Hakan Demirel
Abit Balin
Erkan Çelik
Fuat Alarçin

http://dx.doi.org/10.21278/brod69304

ISSN 0007-215X
eISSN 1845-5859

A FUZZY AHP AND ELECTRE METHOD FOR SELECTING STABILIZING DEVICE IN SHIP INDUSTRY

UDC 629.5.025.22:629.562.2
Original scientific paper

Summary

Roll stabilizer systems are studied for different types of ships by many researchers. It is well known that roll motion is caused by external disturbances (wave,wind etc) and large roll motion can cause capsizing easily. In addition, undesirable roll motion effect badly crew performance and passenger comfort. So, roll reduction has an important role for all types of ships. In our study, we proposed a fuzzy AHP (Analytic Hierarchy Process) and ELECTRE (Elemination and Choice Translating Reality English) method for selecting the most effective roll stabilizing system for a trawler type fishing vessel. Alternatives and criteria in relation to the stabilizers are determined by experts' experiences and literature review. This paper intends to give a comprehensive procedure for determining the most suitable roll motion stabilizing system of trawler for safety and efficiency fishing in the open literature.

Key words: *AHP; ELECTRE; fuzzy sets; roll stabilizing system; trawler*

1. Introduction

Although significant advances have been made in fishing vessel, fishing still remains a highly dangerous profession. One of the fundemental means by which the operation of fishing vessel can be improved is through reduction in the roll motion. Excessive roll not only increases fuel consumption but also makes working on deck hazardous, affecting the efficiency and safety of the crew. So, roll motion stabilizing devices are very crucial in severe sea states. Many types of roll stabilizers are suggested for different ships by researchers in literature.

Van Amerongen et al. [1] examined rudder roll stabilization system for ships. They revealed that the rudder shows an effective roll reduction in severe sea states. Fortuna and Muscato [2] proposed an automatic roll reduction system for a new monohull ship. They evaluated system performance with simulations and experimental tests. Gawad et al.[3] suggested anti-roll passive tanks for roll motion stabilization. Also, they emphasized both anti-roll tanks and fins can be used for more control in critical operations. Do et al. [4] examined the problem of universal control for underactuated surface ships. They used different method for stabilization. Jones et al. [5] developed a more generic anti-roll tanks for fishing vessels. They suggested two control strategies for stabilizing. Moaleji and Greig [6] reviewed the development of ship anti-roll tanks. They discussed using of roll stabilization tanks on high speed multi-hull craft. Alarcin and Gulez [7] used a neural network (NN) controller for a fishing vessel rudder roll stabilizer system. Marzouk and Nayfeh [8] investigated the performance of passive and active anti-roll tank for a cargo ship in three different sea conditions. Su [9] reviewed the anti-rolling fin control system for ship stabilization. Alarcin et al. [10] suggested the fin roll stabilizer system for a fishing ship. Kula [11] evaluated operational efficiency of roll stabilizers and examined applicability of advanced control methods for stabilizers. Ayob and Yaakob [12] improved method for roll reduction and assessed performance of moving mass device in relation to stabilization.

It is known that the purpose of roll stabilizer systems is to minimize the roll amplitudes of a ship. As can be understood from the above-mentioned studies, roll stabilizer systems for ships have been technically evaluated and the rate of reduction of the roll amplitudes has been the most important criterion. However, a technically successful roll stabilizer system may not always be feasible for a ship. Different criteria, such as the economic criterion, can create an obstacle to the selection of a stabilizer system for that ship. Therefore, in this study, considering the different criteria, the most suitable one among the four stabilizer systems for a trawler type fishing boat was determined by means of the fuzzy AHP and ELECTRE method considering the expert opinions on these criteria and alternatives. This paper aims to present and contribute a robust methodological approach utilising AHP and ELECTRE under fuzzy environment which is able to deal with uncertainty of experts' judgement and expression in decision-making. The proposed approach is capable of for selecting stabilizing device in ship industry.

2. Research methodology

This section initially describes theoretical background of methods used in proposed approach. Then, the section shows how proposed approach is constructed.

2.1 Fuzzy sets

Fuzzy logic, introduced in 1965 by Lotfi A. Zadeh [13], is robust tool to deal with the vagueness, ambiguity and uncertainty of human judgments and assessment in making decisions process. In real world decision making problems, many decisions involve imprecision since goals, constraints, and possible actions are not known precisely [13]. Instead of combining various experiences, opinions, ideas, and motivations of an individual or group decision maker, it is better to convert the linguistic terms into fuzzy numbers. Therefore, the problems of group decision-making have necessary produced fuzzy numbers in practice. A triangular fuzzy number can be defined as a triplet $\tilde{A} = (l, m, u)$where l, m and u denotes lower, medium and upper numbers of the fuzzy which is crisp and real numbers ($x \leq y \leq z$). In this context, Figure 1 shows a triangular fuzzy number. The membership function of a triangular fuzzy number can be defined as follows.

$$\mu_{\tilde{A}} = \begin{cases} 0, & x < l \\ (x-l)/(m-l), & l \leq x \leq m \\ (u-x)/(u-m), & m \leq x \leq u \\ 0 & x \geq u \end{cases} \tag{1}$$

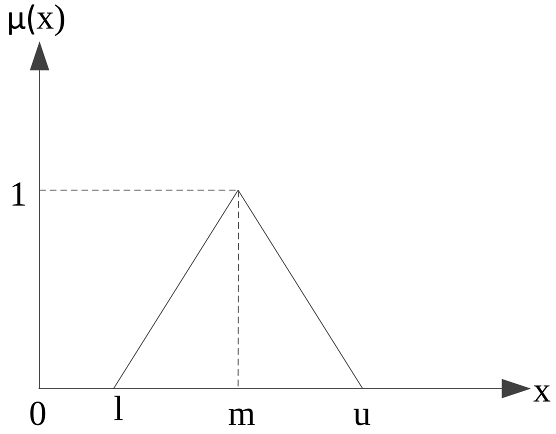

Fig. 1 Triangular fuzzy number

For any two triangular fuzzy numbers $\tilde{A}_1 = (l_1, m_1, u_1)$ and $\tilde{A}_2 = (l_2, m_2, u_2)$, the mathematical calculation of the two triangular fuzzy numbers can be defined as follows:

The addition operation between the triangular fuzzy numbers;

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

The subtraction operation between the triangular fuzzy numbers;

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

The multiplication operation between the triangular fuzzy numbers;

$$\tilde{A}_1 \, x \, \tilde{A}_2 = (l_1 x l_2, m_1 x m_2, u_1 x u_2) \tag{4}$$

The arithmetic operation for the triangular fuzzy numbers;

$$kx\tilde{A}_1 = (kxl_1, kxm_1, kxu_1), (k > 0) \tag{5}$$

$$\frac{\tilde{A}_1}{k} = \left(\frac{l_1}{k}, \frac{m_1}{k}, \frac{u_1}{k}\right), (k > 0) \tag{6}$$

