AN INTEGRATED FUZZY MCDM MODEL FOR EVALUATION AND SELECTION OF A SUITABLE TUGBOAT

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SUMMARY

Tugboats are of vital importance in ports where a significant portion of world trade takes place. Selection of a tugboat that suitable for different operations in a port is a challenging problem that requires many different criteria to be evaluated at the same time. This selection requires high experience as well as technical knowledge of the tugboats and the operations to be carried out. In the present paper, an integrated model for evaluation and selection of tugboats is given. Based on the statistical data available in the study, assessment of the effect of different criteria on different harbour tugboats categorized according to the propulsion systems were carried out. The criteria for the tugboat alternatives were assessed through a questionnaire by subject-matter-experts containing comparative technical, financial and operational questions. The weights of each criteria were calculated using fuzzy Shannon's entropy and fuzzy TOPSIS was utilized to rank the alternatives. Finally, the most suitable tugboat according to propulsion system was selected.

1. INTRODUCTION

International changes and developments are influential in the concept of transportation. Therefore, all alternatives in the maritime industry need elaborate formulation and evaluation with the most critical problems which are faced by decision makers. The global growth in marine transport and the accompanying increase in the volume and complexity of harbour operations have augmented the tugboat sector recently.

A tugboat is a type of vessel capable of manoeuvring other vessels by pushing or towing them either by direct contact or by means of a tow line. At the port entrances and exits, tugs are mostly used help the vessels to make berthing manoeuvres easier, faster and safer. Despite being small in size, they have the ability to handle large ships and marine vessels owing to their high engine power and operational characteristics (Das and Tejpal 2008).

Regarding towing, tugboats with different design features possess various handling characteristics. These could be, but are not limited to, a combination of hull form, propulsion type and thruster's configuration and towing winch design, power and location. The propulsion system installed is entirely effective on the power of a tugboat. Since tugboats are designed to be highly manoeuvrable, some kinds of propulsion systems have been advanced. Propellers such as the cycloid propeller, z-drive propeller, etc. have replaced paddle wheels that used earlier in tugboats as main propulsion.

Typically, tugboats are classified in relation to the type of operation they do, and then, by the configuration or type of propulsion system used. Main propulsion systems of the tugboats differ in relation to the operational requirements and capabilities of the tugboat. Generally, three basic types of harbour tugboats are available regarding the propulsion systems: Conventional, azimuth stern drive and tractor (Radišić, 2003). The main difference between these 3 types stems from the equipment used in the propulsion system and the locations of this equipment. The hull form of a tugboat should be designed taking into account these design and layout requirements. As a result of this, some tugboats can show superior features in some types of operation. Therefore the selection of the suitable tugboat is becoming an important problem.

A wide range of variations in the requirements for towage or other tug assistance to ships is available. Thus, the identification of the main propulsion systems of the tugboats varies regarding the working conditions and capabilities of the tugboat (Eke, 2010; Liu & Wang, 2004). In combination with technical features, different criteria have effects on the selection of a suitable tugboat having appropriate size, power and propulsion arrangements that will enable the job to be efficiently performed. In other words, selection of a suitable tugboat is a good sample of multi-criteria decision making (MCDM) problem that includes many criteria necessarily assessed at the same time and some of the criteria may be in confliction with each other.

Numerous works has been performed in the literature on MCDM problems in very different disciplines. Similar problems were also studied on several subject in the maritime field. Sii et al. (2001) evaluated the variables for maritime and offshore safety and showed the model risk levels. They used a fuzzy-logic-based approach for a qualitative safety model for maritime risk analysis. Olcer and Odabasi (2005) proposed a generalised fuzzy multiple attribute decision-making (FMADM) method to deal with the problem of ranking and selection of alternatives and applied to the propulsion/manoeuvring system selection problem as a case study. Celik et al. (2009) evaluated the shipping registry alternatives for Turkish ship owners using fuzzy Analytic Hierarchy Process (AHP) methodology. Celik and Kandakoglu

(2012) analysed the flagging out problem in the Turkish maritime industry using a fuzzy quantified SWOT scheme. Yanar and Tozan (2012) proposed a model for the propulsion system selection using fuzzy set theory in Turkish Maritime sector. Kafalı and Özkök (2015) focused on the shipyard selection process and presented the importance of selection criteria for ship owners. They used a fuzzy AHP technique to determine the degree of importance of selected criteria and finally the most significant criteria/sub-criteria were obtained. Uğurlu (2015) studied the ideal types of ship for oceangoing watchkeeping officer and ranked the alternatives using Fuzzy Extended AHP. Beşikçi et al. (2016) examined the fuel economy and ship energy efficiency in maritime industry using the fuzzy AHP. Haidar et al. (2017) determined the critical scores for failure modes of equipment of fire and rescue vessels using MCDM.

