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USE OF THE FUZZY AHP-TOPSIS METHOD TO SELECT THE MOST ATTRACTIVE CONTAINER PORT

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Key words: fuzzy, AHP-TOPSIS, attractiveness, container port.

ABSTRACT

The unique attractiveness factor of a container port has a direct influence on the carriers' deployment of their routes and schedules, that is, the attractiveness of the port will affect the port selecting evaluation of the carriers, which will directly impact the future status and competitiveness of a port. Therefore, this paper aimed to establish a fuzzy AHP-TOPSIS (Analytic Hierarchy Process-Technique for Order Preference by Similarity to Ideal Solution) evaluation model for selecting the most attractive port for container carriers. Firstly, this paper concluded the six evaluation dimensions and 24 important attractiveness criteria (factors) for carriers to select a port. Secondly, the weight of the evaluation criteria layer was calculated using the fuzzy AHP method. Then, combined with the concept of fuzzy TOPSIS, an evaluation method suitable for container carriers to choose the most attractive port was created. Finally, this paper used a simulation to interpret the fuzzy AHP-TOPSIS evaluation model developed in this paper. In the future, carriers evaluating attractive ports can modify this model according to the actual situation to better meet their decision-making purposes.

I. INTRODUCTION

A commercial port is a junction and link point for water and land transportation. It mainly offers services for ships, passengers, and goods and can become a collection and distribution center for domestic and foreign trade goods or a transshipment station for sea and land transportation, which is essentially a marine terminal (Carbone and Martino, 2003; Tsai et al., 2018). An effective marine terminal (Notteboom, 2011; Talley and Ng, 2013; Fraser and Notteboom, 2014; Cantillo et al., 2018; Xing et al., 2018) should be able to: (1) facilitate passengers and provide the commercial functions of cargo transportation and exchange; (2) provide a place for ships to import industrial raw materials and export semi-finished or finished products and provide the industrial function of making its hinterland an industrial city; (3) provide the function of transshipping cargo shipped to inland ports or other ports; and (4) provide the value-added service function of physical logistics. Taiwan is an economy surrounded by the sea on all sides. The existence of commercial ports and their economic progress are mutually causal. For oceanic countries like Taiwan, port development has a decisive influence on its economic development.

Container transportation has been the main mode of transportation of liner shipping since its inception in the 1960s, and it has become one of the main international shipping methods (Tseng et al., 2018). The so-called liner shipping refers to marine transportation service between ports with fixed routes according to a pre-arranged sailing schedule and carrying sporadic groceries or containerized goods. Due to the rapid development of global trade, container carriers are being encouraged to put their shipping capacity into the cargo source area to expand their route allocation and operation scale; on the other hand, ports in the cargo source area are also becoming regional hubs by continually investing in infrastructure and facilities in order to make the port a more efficient logistics service station or a more efficient shipping terminal, thereby attracting and serving more container carriers. Therefore, the issue of port competitiveness (Song and Yeo, 2004; Cullinane et al., 2005; De Langen, 2007; Tongzon and Sawant, 2007; De Martino and Morvillo, 2008; Yeo et al., 2008; Yuen et al., 2012; Xing et al., 2018) has become one of the hottest directions in academic research.

Efforts to increase the competitiveness of a container port chiefly focus on how a container port should meet the needs of port users (mainly carriers, shipping agents, and import and export shippers) and offer better port services (Yuen et al., 2012), with the ultimate goals of developing the services required by port users, enhancing the satisfaction and loyalty of port users, and strengthening the container port's sustainable

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competitive advantage. In line with the practice of 'ships following cargo' (Ding et al., 2017), the choice of port (Lirn et al., 2004; Tai and Hwang, 2005; Guy and Urli, 2006; Ugboma et al., 2006; De Langen, 2007; Tongzon and Sawant, 2007; Tang et al., 2011; Steven and Corsi, 2012) is regarded by carriers as an important issue involving transport and distribution by shipping companies, and has also become a leading issue in the study of port competitiveness. If a port system is not competitive in terms of service quality or circulation efficiency, this will lead to the transfer of import and export goods to other relatively effective or competitive ports (UNCTAD, 2012). Port selection factors and criteria are therefore important reference indicators guiding carriers' port decisions and reflecting port competitiveness. Determining whether a port can meet the service demands of port users is also an important link in the improvement of port competitiveness.

With regard to the issue of port selection, the literature often uses the terms "competitiveness" and "attractiveness" (Song and Yeo, 2004; Cullinane et al., 2005; Ng, 2006; De Langen, 2007; Tongzon and Sawant, 2007; Yeo et al., 2008; Yuen et al., 2012; Fraser and Notteboom, 2014) in conjunction with port selection factors. According to strategic management theory (Hafeez et al., 2002), competitiveness refers to an enterprise achieving higher operating performance than its competitors in a certain business field according to certain indicators through the effective use of its resources and relevant capabilities, which gives the enterprise a greater competitive advantage. According to marketing theory (Kotler, 2000), the attractiveness of a market or product refers to a unique appeal that can arouse consumer interest and consumption, and exert a force on consumer behavior. When shippers and carriers are faced with the choice of berthing ports, port attractiveness (Ng, 2006) usually consists of the prerequisites for the port's competitiveness, and is also a springboard for exploring a port's competitive advantage. Therefore, to determine whether a port is competitive, it is necessary to first investigate whether the port has certain factors that are sufficient to attract users. The competitiveness of a port is based on its attractiveness, which by attracting users to berth, load, unload, and warehouse goods, and by adding value to the logistics activities at the port, can thereby induces users to include the port as a port of call in its route planning.

Container carriers first select certain ports and then plan their route and frequency, and these decisions will directly affect the ports' status and competitiveness. As a consequence, a port's possession or lack of attractive factors will influence its evaluation by container carriers during their selection of ports. Ports' attractive factors have characteristics that made the use of multi-criteria decision-making (MCDM) an appropriate means of port selection, and the various port criteria have qualitative, fuzzy, and vague characteristics (Zadeh, 1965). Since it would be extremely difficult to adequately express the fuzzy information contained in decision-making criteria and evaluation schemes while dealing with ambiguous criteria weights and inaccuracy in the transmission of decision-making information, thus, the precision-based MCDM may not be practical. It seems that a fuzzy MCDM method is needed. Although the fuzzy MCDM method has been widely used for assessment in various areas of maritime affairs (Ding, 2013; Stanić et al., 2017) and port selection (Ding and Chou, 2013; Zavadskas et al., 2015), a systematic and fuzziness-based MCDM method can efficiently be utilized to select the best container port from the view point of attraction is rare.

