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

K.L. LEE
Overseas Chinese University, Taiwan
lee.kl@ocu.edu.tw

S.C. LIN
Overseas Chinese University, Taiwan
shuchen@ocu.edu.tw

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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.

**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

<table>
<thead>
<tr>
<th>Criteria</th>
<th>IM/EX</th>
<th>Re-import</th>
<th>Transship</th>
<th>Re-export</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation convenience ($C_1$)</td>
<td>❌</td>
<td>❌</td>
<td>❌</td>
<td>❌</td>
</tr>
<tr>
<td>Rental cost ($C_2$)</td>
<td>❌</td>
<td>❌</td>
<td>❌</td>
<td>❌</td>
</tr>
<tr>
<td>Nature environment ($C_3$)</td>
<td>❌</td>
<td>❌</td>
<td>❌</td>
<td>❌</td>
</tr>
<tr>
<td>Distance from main consumer market ($C_4$)</td>
<td>❌</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance from industrial zone ($C_5$)</td>
<td></td>
<td>❌</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance from airport/seaport ($C_6$)</td>
<td>❌</td>
<td>❌</td>
<td>❌</td>
<td>❌</td>
</tr>
<tr>
<td>Distance from export processing zone ($C_7$)</td>
<td></td>
<td></td>
<td></td>
<td>❌</td>
</tr>
</tbody>
</table>

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

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

Where, $R_{ijk}$ 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, $R_{ij}$ 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:

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

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

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

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

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

(4)

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

(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, \(N_{ij} < N_0\). \(\Sigma\) 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:

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

(6)

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
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 \( \alpha_{ijk} \) 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
\( \alpha_{ijk} \), which can be shown by the ratio between two ordinary integrals of membership
functions as below:

\[
\alpha_{ijk} = \frac{\int_{y \in D_i} u_{ij}(y) dy}{\int_{x \in D_i} u_{ik}(x) dx}, \forall i, j, k
\]  

(7)

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

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

\[
R'_1 = \{ R_1, R_2, or R_3 or...or , R_p \}
\]  

\[
R'_2 = \{ R_2, R_3, or R_4 or...or , R_p \}
\]  

\vdots

\[
R'_{p-1} = \{ R_{p-1}, R_p \}
\]

The fuzzy value \( \tilde{r}_{ij} \) may be evaluated according to \( R'_1, R'_2, ..., R'_{p-1} \) 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. \( \beta_1 \geq M \quad then \quad \tilde{r}_{ij} \in R_1; otherwise \)
2. \( \beta_2 \geq M \quad then \quad \tilde{r}_{ij} \in R_2; otherwise \)

\vdots

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

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 \( R_i \) reaches the threshold value \( M \), the fuzzy value \( \tilde{r}_{ij} \) under \( c_i \) 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 \( \beta_1 \) and \( \beta_2 \) respectively
represent the membership grades of \( r_{ij} \in R_1 \) and \( r_{ij} \in R_2 \), and \( \beta_1 + \beta_2 = 1 \), the following three cases are found:

1. \( \beta_1 > M \), then \( r_{ij} \in R_1 \)
2. \( \beta_1 = M \), then \( r_{ij} \in R_1 \) or \( r_{ij} \in R_2 \)
3. \( \beta_2 > M \), then \( r_{ij} \in R_2 \)

Further, when the grade is classified into three variables: \( R = \{R_1, R_2, R_3\} \), the grade classification of the fuzzy value \( r_{ij} \) may be evaluated as 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 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 \( \beta_1 \) and \( \beta_2 \) as detailed below:

1. \( \beta_1 \geq M \), then \( r_{ij} \in R_1 \)
2. \( \overline{\beta}_1 \geq M \), then \( r_{ij} \in R_2 \) or \( r_{ij} \in R_3 \), depend on \( \beta_2 \)

(1) \( \beta_2 \geq M \), then \( r_{ij} \in R_2 \)

(2) \( \overline{\beta}_2 \geq M \), then \( r_{ij} \in R_3 \)