Despite the use of fuzzy methods on different MCDM problems in many disciplines, even in maritime, there are hardly any studies on the importance of criteria in the selection of a suitable tugboat. In the present study, the order of alternatives using a fuzzy method for a new multi-criteria decision making (MCDM) problem has been identified and the solution to the problem by selecting the most appropriate one has been presented. To that end, the structure of the methodology applied concerning the selection problem of the suitable tugboat has been stated. A realistic decision making model has been suggested for the identified problem and related alternatives has been analysed. By means of this research, it is aimed to develop MCDM method with multiple decision makers that can work in a fuzzy environment.

Through fuzzy Shannon's Entropy, at first, the criteria and alternatives' importance weights have been compared with the criteria-alternatives matrix. Therefore, the evaluation of the criteria regarding the main goal has been carried out. After that, according to all these evaluation procedure, the weights of the criteria have been calculated. The weights have been used in fuzzy TOPSIS calculation for the final evaluation on ranking the alternatives.

The sections of the study are given as follows: Section 2 presents fuzzy Shannon's entropy based on α- level sets and fuzzy TOPSIS methodologies detailed based on the general structure of fuzzy sets and fuzzy numbers. Section 3 gives an application on tugboat selection which was chosen as a real case study to illustrate the feasibility of the proposed approach. In the final section, the research is summed up and evaluations are carried out on the results.

2. FUZZY SETS AND FUZZY NUMBERS

Introduced by Zadeh (1975) to deal with problems in which a source of vagueness is involved, fuzzy set theory has been used to integrate imprecise data into the decision framework. A fuzzy set can be defined mathematically by a membership function which allocates each element x in the universe of discourse X a real number in the interval [0, 1]. A triangular fuzzy number which is used in the pair-wise comparison is defined by three real numbers expressed as a triplet (l, m, u) where have been suggested in literature, as illustrated in Figure 1.

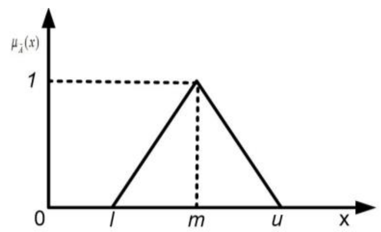

Figure 1: The membership functions of the triangular fuzzy number

The membership function $\mu_{\tilde{A}}(X)$ is defined as:

$$\mu_{\tilde{A}}(x) = \begin{cases} (x-l)/(m-l), & l \le x \le m \\ (u-x)/(u-m), & m \le x \le u \\ 0 & ,otherwise \end{cases} \quad (1)$$

The operations on TFNs can be addition, multiplication, and inverse. Suppose A_1 and A_2 are TFNs where $A_1 = (l_1, m_1, u_1)$, where $l_1 \le m_1 \le u_1$, and $A_2 = (l_2, m_2, u_2)$, where $l_2 \le m_2 \le u_2$, Basic arithmetic operations on triangular fuzzy numbers can be shown as follows:

Addition:

$$\tilde{A}_1 \oplus \tilde{A}_2 = (l_1, m_1, u_1) \oplus (l_2, m_2, u_2) = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \quad (2)$$

Subtraction:

$$\tilde{A}_1 \Theta \tilde{A}_2 = (l_1, m_1, u_1) \Theta (l_2, m_2, u_2) = (l_1 - u_2, m_1 - m_2, u_1 - l_2) \quad (3)$$

Multiplication: If k is scalar,

$$k \otimes \tilde{A}_1 = \begin{Bmatrix} (kl_1, km_1, ku_1), & k > 0 \\ (ku_1, km_1, kl_1), & k < 0 \end{Bmatrix} \quad (4)$$

$$\tilde{A}_1 \otimes \tilde{A}_2 \simeq (l_1 l_2, m_1 m_2, u_1 u_2)$$
$$if \;\; l_1, l_2 > 0; m_1, m_2 > 0; \; u_1, u_2 > 0 \quad (5)$$

Division:

$$\tilde{A}_1 \varnothing \tilde{A}_2 = (l_1, m_1, u_1) \varnothing (l_2, m_2, u_2)$$
$$= (\frac{l_1}{u_2}, \frac{m_1}{m_2}, \frac{u_1}{l_2}) \;\; if \;\; l_1, l_2 > 0; m_1, m_2 > 0; \; u_1, u_2 > 0 \quad (6)$$