Generally speaking, there are two key steps requiring attention during use of the fuzzy MCDM method, where the first step consists of determining the weights of the assessment criteria and sub-criteria, and the second consists of obtaining the performance values of the solutions in terms of the various criteria, and then obtaining the overall performance value of each possible solution, which will enable comparison of the solutions and selection of the optimal solution. During the first step (i.e., determining the criteria weights), because the fuzzy AHP method (Analytic Hierarchy Process) (Ding, 2013; Ding et al., 2017; Stanić et al., 2017) can effectively analyze the interactions between different criteria, obtain the consensus views of a majority of experts and decision-makers, and express the relative importance of the different criteria as concrete weight values, this study chose to use the fuzzy AHP method to find the weights of the assessment criteria and sub-criteria. During the second step (i.e., solution assessment), because some solutions may have criteria that are mutually exclusive, non-quantifiable, or cannot be measured on the same scale, it is possible that there is no one solution that is optimal on the basis of satisfying all criteria. At that time fuzzy TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) can be used to resolve the problem through the ranking of candidate solutions (Hwang and Yoon, 1981). The basic concept of TOPSIS is to first define a positive ideal solution and a negative ideal solution (also known as an ideal solution and an anti-ideal solution (Liang, 1999)), where the positive ideal solution has the highest values of the candidate solutions' effectiveness criteria and the lowest values of their cost criteria. Conversely, the negative ideal solution has the lowest values of the candidate solutions' effectiveness criteria and the highest values of their cost criteria. Afterwards, when selecting a solution, the optimal solution is the solution closest to the positive ideal solution and farthest from the negative ideal solution.

In summary, the chief purpose of this paper is to develop an evaluation model based on the fuzzy MCDM method—namely the fuzzy AHP-TOPSIS method—for selecting the most attractive port for container carriers. The following section introduces the research methods, the third section proposes the fuzzy AHP-TOPSIS method, the fourth section provides a case illustration, and the final section presents conclusions.

II. RESEARCH METHODS

This section briefly introduces the research methods adopted in this paper.

1. Fuzzy Sets Theory

Fuzzy set theory was first proposed by Zadeh in 1965, who realized that since human thinking, reasoning, and cognition is often ambiguous, traditional analytical methods relying on precise numerical values cannot be completely applicable to the volatility and complexity of human-centered systems. This study therefore used fuzzy mathematical methods instead of traditional quantitative methods when dealing with decision analysis in fuzzy business situations.

2. Triangular Fuzzy Numbers and Its Algebraic Operations

In a universe of discourse X, a fuzzy subset $\tilde{A}$ of X is defined by a membership function $\mu_{\tilde{A}}(x)$, which maps each element x in X to a real number in the interval [0, 1]. The function value $\mu_{\tilde{A}}(x)$ represents the grade of membership of x in $\tilde{A}$.

A fuzzy number $\tilde{A}$ (Dubois and Prade, 1978) in real line $\Re$ is a triangular fuzzy number (TFN) if its membership function $\mu_{\tilde{A}}: \Re \to [0,1]$ is

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

with $-\infty < a \le b \le c < \infty$. The TFN can be denoted by $\tilde{A} = (a, b, c)$.

According to extension principle (Zadeh, 1965), let $\tilde{A}_1 = (a_1, b_1, c_1)$ and $\tilde{A}_2 = (a_2, b_2, c_2)$ be TFNs, the algebraic operations of any two TFNs $\tilde{A}_1$ and $\tilde{A}_2$ can be expressed as

(1) Fuzzy addition, $\oplus$:

$\tilde{A}_1 \oplus \tilde{A}_2 = (a_1 + a_2, b_1 + b_2, c_1 + c_2)$;

(2) Fuzzy subtraction, $\ominus$:

$\tilde{A}_1 \ominus \tilde{A}_2 = (a_1 - c_2, b_1 - b_2, c_1 - a_2)$;

(3) Fuzzy multiplication, $\otimes$:

$k \otimes \tilde{A} = (ka, kb, kc), \quad k \ge 0, k \in R$;

$\tilde{A}_1 \otimes \tilde{A}_2 \cong (a_1 a_2, b_1 b_2, c_1 c_2), \ a_1 \ge 0, a_2 \ge 0$;

(4) Fuzzy division, $\varnothing$:

$\tilde{A}_1 \varnothing \tilde{A}_2 \cong (a_1/c_2, b_1/b_2, c_1/a_2), \ a_1 \ge 0, a_2 > 0$.

3. Linguistic Variables

Zadeh proposed the concept of linguistic variables (Zadeh, 1975; 1976), which can provide a convenient quantitative syntax for complex or imperfectly defined descriptions. A linguistic variable is a variable expressed in words or natural sentences. For example, the "degree of preference" is a linguistic variable and has a linguistic value rather than numeric value, such as "very bad," "normal," or "very good." Linguistic values can be reasonably expressed through the approximate reasoning of fuzzy set theory. Linguistic values are used in this paper to express the "goodness" or "badness" of alternatives relative to subjective criteria. We used TFNs to convey this information. In this paper, the linguistic value set of the superiority evaluation is $S = \{VP, P, F, G, VG\}$. The membership function of the linguistic value contained in set S can be subjectively defined by the decision-maker (DM) as follows: Very Poor (VP) = (0, 0, 0.25); Poor (P) = (0, 0.25, 0.5); Fair (F) = (0.25, 0.5, 0.75); Good (G) = (0.5, 0.75, 1); Very Good (VG) = (0.75, 1, 1).

4. Distance Method

Heilpern's (1997) mean distance method and the geometric distance method are well-known distance methods. Hsieh and Chen (1999) proposed a modified geometric distance formula to make up for the deficiency of Heilpern's geometric distance formula. According to the modified geometric distance formula proposed by Hsieh and Chen (1999), the two-dimensional distance of the TFN $\tilde{A}_i = (a_i, b_i, c_i)$ and $\tilde{A}_j = (a_j, b_j, c_j)$ can be obtained, which is expressed as:

$$D_m(\tilde{A}_i, \tilde{A}_j) = \left\{1/4\left[(a_i - a_j)^2 + 2(b_i - b_j)^2 + (c_i - c_j)^2\right]\right\}^{1/2} \quad (2)$$

Based on the modified geometric distance method as an extension of the traditional precise steering distance, this paper proposed using the distance formula of Eq. (2) as the basis for solving the distance between the subsequent two TFNs.

5. Ranking of TFNs

Ranking methods for TFNs have been studied by numerous scholars (Heilpern, 1997; Hsieh and Chen, 1999; Yang et al., 2005). Chen and Hsieh (2000) proposed the graded mean integration representation method (GMIR) after comparing various methods. In this paper, the GMIR method was used to solve the problems of the defuzzification of TFNs and the fuzzy number ranking of the advantage evaluation for each alternative.

According to the GMIR method proposed by Chen and Hsieh (2000), if $\tilde{A}_i = (a_i, b_i, c_i)$, $i = 1, 2, \ldots, n$, are n TFNs, the GMIR representative values of the TFNs after defuzzification can be expressed as follows:

$$G(\tilde{A}_i) = \frac{a_i + 4b_i + c_i}{6} \quad (3)$$

Suppose $G(\tilde{A}_i)$ and $G(\tilde{A}_j)$ are the GMIR representative values of the TFNs $\tilde{A}_i$ and $\tilde{A}_j$, respectively. We define:

(1) $\tilde{A}_i > \tilde{A}_j \Leftrightarrow G(\tilde{A}_i) > G(\tilde{A}_j)$;

(2) $\tilde{A}_i = \tilde{A}_j \Leftrightarrow G(\tilde{A}_i) = G(\tilde{A}_j)$;

(3) $\tilde{A}_i < \tilde{A}_j \Leftrightarrow G(\tilde{A}_i) < G(\tilde{A}_j)$.

