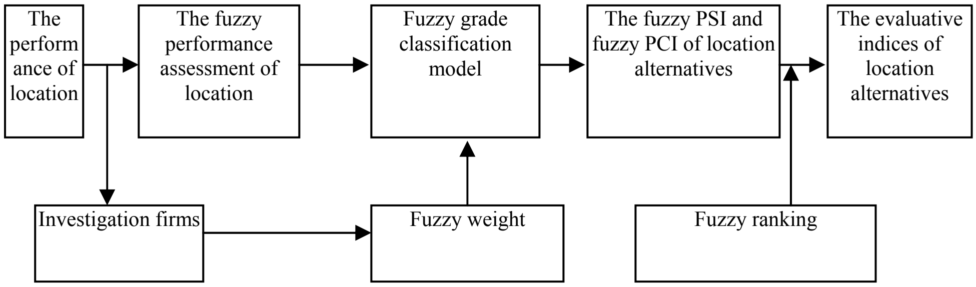


Figure 5: Decision approach of international distribution park

4.2. Analysis

A structured questionnaire is used to assess the preference relationships between distribution parks based on the seven stages outlined by Churchill [3]. Due to the limitations of time and cost, the questionnaire was sent to the managers of international logistic services providers (28), and multinational manufacturing firms (24) in central Taiwan. Amongst the evaluation criteria of the four types of distribution parks, the satisfaction grade of the various potential locations may be classified into "very good(R_1)", "good(R_2)", "medium (R_3)", "poor(R_4)" and "very poor(R_5)". For the different preferences of each logistics professional, the fuzzy measurement method was used to assess the preference, and the fuzzy grade classification method was used to obtain the grade of potential locations under each evaluation criterion, with the detailed results listed in Table 2.

Table 2: The classification contribution of candidate location at each criterium

	Criteria						
Location	C_1	C_2	C_3	C_4	C_5	C_6	C_7
L_1	R_2	R_4	R_2	R_3	R_2	R_1	R_3
L_2	R_2	R_3	R_3	R_3	R_3	R_3	R_2
L_3	R_3	R_3	R_3	R_2	R_2	R_2	R_4
L_4	R_2	R_3	R_3	R_2	R_2	R_1	R_4
L_5	R_2	R_4	R_3	R_3	R_3	R_4	R_2
L_6	R_3	R_3	R_3	R_3	R_2	R_2	R_3
L_7	R_3	R_2	R_3	R_3	R_3	R_3	R_2
L_8	R_3	R_3	R_3	R_3	R_3	R_4	R_2

In terms of the weight of criteria, we classified the importance level of evaluation criteria into five grades, i.e. "absolute importance (V_1))","demonstrated importance (V_2)", "essential importance (V_3)", "weak importance (V_4)" and "importance (V_5)". The logistics professionals tend to judge the grade according to the importance of every evaluation criterion, which often generates different results of judgment. So, we intended to obtain the fuzzy weight particular to common grade via majority rule, with the results listed in Table 3.

Table 3: The consensus grade and fuzzy weight of criteria C_j

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

It is possible to analyze and obtain four groups of fuzzy project satisfaction index ($\tilde{PS}_i$), fuzzy project comparison index ($\tilde{PC}_i$), and corresponding crisp values($\mu_T(\tilde{PS}_i)$, $\mu_T(\tilde{PC}_i)$) via fuzzy MCQA method (see Table 4, Table 5, Table 6, Table 7). Then, the project rating index (*PRI*) of various potential locations can be obtained from formula (33) according to the crisp value of $\tilde{PS}_i$ and $\tilde{PC}_i$. Given the same importance of four types of distribution parks in international distribution park, it is possible to calculate the gross project rating index of various potential locations, the smaller the value, the better the results are. Therefore, ranking the priority of various potential international distribution park locations provides the results listed in Table 8. There can be found the satisfaction grade of 52 logistics professionals upon 8 potential locations of distribution park, where the top three are Taichung port (L_1), Central Taiwan science park (L_4) and Taichung industry zone (L_3).

Table 4: PSI and PCI value of import/export type of distribution park

Location (A_i)	$\tilde{PS}_i$	$\mu_T(\tilde{PS}_i)$	$\tilde{PC}_i$	$\mu_T(\tilde{PC}_i)$
L_1	(1.63, 2.44, 3.06)	0.60	(0.50, 0.75, 1.00)	0.39
L_2	(1.00, 1.44, 1.69)	0.31	(0.00, 0.00, 0.00)	0.00
L_3	(1.13, 1.69, 2.19)	0.41	(0.00, 0.00, 0.00)	0.00
L_4	(1.88, 2.75, 3.44)	0.69	(0.00, 0.00, 0.00)	0.00
L_5	(0.75, 1.06, 1.19)	0.19	(0.00, 0.00, 0.00)	0.00
L_6	(0.88, 1.31, 1.69)	0.30	(0.00, 0.00, 0.00)	0.00
L_7	(0.88, 1.31, 1.69)	0.30	(0.00, 0.00, 0.00)	0.00
L_8	(0.50, 0.75, 0.94)	0.10	(0.00, 0.00, 0.00)	0.00