2.2 Fuzzy AHP

AHP is a general tool for comparing a number of criteria or alternatives according to the an complete goal in a consistent manner [14,15,16]. Decision-makers generally reveal that it is more suitable to answer interval judgments than fixed-value judgements regarding to the vagueness and uncertainty from the subjective perception in the decision-making process [17,18]. This is mostly because usually he/she is unable to specific about his/her perception because of the fuzzy nature of the comparison process [19]. The assessment rate of linguistic data are measured with Triangular Fuzzy Numbers (TFNs) [20]. A TFN can be shown as (l|m, m|u) or (l, m, u). The parameters l, m and u, denote the smallest possible, the most promising, and the largest possible value that describes a fuzzy case, respectively. The membership function of the TFN can be specified as.

$$\mu\left(x/\tilde{M}\right) = \begin{cases} 0, & x < l \\ (x-1)/(m-l), & 1 \le x \le m \\ (u-x)/(u-m), & m \le x \le u \\ 0, & x > u \end{cases} \tag{7}$$

Several methods have been proposed to address fuzzy comparison matrices. For example, Logarithmic Least Squares Method (LLSM) is proposed by Van Laarhoven and Pedrycz [21] to get triangular fuzzy weights from a triangular fuzzy comparison matrix. a modified fuzzy LLSM is presented by Wang et al. [22]. Buckley [23] employs the geometric mean method to compute fuzzy weights. Chang [24] proposes an extent analysis method, which derives crisp weights for fuzzy comparison matrices. Xu [25] brings forward a fuzzy Least Squares priority Method (LSM). A fuzzy Preference Programming Method (PPM) is also proposed by Mikhailov [26]. Lambda-Max method is proposed by Csutora and Buckley [27] which is the fuzzification of the *k*max method.

We use Buckley's Fuzzy-AHP to find importance weights since it is simple to cover to the fuzzy case and assurances a sole solution to the reciprocal comparison matrix [28]. It is rather easier than the other Fuzzy-AHP approaches. The steps of the applied Buckley's Fuzzy-AHP algorithm can be presented as follows [23,29]:

Table 1 Linguistic variables for importance weights

Linguistic variables	*Fuzzy numbers*
Absolutely Strong (AS)	*(7, 9, 9)*
Very Strong (VS)	*(5, 7, 9)*
Fairly Strong (FS)	*(3, 5, 7)*
Slightly Strong (SS)	*(1, 3, 5)*
Equally (E)	*(1, 1, 3)*
Slightly Weak (SW)	*(0.20, 0.33, 1)*
Fairly Weak (FW)	*(0.14, 0.20, 0.33)*
Very Weak (VW)	*(0.11, 0.14, 0.20)*
Absolutely Weak (AW)	*(0.11, 0.11, 0.14)*

Step 1. Build pairwise comparison matrices among all the criteria. The linguistic variable is assigned according to the Equation (9). It is questioned which is the more important of each two criteria, such as:

$$\tilde{M} = \begin{pmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & 1 \end{pmatrix} = \begin{pmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ 1/\tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/\tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & 1 \end{pmatrix} \tag{8}$$

where,

$$\tilde{a}_{ij} = \begin{cases} \tilde{1}, \tilde{3}, \tilde{5}, \tilde{7}, \tilde{9} & \text{criterion } i \text{ has relative importance to criterion } j \\ 1. & i = j \\ \tilde{1}^{-1}, \tilde{3}^{-1}, \tilde{5}^{-1}, \tilde{7}^{-1}, \tilde{9}^{-1} & \text{criterion } i \text{ has less importance to criterion j} \end{cases} \tag{9}$$

Step 2. Apply geometric mean to explain the fuzzy geometric mean as follows:

$$\tilde{r}_i = \left(\tilde{a}_{i1} \otimes \tilde{a}_{i2} \otimes \cdots \otimes \tilde{a}_{in} \right)^{1/n} \tag{10}$$

where $\tilde{a}_{in}$ is fuzzy comparison value of criterion i to criterion n, thus, is geometric mean of fuzzy comparison value of criterion i to each criterion.

Step 3. Compute the fuzzy weights of each criterion

$$\tilde{w}_i = \tilde{r}_i \otimes \left(\tilde{r}_1 \oplus \tilde{r}_2 \oplus \cdots \oplus \tilde{r}_n \right)^{-1} \tag{11}$$

where $\tilde{w}_i$ is the fuzzy weight of the ith criterion, can be indicated by $\tilde{w}_i = (lw_i, mw_i, uw_i)$. Here lw_i, mw_i , and uw_i represent the lower, middle and upper values of the fuzzy weight of the ith criterion.

Step 4. Apply Center of Area (COA) method to learn the Best Nonfuzzy Performance (BNP) value of each criterion by the Equation (12).

$$BNP\tilde{w}_i = [(uw_i - lw_i) + (mw_i - lw_i)]/3 + lw_i \tag{12}$$

According to the BNP value for each of the alternatives, the ranking of each alternative can then continue.

2.3 Fuzzy ELECTRE

ELECTRE method is first proposed by Benayoun et al. [30]. A detailed comprehensive review of ELECTRE method is presented [31]. They presented for four classification as applied papers; survey, review and overview papers; papers on MCDA method and model selection; preference disaggregation and theoretical and non-application papers application. Fuzzy sets might provide more flexibility to show the vague/imprecise information stemmin from the lack of information [32,33,34]. Assume that there is a set X of alternatives, where $X = \{x_1, x_2, ..., x_n\}$ and assume that there is a set C of criteria $C = \{c_1, c_2, ..., c_m\}$ and assume that there are k decision-makers $D_1, D_2, ..., D_k$. Then, the steps of the proposed method are as given below.

Step 1. In a group decision environment, assume that a decision group has *k* decision makers, and the rating of alternatives according to each criterion can be calculated as:

$$Y_k = \left(\tilde{c}_{ij}^k\right)_{n\times m} = \begin{array}{c} \\ x_1 \\ x_2 \\ \vdots \\ x_n \end{array}\begin{array}{c} \begin{array}{cccc} c_1 & c_2 & \cdots & c_m \end{array} \\ \begin{bmatrix} \tilde{c}_{11}^k & \tilde{c}_{12}^k & \cdots & \tilde{c}_{1m}^k \\ \tilde{c}_{21}^k & \tilde{c}_{22}^k & \cdots & \tilde{c}_{2m}^k \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{c}_{n1}^k & \tilde{c}_{n2}^k & \cdots & \tilde{c}_{nm}^k \end{bmatrix} \end{array} \tag{13}$$

$$\bar{Y} = \left(\tilde{c}_{ij}\right)_{n\times m} \tag{14}$$

where $\tilde{c}_{ij} = \left(\dfrac{\tilde{c}_{ij}^1 + \tilde{c}_{ij}^2 + \cdots + \tilde{c}_{ij}^k}{k}\right)$, $\tilde{\tilde{c}}_{ij}$ is fuzzy set $1 \le i \le m,\ 1 \le j \le n,\ 1 \le p \le k$ and k denotes the number of decision-makers. In this step, average operator is applied as aggregation operation. It is calculated the weight of each criterion by summing the assigned fuzzy sets by experts and then dividing the sum by the number of experts [35,36].

