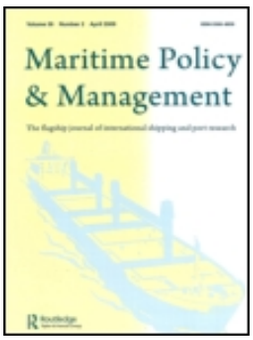

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Application of a fuzzy multi-criteria decision-making model for shipping company performance evaluation

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Combining fuzzy set theory, Analytic Hierarchy Process (AHP) and concept of entropy, a fuzzy Multiple Criteria Decision-Making (MCDM) model for shipping company performance evaluation is proposed. First, the AHP is used to construct subjective weights for all criteria and sub-criteria. Then, linguistic values characterized by triangular fuzzy numbers and trapezoidal fuzzy numbers are used to denote the evaluation values of all alternatives with respect to various subjective and objective criteria. Finally, the aggregation fuzzy assessment of different shipping companies is ranked to determine the best selection. Utilizing this fuzzy MCDM model, the decision-maker's fuzzy assessment and the trade-off between various evaluations criteria can be taken into account in the aggregation process, thus ensuring more effective and accurate decision-making.

1. Introduction

Due to Taiwan's geographic position and key role of East Asia transportation, import and export is one of the main economic activities of Taiwan, and the shipping industry is a primary for import and export. In shipping companies, as in other business, pursuing optimum performance is a business goal, and can directly reflect management ability and style of a professional manager.

Since financial evaluation is an important task of investors and managers, financial performance estimation criteria are necessary for an organization's internal audits and for investor evaluation.

The shipping industry is a service trade, and to upgrade service quality is a goal for each company. Although there are many customer service quality policies to improve service quality, it is also necessary to integrate freely with internal information flow and standardize operation processes. In consideration of this point, this paper uses logistic service quality evaluation criteria [1]. To integrate these criteria, this paper constructs a multiple criteria evaluation model, which both enables managers to better audit their own organizations, and also serves as a reference for potential investors.

In practice, when decision-makers evaluate the performance of shipping companies, they use subjective criteria such as company operation condition, safety and convenience, together with objective criteria such as sales revenue/total assets, current assets/current liability. In doing so, they usually depend on their wisdom, experience, professional knowledge and information that is difficult to define and/or describe exactly. However, linguistic values such as 'very important', 'very good' and 'about 300 dollars' can be used to convey an evaluation about importance of criteria

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and superiority of alternatives. Thus, a fuzziness-based decision model should be more appropriate and effective than traditional precision-based models for shipping companies. This text combines fuzzy sets theory, Analytic Hierarchy Process and the concept of entropy to develop a decision-making model that can assist shipping companies to evaluate their organizational performance using fuzzy scenarios.

2. Research methods

In this section, some research methods used in this paper are briefly introduced.

2.1. *Analytic Hierarchy Process*

The Analytic Hierarchy Process (AHP) was initially presented by Saaty [2] in 1980 for use in solving multiple criteria decision problems. Using a systematic hierarchy structure, complex estimation criteria can be represented clearly and definitely. Ratio scales are utilized to make reciprocal comparisons for each element and each layer. After completing the reciprocal matrix, one can obtain comparative weights for each element.

Let's consider the criteria $C_1, \ldots, C_i, \ldots, C_j, \ldots, C_n$ some one level in hierarchy. One wishes to find their weights of importance, $w_1, \ldots, w_i, \ldots, w_j, \ldots, w_n$, on some elements in the next level. Allow $a_{ij}, i,j = 1, 2, \ldots, n$ to be the importance strength of C_i when compared with C_j. The matrix of these numbers a_{ij} is denoted A, or

$$A = \begin{bmatrix} a_{11} & a_{12} & \ldots & a_{1j} & \ldots & a_{1n} \\ \vdots & \vdots & & \vdots & & \vdots \\ a_{i1} & a_{i2} & \ldots & a_{ij} & \ldots & a_{in} \\ \vdots & \vdots & & \vdots & & \vdots \\ a_{n1} & a_{n2} & \ldots & a_{nj} & \ldots & a_{nn} \end{bmatrix}_{n\times n},$$

where $a_{ji} = 1/a_{ij}$, that is, A is reciprocal. If one's judgement is perfect in all comparisons, then $a_{ik} = a_{ij} \bullet a_{jk}$ for all i,j,k and one calls the matrix A consistent [2].

An obvious case of a consistent matrix A is its elements

$$a_{ij} = w_i/w_j, i,j = 1, 2, \ldots, n.$$

Thus, when matrix A is multiplied by the vector formed by each weighting $w = (w_1, w_2, \ldots w_n)^T$, one gets:

$$Aw = \begin{bmatrix} w_1/w_1 & w_1/w_2 & \cdots & w_1/w_j & \cdots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \cdots & w_2/w_j & \cdots & w_2/w_n \\ \vdots & \vdots & & \vdots & & \vdots \\ w_i/w_1 & w_i/w_2 & \cdots & w_i/w_j & \cdots & w_i/w_n \\ \vdots & \vdots & & \vdots & & \vdots \\ w_n/w_1 & w_n/w_2 & \cdots & w_n/w_j & \cdots & w_n/w_n \end{bmatrix}_{n\times n} \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_j \\ \vdots \\ w_n \end{bmatrix}_{n\times 1} = n \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_j \\ \vdots \\ w_n \end{bmatrix}_{n\times 1} = nw.$$

Because a_{ij} is the subjective rating given by the decision-maker, there must be a distance between it and the actual values w_i/w_j. Thus, $Aw = nw$ can not be calculated directly. Therefore, Saaty suggested using the maximum eigenvalue, $\lambda_{\max}$, of the solution of matrix A to replace n, then

$$Aw = \lambda_{\max} w.$$

By this method, one can obtain the characteristic vector, referred to as the priority vector.

Obtaining an exact priority vector is complex, so this paper uses the Normalization of Row Average (NRA) [3] method to replace the more complex operation. This method sums up each row element and standardizes it by summing all elements of the matrix.