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 \( \beta_{ijk} \) can be obtained from the following formula:

\[
\beta_{ijk} = \frac{\sum_{k=1}^{p} \alpha_{ijk}}{\sum_{k=1}^{p} \alpha_{ijk}}
\]

\[
\beta_{ij2} = \frac{\sum_{k=1}^{p} \alpha_{ijk}}{\sum_{k=1}^{p} \alpha_{ijk}}
\]

\[
\vdots\]

\[
\beta_{ip(p-1)} = \frac{\sum_{k=1}^{p-1} \alpha_{ijk}}{\sum_{k=1}^{p} \alpha_{ijk}}
\]

\[
\beta_{ip} = 1
\]

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 \( V = \{V_1[l=1,2,...,5]\} \), where \( V_1[l] \) indicates “absolute importance”, \( V_2[l] \) “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 $\tilde{V} = \{V_l\}_{l=1,2,\ldots,S}$ 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 $x_{la} \geq x_{lb} \geq x_{lc}$.

![Figure 3: $R_k$ grade attribution](image)

If $N$ logistics professionals judge the importance level of evaluation criteria as $V_l(l=1,2,\ldots,S)$ grades, then $Y_{ij}$:

$$Y_{ij} = V_l, \quad j=1,2,\ldots,m; \quad h=1,2,\ldots,N; \quad l=1,2,\ldots,S$$

(9)

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

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

(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 $Z[V_l]_j$ as the number of $N$ logistics professionals who judge the importance under $C_j$ criteria as grade $V_l$, and $Z[\Sigma V_l]_j$ as the number of professionals who grade $V_l$ summated to grade $V_l$, namely:

$$Z[\Sigma V_l]_j = \sum_{g=1}^{j} Z[V_g]_j, \quad \forall \; j.$$  

(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 $V_2 \sim V_5$. 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 \( V_5 \), namely, grade \( V_2 \) implies grades \( V_3 \sim V_5 \) apart from grade \( V_1 \). According to the majority rule, \( Z[\sum V_j] \geq M \) must exceed a certain majority value \( M \), namely:

\[
Z[\sum V_j] \geq M
\]  

(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]:

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

(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. \( \tilde{w}_j \):

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

(14)

3.4. Fuzzy MCQA approach

In the case of grade \( R_k \), grade \( R_{ijk} \) within preference structure matrix \( \tilde{P}_R \) 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 \( B_{R_k} \) (\( k = 1, 2, \ldots, p \)):

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

(15)

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

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

\[
S_{R_k} = B_{R_k} \left[ B_{R_k} \right]^T - e^T e
\]  

(17)

Where, \( S_{R_k} \) : under \( R_k \) grade \( q \)-connectivity matrix

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

\[
\tilde{PS}_i = \sum_k \tilde{R}_i \otimes \tilde{T}_k, \quad \forall i
\]

\[
\tilde{T}_k = \sum_j h_j^k \otimes \tilde{w}_j, \quad \forall i,k
\]

\[
\tilde{PC}_i = \sum_k \tilde{R}_i [\hat{q}_{ik} - q_{ik}^*] , \quad \forall i
\]

\[
q_{ik}^* = \max_{i=1,2,\ldots,n} S_{ik}^R (i,i')
\]

\[
\hat{q}_{ik} = S_{ik}^R (i,i)
\]

where \(\hat{q}_{ik} = S_{ik}^R (i,i)\) is represented by the dimension of \(A_i\) alternative under grade \(R_k\) and \(q_{ik}^* = \max_{i=1,2,\ldots,n} S_{ik}^R (i,i')\) 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 \(q_{ik}^*\) for comparison with \(\hat{q}_{ik}\) 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 \(PH_i\) as the general expression of \(\tilde{PS}_i\) and \(\tilde{PC}_i\) as shown below:

\[
PH_i = (LH_i, MH_i, RH_i), \quad i = 1,2,\ldots,n
\]
Take $S$ as the range of all alternative 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 $\alpha_i$ value between $[0, 1]$ as the optimistic attitude of experts upon alternatives, whereas $(1-\alpha_i)$ shows a pessimistic attitude. If $u_o(\tilde{PH}_i)$ represents the optimistic membership grade of the fuzzy satisfaction index in $A_o$ and $u_p(\tilde{PH}_i)$ represents the pessimistic membership grade, $u_r(\tilde{PH}_i)$ value can be obtained from the following formula.

