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Full Length Research Paper

A fuzzy MCDM model of service performance for container ports

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To achieve the aim of management control function and monitor the service systems at container ports, it is essential to study the evaluation of service performance. The main purpose of this paper is to develop a fuzzy MCDM algorithm (multiple criteria decision-making model) to evaluate the service performance for container ports. Firstly, some concepts and methods used to develop a fuzzy MCDM algorithm are briefly introduced. Secondly, a step-by-step fuzzy MCDM algorithm based on the concept of α-cut is proposed. Finally, a numerical example with a hierarchy structure of five criteria, thirty-one sub-criteria and three alternatives is illustrated, by using the proposed fuzzy MCDM approach. Furthermore, the numerical example shows that the proposed approach can successfully accomplish the study's goal.

Key words: Fuzzy MCDM, service performance, container ports.

INTRODUCTION

In 1999, the UNCTAD originated the expression, "the fourth-generation port," for those ports in the nineteen nineties that their container cargoes are mainly handling objectives. Moreover, there are some characteristics which appeared on those ports such as: (a) integrating the information technology (IT) and operating the administrative systems and marketing function into promoting productivity, (b) developing the hub and feeder network systems, and (c) coordinating the ports as comprhensive logistics centers. Besides, the positive marketing and customer-oriented services emerged from the marketing function of the port business. With reference to the first and second generation port (UNCTAD, 1992), the general and bulk cargoes were mainly handling objectives. Before the ages of the nineteen eighties, collection and distribution were the main activities; however, service activity was not yet the major activity. Fast development of the container transport was subsequently boosted in the third-generation at the period of the nineteen eighties to nineteen nineties (UNCTAD, 1992), when service activity was gradually focused on by the shipping market players. After the nineteen nineties, the service activity got attention from the shipping and port players on the fourth-generation port (UNCTAD, 1999).

A container port is a nodal point used to handle container cargo to offer value-added services such as collection, warehousing, packing and distribution among international trade and logistics systems. In particular, when the global container shipping transport network emerged, the container port in the nodal points had already strengthened her competitive ability to withstand the keen environment, where the risks and uncertainties were greater than before (Bruyninckx, 2002; Cable, 2001; Heaver et al., 2001; Winkelmans, 2002). As such, the keen competition and many structural changes with global challenges have arisen among port and shipping chains focusing on landside and seaside competitions and business logistics (Ding, 2009a; 2009b). Therefore, the container port was actively boosting the service added values and service functions to effectively connect

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the global transport networks, and then, the port might become an important logistics center in the world (Hanyes et al., 1997).

In many port literature, the input element (that is, providing different resources and services), the process one (that is, operating different functional systems) and the output one (that is, evaluating the operation and service performance) in container ports are important issues to be studied. To achieve the goal of management control function, the service performance indicators can be made to measure the port efficiency or productivities by the port operators. Moreover, these indicators should be affiliated with the different port service systems to observe the effectiveness for all operation systems in container ports. A reasonable standard of service performance can be made to inform the relative relationship of both resources' input and operation process, as well as the output of productivities. A good exhibition of service performance can monitor the input and process stages of port operations based on the control function of management. Hence, we intend to evaluate the service performance for container ports in this paper.

Since the evaluation of service performance is crucial, however, experience has shown that it is not an easy matter. It involves a multiplicity of complex considerations and poses a unique characteristic of multiple criteria decision-making (MCDM). The criteria are usually subjective in nature and often changing with the decision-making conditions, which create the fuzzy and uncertain nature among the criteria and the important weights of the criteria. Further, there are situations in which information is incomplete or imprecise or views that are subjective or endowed with linguistic characteristics, thereby creating a fuzzy decision-making environment (Ding, 2005). Therefore, the fuzzy set theory (Zadeh, 1965), combined with the MCDM method (Anisseh et al., 2009; Balli and Korukoğlu, 2009; Büyüközkan et al., 2008; Chou, 2010a; 2010b; Ding, 2005; 2010; Ertuğrul and Karakaşoğlu, 2008; Sreekumar and Mahapatra, 2009), is adopted as an evaluation tool to improve the quality of the study. In the light of this, a fuzzy MCDM model is used to evaluate service performance for container ports.