Table 2 Linguistic variables for alternative ratings

Linguistic variables	*Fuzzy numbers*
Very Poor (VP)	*(0, 0, 1)*
Poor (P)	*(0, 1, 3)*
Medium Poor (MP)	*(1, 3, 5)*
Fair (F)	*(3, 5, 7)*
Medium Good (MG)	*(5, 7, 9)*
Good (G)	*(7, 9, 10)*
Very good (VG)	*(9, 10, 10)*

Step 2. Construct the weighting matrix W_k of the criteria of the *k*th decision-maker and build the average weighting matrix W, respectively, shown as follows:

$$W_k = \left(\tilde{w}_i^k\right)_{1\times m} = \begin{array}{c} \begin{array}{cccc} c_1 & c_2 & \cdots & c_m \end{array} \\ \begin{bmatrix} \tilde{w}_1^k & \tilde{w}_2^k & \cdots & \tilde{w}_m^k \end{bmatrix} \end{array} \tag{15}$$

$$\bar{W} = \left(\tilde{w}_i\right)_{1\times m} \tag{16}$$

where $\tilde{\tilde{w}}_i = \dfrac{\tilde{\tilde{w}}_i^1 + \tilde{\tilde{w}}_i^2 + \cdots + \tilde{\tilde{w}}_i^k}{k}$, $\tilde{\tilde{w}}_i$ is an fuzzy set $1 \le i \le m,\ 1 \le p \le k$ and k denotes the number of decision-makers.

Step 3. Given $\tilde{c}_{ij} = \left(c_{11}, c_{12}, c_{13}\right)$; the normalized performance rating for beneficial criterion can be calculated as:

$$\tilde{n}_{ij} = \left(\frac{c_{11}}{c^*}, \frac{c_{12}}{c^*}, \frac{c_{13}}{c^*}\right) \tag{17}$$

Where $c^* = \text{Max}\ c_{ij}$

Step 4. Formulate the weighted decision matrix.

$$\bar{Y}_w = \left(\tilde{v}_{ij}\right)_{n\times m} = \begin{array}{c} \\ x_1 \\ x_2 \\ \vdots \\ x_n \end{array} \begin{array}{c} \begin{array}{cccc} c_1 & c_2 & \cdots & c_m \end{array} \\ \begin{bmatrix} \tilde{v}_{11}^k & \tilde{v}_{12}^k & \cdots & \tilde{v}_{1m}^k \\ \tilde{v}_{21}^k & \tilde{v}_{22}^k & \cdots & \tilde{v}_{2m}^k \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{v}_{n1}^k & \tilde{v}_{n2}^k & \cdots & \tilde{v}_{nm}^k \end{bmatrix} \end{array} \qquad (18)$$

Where $\tilde{v}_{ij} = \tilde{w}_i \otimes \tilde{n}_{ij}, 1 \le i \le m,$ and $1 \le j \le n.$

Step 5. Specify concordance and discordance fuzzy sets for each fuzzy pairs of k and l alternatives $k, l = 1, 2, ..., n; l \ne k.$ The set of fuzzy indicators $\left(J = \{ j \mid j = 1, 2, ..., n\}\right)$ is divided into two different sets as concordance $\tilde{S}_{kl}$ and discordance fuzzy set $\tilde{D}_{kl}$

$$\tilde{S}_{kl} = \left\{ j \middle| \left[\left(v_{1kj}, v_{2kj}, v_{3kj},\right)\right] \ge \left[\left(v_{1lj}, v_{2lj}, v_{3lj}\right)\right]\right\} \qquad (19)$$

Vice versa the complementary subset named discordance set is a set of indicators that for each of them:

$$\tilde{D}_{kl} = \left\{ j \middle| \left[\left(v_{1kj}, v_{2kj}, v_{3kj}\right)\right] < \left[\left(v_{1lj}, v_{2lj}, v_{3lj}\right)\right]\right\} \qquad (20)$$

Step 6. Compute the concordance fuzzy matrix.

Concordance fuzzy index is equal to the sum of fuzzy weights $\bar{W} = \left(\tilde{w}_i\right)_{1\times m}$ for those indices which form the set. Thus, concordance fuzzy index $\tilde{I}_{k,l}$ between x_k and x_l is as follows:

$$\tilde{I}_{k,l} = \sum_{j \in S_{k,l}} \bar{W} \sqrt{b^2 - 4ac} \qquad (21)$$

The higher value of $\tilde{\tilde{I}}_{k,l}$ presents both the superiority and concordance of x_k to x_l. The asymmetrical concordance fuzzy matrix ($\tilde{\tilde{I}}_{k,l}$) as follows:

$$\tilde{I} = \begin{vmatrix} - & \tilde{I}_{1,2} & \cdots & \tilde{I}_{1,n} \\ \tilde{I}_{2,1} & - & \cdots & \tilde{I}_{2,n} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{I}_{n,1} & \cdots & \tilde{I}_{n,(n-1)} & - \end{vmatrix} \qquad (22)$$

Step 7. Calculate the discordance fuzzy matrix.

Discordance fuzzy index in contrast to the index $N\tilde{I}_{k,l}$ shows that x_l is strongly superior according to x_k. The index $N\tilde{I}_{k,l}$ is computed using the members of matrix $\bar{Y}_w$ for each element of discordance fuzzy set as follows:

$$N\tilde{I}_{k,l} = defuzzified(\sum_{j^* \in \tilde{\tilde{D}}} |\tilde{v}_k - \tilde{v}_l|) \tag{23}$$

Discordance fuzzy matrix for all pair wise comparisons of alternatives converts into a matrix with exact numbers which is:

$$N\tilde{I} = \begin{vmatrix} - & N\tilde{I}_{1,2} & N\tilde{I}_{1,3} & \cdots & N\tilde{I}_{1,n} \\ N\tilde{I}_{2,1} & - & \cdots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ N\tilde{I}_{n,1} & N\tilde{I}_{n,2} & \cdots & N\tilde{I}_{n,(n-1)} & - \end{vmatrix} \tag{24}$$

These have subsidiary relationship such that fuzzy matrix $\tilde{I}$ is descriptive of the weights resulted from concordance indices, and asymmetrical matrix $N\tilde{I}$ reflects the high relative difference of for each discordance indices.

Step 8. Specify the effective concordance fuzzy matrix.

The values of indices $\tilde{\tilde{I}}_{k,l}$ of concordance fuzzy matrix should be compared against a threshold value so that the superiority chance of x_k according to x_l is better judged. In the case when $\tilde{\tilde{I}}_{k,l}$ exceeds from a minimum threshold $\bar{I}$ this chance increases.