Inverse:

$$\tilde{A}_1^{-1} = (l_1, m_1, u_1)^{-1} = (1/u_1, 1/m_1, 1/l_1)$$
$$if \;\; l_1, l_2 > 0; m_1, m_2 > 0; \; u_1, u_2 > 0 \quad (7)$$

Kaufmann and Gupta (1988) discussed that although multiplication and division operations on triangular fuzzy numbers never necessarily yield a triangular fuzzy number, triangular fuzzy number approximations open to be used for many practical applications. Triangular fuzzy numbers are suitable for quantifying the vague information about most decision problems including personnel selection (e.g. rating for creativity, personality, leadership, etc.). Karsak (2002) explained the primary cause for using triangular fuzzy numbers as their intuitive and computational-efficient representation. Zadeh (1975) proposed a linguistic variable can be defined as a variable whose values are not numbers, but words or sentences in natural or artificial language. The concept of a linguistic variable seems to be a useful means for providing approximate characterization of phenomena which are extremely complex or ill-defined to be depicted in conventional quantitative terms.

This paper presents the calculation of the weights of each criterion by use of fuzzy Shannon's Entropy. Then, fuzzy TOPSIS is used to rank the alternatives. Lastly, the best tugboat according to propulsion system based on these results is selected.

2.1 FUZZY SHANNON'S ENTROPY BASED ON α-LEVEL SETS

Hosseinzadeh and Fallahnejad (2010), Chaghooshi *et al*. (2012), Chen *et al*. (2018), Bhowmik *et al*. (2018) and Aikhuele (2017) improve the Shannon entropy for the imprecise data, especially interval and fuzzy data cases. In the present paper, the weights of criteria has been obtained based on their method. The steps of fuzzy Shannon's Entropy are explained as follow:

• Step 1: Transforming fuzzy data into interval data by using the α-level sets:

The α-level set of a fuzzy variable $\tilde{x}_{ij}$ is defined by a set of elements that belong to the fuzzy variable $\tilde{x}_{ij}$ with membership of at least α i.e., $(\tilde{x}_{ij})_a = \left\{x_{ij} \in R \middle| \mu_{\tilde{x}_{ij}}(x_{ij}) \ge a\right\}$

The α-level set can also be expressed in the following interval form:

$$\begin{aligned}(\tilde{x}_{ij})_a &= \left\{x_{ij} \in R \middle| \mu_{\tilde{x}_{ij}}(x_{ij}) \ge a\right\} \\ &\left[(\tilde{x}_{ij})^l_a, (\tilde{x}_{ij})^U_a\right] \\ &= \left[\min_{x_{ij}}\left\{x_{ij} \in R \middle| \mu_{\tilde{x}_{ij}}(x_{ij}) \ge a\right\}, \max_{x_{ij}}\left\{x_{ij} \in R \middle| \mu_{\tilde{x}_{ij}}(x_{ij}) \ge a\right\}\right]\end{aligned} \tag{8}$$

where $0 < a \le 1$. By setting different levels of confidence, namely 1-α, fuzzy data are accordingly transformed into different α -level sets $\left\{(\tilde{x}_{ij})_a \middle| 0 < a \le 1\right\}$, which are all intervals.

• Step 2: The normalized values $p^{'}_{ij}$ and $p^{"}_{ij}$ are calculated as:

$$p^{'}_{ij} = \frac{x^{'}_{ij}}{\sum_{j=1}^{m} x^{"}_{ij}} \quad p^{"}_{ij} = \frac{x^{"}_{ij}}{\sum_{j=1}^{m} x^{"}_{ij}} \quad i = 1,2,...,n; j = 1,2,...,m \tag{9}$$

• Step 3: Lower bound $h^{'}_{i}$ and upper bound $h^{"}_{i}$ of interval entropy can be obtained by:

$$\begin{aligned}h^{'}_{i} &= \min\left\{-h_0 \sum_{j=1}^{m} p^{'}_{ij}.Lnp^{'}_{ij}, -h_0 \sum_{j=1}^{m} p^{"}_{ij}.Lnp^{"}_{ij}\right\}, i = 1,2,...,n \\ h^{"}_{i} &= \max\left\{-h_0 \sum_{j=1}^{m} p^{'}_{ij}.Lnp^{'}_{ij}, -h_0 \sum_{j=1}^{m} p^{"}_{ij}.Lnp^{"}_{ij}\right\}, i = 1,2,...,n\end{aligned} \tag{10}$$

where h_0 is equal to $(Ln \quad m)^{-1}$, and $p^{'}_{ij}$. $Ln \quad p^{'}_{ij}$ or $p^{"}_{ij}$. $Ln \quad p^{"}_{ij}$ is defined as 0 if $p^{'}_{ij} = 0$ or $p^{"}_{ij} = 0$.