In summary, the aim of this paper is to develop a fuzzy MCDM model to improve the quality of decision-making in evaluating service performance for container ports.

RESEARCH METHODS

Here, some of the research methods are briefly introduced. To effectively resolve the perplexity of decision making problems, the fuzzy MCDM method based on the α-cut concept is developed in the following description.

Triangular fuzzy numbers and algebraic operations

A fuzzy number A (Dubois and Prade, 1978) is described as a subset of real number whose membership function f_A is a continuous mapping from the real line $\Re$ to a closed interval $[0,1]$, which has the following characteristics: (1) $f_A(x)=0,$ for all $x\in(-\infty, c]\cup[d,\infty)$; (2) f_A is strictly increasing in $[c, a]$ and strictly decreasing in $[b, d]$; (3) $f_A(x)=1,$ for all $x\in[a, b]$, where c, a, b, and d are real numbers, and $-\infty<c\le a\le b\le d<\infty$. For convenience, let f_A^L denote the left membership function of fuzzy number A, i.e. $f_A^L(x)=f_A(x),$ for all $x\in[c, a]$; and f_A^R is the right membership function of fuzzy number A, i.e. $f_A^R(x)=f_A(x),$ for all $x\in[b, d]$. When $f_A^L(x)=(x-c)/(a-c), \quad c\le x\le a$; $f_A^R(x)=(x-d)/(a-d), \quad a\le x\le d$, then A is called a triangular fuzzy number, which can be denoted by (c, a, d). In this paper, the triangular fuzzy numbers are used to characterize the aggregation results of multiple decision-makers' (DMs) opinions.

The α-cut of fuzzy number A with membership function $f_A(x)$ is defined as $A^\alpha=\{x|f_A(x)\ge\alpha, \quad 0\le\alpha\le 1\}$ and denoted it by $[A_l^\alpha, A_u^\alpha],$ i.e., $A^\alpha=[A_l^\alpha, A_u^\alpha].$ If $A_l^\alpha>0,$ for all $\alpha\in[0, 1],$ A is named as positive fuzzy number.

Let A and B be two positive fuzzy numbers. $A^\alpha=[A_l^\alpha, A_u^\alpha]$ and $B^\alpha=[B_l^\alpha, B_u^\alpha]$ are the α-cut of A and B, respectively. According to the extension principle (Zadeh, 1965) and vertex method (Dong and Shah, 1987), the algebraic operations of any two positive fuzzy numbers A and B can be expressed as:

Addition ⊕: $(A\oplus B)^\alpha=[A_l^\alpha+B_l^\alpha, A_u^\alpha+B_u^\alpha]$,

Subtraction ⊖: $(A\ominus B)^\alpha=[A_l^\alpha-B_u^\alpha, A_u^\alpha-B_l^\alpha]$,

Multiplication ⊗: $(A\otimes B)^\alpha=[A_l^\alpha B_l^\alpha, A_u^\alpha B_u^\alpha]$,

Division ⊘: $(A\oslash B)^\alpha=[A_l^\alpha/B_u^\alpha, A_u^\alpha/B_l^\alpha]$.

Ranking method

For matching the following fuzzy MCDM algorithm developed in this paper and the prevailing nature of solving the problem, a systematic method based on the concepts of integral value (Liou and Wang, 1992; Yager, 1981) and α-cut (Liu, 1998) is used to rank the final ratings.