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

Table 5: PSI and PCI value of re-import type of distribution park

Location (A_i)	$\tilde{PS}_i$	$\mu_T(\tilde{PS}_i)$	$\tilde{PC}_i$	$\mu_T(\tilde{PC}_i)$
L_1	(1.25, 1.88, 2.31)	0.55	(0.50, 0.75, 1.00)	0.39
L_2	(1.00, 1.44, 1.69)	0.37	(0.00, 0.00, 0.00)	0.00
L_3	(1.13, 1.69, 2.19)	0.50	(0.50, 0.75, 1.00)	0.39
L_4	(1.50, 2.19, 2.69)	0.67	(0.00, 0.00, 0.00)	0.00
L_5	(0.88, 1.25, 1.44)	0.29	(0.00, 0.00, 0.00)	0.00
L_6	(0.88, 1.31, 1.69)	0.35	(0.50, 0.75, 1.00)	0.39
L_7	(0.88, 1.31, 1.69)	0.35	(0.00, 0.00, 0.00)	0.00
L_8	(0.63, 0.94, 1.19)	0.18	(0.00, 0.00, 0.00)	0.00

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

Table 6: PSI and PCI value of transshipment type of distribution park

Location (A_i)	$\tilde{PS}_i$	$\mu_T(\tilde{PS}_i)$	$\tilde{PC}_i$	$\mu_T(\tilde{PC}_i)$
L_1	(1.50, 2.25, 2.81)	0.68	(0.50, 0.75, 1.00)	0.70
L_2	(0.88, 1.25, 1.44)	0.34	(0.00, 0.00, 0.00)	0.00
L_3	(0.75, 1.13, 1.44)	0.32	(0.00, 0.00, 0.00)	0.00
L_4	(1.50, 2.19, 2.69)	0.67	(0.00, 0.00, 0.00)	0.00
L_5	(0.63, 0.99, 0.94)	0.19	(0.00, 0.00, 0.00)	0.00
L_6	(0.75, 1.13, 1.44)	0.32	(0.00, 0.00, 0.00)	0.00
L_7	(0.75, 1.13, 1.44)	0.32	(0.00, 0.00, 0.00)	0.00
L_8	(0.38, 0.56, 0.69)	0.09	(0.00, 0.00, 0.00)	0.00

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

Table 7: PSI and PCI value of re-export type of distribution park

Location (A_i)	$\tilde{PS}_i$	$\mu_T(\tilde{PS}_i)$	$\tilde{PC}_i$	$\mu_T(\tilde{PC}_i)$
L_1	(0.88, 1.31, 1.56)	0.54	(0.50, 0.75, 1.00)	0.70
L_2	(1.13, 1.63, 1.94)	0.69	(0.00, 0.00, 0.00)	0.00
L_3	(0.38, 0.56, 0.69)	0.14	(0.00, 0.00, 0.00)	0.00
L_4	(0.75, 1.06, 1.19)	0.40	(0.00, 0.00, 0.00)	0.00
L_5	(1.00, 1.44, 1.69)	0.60	(0.00, 0.00, 0.00)	0.00
L_6	(0.50, 0.75, 0.94)	0.26	(0.00, 0.00, 0.00)	0.00
L_7	(0.75, 1.13, 1.44)	0.47	(0.00, 0.00, 0.00)	0.00
L_8	(0.75, 1.13, 1.44)	0.47	(0.00, 0.00, 0.00)	0.00

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

Table 8: Ranking order for location developing distribution park in middle Taiwan

Location	Type				$TPRI_i$	Order
	IM/EX	Re-import	Transship.	Re-export		
	PRI_i	PRI_i	PRI_i	PRI_i		
L_1	0.73	0.76	0.44	0.55	2.48	1
L_2	1.21	1.18	1.20	1.05	4.64	5
L_3	1.16	0.79	1.21	1.32	4.48	3
L_4	1.05	1.05	1.05	1.17	4.32	2
L_5	1.29	1.23	1.28	1.08	4.88	7
L_6	1.22	0.89	1.21	1.25	4.57	4
L_7	1.22	1.19	1.21	1.13	4.75	6
L_8	1.34	1.29	1.35	1.13	5.11	8

5. CONCLUSION

The location decision of distribution parks takes into account the influence of multiple criteria and uncertainties. The main contribution of this paper is that we propose a fuzzy MCQA approach that integrates the fuzzy grade measurement, fuzzy grade classification and MCQA method to help decision makers make subjective judgments via linguistics variables, which are fuzzy in nature. This approach requires respondents to merely judge the satisfaction grade of alternatives rather than granting scores, thereby making judgments in a timely and efficient way while maintaining the advantages of the traditional MCQA method.

The paper explores the location decision for establishing distribution parks in central Taiwan, and eight locations, which were subsequently compared for distribution parks based on respondents' perceptions of their ability to meet evaluation criteria. After separately analyzing the impact upon the rank of potential locations for distribution parks, the results show that the Taichung Port, the Central Taiwan Science Park, and the Taichung industrial Zone were the respondents' preferred investment locations.

For management, the implication of this paper is that the approach here demonstrated will actually lead to improved location choice for distribution centers. It can be inferred that as locations become more competitive, adopting new processes, operational routines, and investing in new technological systems, distribution center effectiveness in terms of ability to fulfill promises, meet standards and solve problems, will improve.

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