Also, we can compute the average of each arbitrary fuzzy index $\bar{I}$ from concordance fuzzy indices in the following manner:

$$\bar{I} = \sum_{k=1}^{n} \sum_{l=1}^{n} \left[\tilde{I}_{k,l} \right] / n(n-1) \tag{25}$$

A Boolean matrix F is constructed based upon minimum threshold $\bar{I}$ which has elements 0 and 1 as:

$$\begin{cases} f_{kl} = 1 \; if \; \tilde{I}_{k,l} \geq \bar{I} \\ f_{kl} = 0 \text{ if } \tilde{I}_{k,l} < \bar{I} \end{cases} \tag{26}$$

An effective and dominant alternative against the other alternatives is obtained with respect to the each element I in matrix F (effective concordance fuzzy matrix).

Step 9. Specify the effective discordance fuzzy matrix.

Elements $\tilde{N}I_{k,l}$ from discordance matrix that is provided in Step 6 is assessed according to a threshold value. This threshold value ($\bar{N}I$) is calculated with the following formula.

$$\bar{N}I = \sum_{k=1}^{n}\sum_{l=1}^{n}\left[\tilde{N}I_{k,l}\right]/n(n-1) \tag{27}$$

A Boolean matrix G (effective discordance matrix) is then built as:

$$\begin{cases} g_{kl} = 1 \text{ if } \tilde{N}I_{k,l} \leq \bar{N}I \\ g_{kl} = 0 \text{ if } \tilde{N}I_{k,l} > \bar{N}I \end{cases} \tag{28}$$

Dominance relations among alternatives is obtained to unit elements in matrix.

Step 10. Specify effective and outranking matrix.

Common elements ($h_{k,l}$) is obtained outranking matrix (H) for making decision from matrices F and G.

$$h_{k,l} = f_{k,l} \otimes g_{k,l} \tag{29}$$

Step 11. Eliminate the less attractive alternatives.

The order of relative superiority of alternatives is presented by Outranking matrix (H). If $h_{k,l} = 1$, x_k is superior to x_l in terms of both concordance and discordance indices. However, x_k might be still dominated by other alternatives. Therefore, the condition which makes x_k an effective alternative is as follows:

$$\begin{cases} h_{k,l} = 1 \text{ for at least one unit element for } l = 1,2,..,n; k \neq l \\ h_{k,l} = 0 \text{ for all } i \qquad\qquad \text{for } l = 1,2,..,n; i \neq k; i \neq l \end{cases} \tag{30}$$

In the cases where these two conditions are not simultaneously fulfilled, the effective alternatives from matrix (H) can be simply recognized. Then, we can exclude those columns of (H) which at least have a unit element (1) from matrix (H) because those columns are dominated by other row or rows. It is that the threshold values of $\bar{I}$ and $\bar{N}I$ which are showed in steps 8 and 9 are approximate and used to enable generating a criterion to select the best alternative between all alternatives. As long as Eq. (30) is not true for any of the alternatives, we can increase $\bar{I}$ and reduce $\bar{N}I$ until the above condition is satisfied to come up with the best alternative.

3 Application

Roll stabilization systems have been the subject of scientific investigation for many years. It is well known that the rolling motion of a ship is an undesirable feature of its behaviour. The variety of stabilizers have been proposed and installed successfully for the elimination or moderation of ship roll. Recently, interest has centered on the stabilizer types, which is better suited to which type of ship. This paper undertakes a review of the whole field of stabilization devices and proposes selection procedure of the most suitable roll motion stabilization system for a trawler type fishing vessel. Looked at in this way, the four major stabilizers: activated fins, anti-rolling tanks, bilge keel, rudder roll stabilization devices are taken up one by one, evaluated and discussed in detail. Various criteria for determining the most suitable roll motion stabilizer for a trawler type of fishing vessel are compared. Stabilizers are classified and their relative merits discussed. The general approach developed in this paper is applied for a trawler type fishing vessel as an example.

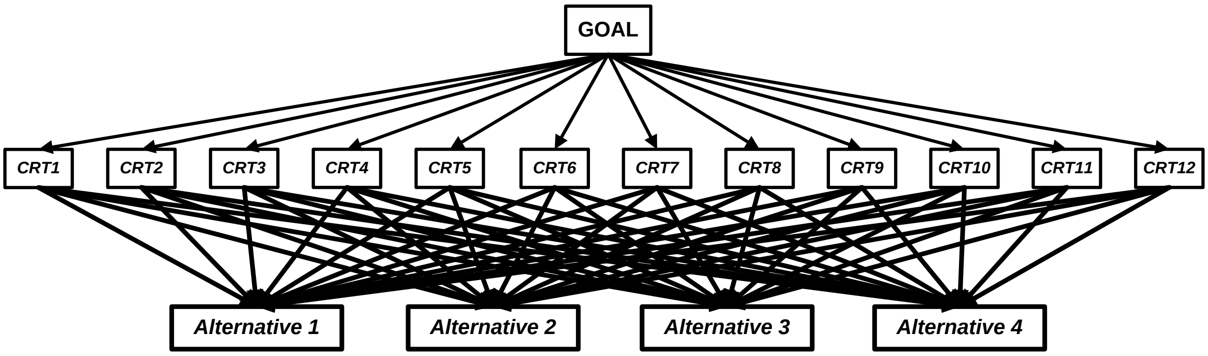

Fig 2. Hierarchical Structure

The hierarchical structure adopted in this study to deal with the problems of selection of the roll motion stabilizing system for a trawler type fishing vessel is shown in Fig 2.

The key dimensions of the criteria for evaluation and selection of the roll motion stabilizing system for a trawler type fishing vessel were derived through comprehensive investigation and consultation with five experts, including two professor in the department of Naval Architecture and Marine Engineering. They were asked to rate the accuracy, adequacy and relevance of the criteria and dimensions and to verify their ‘‘content validity’’ in terms of the stabilizer assessment. Twelve types of criteria of high priority come forth when these criteria are examined. Criteria are coded as C_i where i is the number of relevant criteria as below in Table 3.

Table 3 Criteria for Selection of Stabilizing Systems [37]

Symbol	*Criteria*	*Symbol*	*Criteria*
C1	*Total İnitial Costs*	*C7*	*Underwater Noice*
C2	*Cargo Carrying Capability*	*C8*	*Expensive Pieces Of Equipment*
C3	*Crew Performance And/Or Passenger Comfort*	*C9*	*Working on Low Speed Range*
C4	*Influence On Speed, Power And Resistance*	*C10*	*Working on High Speed Range*
C5	*Maintenance Requirements*	*C11*	*Motion Limitations*
C6	*Roll Reduction*	*C12*	*Wave Conditions*

When aforementioned criteria which differ from one another on the basis of basic characteristics are examined with the intention of categorizing, it appears that each has a relationship with different stabilizer systems. It is also known that critera in certain experts develop a relationship along with the ones in other experts. As far as factors for criteria are concerned, stabilizer systems in connection with the criteria can be grouped in Table 4.