Suppose that g_A^L is the inverse function of f_A^L, and g_A^R is the inverse function of f_A^R. Define the left integral value of A as $I^L(A)=\int_0^1 g_A^L(y)dy$, and the right integral value of A as

$$I^R(A)=\int_0^1 g_A^R(y)dy.$$

Let $\alpha_j\in[0,1], \quad j=0,1,\ldots,k$, and

$0 = \alpha_0 < \alpha_1 \cdots < \alpha_j < \cdots < \alpha_k = 1$, then based on the trapezoidal rule (Gerald and Wheatly, 1990), the left integral value and the right integral value of fuzzy number *A* can be obtained:

$$I^L(A) = \tfrac{1}{2}\lim_{k\to\infty}\left\{\sum_{j=1}^{k}[g_A^L(\alpha_j) + g_A^L(\alpha_{j-1})]\Delta\alpha_j\right\} \quad (1)$$

$$I^R(A) = \tfrac{1}{2}\lim_{k\to\infty}\left\{\sum_{j=1}^{k}[g_A^R(\alpha_j) + g_A^R(\alpha_{j-1})]\Delta\alpha_j\right\} \quad (2)$$

where $\Delta\alpha_j = \alpha_j - \alpha_{j-1}$.

The ranking value $R(A)$ of fuzzy numbers *A* is defined as

$$R(A) = \beta I^R(A) + (1-\beta)I^L(A)\,, 0 \le \beta \le 1. \quad (3)$$

The value β can be referred to as the DM's risk attitude index. If $\beta < 0.5$, $\beta = 0.5$, and $\beta > 0.5$, respectively, it implies that the DM is a risk-averter (pessimism), risk-neuter (moderatism), and risk-lover (optimism), respectively.

The value β can be determined by two procedures. First way is that DM gives the value β at the data output stage (Kim and Park, 1990), e.g., β =0.3, 0.5, 0.75. However it is difficult to apply this procedure directly in multiple DMs problem. Hence, Chang and Chen (1994) suggested that it is reasonable to evaluate β through the evaluation data conveyed by the DMs at the data input stage. In this paper, the method developed by Chang & Chen (1994) is cited to find the total risk attitude index β.

The ranking of fuzzy numbers A_i and A_j are defined based on the following rules:

(a) $A_i > A_j \Leftrightarrow R(A_i) > R(A_j)$;

(b) $A_i < A_j \Leftrightarrow R(A_i) < R(A_j)$ and

(c) $A_i = A_j \Leftrightarrow R(A_i) = R(A_j)$.

Let A_i , $i = 1, 2, \ldots, n,$ be n fuzzy numbers. By using Equations (1), (2) and (3), the ranking value $R(A_i)$ of the fuzzy number A_i can be obtained. Then based on the described ranking rules, the ranking of the n fuzzy numbers can be effectively determined.

The proposed fuzzy MCDM algorithm

Here, a systematic approach to the fuzzy MCDM based on the concept of α-cut is proposed. The steps to be taken are thus described.

Step 1: Forming a committee of DMs and, then, selecting the evaluation criteria and identifying the feasible alternatives to develop a hierarchical structure. The concepts of the hierarchical structure analysis with three distinct layers, that is, criteria layer, sub-criteria layer and alternatives layer, are used in this paper. In this paper, there are k criteria (represented as C_t, $t = 1, 2, \ldots, k$), $n_1 + \cdots + n_t + \cdots + n_k$ sub-criteria (represented as $SC_{11} \cdots SC_{1n_1} \cdots SC_{t1} \cdots SC_{tn_t} \cdots SC_{k1} \cdots SC_{kn_k}$), and *m* alternatives (represented as A_i, $i = 1, 2, \ldots, m$) in the hierarchical structure.

Step 2: Choosing evaluation ratings for criteria weights and appropriateness of alternatives versus sub-criteria. In this paper, the Likert's 7-point scale is used by DMs to assess the importance weights of all criteria and appropriateness ratings of all alternatives versus sub-criteria. The scales for importance weights are absolutely high (AH) = 7, very high (VH) = 6, high (H) = 5, medium (M) = 4, low (L) = 3, very low (VL) = 2 and absolutely low (AL) = 1; while for appropriateness ratings, they are absolutely good (AG) = 7, very good (VG) = 6, good (G) = 5, fair (F) = 4, poor (P) = 3, very poor (VP) = 2 and absolutely poor (AP) = 1.