III. THE PROPOSED FUZZY AHP-TOPSIS METHOD

This study constructed a fuzzy AHP-TOPSIS port selection evaluation model for container carriers, and we hoped that the establishment of this systematic model will make selection more objective and easier to perform.

1. Sort Out the Attractiveness Evaluation Criteria of Container Port

To determine whether a port is competitive, it is necessary to first check whether the port has certain determinants sufficient to attract port users. In order to screen out the more important criteria and construct a hierarchical structure, we therefore gathered a wide range of attractive factors that affect container carriers' choice of ports.

Based on literature concerning port selection factors (Lirn et al., 2004; Song and Yeo, 2004; Cullinane et al., 2005; Tai and Hwang, 2005; Guy and Urli, 2006; Ng, 2006; Ugboma et al., 2006; De Langen, 2007; Tongzon and Sawant, 2007; De Martino and Morvillo, 2008; Yeo et al., 2008; Notteboom, 2011; Tang et al., 2011; Steven and Corsi, 2012; Yuen et al., 2012; Talley and Ng, 2013; Fraser and Notteboom, 2014; Cantillo et al., 2018; UNCTAD, 2012; Xing et al., 2018), as well as the recommendations of the interviewed experts, scholars, and carrier personnel, this study ultimately determined attractive factors affecting container carriers' choice of ports, and found a total of six major evaluation dimensions and 24 important evaluation criteria as follows:

(1) Sources of goods of location and hinterland (C_1): This evaluation dimension includes the four evaluation criteria of 'geographic location (C_{11}),' 'trade activities and sources of goods (C_{12}),' 'port hinterland accessibility and connectivity (C_{13}),' and 'outbound traffic conditions (C_{14}).'

(2) Physical facilities of the port (C_2): This evaluation dimension includes the four evaluation criteria of the 'port's natural conditions (C_{21}),' 'port infrastructure and facilities (C_{22}),' 'wharf and back-line land (C_{23}),' and 'loading and unloading machinery equipment (C_{24}).'

(3) The port's operation function (C_3): This evaluation dimension includes 'loading and unloading technology (C_{31}),' 'stack-end operation efficiency (C_{32}),' 'port back-up operative activities and services (C_{33}),' and 'the use of the ICT level (C_{34}).'

(4) Time and cost (C_4): This evaluation dimension includes the four evaluation criteria of 'port charges (C_{41}),' 'port transshipment cost (C_{42}),' 'ship detention time (C_{43}),' and 'customs administrative effectiveness (C_{44}).'

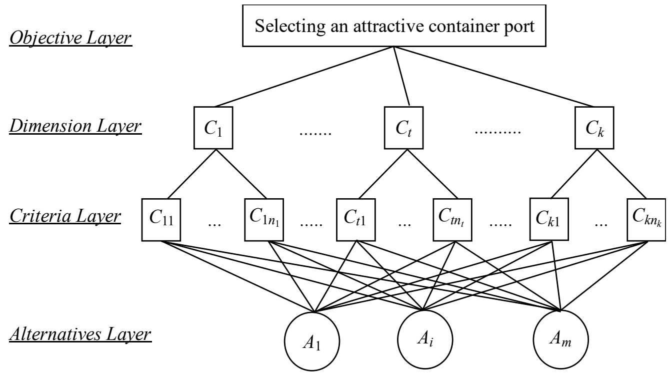

Fig. 1. Hierarchy structure.

(5) Service and quality (C_5): This evaluation dimension includes the four evaluation criteria of 'high-quality port services (C_{51}),' 'dense airline networks and flights (C_{52}),' 'fast-response to customers (C_{53}),' and 'reputation for port goodwill/brand (C_{54}).'

(6) External environment of the ports (C_6): This evaluation dimension includes the four evaluation criteria of 'local political and legal environment stability (C_{61}),' 'social situation and labor force environment (C_{62}),' 'port safety management system (C_{63}),' and 'implementation of green energy and environmental protection policy (C_{64}).'

2. Establish A Hierarchical Structure

A hierarchical structure (Ding and Liang, 2005) can be used to study the interactions between various elements in the hierarchy and their impact on the system as a whole, and the complexity of a hierarchical system will be determined by the needs of analysis. This paper used the hierarchical structure shown in Fig. 1 as the basis for container carriers' selection of the most attractive port. In this structure, the 1st layer consisted of the goal, which was the selection of the best container port from the ports evaluated. The 2nd layer consisted of the k evaluation dimensions. The 3rd layer consisted of the $n_1 + \cdots + n_t + \cdots n_k$ evaluation criteria under all evaluation dimensions, and the 4th layer consisted of the m alternative schemes.

3. Use the Fuzzy AHP Method to Solve the Weights

This paper used fuzzy AHP (Saaty, 1980; Ding et al., 2017; Stanić et al., 2017; Tsai et al., 2018) to obtain the weights of the evaluation dimensions and evaluation criteria. The steps of fuzzy AHP could be summarized as follows:

Step 1: Establishment of a pairwise comparison for crisp values.

A paired comparison questionnaire was used to get the opinion of the experts on the relative importance of the two evaluation dimensions.

(1) Set $y_{ij}^{E} \in [\frac{1}{9}, \frac{1}{8}, \ldots, \frac{1}{2}, 1] \cup [1, 2, \ldots, 8, 9]$ as the opinion

of expert E, $E = 1, 2, \ldots, h$, on the relative importance of any two evaluation dimensions i, j in the 2nd layer. Its pairwise comparison matrix will be $[y_{ij}^E]_{k\times k}$ in the 2nd layer.

(2) Set $y_{uv}^E \in [\frac{1}{9}, \frac{1}{8}, \ldots, \frac{1}{2}, 1] \cup [1, 2, \ldots, 8, 9]$ as the opinions of expert E, $E = 1, 2, \ldots, h$, on the relative importance of the two evaluation criteria u, v in the 3rd layer under evaluation dimensions $C_1, \ldots, C_t, \ldots, C_k$ of the 2nd layer. Then, the pairwise comparison matrix with respect to each evaluation dimensions $C_1, \ldots, C_t, \ldots, C_k$ in the 3rd layer are $[y_{uv}^E]_{n_1\times n_1}$, …, $[y_{uv}^E]_{n_t\times n_t}$, …, $[y_{uv}^E]_{n_k\times n_k}$, respectively.

Step 2: Establishment of a pairwise comparison for crisp values.

Hsu (1998) regarded the minimum of the evaluation value of a certain selection criterion as the lower bound of the TFN and the maximum of the evaluation value as the upper bound of the TFN, and took the geometric mean of all evaluation values as a value of one in the TFN membership degree.