The equation is:

$$w_i = \frac{\sum_{j=1}^{n} a_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{n} a_{ij}}, i = 1, 2, \ldots, n.$$

Generally, we can represent the comparative importance scale of criteria as shown in table 1.

2.2. *Entropy value weighting method*

The entropy weighting method [4] can effectively measure the average essence of information quantity; and the larger the entropy value, the lower the information express quantity [4,5]. This paper tries to solve the objective weight of financial evaluation criteria above the substitutive alternative level. Thus, it can represent actual conditions of decision-making, and express the explanation ability and reliability of criteria. The steps can be summarized as follows.

Step 1: Allow $X_{ij}, i = 1, 2, \ldots m, j = 1, 2, \ldots, n$ to be evaluation value of the jth financial criterion attained by the ith alternative (shipping company).

Let $X_j^*(X_j^{\sim})$ denote the ideal value with respect to the jth direct (inverse) financial evaluation criterion. Then, the degree of closeness, denoted by d_{ij}, of X_{ij} to an ideal value can be defined as:

(1) For the direct criterion j:

$$d_{ij} = X_{ij}/X_j^*$$

where

Table 1. Comparative importance scale of criteria

Scales	Definition	Description
1	Equally important	The importance of both comparative alternatives is equal.
3	Weakly Important	Experience and judgement weakly tend to prefer one alternative.
5	Strongly important	Experience and judgement strongly tend to prefer one alternative.
7	Demonstrably important	Experience and judgement demonstrably tend to prefer one alternative.
9	Absolutely important	Experience and judgement absolutely tend to prefer one alternative
2, 4, 6, 8	Intermediate values between adjacent judgements	Need to compromise.

$$X_j^* = \max_i \{X_{ij}\}.$$

(2) For the inverse criterion j:

$$d_{ij} = X_j^{\sim} / X_{ij}$$

where

$$X_j^{\sim} = \min_i \{X_{ij}\}.$$

Then

$$0 \le d_{ij} \le 1.$$

Define

$$D = [d_{ij}], i = 1, 2, \ldots, m; j = 1, 2, \ldots, n,$$

$$D_j = \sum_{i=1}^{m} d_{ij}, j = 1, 2, \ldots, n.$$

Step 2: The entropy measure of the jth financial evaluation criterion contrast intensity is:

$$e_j = -k \sum_{i=1}^{m} \frac{d_{ij}}{D_j} 1\mathrm{n} \frac{d_{ij}}{D_j}$$

where $k = 1/\ln m > 0$, and $e_j \ge 0$.

Step 3: Compute the total entropy:

$$e = \sum_{j=1}^{n} e_j.$$

Step 4: The weight λ_j of the jth financial evaluation criterion can be calculated by:

$$\lambda_j = \frac{1 - e_j}{\sum_{j=1}^{n} (1 - e_j)} = \frac{1 - e_j}{n - e}, \quad 0 \le \lambda_j \le 1, \sum_{j=1}^{n} \lambda_j = 1. \tag{1}$$

By combining the objective weight λ_j and the subjective weight w_j computed by the AHP method, the integrated weight w_j^* of the jth financial evaluation criterion can be obtained:

$$w_j^* = \frac{w_j \lambda_j}{\sum_{j=1}^{n} w_j \lambda_j}, j = 1, 2, \ldots, n. \tag{2}$$

2.3. *Fuzzy set theory*

Fuzzy set theory was introduced by Zadeh [6] to deal with problems involving the absence of sharply defined criteria. Subsequently, the improvement and application of fuzzy number was presented by Dubois and Prade [7].

2.3.1. *Trapezoidal and triangular fuzzy numbers*. In a universe of discourse of X, a fuzzy subset A of X is characterized by a membership function f_A, which maps each element x in X to a real number in the interval [0, 1]. The function value represents the grade of membership of x in A.

A fuzzy number A [7,8] in $\Re$ (real line) is a trapezoidal fuzzy number if its membership function $f_A : \Re \to [0, 1]$ is

$$f_A(x) = \begin{cases} (x-c)/(a-c), & c \le x \le a \\ 1, & a \le x \le b \\ (x-d)/(b-d), & b \le x \le d \\ 0, & o.w. \end{cases}$$

with $-\infty < c \le a \le b \le d \le \infty$, the trapezoidal fuzzy number A can be represented by (c, a, b, d) (figure 1).

The strongest grade of membership is for the trapezoidal fuzzy number A in the interval $[a, b]$, that is $f_A(x) = 1, x \in [a, b]$; this is the most possible value of evaluation data. In addition, 'c' and 'd' are the lower and upper bounds of the available area for the evaluation data. They are used to reflect the fuzziness of the evaluation data. The narrower the interval $[c, d]$, the lower the fuzziness of the evaluation data.

Triangular fuzzy numbers are a special case of trapezoidal fuzzy numbers (figure 2), that is 'a' is equal to 'b', and it can be represented by (c, a, a, d) or (c, a, d). The reason for using the trapezoidal fuzzy numbers or triangular fuzzy numbers is that it is easy to use and interpret during economic analysis. For example, 'approximately 50' can be represented by (45, 50, 50, 55) or by (45, 50, 55); 'approximately between 50 and 60', can be represented by (45, 50, 60, 65); and it can be represented more blurred by (40, 50, 60, 70).

An exact number 'a' can be represented by (a, a, a, a). In this paper, the linguistic value of 'acceptable' can be represented by (0.2, 0.5, 0.8).

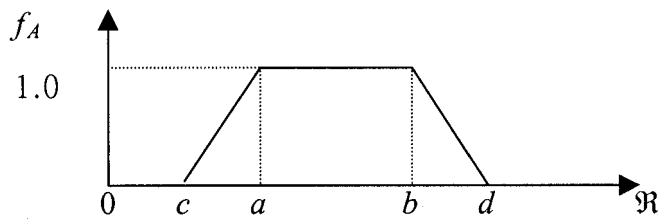

Figure 1. Membership function of a trapezoidal fuzzy number $A = (c, a, b, d)$.