Step 3: Calculating the fuzzy subjective weights of all criteria and sub-criteria by scales for importance weights. The triangular fuzzy numbers, characterized by the use of min, max and geometric mean operations, are used to convey the opinions of all DMs. That is, let x_{tq}, $q = 1, 2, \ldots, n,$ be the numerical value weightings given to criterion C_t by DM *q*. Then, the fuzzy subjective weight of the criterion C_t is defined as $W_t = (c_t, a_t, b_t)$, $t = 1, 2, \ldots, k;$ where $c_t = \min\{x_{t1}, x_{t2}, \ldots, x_{tn}\}$, $a_t = \left(\prod_{q=1}^{n} x_{tq}\right)^{1/n}$, $b_t = \max\{x_{t1}, x_{t2}, \ldots, x_{tn}\}$. And, let y_{tjq}, $q = 1, 2, \ldots, n,$ be the weight given to sub-criterion C_{tj} by the q^{th} DM. Then, the weight of sub-criterion C_{tj} can be represented as $W_{tj} = (c_{tj}, a_{tj}, b_{tj}),$ $t = 1, 2, \ldots, k;$ $j = 1, 2, \ldots, n_t;$ where $c_{tj} = \min\{y_{tj1}, x_{tj2}, \ldots, x_{tjn}\}$, $a_{tj} = \left(\prod_{q=1}^{n} y_{tjq}\right)^{1/n}$, $b_{tj} = \max\{y_{tj1}, y_{tj2}, \ldots, y_{tjn}\}$.

Step 4: Estimating the fuzzy ratings of all feasible alternatives versus all sub-criteria. The appropriateness of alternatives versus various sub-criteria can be obtained by using the scales for appropriateness ratings. For example, let z_{itjr}, $r = 1, 2, \ldots, p,$ be the appropriateness ratings given to alternative A_i versus some sub-criterion C_{tj} by DM r. Then, the fuzzy appropriateness rating of alternative A_i versus sub-criterion C_{tj} can be denoted by $S_{itj} = (c_{itj}, a_{itj}, b_{itj})$, $i = 1, 2, \ldots, m; \quad t = 1, 2, \ldots, k; \quad j = 1, 2, \ldots, n_t$; where $c_{itj} = \min\{z_{itj1}, z_{itj2}, \ldots, z_{itjp}\}$, $a_{itj} = \left(\prod_{r=1}^{p} z_{itjr}\right)^{1/p}$, $b_{itj} = \max\{z_{itj1}, z_{itj2}, \ldots, z_{itjp}\}$.

Step 5: Calculating the aggregation evaluation ratings of all feasible alternatives. Let W_t^{α}, W_{tj}^{α}, and S_{itj}^{α} to be α-cut of W_t, W_{tj}, and S_{itj}, respectively. The α-cut of aggregation appropriateness ratings of alternative A_i versus criterion C_t ($t = 1, 2, \ldots, k$) can be denoted as:

$$R_{it}^{\alpha} = \frac{1}{n_t} \otimes [(S_{it1}^{\alpha} \otimes W_{t1}^{\alpha}) \oplus (S_{it2}^{\alpha} \otimes W_{t2}^{\alpha}) \oplus \cdots \oplus (S_{itj}^{\alpha} \otimes W_{tj}^{\alpha}) \oplus \cdots \oplus (S_{itn_t}^{\alpha} \otimes W_{tn_t}^{\alpha})],$$
$$t = 1, 2, \ldots, k; i = 1, 2, \ldots, m. \quad (4)$$

Furthermore, the final aggregation appropriateness rating with α-cut of alternative A_i can be denoted as:

$$F_i^{\alpha} = \frac{1}{k} \otimes [(R_{i1}^{\alpha} \otimes W_1^{\alpha}) \oplus (R_{i2}^{\alpha} \otimes W_2^{\alpha}) \oplus \cdots \oplus (R_{it}^{\alpha} \otimes W_t^{\alpha}) \oplus \cdots \oplus (R_{ik}^{\alpha} \otimes W_k^{\alpha})],$$
$$i = 1, 2, \ldots, m. \quad (5)$$