$$\mu_r(\tilde{PH}_i) = \alpha_i \mu_o(\tilde{PH}_i) + (1-\alpha_i) \mu_p(\tilde{PH}_i), \quad i = 1, 2, \ldots, n$$ \hspace{1cm} (24)

$$\alpha_i = (RH_i - MH_i) / (RH_i - LH_i), \quad \forall \ i$$ \hspace{1cm} (25)

$$\mu_o(\tilde{PH}_i) = (x_i - s_{\min})/(s_{\max} - s_{\min}), \quad \forall \ i$$ \hspace{1cm} (26)

$$\mu_p(\tilde{PH}_i) = 1 - \left(\frac{s_{\max} - s_i}{s_{\max} - s_{\min}}\right), \quad \forall \ i$$ \hspace{1cm} (27)

$$s_i = \frac{s_{\max} - s_{\min}}{(RH_i - MH_i) + (s_{\max} - s_{\min})}$$ \hspace{1cm} (28)

$$s_{\min} = \inf S$$ \hspace{1cm} (30)

$$s_{\max} = \sup S$$ \hspace{1cm} (31)

$$s = \bigcup_{i=1}^{n} PH_i$$ \hspace{1cm} (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:

$$PRI_i = \left[1 - u_o(\tilde{PS}_i)\right]^{\gamma} + \left[1 - u_p(\tilde{PC}_i)\right]^{\gamma}, \quad \forall \ i$$ \hspace{1cm} (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](image)

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.

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>
<thead>
<tr>
<th>Location</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_1$</td>
<td>$R_2$</td>
</tr>
<tr>
<td>$L_2$</td>
<td>$R_3$</td>
</tr>
<tr>
<td>$L_3$</td>
<td>$R_3$</td>
</tr>
<tr>
<td>$L_4$</td>
<td>$R_3$</td>
</tr>
<tr>
<td>$L_5$</td>
<td>$R_3$</td>
</tr>
<tr>
<td>$L_6$</td>
<td>$R_3$</td>
</tr>
<tr>
<td>$L_7$</td>
<td>$R_3$</td>
</tr>
<tr>
<td>$L_8$</td>
<td>$R_3$</td>
</tr>
</tbody>
</table>

Figure 5: Decision approach of international distribution park

Table 2: The classification contribution of candidate location at each criterium
In terms of the weight of criteria, we classified the importance level of evaluation criteria into five grades, i.e. “absolute importance (V₁)”, “demonstrated importance (V₂)”, “essential importance (V₃)”, “weak importance (V₄)” and “importance (V₅)”. 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 \( C_j \)

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Consensus grade</th>
<th>Fuzzy weight</th>
<th>Criteria</th>
<th>Consensus grade</th>
<th>Fuzzy weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>( C_1 )</td>
<td>( V_j )</td>
<td>(0.75, 1.0, 1.0)</td>
<td>( C_5 )</td>
<td>( V_j )</td>
<td>(0.5, 0.75, 1.0)</td>
</tr>
<tr>
<td>( C_2 )</td>
<td>( V_j )</td>
<td>(0.5, 0.75, 1.0)</td>
<td>( C_6 )</td>
<td>( V_j )</td>
<td>(0.5, 0.75, 1.0)</td>
</tr>
<tr>
<td>( C_3 )</td>
<td>( V_j )</td>
<td>(0.25, 0.5, 0.75)</td>
<td>( C_7 )</td>
<td>( V_j )</td>
<td>(0.5, 0.75, 1.0)</td>
</tr>
<tr>
<td>( C_4 )</td>
<td>( V_j )</td>
<td>(0.5, 0.75, 1.0)</td>
<td>( C_8 )</td>
<td>( V_j )</td>
<td>(0.5, 0.75, 1.0)</td>
</tr>
</tbody>
</table>

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 (\( \mu_{\tilde{PS}_i} (PS)_i \), \( \mu_{\tilde{PC}_i} (PC)_i \)) 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 (\( L_3 \)) and Taichung industry zone (\( L_3 \)).