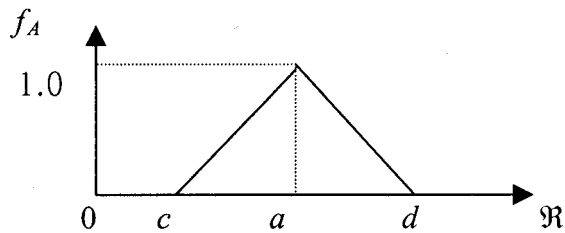

Figure 2. Membership function of a triangular fuzzy number $A = (c, a, d)$.

By the extension principle [6], the extended algebraic operations of any two trapezoidal fuzzy numbers $A_1 = (c_1, a_1, b_1, d_1)$ and $A_2 = (c_2, a_2, b_2, d_2)$ can be expressed as:

Addition $\oplus$:
$A_1 \oplus A_2 = (c_1, a_1, b_1, d_1) \oplus (c_2, a_2, b_2, d_2) = (c_1 + c_2, a_1 + a_2, b_1 + b_2, d_1 + d_2)$
Multiplication $\otimes$:
$k \otimes A = k \otimes (c, a, b, d) = (kc, ka, kb, kd), k \geq 0, k \in \Re$

In this case, the evaluation value of the jth financial performance index for the ith shipping company is represented by $(c_{ij}, a_{ij}, b_{ij}, d_{ij})$. In addition, c_{ij} and d_{ij} are minimum and maximum values of financial effect over time, whereas a_{ij} and b_{ij} are the first quartile and third quartile of financial effect over time. In fact, if one only has financial data for four close years, the $c_{ij}, a_{ij}, b_{ij}, d_{ij}$ can be sorted from minimum to maximum. For example, if the current ratios of a company in the past 4 years are 149%, 136%, 100% and 108%, the trapezoidal fuzzy number of evaluation value is 100%, 108%, 136%, 149%.

2.3.2. *Linguistic value*. The concept of linguistic variable [7, 9, 10] is useful in describing situations that are complex or poorly defined by quantitative expressions. A linguistic variable is a variable whose values are expressed in words of natural language. For example 'rating' is a linguistic variable, with values of very bad, bad, medium, good, very good, etc. Linguistic value can be represented by the approximate reasoning of fuzzy set theory. For example, {VG, G, M, B, VB}, where VG = Very Good, G = Good, M = Medium, B = Bad, VB = Very Bad, and the membership functions of those linguistic values are shown in figure 3.

2.3.3. *Ranking method*. The ranking of fuzzy numbers is important for the fuzzy evaluation of an investment environment. Here, the centroid method is used to determine the fuzzy number score ranking for each company.

Let $f_A(x)$ be a membership function for trapezoidal fuzzy number $A = (c, a, b, d)$, then the centroid ranking method formula [9] of trapezoidal fuzzy number A is

$$R(A) = \int_c^d x f_A(x) dx \Big/ \int_c^d f_A(x) \mathrm{d}x.$$

Define $A_i = (c_i, a_i, b_i, d_i), i = 1, 2, \ldots, n$ be n trapezoidal fuzzy numbers. By the formula stated above, one can obtain

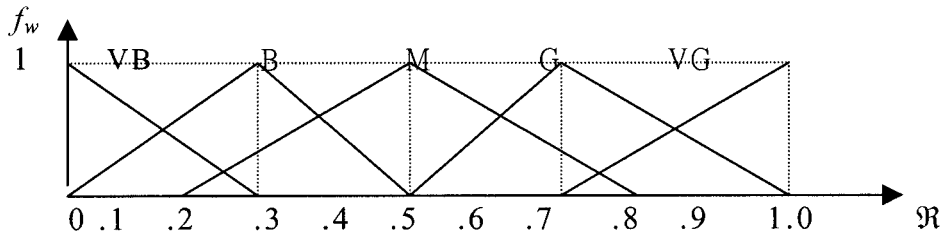

Figure 3. Linguistic value membership function, VB: (0,0,0.3), B: (0,0.3,0.5), M: (0.2, 0.5, 0.8), G: (0.5,0.7,1), VG: (0.7,1,1).

$$\int_{c_i}^{d_i} f_{A_i}(x)\mathrm{d}x = \tfrac{1}{2}[(d_i - c_i) + (b_i - a_i)]$$

$$\int_{c_i}^{d_i} x f_{A_i}(x)\mathrm{d}x = \frac{1}{a_i - c_i}(\tfrac{1}{3}a_i^3 - \tfrac{1}{2}a_i^2 c_i + \tfrac{1}{6}c_i^3) + \frac{1}{d_i - b_i}(\tfrac{1}{3}b_i^3 - \tfrac{1}{2}b_i^2 d_i + \tfrac{1}{6}d_i^3) + \tfrac{1}{2}(b_i^2 - a_i^2)$$

then

$$R(A_i) = 2\left\{\left[\frac{1}{a_i - c_i}(\tfrac{1}{3}a_i^3 - \tfrac{1}{2}a_i^2 c_i + \tfrac{1}{6}c_i^3) + \frac{1}{d_i - b_i}(\tfrac{1}{3}b_i^3 - \tfrac{1}{2}b_i^2 d_i + \tfrac{1}{6}d_i^3) + \tfrac{1}{2}(b_i^2 - a_i^2)\right] \Big/ [(d_i - c_i) + (b_i - a_i)]\right\}. \tag{3}$$

Using equation (3), the ranking value of n trapezoidal fuzzy numbers can be easily calculated and the ranking of the n trapezoidal fuzzy numbers can be effectively determined.

Remark: For a triangular fuzzy number (c_i, a_i, d_i), one can set $a_i = b_i$ in $R(A_i)$ for sorting of triangular fuzzy numbers.