Therefore, set $y_{ij}^E \in [\frac{1}{9}, \frac{1}{8}, \ldots, \frac{1}{2}, 1] \cup [1, 2, \ldots, 8, 9]$ as the opinions of expert E, $E = 1, 2, \ldots, h$, on the relative importance of the two evaluation dimensions i and j, $\forall i, j = 1, 2, \ldots, k$ in the 2nd layer. Here $\tilde{H}_{ij} = (a_{ij}, b_{ij}, c_{ij})$ is the integrated TFN of all E experts in the 2nd layer, wherein $a_{ij} = \min\left\{y_{ij}^1, y_{ij}^2, \ldots, y_{ij}^h\right\}$, $b_{ij} = \left(\prod_{E=1}^{h} y_{ij}^E\right)^{1/h}$, $c_{ij} = \max\left\{y_{ij}^1, y_{ij}^2, \ldots, y_{ij}^h\right\}$.

Similarly, the integrated TFN of all E experts in the 3rd layer is $\tilde{H}_{uv} = (a_{uv}, b_{uv}, c_{uv})$, $\forall u, v = 1, 2, \ldots, n_1; \ldots \forall u, v = 1, 2, \ldots, n_t, \cdots \forall u, v = 1, 2, \ldots, n_k$, wherein $a_{uv} = \min\left\{y_{uv}^1, y_{uv}^2, \ldots, y_{uv}^h\right\}$, $b_{uv} = \left(\prod_{E=1}^{h} y_{uv}^E\right)^{1/h}$, $c_{uv} = \max\left\{y_{uv}^1, y_{uv}^2, \ldots, y_{uv}^h\right\}$.

Step 3: Establishment of a fuzzy positive reciprocal matrix.

A fuzzy positive reciprocal matrix was established for the integrated fuzzy numbers after pairwise comparison by the experts at each layer. For the 2nd layer, the fuzzy positive reciprocal matrix was

$$H = \left[\tilde{H}_{ij}\right] = \begin{bmatrix} 1 & \tilde{H}_{12} & \cdots & \tilde{H}_{1k} \\ 1/\tilde{H}_{12} & 1 & \cdots & \tilde{H}_{2k} \\ \vdots & \vdots & \ddots & \vdots \\ 1/\tilde{H}_{1k} & 1/\tilde{H}_{2k} & \cdots & 1 \end{bmatrix},$$

where $\tilde{H}_{ij} \otimes \tilde{H}_{ji} \cong 1$, $\forall i, j = 1, 2, \ldots, k$.

To save space, the equations of fuzzy positive reciprocal matrices are omitted by reason of analogy on the 3rd layer.

Step 4: Calculation of the fuzzy weights of the fuzzy positive reciprocal matrices.

For the 2nd layer, if $\tilde{Z}_i \cong \left(\tilde{H}_{i1} \otimes \tilde{H}_{i2} \otimes \cdots \otimes \tilde{H}_{ik}\right)^{1/k}$, $\forall i = 1, 2, \ldots, k$, will be the geometric mean of the TFN of the ith evaluation dimension. The fuzzy weight of the ith evaluation dimension can be expressed as $\tilde{W}_i \cong \tilde{Z}_i \otimes \left(\tilde{Z}_1 \oplus \tilde{Z}_2 \oplus \cdots \otimes \tilde{Z}_k\right)^{-1}$. For symbolic convenience, the TFN is expressed as $\tilde{W}_i = (w_i^a, w_i^b, w_i^c)$.

To save space, the equations of fuzzy weights are omitted by reason of analogy on the 3rd layer.

Step 5: Defuzzification of the fuzzy weights.

This paper used Eq. (3) for defuzzification, as Chen and Hsieh's GMIR method is more effective and easier to use in the process of defuzzification. If $\tilde{W}_i = (w_i^a, w_i^b, w_i^c)$, $\forall i = 1, 2, \ldots, k$, will be k triangular fuzzy weights, and the k explicit weight values after defuzzification will be $G(\tilde{W}_i) = \frac{w_i^a + 4w_i^b + w_i^c}{6}$, $\forall i = 1, 2, \ldots, k$.

To save space, the defuzzification of fuzzy weights is omitted by reason of analogy on the 3rd layer.

Step 6: Standardization of the explicit weights.

In order to facilitate the comparison of the relative importance of each evaluation dimension, it was proposed to standardize the k explicit weight values after the above-mentioned defuzzification as $\zeta_i = \frac{G(\tilde{W}_i)}{\sum_{i=1}^{k} G(\tilde{W}_i)}$.

Step 7: Integrated weights of each layer.

If the explicit weight values of the 2nd and 3rd layer after standardization are expressed with $\zeta_i (\forall i = 1, 2, \ldots, k)$ and $\zeta_u (\forall u, v = 1, 2, \ldots, n_1; \ldots \forall u, v = 1, 2, \ldots, n_t; \ldots \forall u, v = 1, 2, \ldots, n_k)$ respectively. Then

(1) The integrated weight θ_i of each evaluation dimension at the 2nd layer will remain as ζ_i, *i.e.*, $\theta_i = \zeta_i$, $\forall i = 1, 2, \ldots, k$.

(2) The integrated weights θ_u of the evaluation criteria of the 3rd layer will be $\theta_u = \zeta_i \times \zeta_u$, $\forall i = 1, 2, \ldots, k$; $\forall u = 1, 2, \ldots, n_1; \ldots \forall u = 1, 2, \ldots, n_t; \ldots \forall u = 1, 2, \ldots, n_k$.

4. Evaluate the Fuzzy Superiority Values of All Evaluation Criteria versus All Alternatives

Evaluating the performance values of all evaluation criteria versus all alternatives, and then using these performance values as the basis for decision-making, is one of the important processes of the MCDM evaluation. In the real world, evaluation criteria can be generally divided into two types:

(1) Subjective criteria, which can be linguistically or qualitatively defined; *e.g.*, geographic location (C_{11}), trade activities and sources of goods (C_{12}), etc.
(2) Objective criteria, which can be defined as monetary or quantitative terms; *e.g.*, port charges (C_{41}), port transshipment cost (C_{42}), etc.

Let $SC = \{s_1, \ldots, s_t, \ldots, s_q\}$ and $OC = \{o_1, \ldots, o_r, \ldots, o_p\}$ denote all q subjective criteria and p objective criteria above the alternatives layer, respectively.

Case I: For the subjective criteria.

(1) First, for the container port to be evaluated, the superiority of all the evaluation criteria above the alternatives layer are compared, and the linguistic variables shown in Section 2.3 are used to convert the evaluation results of these linguistic variables into TFNs. For example, suppose an expert evaluates the "good geographic location (C_{11})" for port A_1 as "Very Good (VG)". This can then be converted to a TFN as (0.75, 1, 1).
(2) Secondly, the concept of arithmetic mean is used to calculate the fuzzy superiority. Let $\tilde{\pi}_{it}^E = (a_{it}^E, b_{it}^E, c_{it}^E)$ ($i = 1, 2, \ldots, m;\ t = 1, 2, \ldots, q;\ E = 1, 2, \ldots, h$) represent the fuzzy superiority of the E^{th} expert for the t^{th} subjective criterion corresponding to the i^{th} port. By using the concept of arithmetic mean, the average superiority of the t^{th} subjective criterion corresponding to the i^{th} port may be expressed as $\tilde{\gamma}_{it} = \left(\frac{\sum_{E=1}^{h} a_{it}^E}{h}, \frac{\sum_{E=1}^{h} b_{it}^E}{h}, \frac{\sum_{E=1}^{h} c_{it}^E}{h} \right)$.