Step 6: Ranking the alternatives. Let $A = (c, a, b)$ be the importance weight or appropriateness rating obtained by using the aggregation method proposed in Steps 3 and 4. Based on the method developed by Chang and Chen (1994), $\gamma = (a-c)/(b-c)$ can be considered asall DMs' total risk attitude index for someone's importance weight or appropriateness rating. Hence, for the fuzzy MCDM algorithm presented in this paper, the total risk attitude index β of all DMs can be obtained by:

$$\beta = \frac{\sum_{t=1}^{k}\left(\frac{a_t - c_t}{b_t - c_t}\right) + \sum_{t=1}^{k}\sum_{j=1}^{n_t}\left(\frac{a_{tj} - c_{tj}}{b_{tj} - c_{tj}}\right) + \sum_{i=1}^{m}\sum_{t=1}^{k}\sum_{j=1}^{n_t}\left(\frac{a_{itj} - c_{itj}}{b_{itj} - c_{itj}}\right)}{k + \sum_{t=1}^{k} n_t + m \times \sum_{t=1}^{k} n_t} \quad (6)$$

By Equation (5), various α values, for example, α = 0, 0.2, 0.4, 0.5, 0.6, 0.8 and 1, are taken to obtain the final appropriateness ratings of all feasible alternatives. Furthermore, Equations (1), (2) and (6) are used to calculate the left integral value, right integral value and all DMs' risk attitude index β. Then, by Equation (3), the final ranking values of the m alternatives can be obtained.

A numerical study

Here, a numerical example of evaluating service performance for container ports is studied to demonstrate the computational process of the proposed fuzzy MCDM algorithm, step by step, as follows.

Step 1: It is assumed that a researcher needs to evaluate the service performance for container ports. Three container ports, that is, A1, A2 and A3, respectively, are chosen after preliminary screening for further evaluation. A committee of three DMs (that is, E1, E2, and E3, respectively), has been formed to evaluate the best service performance among the three container ports. With regards to the evaluation criteria, some literature had been studied. For example, Chou et al. (2003) and Chou (2007; 2009) had discussed the service performance and competitiveness of major container ports in Eastern Asia region using the SWOT analysis, fuzzy MCDM approach and multiple criteria evaluation method. Here, the five major criteria and thirty-one sub-criteria, proposed by Chou (2009), would be employed in this paper. The code names of these criteria and sub-criteria are shown in parentheses.

Volume of containers (C1): This criterion includes four sub-criteria, that is, volume of transshipment containers (C11), volume of import containers (C12), volume of export containers (C13) and frequency of vessel calls (C14).

Port location (C2): This criterion includes six sub-criteria, that is, geographical aspects (C21), hinterland accessibility (C22), convenience of vessel entry (C23), closeness to main navigation route (C24), proximity of the feeder port (C25) and further development conditions and possibilities (C26).

Port charges (C3): This criterion includes seven sub-criteria, that is, pilot charges (C31), berth charges (C32), loading and discharging charge (C33), tonnage tax (C34), transshipment freight (C35), inland transportation cost (C36) and warehouse charge (C37).

Port facilities (C4): This criterion includes six sub-criteria, that is, infrastructure condition (C41), number of berths (C42), number of deep water wharfs (C43), number of handling equipment (C44), capacity of storage (C45) and intermodal link (C46).

Port service quality (C5): This criterion includes eight sub-criteria, that is, efficiency of container handling (C51), efficiency of container yard (C52), efficiency of custom (C53), efficiency of berthing (C54), electronic data interchange (EDI) system (C55), vessel traffic service (VTS) system (C56), management information system (MIS) (C57) and international free logistics zone (C58).

Step 2: The three DMs use scales for importance weights to evaluate the importance weights of all criteria C_t and all sub-criteria C_{tj}. For example, the three DMs evaluate

Table 1. The fuzzy weights of all criteria and sub-criteria.