3. Method and procedure of shipping company performance evaluation

In this section, a systematic fuzzy MCDM model for shipping company performance evaluation is proposed. The steps can be summarized as follows:

Step 1: Form a committee of decision-makers and select the evaluation criteria.
Step 2: Develop a hierarchical structure.
Step 3: Use an AHP method to obtain the subjective criteria weight for each level.
Step 4: Tabulate the linguistic evaluation value for management performance, customer service quality performance and logistics service quality performance, then transform them into triangular fuzzy numbers.
Step 5: Calculate and transform the ratio of each financial performance criterion into trapezoidal fuzzy number and compute the centroid.
Step 6: Use the entropy weighting method to obtain an objective weight for financial sub-criteria.
Step 7: Utilize the subjective weight and objective weight obtained by steps 3 and 6 to determine the integrated weight of the financial criteria presented above the alternative level.
Step 8: Synthesize the scores of shipping companies and obtain the position in this competition.

3.1. *Select evaluation criteria*

Numerous criteria can be considered in a multi-criteria problem. Such criteria should be identified by considering the specific requirements of the problem. The evaluation criteria used to evaluate the shipping company performance are from a literature review and consultation with experts.

3.1.1. *Management performance criteria.* The factors affecting business management performance can be classified into 12 categories, as shown in table 2 [11, 12].

To relate shipping company characteristics with management theory, 10 criteria to estimate the effectiveness of management are proposed in table 3.

Table 2. Factors affecting business management performance

1. Financial affairs	2. Business operation
3. Output ability	4. Market position
5. Service or customer relationship	6. Public and government relationship
7. Staff relationship and development	8. Shareholder relationship
9. Innovation	10. Contribution value
11. Material resources and financial resource	12. Benefit creating ability
13. Social duty	14. Staff's effects and attitude

There will be a gap between service supplier and acceptor. In the process of providing a service, regardless of the ordering of information flow, transporting or delivery, linking each phase is very important for company operations performance. Relying on a corporate total logistics strategy concept, a service policy can be reached easily, not only to meet customer requests, but also to control internal cost. Based on this concept, this paper divides service quality performance criteria into customer service quality (CSQ) performance criteria and logistics service quality (LSQ) performance criteria.

3.1.2. *Customer service quality (CSQ) performance criteria*. Discussing the criteria used by customers choosing a shipping company, McGinnis [13] identified 11 service quality attributes including freight, reliability and delivery time. Different service quality attributes are presented in other papers, [1, 14]. Based on these references, the six criteria shown in table 4 are used in this paper.

3.1.3. *Logistics service quality (LSQ) performance criteria*. One combines the logistics concept [1] with characteristics of navigation service to build up evaluation criteria. Therefore, one can integrate internal connection and external service to reach the targets of obtaining maximum profit and cost. Table 5 lists the LSQ evaluation criteria.

Table 3. Criteria of management effects (C_1)

Criteria no.	Evaluation criteria	Example and statement
C_{1-1}	Company operation state	Rate of staff growth, market share at forwarder dimension, checking contrast list with bank monthly.
C_{1-2}	Internal and external appreciation	Difference degree of pricing with appreciation same trade, appreciation by staff, appreciation by banks and government.
C_{1-3}	Market analysis	Shipping route and market analysis, planning for new routes.
C_{1-4}	Internal effects	Staff morale, staff identification.
C_{1-5}	Sales ability	Sales' sincerity, negotiation ability.
C_{1-6}	Marketing management	Setting up a marketing plan.
C_{1-7}	Planning ability	Transportation planning ability.
C_{1-8}	Accounting	Building up cost accounting system, examining debt record regularly.
C_{1-9}	Internal organization situation	Soundness of internal organization, authorizing each division.
C_{1-10}	Rate of staff absence	Rate of staff absent from duty.

Table 4. CSQ performance criteria (C_{2-1})

Criteria no.	Evaluation criteria	Example and statement
C_{2-1-1}	Safety and convenience	Safety of cargo transportation, container types available, advertisement universal.
C_{2-1-2}	Promptness and frequency	Sailing on schedule, frequent trains.
C_{2-1-3}	Sales credit and specialty	Ability to solve urgent events, frequent contact with customers, good reputation, sales ability.
C_{2-1-4}	Communication attitude	Response to shipper demands, attitude to customers.
C_{2-1-5}	Price and space	Price, ease of acquiring shipping space.
C_{2-1-6}	Convenient consultation	Special telephone line for convenient consultation.

3.1.4. *Financial performance evaluation criteria.* Financial performance directly reflects the structuring profit and efficiency of a company, so most companies use a financial index to represent their performance [15, 16]. Financial performance evaluation criteria not only refer to other documents, but also cite the shipping industry financial management index from the Join Credit Information Centre [17]. The purpose of this paper is to accommodate the characteristics of navigation, and evaluation criteria are listed in table 6.

3.2. *Assign and calculate the weight of subjective and objective criteria*

By using AHP, the weight of frames and their sub-criteria, such as management performance, service quality performance and financial performance, are obtained. For example, the linguistic value for management performance in proportion to

Table 5. LSQ performance criteria (C_{2-2})

Criteria no.	Evaluation criteria	Example and statement
C_{2-2-1}	Information quality	Information supply, internal information flow.
C_{2-2-2}	Operating procedures	ISO process.
C_{2-2-3}	Order releasing ability	Order requirement fit rate.
C_{2-2-4}	Delivery ability	Customer requirement fit rate.
C_{2-2-5}	Accuracy	Correct processing rate.
C_{2-2-6}	Order quality	Added value service fit rate.
C_{2-2-7}	Discrepancy handling	Correction of delivered quality discrepancies.
C_{2-2-8}	Customer tracing	After sale service, customer tracing.