Case II: For the objective criteria.

Under the objective criteria, the fuzzy superiority of each alternative can be dealt with in the following two ways:

(1) If it is not possible to accurately evaluate the numerical value, it can be evaluated by researchers or decision-making groups using objective data. For example, when the port charge (C_{41}) is about \$50,000 per time, the TFN can be expressed as (48900, 50000, 51300) or (49100, 50000, 50900).
(2) Using the historical data of the past several periods, the following method can be used for conversion. If $x_1, \ldots, x_d, \ldots, x_z$ ($d = 1, 2, \ldots, z$) is used to denote the port charges in the past z period, the fuzzy evaluation value can be expressed as $\left(\min_d \{x_d\}, (\prod_{d=1}^{z} x_d)^{1/z}, \max_d \{x_d\} \right)$.

5. Solve the Ideal and Anti-ideal Solutions of All Evaluation Criteria versus All Alternatives

In this paper, the concepts of the ideal solution and anti-ideal solution (Liang, 1999) were used to obtain the optimal alternative, which was developed from the concept of the relative closeness between the evaluation alternative and the ideal solution. That is, the nearer the evaluation criterion is from the ideal solution and the farther from the anti-ideal solution, the better the alternative that will be determined.

Assuming that there are m alternatives to be evaluated and $n_1 + \cdots + n_t + \cdots n_k = N$ evaluation criteria, let $\tilde{\gamma}_{ij} = (a_{ij}, b_{ij}, c_{ij})$ ($i = 1, 2, \ldots, m;\ j = 1, 2, \ldots, N$) be the average fuzzy superiority of the j^{th} evaluation criterion corresponding to the i^{th} alternative. Since the evaluation criteria include the positive (or benefit) criteria and negative (or cost) criteria, in order to consistently measure the performance value, all benefit criteria and cost criteria must be standardized. That is, the ideal solution will be the maximum value of all benefit criteria or the minimum value of the cost criterion. Based on such a principle, set $\alpha_j = \max_i \{c_{ij}\}$ and $\beta_j = \min_i \{a_{ij}\}$. The fuzzy superiority $\tilde{\rho}_{ij}$ of the j^{th} evaluation criterion corresponding to the i^{th} alternative after standardization can be defined as follows:

(1) For the benefit evaluation criterion j, the larger the value the better. That is, the criterion j has a positive contribution to the performance value, the standardization of the fuzzy superiority $\tilde{\rho}_{ij}$ can be expressed as $\tilde{\rho}_{ij} = \left(e_{ij}, f_{ij}, g_{ij}\right) = \left(\frac{a_{ij}}{\alpha_j}, \frac{b_{ij}}{\alpha_j}, \frac{c_{ij}}{\alpha_j} \right)$.
(2) For the cost evaluation criterion j, the smaller the value the better. That is, the criterion j has a negative contribution to the performance value, the standardization of the fuzzy superiority $\tilde{\rho}_{ij}$ can be expressed as $\tilde{\rho}_{ij} = \left(e_{ij}, f_{ij}, g_{ij}\right) = \left(\frac{\beta_j}{c_{ij}}, \frac{\beta_j}{b_{ij}}, \frac{\beta_j}{a_{ij}} \right)$.

This study adopted the GMIR method to calculate the representative value of $\tilde{\rho}_{ij}$ as $G(\tilde{\rho}_{ij})$ and compared these GMIR values to determine the fuzzy ideal value $\tilde{\varphi}_j^+$ and the fuzzy anti-ideal value $\tilde{\psi}_j^-$. Then

(1) For the benefit evaluation criterion j:
   (i) If $G(\tilde{\rho}_{kj}) = \max_i G(\tilde{\rho}_{ij})$, then the fuzzy ideal value $\tilde{\varphi}_j^+ = \tilde{\rho}_{kj}$.
   (ii) If $G(\tilde{\rho}_{tj}) = \min_i G(\tilde{\rho}_{ij})$, then the fuzzy anti-ideal value $\tilde{\psi}_j^- = \tilde{\rho}_{tj}$.

(2) For the cost evaluation criterion j:

(i) If $G(\tilde{\rho}_{kj}) = \min_i G(\tilde{\rho}_{ij})$, then the fuzzy ideal value $\tilde{\varphi}_j^+ = \tilde{\rho}_{kj}$.

(ii) If $G(\tilde{\rho}_{tj}) = \max_i G(\tilde{\rho}_{ij})$, then the fuzzy anti-ideal value $\tilde{\psi}_j^- = \tilde{\rho}_{tj}$.

Finally, the fuzzy ideal solution $\tilde{\Phi}^+$ and the fuzzy anti-ideal solution $\tilde{\Psi}^-$ can be defined:

$$\tilde{\Phi}^+ = (\tilde{\varphi}_1^+, \tilde{\varphi}_2^+, \ldots, \tilde{\varphi}_j^+, \ldots, \tilde{\varphi}_N^+)$$

and

$$\tilde{\Psi}^- = (\tilde{\psi}_1^-, \tilde{\psi}_2^-, \ldots, \tilde{\psi}_j^-, \ldots, \tilde{\psi}_N^-).$$

6. Solve the Distance of Each Alternative between the Ideal and Anti-ideal Solutions

Let $\omega_j^* (j = 1, 2, \ldots, N)$ be the integrated weight of evaluation criterion j obtained by fuzzy AHP in Section 3.3. The distances between the alternatives to be evaluated and the fuzzy ideal solution $\tilde{\Phi}^+$ and the fuzzy anti-ideal solution $\tilde{\Psi}^-$ can be expressed as δ_i^+ and δ_i^-, respectively.

$$\delta_i^+ = \sqrt{\sum_{j=1}^{N} \left\{ \left(\omega_j^*\right)^2 \times \left[D_m\left(\tilde{\varphi}_j^+, \tilde{\rho}_{ij}\right) \right]^2 \right\}}$$

and

$$\delta_i^- = \sqrt{\sum_{j=1}^{N} \left\{ \left(\omega_j^*\right)^2 \times \left[D_m\left(\tilde{\psi}_j^-, \tilde{\rho}_{ij}\right) \right]^2 \right\}}, i = 1, 2, \ldots, m.$$

Here, $D_m(\bullet)$ can be calculated using Eq. (2) from Section 2.4.

7. Calculate the Relative Closeness of Each Alternative and Select the Best Choice

In this paper, the relative distance between each alternative A_i and the ideal solution was used to measure the priority of the alternatives. That is, the relative closeness index RC_i^* was used to evaluate the priority of the alternatives. Define

$$RC_i^* = \frac{\delta_i^-}{\delta_i^+ + \delta_i^-}, i = 1, 2, \ldots, m.$$

The foregoing equation, where $0 \le RC_i^* \le 1$, implies that the larger RC_i^*, the larger δ_i^- will be, and the farther the distance between alternative A_i and the anti-ideal solution is (*i.e.*, the closer the distance between alternative A_i and the ideal solution), the better the ranking of alternative A_i. The m alternatives can therefore be ranked according to the size of their RC_i^* value, and the best alternative can be chosen.