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

<table>
<thead>
<tr>
<th>Location (( A_i ))</th>
<th>( \tilde{PS}_i )</th>
<th>( \mu_{\tilde{PS}_i} (PS)_i )</th>
<th>( \tilde{PC}_i )</th>
<th>( \mu_{\tilde{PC}_i} (PC)_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( L_1 )</td>
<td>(1.63, 2.44, 3.06)</td>
<td>0.60</td>
<td>(0.50, 0.75, 1.00)</td>
<td>0.39</td>
</tr>
<tr>
<td>( L_2 )</td>
<td>(1.00, 1.44, 1.69)</td>
<td>0.31</td>
<td>(0.00, 0.00, 0.00)</td>
<td>0.00</td>
</tr>
<tr>
<td>( L_3 )</td>
<td>(1.13, 1.69, 2.19)</td>
<td>0.41</td>
<td>(0.00, 0.00, 0.00)</td>
<td>0.00</td>
</tr>
<tr>
<td>( L_4 )</td>
<td>(1.88, 2.75, 3.44)</td>
<td>0.69</td>
<td>(0.00, 0.00, 0.00)</td>
<td>0.00</td>
</tr>
<tr>
<td>( L_5 )</td>
<td>(0.75, 1.06, 1.19)</td>
<td>0.19</td>
<td>(0.00, 0.00, 0.00)</td>
<td>0.00</td>
</tr>
<tr>
<td>( L_6 )</td>
<td>(0.88, 1.31, 1.69)</td>
<td>0.30</td>
<td>(0.00, 0.00, 0.00)</td>
<td>0.00</td>
</tr>
<tr>
<td>( L_7 )</td>
<td>(0.88, 1.31, 1.69)</td>
<td>0.30</td>
<td>(0.00, 0.00, 0.00)</td>
<td>0.00</td>
</tr>
<tr>
<td>( L_8 )</td>
<td>(0.50, 0.75, 0.94)</td>
<td>0.10</td>
<td>(0.00, 0.00, 0.00)</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Remark: PSI: Project Satisfaction Index; PCI: Project Comparison Index
Table 5: PSI and PCI value of re-import type of distribution park

<table>
<thead>
<tr>
<th>Location (A&lt;sub&gt;i&lt;/sub&gt;)</th>
<th>PSI&lt;sub&gt;i&lt;/sub&gt;</th>
<th>μ&lt;sub&gt;i&lt;/sub&gt;(PS&lt;sub&gt;i&lt;/sub&gt;)</th>
<th>PCI&lt;sub&gt;i&lt;/sub&gt;</th>
<th>μ&lt;sub&gt;i&lt;/sub&gt;(PCI&lt;sub&gt;i&lt;/sub&gt;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L&lt;sub&gt;1&lt;/sub&gt;</td>
<td>(1.25, 1.88, 2.31)</td>
<td>0.55</td>
<td>(0.50, 0.75, 1.00)</td>
<td>0.39</td>
</tr>
<tr>
<td>L&lt;sub&gt;2&lt;/sub&gt;</td>
<td>(1.00, 1.44, 1.69)</td>
<td>0.37</td>
<td>(0.00, 0.00, 0.00)</td>
<td>0.00</td>
</tr>
<tr>
<td>L&lt;sub&gt;3&lt;/sub&gt;</td>
<td>(1.13, 1.69, 2.19)</td>
<td>0.50</td>
<td>(0.50, 0.75, 1.00)</td>
<td>0.39</td>
</tr>
<tr>
<td>L&lt;sub&gt;4&lt;/sub&gt;</td>
<td>(1.50, 2.19, 2.69)</td>
<td>0.67</td>
<td>(0.00, 0.00, 0.00)</td>
<td>0.00</td>
</tr>
<tr>
<td>L&lt;sub&gt;5&lt;/sub&gt;</td>
<td>(0.88, 1.25, 1.44)</td>
<td>0.29</td>
<td>(0.00, 0.00, 0.00)</td>
<td>0.00</td>
</tr>
<tr>
<td>L&lt;sub&gt;6&lt;/sub&gt;</td>
<td>(0.88, 1.31, 1.69)</td>
<td>0.35</td>
<td>(0.50, 0.75, 1.00)</td>
<td>0.39</td>
</tr>
<tr>
<td>L&lt;sub&gt;7&lt;/sub&gt;</td>
<td>(0.88, 1.31, 1.69)</td>
<td>0.35</td>
<td>(0.00, 0.00, 0.00)</td>
<td>0.00</td>
</tr>
<tr>
<td>L&lt;sub&gt;8&lt;/sub&gt;</td>
<td>(0.63, 0.94, 1.19)</td>
<td>0.18</td>
<td>(0.00, 0.00, 0.00)</td>
<td>0.00</td>
</tr>
</tbody>
</table>