• Step 4: Set the lower and the upper bound of the interval of diversification $d^{'}_{i}$ and $d^{"}_{i}$ as the degree of diversification as follows:

$$d^{'}_{i} = 1 - h^{"}_{i}, \; d^{"}_{i} = 1 - h^{'}_{i} \quad i = 1,...,n \tag{11}$$

• Step 5: Set, $w^L_i = \frac{d^L_i}{\sum_{s=1}^{n} d^u_s}, w^U_i = \frac{d^U_i}{\sum_{s=1}^{n} d^L_s} \quad i = 1,...,n$ as the lower and upper bound of interval weight of attribute i.

2.2 THE FUZZY TOPSIS METHOD

TOPSIS regards a MADM problem with m alternatives as a geometric system with m points in the n-dimensional space. The method is predicated upon the idea that the chosen alternative should have the shortest distance from the positive-ideal solution and the longest distance from the negative-ideal solution. TOPSIS describes an index named similarity to the positive-ideal solution and the remoteness from the negative-ideal solution. Then the method selects an alternative with the maximum similarity to the positive-ideal solution (Wang & Chang, 2007). A decision-maker's assigning a precise performance rating to an alternative for the attributes under consideration is often difficult. Instead of precise numbers, the merit of using a fuzzy approach is to assign the relative importance of attributes which use fuzzy numbers. This section broadens the scope of the TOPSIS to the fuzzy environment (Yang & Hung, 2007). This method is particularly appropriate for the solution of the group decision-making problem under fuzzy environment. The rationale of fuzzy theory before the development of fuzzy TOPSIS is shortly reviewed. The mathematics concept borrowed from (Ashtiani *et al*. 2007; Büyükozkan *et al*. 2007; Wang & Chang 2007).

• Step 1: Determine the weighting of evaluation criteria

A systematic approach to widen the scope of the TOPSIS is suggested to choose tugboat according to propulsion system under a fuzzy environment in this section. With the aim of performing a pairwise comparison among the parameters, a linguistic scale has been improved. Table 1 gives the corresponding explanations of our scale. Seven main linguistic terms to compare the alternative-criteria have been used: ''VP-Very Poor'', ''P-Poor'', ''MP-Medium Poor'', ''F-Fair'' "MG-Medium Good", "G-Good" and ''VG-Very Good''. For Alternative-Criteria matrix, if there is a "good" relationship between the alternative A and the criteria C, it can be said that there is also a "good" relationship between C and A.

Table 1: The linguistic scale and corresponding triangular fuzzy numbers

Linguistic Scale	**TFNs**
VP- Very Poor	(0.00, 0.00, 1.00)
P-Poor	(0.00, 1.00, 3.00)
MP-Medium Poor	(1.00, 3.00, 5.00)
F-Fair	(3.00, 5.00, 7.00)
MG-Medium Good	(5.00, 7.00, 9.00)
G-Good	(7.00, 9.00, 10.00)
VG-Very Good	(9.00, 10.00, 10.00)

• Step 2: Construct the fuzzy decision matrix

To construct the fuzzy judgment matrix $\tilde{D}=\tilde{x}_{ij}$ of n criteria and m alternatives via pair-wise comparison, the TFNs are used as follows:

$$\tilde{D}=\begin{matrix} & C_1 & C_2 & \cdots & C_N \\ A_1 & \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ A_2 & \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ A_M & \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn}\end{matrix} \quad i=1,2,...,m; j=1,2,...,n \tag{12}$$

$$\tilde{x}_{ij}=\frac{1}{k}(\tilde{x}_{ij}^1\oplus\tilde{x}_{ij}^2\oplus...\oplus\tilde{x}_{ij}^k) \tag{13}$$

where $\tilde{x}_{ij}^k$ is the rating of alternative A_i with respect to criterion C_i evaluated by k^{th} expert and $\tilde{x}_{ij}^k=(l_{ij}^k,m_{ij}^k,u_{ij}^k)$. For each TFN, $\tilde{x}_{ij}$ or A = (*l, m, u*), its membership function $\mu_{\tilde{A}}(x)$ or $\mu_M(x)$ is a continuous mapping from real number $-\infty\leq x\leq\infty$ to the closed interval (0, 1) and can be defined by Equation 1.