Table 6. Financial performance evaluation criteria (C_3)

Criteria no.	Evaluation criteria	Index character
C_{3-1}	Total liability/total assets	Financial structure
C_{3-2}	Fixed assets/(stockholders' equity + long-term liability)	Financial structure
C_{3-3}	Fixed assets/total assets	Financial structure
C_{3-4}	Current assets/current liability	Debt payment ability
C_{3-5}	Liquid assets/current liability	Debt payment ability
C_{3-6}	Sales revenue/average accounts receivable	Operation efficiency
C_{3-7}	Sales revenue/total assets	Operation efficiency
C_{3-8}	Sales revenue/fixed assets	Profit-making ability
C_{3-9}	Gross profit/sales revenue	Profit-making ability
C_{3-10}	Operating income/sales revenue	Profit-making ability
C_{3-11}	Net income after tax/sales revenue	Profit-making ability

service quality performance is 'strongly important', and financial performance in proportion to management performance is 'weakly important', but the proportion with respect to service quality performance is 'demonstrably important'. Then, one can form the matrix as follows:

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} = \begin{bmatrix} 1 & 5 & 1/3 \\ 1/5 & 1 & 1/7 \\ 3 & 7 & 1 \end{bmatrix}.$$

Summing each row, one obtains:

$$\sum_{j=1}^{3} a_{1j} = 1 + 5 + 1/3 = 6.3333,$$

$$\sum_{j=1}^{3} a_{2j} = 1/5 + 1 + 1/7 = 1.3429,$$

$$\sum_{j=1}^{3} a_{3j} = 3 + 7 + 1 = 11.$$

The weight of all constructs are:

$$w_1 = \sum_{j=1}^{3} a_{1j} \Big/ \sum_{i=1}^{3}\sum_{j=1}^{3} a_{ij} = 0.3391,$$

$$w_2 = \sum_{j=1}^{3} a_{2j} \Big/ \sum_{i=1}^{3}\sum_{j=1}^{3} a_{ij} = 0.0719,$$

$$w_3 = \sum_{j=1}^{3} a_{3j} \Big/ \sum_{i=j}^{3}\sum_{j=1}^{3} a_{ij} = 0.5890.$$

3.3. *Tabulate the linguistic evaluation values of subjective criteria for each alternative and transform into triangular fuzzy numbers*

One evaluated the criteria which existed above the alternative layer, using linguistic value set as {VG, G, M, B, VB}, and then transfer the linguistic values to triangular fuzzy numbers. For example, for a shipping company whose market analysis is judged 'G', one then transfers the linguistic value to a triangular fuzzy number, (0.5, 0.7, 1.0).

3.4. *Calculate the financial ratios for each alternative*

Based on shipping company financial statement data for 4 years, one can determine the ratios of financial performance criteria. If company Y has ratios of 'total liability/ total assets' for 4 years of 0.4460, 0.4380, 0.4582 and 0.5369, then the trapezoid fuzzy number is represented by (0.4380, 0.4460, 0.4582, 0.5369).

3.5. *Standardize trapezoidal fuzzy numbers of financial performance sub-criteria*
The rating of direct relationship criterion can be defined as follows: Allow $(c_{ij}, a_{ij}, b_{ij}, d_{ij}), i = 1, 2, \ldots, m; j = 1, 2, \ldots, n,$ to denote the fuzzy (or non-fuzzy) financial performance assigned to alternative A_i versus objective/sub-criterion c_j, be defined as:

(1) For the direct relationship

$$RT_{ij} = \left(c_{ij} \Big/ \sum_{i=1}^{m} d_{ij}, a_{ij} \Big/ \sum_{i=1}^{m} b_{ij}, b_{ij} \Big/ \sum_{i=1}^{m} a_{ij}, d_{ij} \Big/ \sum_{i=1}^{m} c_{ij} \right).$$

(2) For the inverse relationship

$$RT_{ij} = \left(d_{ij}^{-1} \Big/ \sum_{i=1}^{m} c_{ij}^{-1}, b_{ij}^{-1} \Big/ \sum_{i=1}^{m} a_{ij}^{-1}, a_{ij}^{-1} \Big/ \sum_{i=1}^{m} b_{ij}^{-1}, c_{ij}^{-1} \Big/ \sum_{i=1}^{m} d_{ij}^{-1} \right).$$

3.6. *Determine the criteria weights*
By using the NRA method, the subjective criteria and sub-criteria weight of management performance, service quality performance and financial performance can be obtained. Then, using the sorted centriod values of trapezoidal fuzzy numbers and entropy weighting method, one can determine the appropriate weight for objective criteria.

4. Numerical example

In this section, a hypothetical shipping company performance evaluation problem is presented to demonstrate the computational process of the fuzzy MCDM model proposed above.

Assume that there is an investment company that wants to know the performance of four shipping companies Y, E, W and U, to choose one for investment.

Step 1: Suppose that there is a committee of four decision-makers in the investment company, i.e. A, B, C and D, to determine the most suitable shipping company. The committee adopts the criteria proposed in this paper.

Step 2: The hierarchical structure of the shipping company performance evaluation problem is depicted in figure 4. Each of the three criteria consists of sub-criteria which are shown in tables 3–6.

Step 3: Use the scales of importance shown in table 1 to assign comparative importance for estimation constructs and criteria, then input data into the decision-making system.

Due to space limitations, one lists only the results of subjective weights obtained by the AHP method, as shown in table 7.

Step 4: The decision-makers utilize the linguistic rating set S = {VG, G, M, B, VB}, to evaluate the performance of shipping companies under each of the sub-criterias of management, CSQ and LSQ performance criteria.

These results are shown in table 8. By using the linguistic value transforming rule (table 9), the average fuzzy evaluation value of shipping companies, i.e. Y, E, W and U, can be obtained. Table 10 presents the calculated average fuzzy evaluation values.

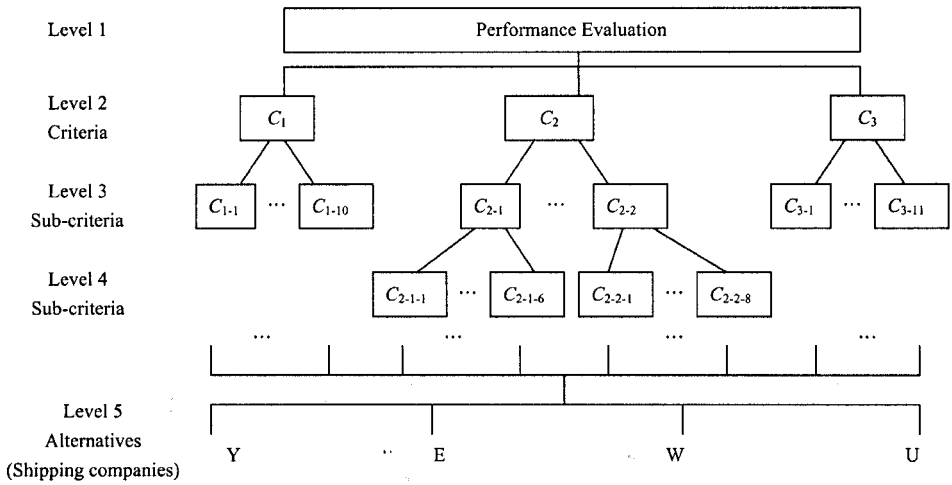

Figure 4. Hierarchical structure of the shipping company performance evaluation.