Table 4 Roll Stabilizing Systems

Symbol	*Alternatives*
A1	*Anti-Rolling Tanks*
A2	*Bilge Keels*
A3	*Activated Fins*
A4	*Rudder Roll Stabilization*

According to Table 5 the fuzzy linguistic variables of criteria are shown. In this step, the fuzzy importance weights of criteria are determined using fuzzy AHP. The importance of each criterion is evaluated by experts. The linguistic variables are convert to the fuzzy sets using Table 1 and the aggregated fuzzy pairwise comparison is presented in Table 6. Finally, the fuzzy weights of the each criterion are calculated and it is presented in Table 7.

Table 5 The pairwise comparisons of criteria

	C1	***C2***	**…**	***C11***	***C12***
C1	*(E, E, E, E, E)*	*(SS, SW, E, SS, E)*	...	*(SS, E, FS, VS, VS)*	*(FS, SW, VS, SW, FS)*
C2	*(SW, SS, E, SW, E)*	*(E, E, E, E, E)*	...	*(E, SS, FS, FS, VS)*	*(SS, E, VS, FW, FS)*
C3	*(VW, E, SW, SW,*	*(SW, SW, SW, E, SW)*	...	*(SW, E, E, FS, FS)*	*(E, SW, FS, FW, SS)*
C4	*(SS, FW, SW, E, SW)*	*(SS, VW, SW, SS, SW)*	...	*(SS, FW, E, VS, FS)*	*(FS, VW, FS, SW, SS)*
C5	*(E, SW, FW, FW,*	*(SS, FW, FW, SW, FW)*	...	*(SS, SW, SW, SS, SS)*	*(FS, FW, SS, VW, E)*
C6	*(FW, SS, VW, FW,*	*(SW, E, VW, SW, VW)*	...	*(SW, SS, FW, SS, E)*	*(E, E, E, VW, SW)*
C7	*(SW, VW, AW, VW,*	*(E, AW, AW, FW, AW)*	...	*(E, VW, VW, E, SW)*	*(SS, AW, SW, AW,*
C8	*(SW, SW, SW, E, E)*	*(E, FW, SW, SS, E)*	...	*(E, SW, E, VS, VS)*	*(SS, FW, FS, SW, FS)*
C9	*(AW, VW, AW, VW,*	*(VW, AW, AW, FW, AW)*	...	*(FW, VW, VW, E,*	*(SW, AW, SW, AW,*
C10	*(AW, SW, FW, SW,*	*(VW, FW, FW, E, VW)*	...	*(VW, SW, SW, FS, E)*	*(SW, FW, SS, FW,*
C11	*(SW, E, FW, VW,*	*(E, SW, FW, FW, VW)*	...	*(E, E, E, E, E)*	*(SS, SW, FS, AW,*
C12	*(FW, SS, VW, SS,*	*(SW, E, VW, FS, FW)*	...	*(SW, SS, FW, AS, SS)*	*(E, E, E, E, E)*

Table 6 The fuzzy weights of each criterion

	C1	*C2*	...	*C11*	*C12*
C1	*(1, 1, 3)*	*(0,84, 1,67, 3,4)*	...	*(3, 4,6, 6,6)*	*(2,28, 3,53, 5)*
C2	*(0,68, 1,13, 2,6)*	*(1, 1, 3)*	...	*(1, 1, 3)*	*(2,03, 3,24, 4,87)*
C3	*(0,34, 0,43, 1,24)*	*(0,36, 0,47, 1,4)*	...	*(0,36, 0,47, 1,4)*	*(1,07, 1,91, 3,27)*
C4	*(0,51, 0,97, 2,07)*	*(0,5, 1,36, 2,44)*	...	*(0,5, 1,36, 2,44)*	*(1,46, 2,7, 4,04)*
C5	*(0,33, 0,39, 1)*	*(0,33, 0,79, 1,4)*	...	*(0,33, 0,79, 1,4)*	*(1,05, 1,87, 3,11)*
C6	*(0,3, 0,74, 1,21)*	*(0,32, 0,39, 1,08)*	...	*(0,32, 0,39, 1,08)*	*(0,66, 0,7, 2,04)*
C7	*(0,13, 0,17, 0,34)*	*(0,3, 0,31, 0,75)*	...	*(0,3, 0,31, 0,75)*	*(0,31, 0,75, 1,32)*
C8	*(0,52, 0,6, 1,8)*	*(0,67, 1,11, 2,47)*	...	*(0,67, 1,11, 2,47)*	*(1,47, 2,71, 4,07)*
C9	*(0,11, 0,12, 0,17)*	*(0,12, 0,14, 0,19)*	...	*(0,12, 0,14, 0,19)*	*(0,15, 0,22, 0,52)*
C10	*(0,15, 0,22, 0,54)*	*(0,3, 0,34, 0,81)*	...	*(0,3, 0,34, 0,81)*	*(0,34, 0,81, 1,53)*
C11	*(0,31, 0,36, 0,95)*	*(0,32, 0,38, 0,97)*	...	*(0,32, 0,38, 0,97)*	*(0,9, 1,76, 2,83)*
C12	*(0,48, 1,31, 2,17)*	*(0,89, 1,34, 2,31)*	...	*(0,89, 1,34, 2,31)*	*(1, 1, 3)*

Table 7 The fuzzy weights of criteria

	The fuzzy geometric means	*The fuzzy weights*
C1	*(2,15, 3,45, 5,41)*	*(0,06, 0,18, 0,46)*
C2	*(1,97, 3,13, 5,02)*	*(0,06, 0,16, 0,42)*
C3	*(1,1, 1,76, 3,39)*	*(0,03, 0,09, 0,28)*
C4	*(1,43, 2,41, 4,09)*	*(0,04, 0,13, 0,34)*
C5	*(0,9, 1,56, 2,85)*	*(0,03, 0,08, 0,24)*
C6	*(0,81, 1,29, 2,42)*	*(0,02, 0,07, 0,2)*
C7	*(0,36, 0,53, 1,14)*	*(0,01, 0,03, 0,1)*
C8	*(1,52, 2,39, 4,22)*	*(0,05, 0,13, 0,35)*
C9	*(0,22, 0,27, 0,58)*	*(0,01, 0,01, 0,05)*
C10	*(0,56, 0,9, 1,9)*	*(0,02, 0,05, 0,16)*
C11	*(0,89, 1,38, 2,69)*	*(0,03, 0,07, 0,23)*
C12	*(1,43, 2,34, 3,72)*	*(0,04, 0,12, 0,31)*

The ratings of stabilizer systems according to criteria are evaluated by five experts, who are working in ship sector as managers and instructors are presented in Table 8. Table 2 is used for conversion of evaluations into fuzzy numbers. Table 9 presents the aggregated judgment of the experts. The normalized decision matrix is obtained and it is shown in Table 10.