IV. CASE ILLUSTRATION

This paper took three container ports as simulation cases to illustrate the evaluation method of fuzzy AHP-TOPSIS proposed in this paper. The operational steps of this simulation case were as follows:

Step 1: Form a review committee and construct a hierarchical structure.

Firstly, a hierarchy was established, as shown in Fig 1, for evaluating the attraction of container ports. The hierarchy consisted of four levels; layer 1 was the goal, which is hopefully the priority of container ports in the alternative solutions; layer 2 was the six dimensions used to evaluate the container ports; layer 3 was the 24 criteria proposed in Section 3; and layer 4 was the solutions of 3 container ports. Then, AHP and TOPSIS expert questionnaires based above hierarchy were designed. Furthermore, three experts (*i.e.*, X, Y, Z) in the areas of marine transport and port affairs (one container carrier, one shipping agent, and an import and export shipper) are employed to evaluate the attraction of three container ports (*i.e.*, A_1, A_2, A_3) based on designed expert questionnaires.

Step 2: Use the fuzzy AHP method to solve the weights of all evaluation dimensions and evaluation criteria.

In this paper, the AHP expert questionnaire and fuzzy AHP method were used to evaluate the integrated weights of the six evaluation dimensions and the 24 evaluation criteria. Finally, the integrated weights of the evaluation dimensions and evaluation criteria could be obtained by using the fuzzy AHP steps. The results are shown in Table 1.

Step 3: Evaluate the fuzzy superiority of all evaluation criteria versus three schemes.

Using the concept of Section 3.4, it is assumed that the three experts will evaluate the value of the fuzzy superiority of all criteria versus the three container ports. In our case, three criteria (*i.e.*, C_{41}, C_{42}, and C_{43}) are objective and cost criteria; while the other 21 criteria are subjective and benefit criteria. The three experts in this paper evaluate the fuzzy superiority of the 21 subjective criteria and three objective criteria in the three ports, and the results are shown in Table 2 and Table 3.

Step 4: Calculate the ideal solution and anti-ideal solution.

Firstly, there are 21 subjective criteria and three objective criteria, as well as 23 benefit criteria and three cost criteria in this case. In order to provide a consistent performance value, the concept of Section 3.5 is used to standardize all benefit criteria and cost criteria to obtain the fuzzy superiority $\tilde{\rho}_{ij}$ and GMIR value after standardization. The results are shown in Table 4.

Table 1. The integrated weights of all evaluation dimensions and evaluation criteria.

Evaluation aspects	Relative weights (A)	Evaluation factors	Relative weights (B)	Integrated weights (C) = (A)*(B)
C_1	0.199	C_{11}	0.2427	0.0483
		C_{12}	0.3874	0.0771
		C_{13}	0.1915	0.0381
		C_{14}	0.1784	0.0355
C_2	0.148	C_{21}	0.1669	0.0247
		C_{22}	0.2108	0.0312
		C_{23}	0.3608	0.0534
		C_{24}	0.2615	0.0387
C_3	0.162	C_{31}	0.2167	0.0351
		C_{32}	0.3377	0.0547
		C_{33}	0.2136	0.0346
		C_{34}	0.2320	0.0376
C_4	0.204	C_{41}	0.3059	0.0624
		C_{42}	0.2784	0.0568
		C_{43}	0.2358	0.0481
		C_{44}	0.1799	0.0367
C_5	0.186	C_{51}	0.2833	0.0527
		C_{52}	0.3247	0.0604
		C_{53}	0.2102	0.0391
		C_{54}	0.1818	0.0338
C_6	0.101	C_{61}	0.2980	0.0301
		C_{62}	0.3307	0.0334
		C_{63}	0.1990	0.0201
		C_{64}	0.1723	0.0174

Table 2. The fuzzy superiority of 21 subjective criteria evaluated by three experts in three ports.

Criteria	Experts	Linguistic values			Fuzzy superiority values		
		A_1	A_2	A_3	A_1	A_2	A_3
C_{11}	X	G	F	VP	(0.333, 0.583, 0.833)	(0.333, 0.583, 0.833)	(0.083, 0.25, 0.5)
	Y	G	G	F			
	Z	P	F	P			
C_{12}	X	F	VG	F	(0.333, 0.5, 0.667)	(0.667, 0.917, 1)	(0.25, 0.5, 0.75)
	Y	VP	VG	F			
	Z	VG	G	F			
C_{13}	X	G	G	P	(0.417, 0.667, 0.917)	(0.417, 0.667,0.917)	(0.25, 0.5, 0.667)
	Y	G	G	P			
	Z	F	F	VG			
C_{14}	X	F	VG	F	(0.083, 0.167, 0.417)	(0.667, 0.917, 1)	(0.25, 0.5, 0.75)
	Y	VP	VG	F			
	Z	VP	G	F			
C_{21}	X	VP	VG	P	(0.25, 0.417, 0.667)	(0.5, 0.75, 0.917)	(0, 0.167, 0.417)
	Y	G	G	P			
	Z	F	F	VP			
C_{22}	X	F	P	F	(0.167, 0.333, 0.583)	(0.25, 0.417, 0.583)	(0.25, 0.417, 0.667)
	Y	F	G	G			
	Z	VP	VP	VP			

Table 2. (Continued)