Table 7. Subjective weights obtained by the AHP method

C_1		C_2				C_3	
0.15047		0.07911				0.77042	
C_{1-1}	0.03070	C_{2-1}	0.05933	C_{2-2}	0.01978	C_{3-1}	0.02937
C_{1-2}	0.01192	C_{2-1-1}	0.01559	C_{2-2-1}	0.00480	C_{3-2}	0.02058
C_{1-3}	0.01971	C_{2-1-2}	0.02063	C_{2-2-2}	0.00267	C_{3-3}	0.01957
C_{1-4}	0.02212	C_{2-1-3}	0.00691	C_{2-2-3}	0.00320	C_{3-4}	0.01668
C_{1-5}	0.01458	C_{2-1-4}	0.00752	C_{2-2-4}	0.00367	C_{3-5}	0.01088
C_{1-6}	0.01145	C_{2-1-5}	0.00657	C_{2-2-5}	0.00188	C_{3-6}	0.06118
C_{1-7}	0.01106	C_{2-1-6}	0.00212	C_{2-2-6}	0.00136	C_{3-7}	0.09038
C_{1-8}	0.01670			C_{2-2-7}	0.00141	C_{3-8}	0.08704
C_{1-9}	0.00856			C_{2-2-8}	0.00078	C_{3-9}	0.11861
C_{1-10}	0.00366					C_{3-10}	0.15027
						C_{3-11}	0.16587

Step 5: The financial ratios of the four shipping companies Y, E, W and U are presented in table 11.

The centroid value of the financial ratio was found by equation (3), with the results as shown in Table 12.

Step 6: Using the entropy weight method (equation (1)), one can obtain the objective weights of financial performance sub-criteria, with the results as shown in table 13.

Step 7: By using the data of table 7 and 13, as well as equation (2), one obtains 11 integrated weights of financial criteria, as shown in table 14.

Step 8: Combining the integrated weights of criteria and scores of shipping companies under all criteria, one obtains the final results, as shown in table 15, indicating that company W has the best forecast for investment.

Table 8. Score List

	Auditor	Y	E	W	U
Management criteria					
Company operations condition	A	G	G	G	M
	B	G	G	G	G
	C	M	G	G	M
Internal and external appreciation	A	G	G	M	M
	B	G	G	G	M
	C	G	G	G	G
Market analysis	A	G	M	M	M
	B	M	G	M	M
	C	M	G	G	M
Interior effects	A	M	G	G	G
	B	G	G	G	M
	C	M	G	M	M
Sales ability	A	M	G	G	M
	B	G	G	G	M
	C	G	G	M	G
Marketing management	A	G	VG	VG	G
	B	VG	G	G	M
	C	G	VG	VG	G
Planning ability	A	G	G	G	G
	B	M	VG	VG	M
	C	G	G	G	M
Accounting review	A	M	G	M	M
	B	M	G	M	M
	C	G	G	G	G
Internal organization	A	M	G	M	G
	B	G	G	G	M
	C	G	G	G	G
Rate of staff absence	A	M	G	G	G
	B	G	G	G	G
	C	M	G	G	G
SQ criteria					
Safety and convenience	A	G	G	VG	G
	B	M	G	G	G
	C	G	G	G	M
Promptness and frequency	A	G	VG	G	G
	B	G	G	G	G
	C	G	G	G	G
Sales credit and specialty	A	VG	VG	G	G
	B	G	G	VG	G
	C	G	VG	G	G
Communications attitude	A	M	G	G	M
	B	G	G	M	M
	C	G	G	M	M
Price and space	A	M	G	G	M
	B	G	G	G	M
	C	G	G	VG	G
Convenient consultation	A	G	G	G	G
	B	M	G	G	G
	C	G	G	M	M
Information quality	A	G	G	G	M
	B	G	G	M	M
	C	G	G	M	G

Continued

Table 8. *continued*

	Auditor	Y	E	W	U
Operating procedures	A	M	G	G	G
	B	G	G	M	M
	C	G	G	G	G
Order releasing ability	A	M	M	G	M
	B	G	G	M	M
	C	M	G	G	M
Delivery ability	A	G	G	G	G
	B	G	G	G	G
	C	G	G	G	G
Correctness	A	M	G	G	M
	B	G	G	M	G
	C	M	G	G	M
Order quality	A	M	G	G	G
	B	G	G	G	G
	C	G	G	G	G
Discrepancy handling	A	M	M	G	M
	B	G	G	M	M
	C	M	G	G	G
Customer tracing	A	M	M	G	N
	B	G	G	M	M
	C	M	G	G	G

Table 9. Linguistic value transforming rule

Linguistic values	Triangular fuzzy numbers
VG	(0.7,1.0,1.0)
G	(0.5,0.7,1.0)
M	(0.2,0.5,0.8)
B	(0.0,0.3,0.5)
VB	(0.0,0.0,0.3)

5. Conclusion

Combining fuzzy set theory, Analytic Hierarchy Process and concept of entropy, a MCDM model is proposed to solve the shipping company performance evaluation problem in a fuzzy environment.