• Step 3: Normalize the fuzzy decision matrix

The normalized fuzzy decision matrix denoted by $\tilde{R}$ is shown as following formula:

$$\tilde{R}=\left[\tilde{r}_{ij}\right]_{mxn} i=1,2,...,m; j=1,2,...,n \tag{14}$$

Then the normalization process can be performed by following formula, where

$$\tilde{r}_{ij}=(\frac{l_{ij}}{u_j^+},\frac{m_{ij}}{u_j^+},\frac{u_{ij}}{u_j^+});\ u_j^+=\max_i\{u_{ij}:i=1,2,...,m$$
$$\tilde{r}_{ij}=(\frac{l^-_j}{u_{ij}},\frac{l^-_j}{m_{ij}},\frac{l^-_j}{l_{ij}});l^-_j=\min_i\{l_{ij}:i=1,2,...,m \tag{15}$$

for benefit criteria and cost criteria, respectively.

The normalized $\tilde{r}_{ij}$ are still triangular fuzzy numbers. For trapezoidal fuzzy numbers, the normalization process can be conducted in the same way. The weighted fuzzy normalized decision matrix is shown as following matrix $\tilde{V}$:

$$\tilde{v}=\left[\tilde{v}_{ij}\right]_{mxn} i=1,2,...,m; j=1,2,...,n \tag{16}$$

$$\tilde{v}_{ij}=\tilde{r}_{ij}\otimes\tilde{w}_j \tag{17}$$

• Step 4: Determine the fuzzy positive-ideal solution (FPIS) and fuzzy negative-ideal solution (FNIS)

With reference to the weighted normalized fuzzy decision matrix, the elements are normalized positive TFNs and their ranges belong to the closed interval [0, 1]. Then, the FPIS A^+ and FNIS A^- can be defined as following formula:

$$A^+=(\tilde{V}_1^+,\tilde{V}_2^+,...,\tilde{V}_n^+) \tag{18}$$

$$A^-=(\tilde{V}_1^-,\tilde{V}_2^-,...,\tilde{V}_n^-) \tag{19}$$

Where $\tilde{V}_j^+=(1,1,1)\otimes\tilde{w}_j=(lw_j,mw_j,uw_j)$ and $\tilde{V}_j^-=(0,0,0); j=1,2,...,n$

• Step 5: Calculate the distance of each alternative from FPIS and FNIS

The distances (d_i^+ and d_i^-) of each alternative A^+ from and A^- can be currently calculated by the area compensation method.

$$d_i^+=\sum\nolimits_{j=1}^n d(v_{ij},\tilde{V}_j^+)\ i=1,2,...,m; j=1,2,...,n \tag{20}$$

$$d_i^-=\sum\nolimits_{j=1}^n d(v_{ij},\tilde{V}_j^-)\ i=1,2,...,m; j=1,2,...,n \tag{21}$$

• Step 6: Obtain the closeness coefficient and rank the order of alternatives

The CC_i is defined to determine the ranking order of all alternatives once the d_i^+ and d_i^- of each alternative have been calculated. Calculate similarities to ideal solution. This step enables to solve the similarities to an ideal solution by formula:

$$CC_i = \frac{d_i^-}{d_i^+ + d_i^-} \quad i = 1, 2, ..., m \tag{22}$$

According to the CC_i, the ranking order of all alternatives may be determined and the best one from among a set of feasible alternatives selected.

3. A REAL CASE APPLICATION: SELECTION OF A TUGBOAT ACCORDING TO THE PROPULSION SYSTEM

Selection of a suitable tugboat for a port is a tough problem that includes many criteria necessarily assessed at the same time and some of the criteria may be in confliction with each other. Different criteria exert different effects on the size, power and drive arrangements of a tugboat that enable to efficiently perform the operations expected from it in the port where to be intended to operate. Along with the physical conditions of the port, comments of the subject-matter-experts on the criteria are crucially important for the selection of suitable tugboat.

This study identifies the order of alternatives using a fuzzy method for a new multi-criteria decision making (MCDM) problem and offers the solution to the problem by choosing the most appropriate one. Within this context, regarding the selection problem of the suitable tugboat, the structure of the methodology applied has been explained.

Figure 2 demonstrates hierarchical structure designed in harmony with Fuzzy Shannon Entropy Method including criteria and alternatives which affect tugboat selection based on propulsion system.