Criteria/ sub-criteria	Fuzzy weights	Criteria / sub-criteria	Fuzzy weights
C1	(3, 4.48, 6)	C34	(2, 2.88, 4)
C2	(3, 4.22, 5)	C35	(4, 4.31, 5)
C3	(4, 4.93, 6)	C36	(5, 5.59, 7)
C4	(4, 5.52, 7)	C37	(4, 4.64, 5)
C5	(5, 5.31, 6)	C41	(5, 5.59, 7)
C11	(4, 4.93, 6)	C42	(4, 5.19, 7)
C12	(4, 4.31, 5)	C43	(5, 5.59, 7)
C13	(3, 3.91, 5)	C44	(5, 5.94, 7)
C14	(4, 4.64, 5)	C45	(4, 4.64, 5)
C21	(4, 5.19, 7)	C46	(6, 6.32, 7)
C22	(4, 4.93, 6)	C51	(5, 5.59, 7)
C23	(4, 4.93, 6)	C52	(5, 5.94, 7)
C24	(4, 4.64, 5)	C53	(5, 5.94, 7)
C25	(4, 4.93, 6)	C54	(4, 4.82, 7)
C26	(5, 5.31, 6)	C55	(5, 5.94, 7)
C31	(3, 3.63, 4)	C56	(5, 5.65, 6)
C32	(3, 3.30, 4)	C57	(6, 6.32, 7)
C33	(6, 6.32, 7)	C58	(6, 6.32, 7)

the importance of C1 with linguistic values H, VH and L, respectively. Then, according to the methods presented in step 3 of the proposed fuzzy MCDM algorithm, the importance evaluation weight of C1 is (3, 4.48, 6). To sum up, the results of the importance weights of all criteria and sub-criteria are shown in Table 1. Similarly, the appropriateness ratings of the three alternatives versus all sub-criteria can be obtained by the methods (step 4) of the proposed fuzzy MCDM algorithm, and as such, the results are shown in Table 2.

Step 3: For space saving and ease of representation, only seven α values, that is, $\alpha = 0, 0.2, 0.4, 0.5, 0.6, 0.8$ and 1, are chosen to be calculated herein. By utilizing Equation (4), the α-cut of aggregation appropriateness ratings of the three alternatives versus thirty-one sub-criteria can be obtained. As such, the results are shown in Table 3; whereas by utilizing Equation (5), the α-cut of the final aggregation appropriateness ratings of the three alternatives can be obtained and as such, the results are shown in Table 4.

Step 4: By using Equation (6), we can obtain the three DMs' total risk attitude index $\beta = 0.424$. Furthermore, by using Equations (1), (2) and (6), the left integral values, right integral values and final ranking values can be obtained. As such, the results are shown in Table 5. However, the ranking order of the three alternatives is A3, A2 and A1. Therefore, it is obvious that the best service performance of container port is A3.

Conclusions

After the nineteen nineties, the service activity was noticed by the shipping and port players on the fourth-generation ports. For monitoring the service systems in order to keep effectiveness and productivities at container ports, the measurement of service performance is essential to the study, since the evaluation process of service performance involves a multiplicity of complex considerations and poses a MCDM situation. Moreover, some evaluation criteria are faced with an ambiguous and uncertain nature. Hence, the evaluation of service performance for container ports is confronted with a fuzzy decision-making environment. In light of this, the aim of this paper is to develop a fuzzy MCDM model to evaluate service performance for container ports.

To effectively evaluate service performance for container ports, a systematically fuzzy MCDM model, based on the concept of α-cut, is proposed. At first, we use the geometric mean operations to develop the aggregation method of multiple DMs' opinions, as well as incorporate the risk attitude index to convey the total risk attitude of all DMs by using the estimation data obtained at the data input stage. Then, we calculated the final aggregation ratings and developed a matching ranking method for the proposed fuzzy MCDM method with multiple DMs. Finally, a step by step numerical example was illustrated to study the computational process of the fuzzy MCDM model. In addition, the proposed approach has successfully accomplished the study's goal.