The performance evaluation problem for a shipping company involves subjective and imprecise assessments which are of a vague nature. The conventional precision-based (non-fuzzy) MCDM approaches tend to be less effective in conveying the imprecision or vagueness nature. Fuzzy assessments expressed in fuzzy numbers or linguistic values characterized by fuzzy numbers are often the most effective and intuitive way for the decision-maker to use the evaluation process. This paper uses trapezoidal fuzzy numbers to present financial evaluation values, uses linguistic values represented by triangular fuzzy number to evaluate subjective criteria, and presents an effective fuzzy MCDM approach which provides crisp ranking outcomes for the shipping company performance evaluation problem. A numerical example of four shipping companies has been carried out to demonstrate the approach.

Table 10. Average fuzzy evaluation values

Construct	Criteria	Y	E	W	U
Management performance					
	Company operations condition	(0.4000,0.6333, 0.9333)	(0.5000,0.7000,1.0000)	(0.5000,0.7000,1.0000)	(0.3000,0.5667,0.8667)
	Internal and external appreciation	(0.5000,0.7000,1.000)	(0.5000,0.7000,1.000)	(0.4000,0.6333,0.9333)	(0.3000,0.5667,0.8667)
	Market analysis	(0.3000,0.5600.1.000)	(0.4000,0.6300,1.000)	(0.3000,0.5667,0.8667)	(0.2000,0.5000,0.8000)
	Interior effects	(0.3000,0.5667,0.8667)	(0.5000,0.7000,1.000)	(0.3000,0.5667,0.8667)	(0.3000,0.5667,0.8667)
	Sales ability	(0.4000,0.6333,0.9333)	(0.5000,0.7000,1.000)	(0.400,0.6333,0.9333)	(0.3000,0.5667,0.8667)
	Marketing management	(0.5667,0.8000,1.000)	(0.6333,0.9000,1.000)	(0.6333,0.9000,1.000)	(0.4000,0.6333,0.9333)
	Planning ability	(0.4000,0.6333,0.9333)	(0.5667,0.8000,1.000)	(0.5667,0.8000,1.000)	(0.3000,0.5667,0.8667)
	Accounting review	(0.3000,0.5667,0.8667)	(0.5000,0.7000,1.000)	(0.3000,0.5667,0.8667)	(0.3000,0.5667,0.8667)
	Internal organization	(0.4000,0.6333,0.9333	(0.5000,0.7000,1.000)	(0.4000,0.6333,0.9333)	(0.4000,0.6333,0.9333)
	Rate of staff absence	(0.3000,0.5667,0.8667)	(0.5000,0.7000,1.000)	(0.5000,0.7000,1.000)	(0.5000,0.7000,1.000)
Service quality					
	Safety and convenience	(0.4000,0.6333,0.9333)	(0.5000,0.7000,1.000	(0.5667,0.8000,1.000)	(0.4000,0.6333,0.9333)
	Promptness and frequency	(0.5000,0.7000,1.000)	(0.5667,0.8000,1.000)	(0.5000,0.7000,1.000)	(0,5000,0.7000,1.000)
	Sales credit and specialty	(0.5667,0.8000,1.000)	(0.6333,0.9000,1.000)	(0.5667,0.8000,1.000)	(0.5000,0.7000,1.000)
	Communication attitude	(0.4000,0.6333,0.9333)	(0.5000,0.7000,1.000)	(0.3000,0.5667,0.8667)	(0.2000,0.5000,0.8000)
	Price and space	(0.4000,0.6333,0.9333)	(0.5000,0.7000,1.000)	(0.5667,0.8000,1.000)	(0.3000,0.5667,0.8667)
	Convenient consultation	(0.4000,0.6333,0.93333)	(0.5000,0.7000,1.000)	(0.4000,0.6333,0.9333)	(0.4000,0.6333,0.9333)
	Information quality	(0.5000,0.7000,1.000)	(0.500,0.7000,1.000)	(0.3000,0.5667,0.9333)	(0.3000,0.5667,0.9333)
	Operating procedures	(0.4000,0.6333,0.9333)	(0.5000,0.7000,1.000)	(0.4000,0.6333,0.9333)	(0.4000,0.6333,0.9333)
	Order releasing ability	(0.3000,0.5667,0.8667)	(0.4000,0.6333,0.9333)	(0.4000,0.6333,0.9333)	(0.2000,0.5000,0.8000)
	Delivery ability	(0.5000,0.7000,1.000)	(0.5000,0.7000,1.000)	(0.5000,0.7000,1.000)	(0.5000,0.7000,1.000)
	Correctness	(0.3000,0.5667,0.8667)	0.5000,0.7000,1.000)	(0.4000,0.6333,0.9333)	(0.3000,0.5667,0.8667)
	Order quality	(0.4000,0.6333,0.9333)	(0.5000,0.7000,1.000)	(0.4000,0.6333,0.9333)	(0.3000,0.5667,0.8667)
	Discrepancy handling	(0.3000,0.5667,0.8667)	0.4000,0.6333,0.9333)	0.4000,0.6333,0.9333)	0.3000,0.5667,0.8667)
	Customer tracing	(0.300,0.5667,0.8667)	(0.4000,0.6333,0.9333)	(0.4000,0.6333,0.9333)	(0.3000,0.5667,0.8667)

The merits of the method are that it can not only release the limitation of crisp evaluation values, but also facilitate its implementation as a computer-based decision support system for solving practical shipping company performance evaluation problems in a fuzzy environment.