Criteria	Experts	Linguistic values			Fuzzy superiority values		
		A_1	A_2	A_3	A_1	A_2	A_3
C_{23}	*X*	*P*	*G*	*P*	(0.167, 0.417, 0.667)	(0.5, 0.75, 0.917)	(0, 0.167, 0.417)
	Y	*F*	*VG*	*VP*			
	Z	*F*	*F*	*P*			
C_{24}	*X*	*F*	*P*	*F*	(0.167, 0.333, 0.583)	(0.333, 0.583, 0.75)	(0.083, 0.25, 0.5)
	Y	*F*	*F*	*P*			
	Z	*VP*	*VG*	*VP*			
C_{31}	*X*	*G*	*VG*	*G*	(0.5, 0.75, 0.917)	(0.583, 0.833, 0.917)	(0.5, 0.75, 0.917)
	Y	*F*	*VG*	*VG*			
	Z	*VG*	*F*	*F*			
C_{32}	*X*	*F*	*G*	*F*	(0.333, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.167, 0.333, 0.583)
	Y	*VG*	*VG*	*VG*			
	Z	*P*	*P*	*P*			
C_{33}	*X*	*F*	*F*	*F*	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.167, 0.333, 0.583)
	Y	*F*	*F*	*VP*			
	Z	*F*	*F*	*F*			
C_{34}	*X*	*F*	*G*	*F*	(0.417, 0.667, 0.833)	(0.583, 0.833, 1)	(0.417, 0.667, 0.833)
	Y	*F*	*G*	*F*			
	Z	*VG*	*VG*	*VG*			
C_{44}	*X*	*G*	*VG*	*G*	(0.25, 0.417, 0.667)	(0.583, 0.833, 0.917)	(0.5, 0.75, 0.917)
	Y	*F*	*VG*	*VG*			
	Z	*VP*	*F*	*F*			
C_{51}	*X*	*F*	*VG*	*F*	(0.333, 0.5, 0.667)	(0.667, 0.917, 1)	(0.25, 0.5, 0.75)
	Y	*VG*	*VG*	*F*			
	Z	*VP*	*G*	*F*			
C_{52}	*X*	*F*	*G*	*F*	(0.333, 0.583, 0.833)	(0.5, 0.75, 0.917)	(0.083, 0.25, 0.5)
	Y	*F*	*VG*	*VP*			
	Z	*G*	*F*	*P*			
C_{53}	*X*	*F*	*VG*	*F*	(0.333, 0.5, 0.667)	(0.667, 0.917, 1)	(0.25, 0.5, 0.75)
	Y	*VG*	*VG*	*F*			
	Z	*VP*	*G*	*F*			
C_{54}	*X*	*G*	*VG*	*G*	(0.25, 0.417, 0.667)	(0.583, 0.833, 0.917)	(0.5, 0.75, 0.917)
	Y	*F*	*VG*	*VG*			
	Z	*VP*	*F*	*F*			
C_{61}	*X*	*F*	*VG*	*F*	(0.333, 0.5, 0.667)	(0.667, 0.917, 1)	(0.417, 0.667, 0.833)
	Y	*VG*	*VG*	*VG*			
	Z	*VP*	*G*	*F*			
C_{62}	*X*	*VP*	*VG*	*P*	(0.083, 0.167, 0.417)	(0.417, 0.667, 0.833)	(0, 0.167, 0.417)
	Y	*F*	*F*	*P*			
	Z	*VP*	*F*	*VP*			
C_{63}	*X*	*F*	*VG*	*F*	(0.333, 0.5, 0.667)	(0.667, 0.917, 1)	(0.25, 0.5, 0.75)
	Y	*VG*	*VG*	*F*			
	Z	*VP*	*G*	*F*			
C_{64}	*X*	*G*	*VG*	*G*	(0.25, 0.417, 0.667)	(0.583, 0.833, 0.917)	(0.5, 0.75, 0.917)
	Y	*F*	*VG*	*VG*			
	Z	*VP*	*F*	*F*			

Table 3. The fuzzy superiority of the three objective criteria evaluated by three experts in three ports.

Criteria	Original data				Fuzzy superiority values		
	Month	A_1	A_2	A_3	A_1	A_2	A_3
C_{41}	Jul.	41.2	37.8	45.6	(41.1, 42.16, 44.1)	(35.4, 38.13, 40.1)	(41.6, 44.83, 49.4)
	Aug.	42.3	35.4	49.4			
	Sep.	44.1	39.4	43.1			
	Oct.	41.1	40.1	41.6			
C_{42}	Jul.	190	182	176	(173, 181.4, 190)	(170, 175.2, 182)	(167, 179.01, 193)
	Aug.	184	173	167			
	Sep.	179	170	193			
	Oct.	173	176	181			
C_{43}	Jul.	3.1	3.6	3.1	(2.2, 2.68, 3.1)	(2.8, 3.21, 3.6)	(2.6, 2.94, 3.2)
	Aug.	2.2	3.4	2.6			
	Sep.	2.8	3.1	3.2			
	Oct.	2.7	2.8	2.9			

Table 4. Standardized superiority and GMIR value for all criteria.

Criteria	A_1		A_2		A_3	
	$\tilde{\rho}_{ij}$	GMIR	$\tilde{\rho}_{ij}$	GMIR	$\tilde{\rho}_{ij}$	GMIR
C_{11}	(0.4, 0.7, 1)	0.7	(0.4, 0.7, 1)	0.7	(0.1, 0.3, 0.6)	0.317
C_{12}	(0.333, 0.5, 0.667)	0.5	(0.667, 0.917, 1)	0.889	(0.25, 0.5, 0.75)	0.5
C_{13}	(0.454, 0.727, 1)	0.727	(0.455, 0.727, 1)	0.727	(0.273, 0.545, 0.727)	0.530
C_{14}	(0.083, 0.167, 0.417)	0.194	(0.667, 0.917, 1)	0.889	(0.25, 0.5, 0.75)	0.5
C_{21}	(0.273, 0.455, 0.727)	0.470	(0.545, 0.818, 1)	0.803	(0, 0.182, 0.455)	0.197
C_{22}	(0.25, 0.5, 0.875)	0.521	(0.375, 0.625, 0.875)	0.625	(0.375, 0.625, 1)	0.646
C_{23}	(0.182, 0.455, 0.727)	0.455	(0.545, 0.818, 1)	0.803	(0, 0.182, 0.455)	0.197
C_{24}	(0.222, 0.444, 0.778)	0.463	(0.444, 0.778, 1)	0.759	(0.111, 0.333, 0.667)	0.352
C_{31}	(0.545, 0.818, 1)	0.803	(0.636, 0.909, 1)	0.879	(0.545, 0.818, 1)	0.803
C_{32}	(0.4, 0.7, 0.9)	0.683	(0.5, 0.8, 1)	0.783	(0.4, 0.7, 0.9)	0.683
C_{33}	(0.333, 0.667, 1)	0.667	(0.333, 0.667, 1)	0.667	(0.222, 0.444, 0.778)	0.463
C_{34}	(0.417, 0.667, 0.833)	0.653	(0.583, 0.833, 1)	0.819	(0.417, 0.667, 0.833)	0.653
C_{41}	(0.803, 0.84, 0.861)	0.837	(0.883, 0.928, 1)	0.933	(0.717, 0.79, 0.851)	0.788
C_{42}	(0.879, 0.921, 0.965)	0.921	(0.918, 0.953, 0.982)	0.952	(0.865, 0.933, 1)	0.933
C_{43}	(0.71, 0.821, 1)	0.832	(0.611, 0.685, 0.786)	0.690	(0.688, 0.748, 0.846)	0.754
C_{44}	(0.273, 0.455, 0.727)	0.470	(0.636, 0.909, 1)	0.879	(0.545, 0.818, 1)	0.803
C_{51}	(0.333, 0.5, 0.667)	0.5	(0.667, 0.917, 1)	0.889	(0.25, 0.5, 0.75)	0.5
C_{52}	(0.364, 0.636, 0.909)	0.636	(0.545, 0.818, 1)	0.803	(0.091, 0.273, 0.545)	0.288
C_{53}	(0.333, 0.5, 0.667)	0.5	(0.667, 0.917, 1)	0.889	(0.25, 0.5, 0.75)	0.5
C_{54}	(0.273, 0.455, 0.727)	0.470	(0.636, 0.909, 1)	0.879	(0.545, 0.818, 1)	0.803
C_{61}	(0.333, 0.5, 0.667)	0.5	(0.667, 0.917, 1)	0.889	(0.417, 0.667, 0.833)	0.653
C_{62}	(0.1, 0.2, 0.5)	0.233	(0.5, 0.8, 1)	0.783	(0, 0.2, 0.5)	0.217
C_{63}	(0.333, 0.5, 0.667)	0.5	(0.667, 0.917, 1)	0.889	(0.25, 0.5, 0.75)	0.5
C_{64}	(0.273, 0.455, 0.727)	0.470	(0.636, 0.909, 1)	0.879	(0.545, 0.818, 1)	0.803

Then, by using the data of Table 4 and by comparing the GMIR values of all the ports corresponding to the three ports, it is possible to determine the fuzzy ideal value $\tilde{\varphi}_j^+$ and the fuzzy anti-ideal value $\tilde{\psi}_j^-$, as shown in Table 5.