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

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

<table>
<thead>
<tr>
<th>Location (A&lt;sub&gt;i&lt;/sub&gt;)</th>
<th>PSI&lt;sub&gt;i&lt;/sub&gt;</th>
<th>μ&lt;sub&gt;i&lt;/sub&gt;(PS&lt;sub&gt;i&lt;/sub&gt;)</th>
<th>PCI&lt;sub&gt;i&lt;/sub&gt;</th>
<th>μ&lt;sub&gt;i&lt;/sub&gt;(PCI&lt;sub&gt;i&lt;/sub&gt;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L&lt;sub&gt;1&lt;/sub&gt;</td>
<td>(1.50, 2.25, 2.81)</td>
<td>0.68</td>
<td>(0.50, 0.75, 1.00)</td>
<td>0.70</td>
</tr>
<tr>
<td>L&lt;sub&gt;2&lt;/sub&gt;</td>
<td>(0.88, 1.25, 1.44)</td>
<td>0.34</td>
<td>(0.00, 0.00, 0.00)</td>
<td>0.00</td>
</tr>
<tr>
<td>L&lt;sub&gt;3&lt;/sub&gt;</td>
<td>(0.75, 1.13, 1.44)</td>
<td>0.32</td>
<td>(0.00, 0.00, 0.00)</td>
<td>0.00</td>
</tr>
<tr>
<td>L&lt;sub&gt;4&lt;/sub&gt;</td>
<td>(1.50, 2.19, 2.69)</td>
<td>0.67</td>
<td>(0.00, 0.00, 0.00)</td>
<td>0.00</td>
</tr>
<tr>
<td>L&lt;sub&gt;5&lt;/sub&gt;</td>
<td>(0.63, 0.99, 0.94)</td>
<td>0.19</td>
<td>(0.00, 0.00, 0.00)</td>
<td>0.00</td>
</tr>
<tr>
<td>L&lt;sub&gt;6&lt;/sub&gt;</td>
<td>(0.75, 1.13, 1.44)</td>
<td>0.32</td>
<td>(0.00, 0.00, 0.00)</td>
<td>0.00</td>
</tr>
<tr>
<td>L&lt;sub&gt;7&lt;/sub&gt;</td>
<td>(0.75, 1.13, 1.44)</td>
<td>0.32</td>
<td>(0.00, 0.00, 0.00)</td>
<td>0.00</td>
</tr>
<tr>
<td>L&lt;sub&gt;8&lt;/sub&gt;</td>
<td>(0.38, 0.56, 0.69)</td>
<td>0.09</td>
<td>(0.00, 0.00, 0.00)</td>
<td>0.00</td>
</tr>
</tbody>
</table>