Furthermore, this paper with its methodologies developed can be employed as a practical tool for business application. The proposed model not only releases the limitation of crisp values, but also facilitates its implementation as a computer-based decision support system in a fuzzy environment. Besides, the proposed algorithm presented in this paper can also be applied to the

Table 2. The appropriateness ratings of the three alternatives versus all sub-criteria.

Sub-criteria	Appropriateness ratings		
	A1	A2	A3
C11	(4, 4.93, 6)	(4, 4.64, 5)	(6, 6.32, 7)
C12	(4, 4.31, 5)	(2, 3.42, 5)	(5, 5.59, 7)
C13	(6, 6.32, 7)	(2, 2.88, 4)	(4, 5.19, 7)
C14	(2, 3.42, 5)	(4, 4.93, 6)	(5, 5.59, 7)
C21	(2, 2.88, 4)	(4, 4.31, 5)	(6, 6.32, 7)
C22	(2, 2.88, 4)	(4, 4.64, 5)	(5, 5.59, 7)
C23	(4, 5.19, 7)	(3, 3.78, 6)	(4, 4.93, 6)
C24	(5, 5.59, 7)	(3, 3.78, 6)	(4, 4.64, 5)
C25	(2, 3.42, 5)	(4, 4.64, 5)	(4, 4.93, 6)
C26	(4, 4.64, 5)	(6, 6.32, 7)	(4, 4.31, 5)
C31	(2, 2.88, 4)	(2, 3.42, 5)	(4, 4.93, 6)
C32	(4, 4.64, 5)	(4, 5.19, 7)	(2, 3.42, 5)
C33	(2, 2.88, 4)	(5, 5.59, 7)	(4, 4.93, 6)
C34	(2, 2.88, 4)	(4, 4.64, 5)	(4, 4.93, 6)
C35	(5, 5.59, 7)	(3, 3.78, 6)	(6, 6.32, 7)
C36	(2, 2.88, 4)	(3, 3.78, 6)	(6, 6.32, 7)
C37	(2, 3.42, 5)	(3, 3.78, 6)	(5, 5.59, 7)
C41	(6, 6.32, 7)	(4, 4.64, 5)	(4, 4.93, 6)
C42	(2, 2.88, 4)	(6, 6.32, 7)	(4, 4.64, 5)
C43	(2, 3.42, 5)	(4, 4.64, 5)	(2, 3.42, 5)
C44	(4, 5.19, 7)	(2, 3.42, 5)	(4, 5.19, 7)
C45	(2, 2.88, 4)	(3, 3.78, 6)	(5, 5.59, 7)
C46	(2, 2.88, 4)	(3, 3.78, 6)	(4, 4.93, 6)
C51	(2, 2.88, 4)	(4, 4.64, 5)	(6, 6.32, 7)
C52	(2, 2.88, 4)	(2, 3.42, 5)	(5, 5.59, 7)
C53	(3, 3.78, 6)	(4, 5.19, 7)	(6, 6.32, 7)
C54	(2, 3.42, 5)	(5, 5.59, 7)	(4, 4.93, 6)
C55	(3, 3.78, 6)	(4, 4.64, 5)	(6, 6.32, 7)
C56	(2, 2.88, 4)	(3, 3.78, 6)	(5, 5.59, 7)
C57	(2, 2.88, 4)	(4, 4.93, 6)	(4, 4.93, 6)
C58	(3, 3.78, 6)	(4, 4.64, 5)	(4, 4.64, 5)

Table 3. The α-cut of aggregation appropriateness ratings of the three alternatives versus thirty-one sub-criteria.