Finally, using the data of Table 5, it is possible to determine the fuzzy ideal solution $\tilde{\Phi}^+$ and the fuzzy anti-ideal solution $\tilde{\Psi}^-$, respectively.

$$\tilde{\Phi}^+ = [(0.4, 0.7, 1), (0.667, 0.917, 1), \ldots, \ldots, (0.667, 0.917, 1), (0.636, 0.909, 1)]$$

Table 5. The fuzzy ideal value $\tilde{\phi}_j^+$ and fuzzy anti-ideal value $\tilde{\psi}_j^-$ for all criteria.

Criteria	Fuzzy ideal value $\tilde{\phi}_j^+$	Fuzzy anti-ideal value $\tilde{\psi}_j^-$
C_{11}	(0.4, 0.7, 1)	(0.1, 0.3, 0.6)
C_{12}	(0.667, 0.917, 1)	(0.25, 0.5, 0.75)
C_{13}	(0.455, 0.727, 1)	(0.273, 0.545, 0.727)
C_{14}	(0.667, 0.917, 1)	(0.083, 0.167, 0.417)
C_{21}	(0.545, 0.818, 1)	(0, 0.182, 0.455)
C_{22}	(0.375, 0.625, 1)	(0.25, 0.5, 0.875)
C_{23}	(0.545, 0.818, 1)	(0, 0.182, 0.455)
C_{24}	(0.444, 0.778, 1)	(0.111, 0.333, 0.667)
C_{31}	(0.636, 0.909, 1)	(0.545, 0.818, 1)
C_{32}	(0.5, 0.8, 1)	(0.4, 0.7, 0.9)
C_{33}	(0.333, 0.667, 1)	(0.222, 0.444, 0.778)
C_{34}	(0.583, 0.833, 1)	(0.417, 0.667, 0.833)
C_{41}	(0.883, 0.928, 1)	(0.717, 0.79, 0.851)
C_{42}	(0.918, 0.953, 0.982)	(0.879, 0.921, 0.965)
C_{43}	(0.71, 0.821, 1)	(0.611, 0.685, 0.786)
C_{44}	(0.636, 0.909, 1)	(0.273, 0.455, 0.727)
C_{51}	(0.667, 0.917, 1)	(0.25, 0.5, 0.75)
C_{52}	(0.545, 0.818, 1)	(0.091, 0.273, 0.545)
C_{53}	(0.667, 0.917, 1)	(0.25, 0.5, 0.75)
C_{54}	(0.636, 0.909, 1)	(0.273, 0.455, 0.727)
C_{61}	(0.667, 0.917, 1)	(0.333, 0.5, 0.667)
C_{62}	(0.5, 0.8, 1)	(0, 0.2, 0.5)
C_{63}	(0.667, 0.917, 1)	(0.25, 0.5, 0.75)
C_{64}	(0.636, 0.909, 1)	(0.273, 0.455, 0.727)

Table 6. Distance between the three alternatives to the ideal solution and anti-ideal solution.

Alternatives	Distance between alternatives and ideal solution δ_i^+	Distance between alternatives and anti-ideal solution δ_i^-
A_1	0.003711098	0.001165407
A_2	0.000059327	0.005951648
A_3	0.005068177	0.000448383

and

$$\tilde{\Psi}^- = [(0.1, 0.3, 0.6), (0.25, 0.5, 0.75), \ldots, \ldots, (0.25, 0.5, 0.75), (0.273, 0.455, 0.727)]$$

Step 5: Calculate the distance between each alternative to the ideal solution and the anti-ideal solution.

The data in Table 1, Table 4, and Table 5, as well as the formula in Section 3.6 can be used to calculate the distance between the three alternatives to the ideal solution and anti-ideal solution. The results are shown in Table 6.

Step 6: Calculate the relative closeness of all alternatives and ranking to select the best choice.

Using the data from Table 6 and the formula in Section 3.7, the relative closeness of each alternative can be calculated. Finally, the RC values of three alternatives versus ideal solution can be obtained:

$$RC_{A_1}^* = \frac{0.001165407}{0.003711098 + 0.001165407} = 0.2390;$$

$$RC_{A_2}^* = \frac{0.005951648}{0.000059327 + 0.005951648} = 0.9901; \text{ and}$$

$$RC_{A_3}^* = \frac{0.000448383}{0.005068177 + 0.000448383} = 0.0813.$$

Because $RC_{A_2}^* > RC_{A_1}^* \leq RC_{A_3}^*$ the alternative A_2 is considered to be the most attractive port for container carriers.

V. CONCLUSIONS

Efforts to improve the competitiveness of container ports should focus on how to provide better port services to meet the needs of users and enhance their satisfaction and loyalty, which will strengthen the ports' sustainable competitive advantage. If a port system is not competitive in terms of service quality or circulation efficiency, this will lead to the transshipment of goods to other, more-effective ports, which will affect route deployment and port selection by container carriers, and eventually result in the port's decline. In contrast, ports providing attractive services and products will effectively strengthen the consumer behavior of container carriers, which will induce carriers to berth, load and unload, warehouse, and increase their value-added logistics activities at the port, which will enhance the port's competitiveness. Port attractiveness is consequently the prerequisite for a port's achieve competitiveness, and is also a means of investigating a port's competitive advantages.

The attractiveness of a port will affect container carriers' port selection choices, which in turn will affect the port's competitiveness. To efficiently tackle the ambiguity frequently arising in available information and do more justice to the essential fuzziness in human judgment, and properly integrate the opinions of the decision-makers, as well as to appropriately score and rank alternatives so as to find an optimal solution, combining the concepts of fuzzy set theory, AHP, and TOPSIS, a fuzzy AHP-TOPSIS evaluation method for selecting the most attractive container port is developed. After first establishing a hierarchical structure, which consisted of a target layer, evaluation dimension layer, criteria layer, and scheme layer, this paper used the fuzzy AHP method to determine the weights of the evaluation criteria layer. Afterwards, this paper used the fuzzy TOPSIS method to construct an evaluation method enabling container carriers to select the most attractive port, and then employed a simulated case to elucidate operating processes of this method.

In our simulation case, a hierarchy structure—with six dimensions, 24 criteria, and three hypothetical container ports—was developed. Three experts were then invited to fill in the questionnaires. Subsequently, the proposed fuzzy AHP-TOPSIS method is utilized to demonstrate the computational process of the systematic approach. Finally, the result of the numerical study showed the container port A_2 is determined as the most attractive port for container carriers based on the proposed fuzzy MCDM algorithm.

The simulated case in this paper involved three experts and three hypothetical ports, and its results of this case supported the use of the proposed method. If container operators and carriers adopt this method to evaluate and select ports in the future, they can freely change the number of experts, feasible ports and valuation criteria. To make this method more suitable for practical decision-making, the method can also be systematized and computerized, so that selection of an optimal port selection can be automatically performed by computer after inputting the relevant data.

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