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

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

<table>
<thead>
<tr>
<th>Location (A&lt;sub&gt;i&lt;/sub&gt;)</th>
<th>PSI&lt;sub&gt;i&lt;/sub&gt;</th>
<th>μ&lt;sub&gt;i&lt;/sub&gt;(PS&lt;sub&gt;i&lt;/sub&gt;)</th>
<th>PCI&lt;sub&gt;i&lt;/sub&gt;</th>
<th>μ&lt;sub&gt;i&lt;/sub&gt;(PCI&lt;sub&gt;i&lt;/sub&gt;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L&lt;sub&gt;1&lt;/sub&gt;</td>
<td>(0.88, 1.31, 1.56)</td>
<td>0.54</td>
<td>(0.50, 0.75, 1.00)</td>
<td>0.70</td>
</tr>
<tr>
<td>L&lt;sub&gt;2&lt;/sub&gt;</td>
<td>(1.13, 1.63, 1.94)</td>
<td>0.69</td>
<td>(0.00, 0.00, 0.00)</td>
<td>0.00</td>
</tr>
<tr>
<td>L&lt;sub&gt;3&lt;/sub&gt;</td>
<td>(0.38, 0.56, 0.69)</td>
<td>0.14</td>
<td>(0.00, 0.00, 0.00)</td>
<td>0.00</td>
</tr>
<tr>
<td>L&lt;sub&gt;4&lt;/sub&gt;</td>
<td>(0.75, 1.06, 1.19)</td>
<td>0.40</td>
<td>(0.00, 0.00, 0.00)</td>
<td>0.00</td>
</tr>
<tr>
<td>L&lt;sub&gt;5&lt;/sub&gt;</td>
<td>(1.00, 1.44, 1.69)</td>
<td>0.60</td>
<td>(0.00, 0.00, 0.00)</td>
<td>0.00</td>
</tr>
<tr>
<td>L&lt;sub&gt;6&lt;/sub&gt;</td>
<td>(0.50, 0.75, 0.94)</td>
<td>0.26</td>
<td>(0.00, 0.00, 0.00)</td>
<td>0.00</td>
</tr>
<tr>
<td>L&lt;sub&gt;7&lt;/sub&gt;</td>
<td>(0.75, 1.13, 1.44)</td>
<td>0.47</td>
<td>(0.00, 0.00, 0.00)</td>
<td>0.00</td>
</tr>
<tr>
<td>L&lt;sub&gt;8&lt;/sub&gt;</td>
<td>(0.75, 1.13, 1.44)</td>
<td>0.47</td>
<td>(0.00, 0.00, 0.00)</td>
<td>0.00</td>
</tr>
</tbody>
</table>

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

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

<table>
<thead>
<tr>
<th>Location (A&lt;sub&gt;i&lt;/sub&gt;)</th>
<th>Type</th>
<th>IM/EX</th>
<th>Re-import</th>
<th>Transship.</th>
<th>Re-export</th>
<th>TPRI&lt;sub&gt;i&lt;/sub&gt;</th>
<th>Order</th>
</tr>
</thead>
<tbody>
<tr>
<td>L&lt;sub&gt;1&lt;/sub&gt;</td>
<td>PRI</td>
<td>0.73</td>
<td>0.76</td>
<td>0.44</td>
<td>0.55</td>
<td>2.48</td>
<td>1</td>
</tr>
<tr>
<td>L&lt;sub&gt;2&lt;/sub&gt;</td>
<td>PRI</td>
<td>1.21</td>
<td>1.18</td>
<td>1.20</td>
<td>1.05</td>
<td>4.64</td>
<td>5</td>
</tr>
<tr>
<td>L&lt;sub&gt;3&lt;/sub&gt;</td>
<td>PRI</td>
<td>1.16</td>
<td>0.79</td>
<td>1.21</td>
<td>1.32</td>
<td>4.48</td>
<td>3</td>
</tr>
<tr>
<td>L&lt;sub&gt;4&lt;/sub&gt;</td>
<td>PRI</td>
<td>1.05</td>
<td>1.05</td>
<td>1.05</td>
<td>1.17</td>
<td>4.32</td>
<td>2</td>
</tr>
<tr>
<td>L&lt;sub&gt;5&lt;/sub&gt;</td>
<td>PRI</td>
<td>1.29</td>
<td>1.23</td>
<td>1.28</td>
<td>1.08</td>
<td>4.88</td>
<td>7</td>
</tr>
<tr>
<td>L&lt;sub&gt;6&lt;/sub&gt;</td>
<td>PRI</td>
<td>1.22</td>
<td>0.89</td>
<td>1.21</td>
<td>1.25</td>
<td>4.57</td>
<td>4</td>
</tr>
<tr>
<td>L&lt;sub&gt;7&lt;/sub&gt;</td>
<td>PRI</td>
<td>1.22</td>
<td>1.19</td>
<td>1.21</td>
<td>1.13</td>
<td>4.75</td>
<td>6</td>
</tr>
<tr>
<td>L&lt;sub&gt;8&lt;/sub&gt;</td>
<td>PRI</td>
<td>1.34</td>
<td>1.29</td>
<td>1.35</td>
<td>1.13</td>
<td>5.11</td>
<td>8</td>
</tr>
</tbody>
</table>
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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REFERENCE