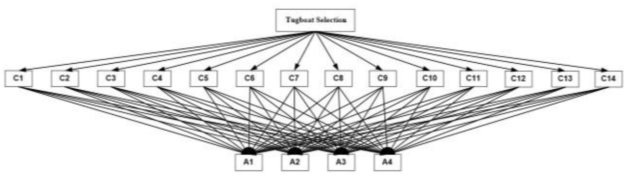

Figure 2: Hierarchical structure for propulsion system type

Considering the hierarchical structure created, pairwise comparisons to the tugboats with different propulsion systems have been used for Fuzzy Shannon Entropy and Fuzzy VIKOR method by subject-matter-experts. All decisions of subject-matter-experts have been assessed likewise. Table 2 below shows the results obtained from the common view owing to fuzzy Shannon's Entropy.

This section demonstrates the application of this method by a real case implementation. By the literature review and working on other papers that concern technical and operational features of tugboats, lastly fourteen criteria have been selected. These criteria are determined to cover technical, operational and financial characteristics of tugboats. Short definitions of the criteria are presented in Table 2.

Table 2: Definitions of selected criteria

No	**Criteria**	**Definition**
C1	Bollard pull	measure of the strength (pulling/towing power) of a tugboat.
C2	Price	Required capital investment
C3	Functionality	easy line handling and best manoeuvring in limited areas
C4	Seakeeping	comfort, crew workability, damage to ship and cargo due to ship motions.
C5	Deck arrangement	the size of working area on deck and the arrangement of the towing equipment e.g. winches, windlass etc.
C6	Hull form	the underwater design of the tugboat and the characteristic of the hull lines
C7	Working environment	the environmental conditions that the tugboat will work
C8	Operational cost	low operation costs, e.g. low fuel consumption, low crew cost
C9	Speed	maximum and/or service speed of a tugboat
C10	Maturity possibility	support to the customer for financing issues
C11	Safety	vessel stability in towing operation and critical equipment installation on deck and engine room
C12	Maintenance	short-time, easy and cheaper maintenance
C13	Delivery time	short-term construction after order confirmation
C14	Tank capacity	capacity of the fuel tank and the other tanks

Table 3: Aggregate decision matrix for fuzzy Shannon's Entropy

	A1			A2			A3			A4		
C1	6.2	8.2	9.4	7.0	9.0	10	6.6	8.6	9.8	5.0	7.0	8.0
C2	5.4	7.4	9.0	1.0	1.0	1.0	5.8	7.8	9.2	5.4	7.4	9.0
C3	4.6	6.6	8.2	4.2	6.2	8.0	1.0	1.0	1.0	1.0	1.0	1.0
C4	6.2	8.2	9.6	5.4	7.4	9.2	5.0	7.0	9.0	5.8	7.8	9.4
C5	5.0	7.0	8.6	5.8	7.8	9.4	5.4	7.4	9.2	5.8	7.8	9.4
C6	5.0	7.0	8.8	5.4	7.4	9.2	5.4	7.4	9.2	5.8	7.8	9.4
C7	5.0	7.0	8.6	5.4	7.4	9.0	5.4	7.0	9.0	5.4	7.4	9.0
C8	4.6	6.6	8.4	6.2	8.2	9.6	5.8	7.8	9.4	7.0	9.0	10
C9	5.0	7.0	8.6	5.8	7.8	9.2	5.0	7.0	8.8	5.4	7.4	9.0
C10	6.6	8.6	9.8	6.2	8.2	9.6	6.6	8.6	9.8	6.6	8.6	9.8
C11	5.0	7.0	9.0	6.6	8.6	9.8	6.6	8.0	9.8	6.2	8.2	9.6
C12	6.2	8.2	9.4	5.0	7.0	8.8	4.6	6.6	8.4	5.0	7.0	8.6
C13	6.6	8.6	9.8	5.4	7.4	9.2	5.0	7.0	9.0	4.2	6.2	8.2
C14	3.8	5.8	7.8	3.4	5.4	7.4	3.4	5.4	7.2	3.4	5.4	7.2

Initially, through fuzzy Shannon's Entropy, the criteria and alternatives' importance weights have been compared. Table 3 presents the aggregate decision matrix for Shannon's Entropy consisting of the common results of the questionnaire answered by subject-matter-experts. To give an example; for the evaluation between C4 criteria and Alternative 1, answers given by the experts were as (G, MG, G, G, MG). By using the corresponding fuzzy numbers [(7,9,10), (5,7,9), (7,9,10), (7,9,10), (5,7,9)] to these answers, listed in Table 1, the final values were obtained as (6.20, 8.20, 9.60) through Equation 13.