	R_{11}^{α}	R_{12}^{α}	R_{13}^{α}	R_{14}^{α}
α = 0	[14.5, 30.25]	[13.333, 31.50]	[10.286, 24.0]	[14.667, 34.833]
α = 0.2	[15.687, 28.256]	[14.609, 29.069]	[11.269, 22.203]	[16.019, 32.038]
α = 0.4	[16.916, 26.320]	[15.950, 26.740]	[12.295, 20.468]	[17.424, 29.354]
α = 0.5	[17.548, 25.374]	[16.645, 25.614]	[12.825, 19.624]	[18.147, 28.053]
α = 0.6	[18.189, 24.443]	[17.355, 24.513]	[13.364, 18.794]	[18.884, 26.780]
α = 0.8	[19.506, 22.625]	[18.826, 22.386]	[14.476, 17.182]	[20.397, 24.317]
α = 1	20.865	20.361	15.631	21.965
	R_{15}^{α}	R_{21}^{α}	R_{22}^{α}	R_{23}^{α}
α = 0	[12.25, 33.625]	[11.5, 26.25]	[17.0, 33.833]	[13.571, 31.286]
α = 0.2	[13.522, 30.452]	[12.690, 24.464]	[18.118, 31.511]	[14.624, 28.696]
α = 0.4	[14.846, 27.416]	[13.929, 22.740]	[19.275, 29.264]	[15.716, 26.196]

Table 3. Contd.

α = 0.5	[15.526, 25.948]	[14.567, 21.901]	[19.868, 28.168]	[16.277, 24.980]
α = 0.6	[16.220, 24.515]	[15.217, 21.078]	[20.470, 27.092]	[16.848, 23.786]
α = 0.8	[17.644, 21.749]	[16.553, 19.477]	[21.704, 24.996]	[18.021, 21.465]
α = 1	19.120	17.938	22.976	19.233
	R_{24}^{α}	R_{25}^{α}	R_{31}^{α}	R_{32}^{α}
α = 0	[17.333, 37.667]	[19.125, 39.50]	[19.0, 36.75]	[18.667, 36.333]
α = 0.2	[18.661, 34.848]	[20.537, 36.750]	[20.196, 34.307]	[19.962, 34.029]
α = 0.4	[20.033, 32.112]	[21.999, 34.092]	[21.432, 31.947]	[21.299, 31.80]
α = 0.5	[20.734, 30.775]	[22.748, 32.798]	[22.064, 30.799]	[21.984, 30.714]
α = 0.6	[21.447, 29.459]	[23.509, 31.528]	[22.706, 29.671]	[22.679, 29.646]
α = 0.8	[22.903, 26.890]	[25.069, 29.056]	[24.019, 27.479]	[24.10, 27.568]
α = 1	24.403	26.678	25.370	25.564
	R_{33}^{α}	R_{34}^{α}	R_{35}^{α}	
α = 0	[17.714, 32.714]	[18.333, 39.667]	[25.50, 44.625]	
α = 0.2	[18.832, 30.782]	[19.851, 36.822]	[26.826, 42.032]	
α = 0.4	[19.983, 28.908]	[21.421, 34.077]	[28.182, 39.516]	
α = 0.5	[20.571, 27.992]	[22.226, 32.743]	[28.872, 38.287]	
α = 0.6	[21.167, 27.092]	[23.044, 31.433]	[29.568, 37.077]	
α = 0.8	[22.384, 25.334]	[24.719, 28.890]	[30.984, 34.715]	
α = 1	23.635	26.447	32.430	

Table 4. The α-cut of final appropriateness ratings of the three alternatives.

	F_1^{α}	F_2^{α}	F_3^{α}
α = 0	[48.912, 185.717]	[60.949, 203.010]	[76.938, 228.774]
α = 0.2	[56.732, 164.705]	[69.219, 181.414]	[86.277, 206.320]
α = 0.4	[65.303, 145.270]	[78.201, 161.337]	[96.351, 185.394]
α = 0.5	[69.879, 136.127]	[82.968, 151.852]	[101.671, 175.488]
α = 0.6	[74.656, 127.355]	[87.923, 142.728]	[107.186, 165.943]
α = 0.8	[84.826, 110.901]	[98.414, 125.533]	[118.810, 147.914]
α = 1	95.847	109.701	131.251

Table 5. Ranking values of the three alternatives.

Alternatives	$I^L(F_i)$	$I^R(F_i)$	$R(F_i)$	Ranking order
A1	70.769	137.784	99.183	3
A2	83.807	153.455	113.338	2
A3	102.534	177.098	134.149	1

selection problems, such as projects, partners and many other areas of management decision problems.

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