Table 11. Financial ratios of four shipping companies

Criteria	Company	Financial ratio after sorting
Total liability/total assets	Y	(0.4380, 0.4460, 0.4582, 0.5369)
	E	(0.3567, 0.4269, 0.4466, 0.4649)
	W	(0.2423, 0.2549, 0.3384, 0.3907)
	U	(0.5300, 0.5308, 0.5788, 0.6110)
Fixed assets/(stockholders' equity + long-term liability)	Y	(0.5063, 0.6284, 0.8021, 0.9894)
	E	(0.4426, 0.2822, 0.5048, 0.6232)
	W	(0.5877, 0.6905, 0.7658, 0.8831)
	U	(0.6846, 0.7623, 0.7965, 0.8217)
Fixed assets/total assets	Y	(0.4364, 0.4412, 0.6900, 0.7881)
	E	(0.3467, 0.3811, 0.4125, 0.4883)
	W	(0.4796, 0.5810, 0.6268, 0.6446)
	U	(0.4797, 0.4990, 0.5448, 0.5449)
Current assets/current liability	Y	(0.6091, 0.7782, 0.8985, 1.3637)
	E	(0.9924, 1.1399, 1.2768, 1.4321)
	W	(1.2536, 1.7663, 1.8252, 2.1379)
	U	(0.9358, 1.0158, 1.1794, 1.2832)
Liquid assets/current liability	Y	(0.2703, 0.3911, 0.4237, 0.7365)
	E	(0.1860, 0.2936, 0.4515, 0.4836)
	W	(0.9881, 1.1405, 1.2256, 1.7903)
	U	(0.2289, 0.2303, 0.3574, 0.3898)
Sales revenue/average accounts receivable	Y	(17.1505, 18.5766, 18.5766, 36.4397)
	E	(1.9827, 2.3548, 2.3548, 5.6885)
	W	(38.2435, 40.5440, 40.5440,43.7314)
	U	(4.4828, 4.8542, 4.8542, 9.5212)
Sales revenue/total assets	Y	(0.4453, 0.4772, 0.8455, 0.8532)
	E	(0.1935, 0.2478, 0.5156, 0.6506)
	W	(0.6598, 0.6716, 0.8818, 0.9878)
	U	(0.5540, 0.5938, 1.0577, 1.1011)
Sales revenue/fixed assets	Y	(1.0094, 10.0826, 1.0935, 1.2254)
	E	(0.5580, 0.6501, 1.2499, 1.3325)
	W	(1.1560, 1.3758, 1.4070, 1.5325)
	U	(1.1102, 1.2379, 1.9413, 2.0207)
Gross profit/sales revenue	Y	(−0.0415, 0.0074, 0.0774, 0.1156)
	E	(0.1467, 0.1592, 0.1910, 0.1960)
	W	(0.1061, 0.1160, 0.1241, 0.1657)
	U	(0.0378, 0.0652, 0.0708, 0.0841)
Operating income/sales revenue	Y	(−0.0623, −0.0145, 0.0530, 0.0915)
	E	(0.0442, 0.0549, 0.0634, 0.01140)
	W	(0.0728, 0.0807, 0.0882, 0.01357)
	U	(0.0118, 0.0300, 0.0406, 0.0460)
Net income after tax/sales revenue	Y	(0.0089, 0.0398, 0.0564, 0.0764)
	E	(0.0187, 0.0206, 0.0388, 0.0129)
	W	(0.0742, 0.0865, 0.0967, 0.1186)
	U	(0.0041, 0.0064, 0.0169, 0.0456)

Table 12. The centroid values of financial ratios

Criteria	Company	Centroid value	Criteria	Company	Centroid value
Total liability/ total assets	Y	0.4743700	Sales revenue/ total assets	Y	0.6552000
	E	0.4207800		E	0.4036300
	W	0.3075000		W	0.8019700
	U	0.5633200		U	0.8266700
Fixed assets/ (stockholders' equity + long-term liability)	Y	0.7341100	Sales revenue/ fixed assets	Y	1.1071500
	E	0.4607800		E	0.9475200
	W	0.7324900		W	1.3611700
	U	0.7636500		U	1.5770100
Fixed assets/ total assets	Y	0.5902600	Gross profit /sales revenue	Y	0.0393800
	E	0.4093500		E	0.1730900
	W	0.5790600		W	0.1299800
	U	0.5168200		U	0.0635500
Current assets/ current liability	Y	0.9302600	Operating income/sales revenue	Y	0.0166200
	E	1.2106400		E	0.0717300
	W	1.7311600		W	0.0969500
	U	1.1042600		U	0.0315400
Quick assets/ current liability	Y	0.4693100	Net income after tax/sales revenue	Y	0.0448300
	E	0.3517500		E	0.0485900
	W	1.3138900		W	0.0945000
	U	0.3019000		U	0.0195600
Sales revenue/ average accounts receivable	Y	24.0556000			
	E	0.0342000			
	W	40.8396000			
	U	6.2860700			

Table 13. Objective weights of financial performance criteria.

Financial criteria	Objective weight
Total liability/total assets	0.01999
Fixed assets/(stockholders' equity + long-term liability)	0.01927
Fixed assets/total assets	0.00886
Current assets/current liability	0.02147
Liquid assets/current liability	0.15440
Sales revenue/average accounts receivable	0.37675
Sales revenue/total assets	0.02649
Sales revenue/fixed assets	0.01449
Gross profit/sales revenue	0.11049
Operating income/sales revenue	0.14290
Net income after tax/sales revenue	0.10491

Table 14. Integrated weight of financial criteria.

Financial criteria	Integrated weight
Total liability/total assets	0.00552
Fixed assets/(stockholders' equity + long-term liability)	0.00373
Fixed assets/total assets	0.00163
Current assets/current liability	0.00337
Liquid assets/current liability	0.01581
Sales revenue/average accounts receivable	0.21687
Sales revenue/total assets	0.02252
Sales revenue/fixed assets	0.01187
Gross profit/sales revenue	0.12331
Operating income/sales revenue	0.20206
Net income after tax/sales revenue	0.16374

Table 15. Scores and results.

Company	Subjective summary (management + SQ score) Objective score	Centroid score	Total score (×100)
Y	(0.085408,0.146562,0.146562,0.213600)	0.148523	34.087
	(0.010591,0.091946,0.226160,0.421433)	0.192350	
E	(0.105777,0.161271,0.161271,0.217390)	0.161479	36.931
	(0.075890,0.121458,0.206966,0.398701)	0.207833	
W	(0.093468,0.149159,0.149159,0.205817)	0.149481	52.552
	(0.182745,0.314264,0.404229,0.591138)	0.376043	
U	(0.070476,0.129673,0.129673,0.192632)	0.130927	24.723
	(0.036570,0.075313,0.129230,0.215564)	0.116299	

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