4. RESULTS AND DISCUSSION

Following the formation of the decision matrix, the transformation of fuzzy data given in Table 3 into interval data has been achieved. With the aim of transforming fuzzy data into interval data, we consider α=0.3. Next, normalization of the interval decision matrix has been performed. Table 4 shows the normalized interval decision matrix.

Table 4: The normalized interval decision matrix

	A1		A2		A3		A4	
C1	0.187	0.248	0.209	0.266	0.198	0.259	0.154	0.227
C2	0.224	0.318	0.037	0.037	0.239	0.327	0.224	0.318
C3	0.303	0.449	0.279	0.434	0.058	0.058	0.058	0.058
C4	0.193	0.261	0.171	0.246	0.159	0.239	0.182	0.254
C5	0.162	0.235	0.185	0.258	0.173	0.250	0.185	0.258
C6	0.162	0.239	0.174	0.251	0.174	0.251	0.186	0.259
C7	0.166	0.241	0.178	0.253	0.178	0.253	0.178	0.253
C8	0.146	0.220	0.191	0.257	0.179	0.250	0.213	0.272
C9	0.166	0.241	0.190	0.261	0.166	0.245	0.178	0.253
C10	0.192	0.252	0.181	0.245	0.192	0.252	0.192	0.252
C11	0.154	0.230	0.197	0.259	0.197	0.259	0.187	0.252
C12	0.204	0.272	0.168	0.248	0.156	0.236	0.168	0.244
C13	0.211	0.277	0.176	0.254	0.164	0.246	0.141	0.223
C14	0.161	0.264	0.146	0.249	0.146	0.244	0.146	0.244

Calculation of the lower bound hi' and upper bound hi'' of criteria is made in the next step. As Table 5 indicates, the degrees of diversification are calculated afterwards.

Finally, the interval weight and crisp weight are eventually calculated, given in Table 6. As shown, according to the evaluations of subject-matter-experts, C2 (0.763) criterion is visibly preceded by the most effective criterion for selection of tugboat according to the type of propulsion system criterion C3 with a value of (0.670).

Table 5: The values of hi', hi'', di' and di''

	[hi', hi'']		[di', di'']	
C1	0.901	0.999	0.001	0.099
C2	0.818	0.878	0.122	0.182
C3	0.757	0.759	0.241	0.243
C4	0.882	1.000	0.000	0.118
C5	0.882	0.999	0.001	0.118
C6	0.877	1.000	0.000	0.123
C7	0.880	1.000	0.000	0.120
C8	0.891	0.998	0.002	0.109
C9	0.880	1.000	0.000	0.120
C10	0.909	1.000	0.000	0.091
C11	0.896	0.999	0.001	0.104
C12	0.876	0.999	0.001	0.124
C13	0.870	0.998	0.002	0.130
C14	0.821	1.000	0.000	0.179

Table 6: The interval and crisp weight of criteria

	w_i^L , w_i^U		w_i	Rank
C1	0.001	0.267	0.995	5
C2	0.066	0.488	0.763	2
C3	0.129	0.653	0.670	1
C4	0.000	0.318	0.999	9
C5	0.000	0.317	0.998	8
C6	0.000	0.330	0.999	11
C7	0.000	0.322	0.999	13
C8	0.001	0.294	0.992	3
C9	0.000	0.323	0.999	10
C10	0.000	0.244	1.000	14
C11	0.000	0.280	0.997	7
C12	0.001	0.333	0.997	6
C13	0.001	0.348	0.993	4
C14	0.000	0.481	0.999	12

Table 6 allows observing that, as a result of alternative-criteria comparisons, the C10, C7, C14, C6, C9 and C4 criteria are placed in the last with (1.000), (0.999), (0.999), (0.999), (0.999) and (0.999) respectively. Under these circumstances, C3 and C2 criteria are apparently the most influential factors in the selection of the tugboat concerning the propulsion system. Besides, we have observed that the C10, C7, C14, C6, C9 and C4 criteria have less influence in the selection of the tugboat than the other criteria.

The weights of the alternatives were calculated by fuzzy Shannon's Entropy and used in fuzzy TOPSIS. Therefore, Table 7 shows normalized decision matrix which was prepared.