Table 8 The comparison of stabilizer systems according to criteria

	C1	***C2***	***C3***	***C4***
A1	*(G, G, VG, G, VG)*	*(MG, G, G, F, MG)*	*(F, MP, MP, F, MP)*	*(F, VG, G, MG, MG)*
A2	*(MG, F, MP, MG, F)*	*(VP, MP, VP, MG, MP)*	*(P, G, G, F, G)*	*(P, MG, MP, G, F)*
A3	*(MP, MP, F, F, F)*	*(VG, MG, MG, MG, MG)*	*(MG, F, F, G, MG)*	*(VG, F, F, F, F)*
A4	*(MP, MP, VP, VP, VP)*	*(VG, F, F, G, MG)*	*(VG, F, F, G, MG)*	*(MG, F, F, F, F)*
	C5	***C6***	***C7***	***C8***
A1	*(VG, VG, VG, VG, G)*	*(F, VP, VP, G, MP)*	*(VG, VG, VG, VG, VG)*	*(VG, G, G, VG, VG)*
A2	*(MG, MP, MP, MG, MG)*	*(MP, MG, G, G, G)*	*(VG, F, F, G, MG)*	*(VG, MP, MP, VG, F)*
A3	*(MP, MP, MP, F, F)*	*(VG, F, F, F, F)*	*(F, F, F, F, F)*	*(MP, F, VP, F, MP)*
A4	*(MP, MP, MP, F, MP)*	*(MG, F, MG, F, MG)*	*(MP, F, F, F, F)*	*(P, MP, VP, F, VP)*
	C9	***C10***	***C11***	***C12***
A1	*(P, MG, MG, VG, MG)*	*(P, F, F, VG, G)*	*(MP, VP, VP, VP, VP)*	*(MP, F, F, VG, F)*
A2	*(P, G, G, G, G)*	*(P, G, G, F, G)*	*(F, F, VP, VP, VP)*	*(F, G, G, VG, VG)*
A3	*(P, MG, G, MG, MG)*	*(P, G, G, MG, MG)*	*(VG, G, G, G, G)*	*(MG, G, G, MG, MG)*
A4	*(P, MG, MG, F, F)*	*(P, F, MG, G, MG)*	*(VG, G, MG, G, MG)*	*(VG, F, F, F, F)*

Table 9. The aggregated fuzzy comparison of stabilizer systems

	C1	***C2***	***C3***	***C4***
A1	*(7,8, 9,4, 10)*	*(5,4, 7,4, 9)*	*(1,8, 3,8, 5,8)*	*(5,8, 7,6, 9)*
A2	*(3,4, 5,4, 7,4)*	*(1,4, 2,6, 4,2)*	*(4,8, 6,6, 8)*	*(3,2, 5, 6,8)*
A3	*(2,2, 4,2, 6,2)*	*(5,8, 7,6, 9,2)*	*(4,6, 6,6, 8,4)*	*(4,2, 6, 7,6)*
A4	*(0,4, 1,2, 2,6)*	*(5,4, 7,2, 8,6)*	*(5,4, 7,2, 8,6)*	*(3,4, 5,4, 7,4)*
	C5	***C6***	***C7***	***C8***
A1	*(8,6, 9,8, 10)*	*(2,2, 3,4, 4,8)*	*(9, 10, 10)*	*(8,2, 9,6, 10)*
A2	*(3,4, 5,4, 7,4)*	*(5,4, 7,4, 8,8)*	*(5,4, 7,2, 8,6)*	*(4,6, 6,2, 7,4)*
A3	*(1,8, 3,8, 5,8)*	*(4,2, 6, 7,6)*	*(3, 5, 7)*	*(1,6, 3,2, 5)*
A4	*(1,4, 3,4, 5,4)*	*(4,2, 6,2, 8,2)*	*(2,6, 4,6, 6,6)*	*(0,8, 1,8, 3,4)*
	C9	***C10***	***C11***	***C12***
A1	*(4,8, 6,4, 8)*	*(4,4, 6, 7,4)*	*(0,2, 0,6, 1,8)*	*(3,8, 5,6, 7,2)*
A2	*(5,6, 7,4, 8,6)*	*(4,8, 6,6, 8)*	*(1,2, 2, 3,4)*	*(7, 8,6, 9,4)*
A3	*(4,4, 6,2, 8)*	*(4,8, 6,6, 8,2)*	*(7,4, 9,2, 10)*	*(5,8, 7,8, 9,4)*
A4	*(3,2, 5, 7)*	*(4, 5,8, 7,6)*	*(6,6, 8,4, 9,6)*	*(4,2, 6, 7,6)*

Table 10 The normalized fuzzy comparison of stabilizer systems

	C1	**C2**	**C3**	**C4**
A1	(0,78, 0,94, 1)	(0,59, 0,8, 0,98)	(0,21, 0,44, 0,67)	(0,64, 0,84, 1)
A2	(0,34, 0,54, 0,74)	(0,15, 0,28, 0,46)	(0,56, 0,77, 0,93)	(0,36, 0,56, 0,76)
A3	(0,22, 0,42, 0,62)	(0,63, 0,83, 1)	(0,53, 0,77, 0,98)	(0,47, 0,67, 0,84)
A4	(0,04, 0,12, 0,26)	(0,59, 0,78, 0,93)	(0,63, 0,84, 1)	(0,38, 0,6, 0,82)
	C5	**C6**	**C7**	**C8**
A1	(0,86, 0,98, 1)	(0,25, 0,39, 0,55)	(0,9, 1, 1)	(0,82, 0,96, 1)
A2	(0,34, 0,54, 0,74)	(0,61, 0,84, 1)	(0,54, 0,72, 0,86)	(0,46, 0,62, 0,74)
A3	(0,18, 0,38, 0,58)	(0,48, 0,68, 0,86)	(0,3, 0,5, 0,7)	(0,16, 0,32, 0,5)
A4	(0,14, 0,34, 0,54)	(0,48, 0,7, 0,93)	(0,26, 0,46, 0,66)	(0,08, 0,18, 0,34)
	C9	**C10**	**C11**	**C12**
A1	(0,56, 0,74, 0,93)	(0,54, 0,73, 0,9)	(0,02, 0,06, 0,18)	(0,4, 0,6, 0,77)
A2	(0,65, 0,86, 1)	(0,59, 0,8, 0,98)	(0,12, 0,2, 0,34)	(0,74, 0,91, 1)
A3	(0,51, 0,72, 0,93)	(0,59, 0,8, 1)	(0,74, 0,92, 1)	(0,62, 0,83, 1)
A4	(0,37, 0,58, 0,81)	(0,49, 0,71, 0,93)	(0,66, 0,84, 0,96)	(0,45, 0,64, 0,81)

The concordance and discordance fuzzy sets are specified. The fuzzy concordance matrix is calculated and it is presented in Table 11. The fuzzy discordance matrix is calculated. Then, the fuzzy discordance matrix is defuzzified using center of area defuzzification method and the results are presented in Table 12.