Table 7: The normalized decision matrix calculated with fuzzy entropy weight

	A1			A2			A3			A4		
C1	0.50	1.56	2.81	0.56	1.72	2.99	0.53	1.64	2.93	0.40	1.33	2.63
C2	0.40	2.92	4.74	0.07	0.39	0.52	0.43	3.08	4.85	0.40	2.92	4.74
C3	0.25	3.69	5.69	0.23	3.46	5.55	0.05	0.55	0.69	0.05	0.55	0.69
C4	0.60	1.86	3.42	0.52	1.68	3.28	0.48	1.59	3.21	0.56	1.77	3.35
C5	0.48	1.58	3.06	0.56	1.76	3.34	0.52	1.67	3.27	0.56	1.76	3.34
C6	0.50	1.65	3.25	0.54	1.74	3.40	0.54	1.74	3.40	0.58	1.83	3.48
C7	0.49	1.60	3.10	0.53	1.70	3.24	0.53	1.70	3.24	0.53	1.70	3.24
C8	0.40	1.39	2.77	0.55	1.72	3.16	0.51	1.64	3.10	0.62	1.89	3.29
C9	0.49	1.61	3.11	0.57	1.80	3.33	0.49	1.61	3.19	0.53	1.70	3.26
C10	0.49	1.50	2.68	0.46	1.43	2.63	0.49	1.50	2.68	0.49	1.50	2.68
C11	0.42	1.40	2.83	0.56	1.72	3.08	0.56	1.72	3.08	0.52	1.64	3.01
C12	0.62	1.95	3.51	0.50	1.66	3.29	0.46	1.57	3.14	0.50	1.66	3.21
C13	0.69	2.14	3.82	0.56	1.84	3.58	0.52	1.74	3.51	0.44	1.54	3.19
C14	0.55	1.99	4.21	0.50	1.85	3.99	0.50	1.85	3.88	0.50	1.85	3.88

Table 8 demonstrates that ASD Type propulsion system has been chosen as the most appropriate alternative with the 0.490 CC value as the common opinion of all subject-matter-experts. Voith Tractor Type Propulsion System has been determined as the last option to be opted in with the 0.470 CC value among four selected alternatives. The other alternatives have been prioritized seriatim so the Conventional Type Propulsion System with 0.482 CC value as the second preferred propulsion system and the ASD Tractor Type Propulsion System with 0.471 CC value as the third preferred propulsion system have been ranked.

Table 8: Final evaluation of the alternatives

Alternatives	**d+**	**d-**	**CC**	**Rank**
A1: ASD propulsion	29.103	27.944	0.490	1
A2: Conventional propulsion	30.656	28.481	0.482	2
A3: ASD Tractor propulsion	31.085	27.647	0.471	3
A4: Voith Tractor propulsion	31.048	27.571	0.470	4

Table 8 shows the fuzzy TOPSIS results. The evaluation of propulsion system selection of tugboat have been carried out and given the CCi values, the ranking of propulsion system are A1 – A2 – A3 – A4 organized from most preferable to least. Although first and second alternatives have been evidently separated from others and been the prominent two of tugboat types to choose, CC values specifying the order of the selection for last two alternatives are considered very close to each other. Selection of the best alternative to CC value is easy, selection of the worst or the last one is relatively difficult because of CC values being very close to each other.

5. CONCLUSIONS

This study structures a two-step fuzzy Shannon's Entropy and fuzzy TOPSIS methodology. Thus, fuzzy Shannon's Entropy result weights are used as input weights. Within the context of the proposed method, the model generated by use of the expert opinion on alternative-criteria has been subjected to an analysis. Experts then recognized that the ranking of propulsion system with CC_i has a value.

Due to linguistic variables, evaluation is hardly an accurate process and fuzzy by its body. So, the deployment of fuzzy Shannon's Entropy weights in fuzzy TOPSIS allows the application to be more realistic and reliable. The developed fuzzy method appears functional to solve this problem.

Intending to produce that result, without ignoring views of subject-matter-experts, fourteen criteria for four tugboat types have been examined. The decision-making models have been modelled and assessed through the technical experts of tugboat operators working at Turkish ports, the engineers of international tugboat design firms and the expert academicians.

Table 6 displays that Functionality and Price criteria are the most significant factors which affect the selection of the Tugboat propulsion system. Taking into account the impact of the criteria on the alternatives of weight ratings, of the tugboat types, propulsion system alternative of ASD Type has been decided as the most functional alternative as a result of the common opinion of all subject-matter-experts. It should be remembered that the results of these evaluations are likely to vary whether the weight of the criteria is altered or as long as the evaluator specialist change.

The selection of tugboats to be invested by companies which operate in various national or international ports may be determined in future studies thanks to similar methods by raising or reducing additional criteria.

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