Table 11 The fuzzy concordance matrix

	A1	**A2**	**A3**	**A4**
A1	-	(0,247, 0,706, 1,912)	(0,195, 0,556, 1,489)	(0,211, 0,767, 1,96)
A2	(0,149, 0,417, 1,235)	-	(0,251, 0,62, 1,397)	(0,236, 0,667, 1,869)
A3	(0,201, 0,567, 1,609)	(0,127, 0,363, 1,437)	-	(0,339, 0,963, 2,658)
A4	(0,125, 0,356, 1,186)	(0,16, 0,456, 1,277)	(0,033, 0,16, 0,488)	-

Table 12 The defuzzified discordance matrix

	A1	**A2**	**A3**	**A4**
A1	-	0,8140	1,0000	0,9402
A2	1,0000	-	1,0000	1,0000
A3	0,7583	0,4200	-	0,2750
A4	0,9829	0,7222	1,0000	-

The effective concordance matrix is specified (Table 13). The effective discordance matrix is obtained (Table 14). Next, we construct the effective and outranking matrix presented in Table 15 by multiplying the effective concordance and discordance level matrices to disregard the effects of the Boolean matrices, separately. The less attractive alternatives are eliminated.

Table 13 The effective concordance level

	A1	*A2*	*A3*	*A4*
A1		*1*	*0*	*1*
A2	*0*		*0*	*1*
A3	*1*	*0*		*1*
A4	*0*	*0*	*0*	

Table 14 The effective discordance level

	A1	*A2*	*A3*	*A4*
A1		*1*	*0*	*0*
A2	*0*		*0*	*0*
A3	*1*	*1*		*1*
A4	*0*	*1*	*0*	

Table 15 The global matrix

	A1	*A2*	*A3*	*A4*
A1	*0*	*1*	*0*	*0*
A2	*0*	*0*	*0*	*0*
A3	*1*	*0*	*0*	*1*
A4	*0*	*0*	*0*	*0*

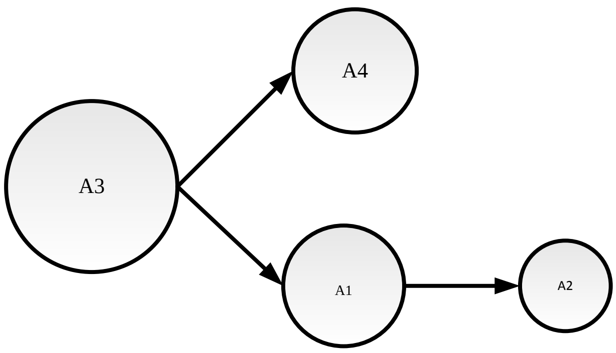

Fig 3. The decision graph for stabilizer system

Finally, we construct the decision graph that is presented in Fig. 3. This decision graph which is derived from a great deal of imprecise data shows the preferable, incomparable or indifferent action. We obtain the priority sequence of stabilizer systems are as A3>A1 and A4. A1>A2 and there is no compare between A2 and A4 also A1 and A4 according to matrix *H*. Thus, it is clear that the most suitable stabilizer system A3 (Activated Fins). In this study, the most suitable stabilizer system is determined by considering twelve different criteria.

4 Conclusion

Stabilizer systems are used in a wide variety of applications for many years. Recently, the field of stabilizing systems in shipping industry has received the attention of many researchers. It is essentially important the determining of effective stabilizer for ships that serving a specific area. As mentioned above, each area has its own specific requirements. This paper presents the selection procedures of the most effective roll stabilization system for trawler type fishing vessel. Tanks, bilge keels, activated fins and rudder roll stabilization system are examined taking into account their advantages and disadvantages for trawler.

In this study, all criteria determined for roll motion stabilizing systems of trawler are evaluated by experts' and literature review.

The fuzzy AHP and ELECTRE method is proposed to select the better effective roll motion stabilizing system for trawler ship industry. Since the proposed methodology has the ability of taking care of all kinds of evaluations from experts, it has been successfully applied to a stabilizer selection for trawler ship industry. In application case, four stabilizer system alternatives are compared for determining the most effective roll motion system of trawler ship industry. The ranking of these alternatives has been obtained as A3>A1 and A4. A1>A2 and there is no compare between A2 and A4 also A1 and A4.

Also, the alternative A3(Activated Fins) is always determined as the best alternative as a result of sensitivity analysis. In addition, the fuzzy AHP analysis determined the best criteria as "C1" for the selection process and led to the following ranking of the evaluation criteria: {C1 (15 %), C2 (13.8 %), C8 (11.2 %), C4 (11 %), C12 (10.2 %), C3 (8.8 %), C5 (7.5 %), C11(7 %), C6(6.3 %), C10 (4.8 %), C7 (2.9 %), C9 (1.5 %)}. For further research, some other decision making approach such as TOPSIS, VIKOR, Choquet Integral, under fuzzy environment can be on the similar problem and the obtained results can be compared.

REFERENCES

[1] Van Amerongen, J., Van der Klugt, P. G. M., & van Nauta Lemke, H. R. (1990). Rudder roll stabilization for ships. Automatica, 26(4), 679-690. https://doi.org/10.1016/0005-1098(90)90045-J.

[2] Fortuna, L., & Muscato, G. (1996). A roll stabilization system for a monohull ship: modeling, identification, and adaptive control. IEEE Transactions on control systems technology, 4(1), 18-28. https://doi.org/10.1109/87.481763.

[3] Gawad, A. F. A., Ragab, S. A., Nayfeh, A. H., & Mook, D. T. (2001). Roll stabilization by anti-roll passive tanks. Ocean Engineering, 28(5), 457-469. https://doi.org/10.1016/S0029-8018(00)00015-9.

[4] Do, K. D., Jiang, Z. P., & Pan, J. (2002). Universal controllers for stabilization and tracking of underactuated ships. Systems & Control Letters, 47(4), 299-317. https://doi.org/10.1016/S0167-6911(02)00214-1.

[5] Jones, E., Roskilly, A. P., Webster, B., & Birmingham, R. W. (2006). Adaptive roll stabilization of fishing vessels. Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment,220(1), 13-27. https://doi.org/10.1243/14750902JEME38.

[6] Moaleji, R., & Greig, A. R. (2007). On the development of ship anti-roll tanks.Ocean Engineering, 34(1), 103-121. https://doi.org/10.1016/j.oceaneng.2005.12.013.

[7] Alarcin, F., & Gulez, K. (2007). Rudder roll stabilization for fishing vessel using neural network approach. Ocean engineering, 34(13), 1811-1817. https://doi.org/10.1016/j.oceaneng.2007.03.001.

[8] Marzouk, O. A., & Nayfeh, A. H. (2009). Control of ship roll using passive and active anti-roll tanks. Ocean engineering, 36(9), 661-671. https://doi.org/10.1016/j.oceaneng.2009.03.005.

[9] Su, K. H. (2013, December). Anti-rolling fin control for ship stabilization. InAutomatic Control Conference (CACS), 2013 CACS International (pp. 389-394). IEEE.

[10] Alarçin, F., Demirel, H., Su, M. E., & Yurtseven, A. (2014). Modified pid control design for roll fin actuator of nonlinear modelling of the fishing boat. Polish Maritime Research, 21(1), 3-8.

[11] Kula, K. S. (2015). An Overview of Roll Stabilizers and Systems for Their Control. TransNav: International Journal on Marine Navigation and Safety of Sea Transportation, 9.

[12] Ayob, A. A. M., & Yaakob, O. (2015). Roll Mitigation of Small Fishing Boat.Journal of Transport System Engineering, 2(2), 46-50.

[13] Zadeh, L.A., (1965). Fuzzy sets. Information and Control 8, 338 - 353. https://doi.org/10.1016/S0019-9958(65)90241-X.

[14] Barlas, B. (2012). Occupational fatalities in shipyards: an analysis in Turkey. Brodogradnja: Teorija i praksa brodogradnje i pomorske tehnike, 63(1), 35-41.

[15] Akyuz, E., & Celik, M. (2017). Using of A'WOT to design an enhanced planned maintenance system (E-PMS) on-board ship. Brodogradnja: Teorija i praksa brodogradnje i pomorske tehnike, 68(1), 61-75.

[16] Barlas, B., Ozsoysal, R., Bayraktarkatal, E., & Ozsoysal, O. A. (2017). A study on the identification of fire hazards on board: A case study. Brodogradnja: Teorija i praksa brodogradnje i pomorske tehnike, 68(4), 71-87.

[17] Celik, E., Gul, M., Aydin, N., Gumus, A. T., & Guneri, A. F. (2015). A comprehensive review of multi criteria decision making approaches based on interval type-2 fuzzy sets. Knowledge-Based Systems, 85, 329-341. https://doi.org/10.1016/j.knosys.2015.06.004.

[18] Gul, M., Celik, E., Aydin, N., Gumus, A. T., & Guneri, A. F. (2016). A state of the art literature review of VIKOR and its fuzzy extensions on applications. Applied Soft Computing, 46, 60-89. https://doi.org/10.1016/j.asoc.2016.04.040.

[19] Zimmermann, H.J. Fuzzy Set Theory and Its Applications. London: Kluwer Academic Publishers, 1994.

[20] Ozkok, M. (2015). Risk evaluation of pin jig work unit in shipbuilding by using fuzzy AHP method. Brodogradnja: Teorija i praksa brodogradnje i pomorske tehnike, 66(1), 39-53.

[21] Van Laarhoven, P.J.M.; Pedrycz, W. A fuzzy extension of Saaty's priority theory. Fuzzy Sets and Systems 1983, 11, pp. 229–241. https://doi.org/10.1016/S0165-0114(83)80082-7.

[22] Wang, Y.M.; Elhag, T.M.S.; Hua, Z. A modified fuzzy logarithmic least squares method for fuzzy analytic hierarchy process. Fuzzy Sets and Systems 2006, 157, pp. 3055–3071. https://doi.org/10.1016/j.fss.2006.08.010.

[23] Buckley, J.J. Fuzzy hierarchical analysis. Fuzzy Sets and Systems 1985, 17 (3), 233–247. https://doi.org/10.1016/0165-0114(85)90090-9.

[24] Chang, D.Y. Applications of the extent analysis method on fuzzy AHP. European Journal of Operational Research 1996, 95 (3), pp. 649–655. https://doi.org/10.1016/0377-2217(95)00300-2.

[25] Xu, R. Fuzzy least-squares priority method in the analytic hierarchy process. Fuzzy Sets and Systems 2000, 112, pp. 359–404. https://doi.org/10.1016/S0165-0114(97)00376-X.

[26] Mikhailov, L. A fuzzy approach to deriving priorities from interval pair wise comparison judgments. European Journal of Operational Research 2004, 159 , 687–704. https://doi.org/10.1016/S0377-2217(03)00432-6.

[27] Csutora, R.; Buckley, J.J. Fuzzy hierarchical analysis: The Lamda-Max method. Fuzzy Sets and Systems 2001, 120, pp. 181–195. https://doi.org/10.1016/S0165-0114(99)00155-4.

[28] Aikhuele, D. O., & Turan, F. B. (2016). Intuitionistic fuzzy-based model for failure detection. SpringerPlus, 5(1), 1938. https://doi.org/10.1186/s40064-016-3446-0.

[29] Balin, A., Demirel, H., & Alarcin, F. (2015). A hierarchical structure for ship diesel engine trouble-shooting problem using fuzzy AHP and fuzzy VIKOR hybrid methods. Brodogradnja: Teorija i praksa brodogradnje i pomorske tehnike, 66(1), 54-65.

[30] Benayoun, R.,Roy, B. andSussman, N., “Manual de reference du programmeelectre,” Note De Synthese et Formaton, No. 25, Direction Scientifique SEMA, Paris, France, 1966.

[31] Govindan, K., & Jepsen, M. B. (2016). ELECTRE: A comprehensive literature review on methodologies and applications. European Journal of Operational Research, 250(1), 1-29. https://doi.org/10.1016/j.ejor.2015.07.019.

[32] Ashtiani,B.,Haghighirad,F.,MakuA., and Montazer,G.A., “Extension of fuzzy TOPSIS method based on interval-valued fuzzy sets.” Applied Soft Computing, Vol. 9, 2009,pp. 457-461. https://doi.org/10.1016/j.asoc.2008.05.005.

[33] Vahdani,B.,Hadipour,H.,Sadaghiani,J.S., and Amiri,M., “Extension of VIKOR method based on Interval-valued fuzzy sets,” International Journal of Advanced Manufacturing Technology, Vol. 47, 2010, pp. 1231-1239. https://doi.org/10.1007/s00170-009-2241-2.

[34] Kuo,M.S., “A novel interval-valued fuzzy MCDM method for improving airlines’ service quality in Chinese cross-strait airlines,” Transportation Research Part E: Logistics and Transportation Review, Vol. 47, 2011,pp. 1177-1193. https://doi.org/10.1016/j.tre.2011.05.007.

[35] Wang TC, Liang LJ, Ho CY (2006). Multi-criteria decision analysis by using fuzzy VIKOR. Proceedings of International Conference on Service Systems and Service Management, 901-906. https://doi.org/10.1109/ICSSSM.2006.320751.

[36] Kaya, T., & Kahraman, C. (2011). Fuzzy multiple criteria forestry decision making based on an integrated VIKOR and AHP approach. Expert Systems with Applications, 38(6), 7326-7333. https://doi.org/10.1016/j.eswa.2010.12.003

[37] Sellars, F. H., & Martin, J. P. (1991). Selection and evaluation of ship roll stabilization systems.

Submitted: 29.09.2017.
Accepted: 18.04.2018.

PhD. Hakan Demirel
hakandemirel@beun.edu.tr
Maritime Faculty, Bulent Ecevit University, Zonguldak/ Turkey
Assist.Prof.Dr. Abit Balin
abitbalin@istanbul.edu.tr
Transportation and Logistics Faculty, Istanbul University, İstanbul /Turkey
Assist.Prof.Dr. Erkan Celik
erkancelik@munzur.edu.tr
Engineering Faculty, Munzur University, Tunceli/Turkey
Prof. Dr. Fuat Alarçin
falarcin@gmail.com
Naval Architecture and Maritime Faculty, Yıldız Technical University, Istanbul /Turkey