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A NOVEL FUZZY MULTI-CRITERIA DECISION-MAKING METHODOLOGY BASED UPON THE SPHERICAL FUZZY SETS FOR STABILIZER SELECTION OF CRUISE SHIPS

Summary

In recent years, studies for the development of cruise shipbuilding and design industry is known to be performed by many countries. It is obvious that cruise ships should be equipped with features that facilitate the mobility of the crew in different sea states by providing passenger comfort in long cruise conditions. At this point, cruise ships which require great cost and experience should be evaluated from different perspectives. In this study, the selection of stabilizer system which directly affects many criteria such as comfort, safety and speed in cruise ships is discussed. Stabilizer system alternatives and the criteria determined for these alternatives have been established by literature review. Extension of TOPSIS method with interval-valued spherical fuzzy sets proposed to determine the most effective stabilizing system alternative for cruise ships. The results obtained indicate the Activated fins as the most effective alternative.

Key words: Cruise ships; Spherical Fuzzy Sets; Decision Making; TOPSIS

1. Introduction

The comfort of crew and passengers is of paramount importance to cruise ships. In addition to this, it is known that people's mobility is directly affected by ship motions. At this point, it is stated that various types of devices are used to stabilize the roll motion which is critical in ship motions [1]. Roll stabilization systems are evaluated in two different groups as active and passive. Active systems require a control system and are referred to as activated fins, active anti-roll tanks and gyroscope stabilizers. The passive systems are fixed mechanisms like bilge keel, passive anti-rolling tanks, fixed fins, and passive moving weight systems [2-3]. The first anti-rolling devices are bilge keels. After these systems, anti-rolling tank systems have been designed and used for roll damping of many types of ships [4-5]. Specifically, different types of active stabilizing systems are used in passenger ships, yachts and special purpose ships and in many studies, it is emphasized that these systems have a positive effect on the comfort and performance of the ships. Perez and Steinmann (2009). analysed the performance of gyrostabilisers to decrease the roll motion of ships [6]. Lee et al.

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(2011) evaluated the performance of fin stabilizers for roll stabilization of cruise ships in regular waves [7]. Kim and Kim (2011) examined the roll and/or pitch motions of a cruise ship in a moderate sea state and suggested an effective control algorithm to reduce these motions for a cruise ship with stabilizing fins [8]. Lee et al. (2012). suggested the fins and pod propellers for the roll stabilization of cruise ships and analysed the effects of these devices [9]. Kim and Kim (2014). examined the factors affecting passenger comfort for cruise ships and suggested the stabilizing fins to improve passenger comfort [10]. Ye et al. (2019). emphasized the rapid development of cruise industry and they interpreted the characteristics of cruise ships related to speed, safety and comfort [11]

As stated above, the choice of stabilizer system is an issue where many criteria and alternatives should be considered. The determination of the most appropriate stabilizer system for ships, each with different advantages and disadvantages, is essentially a multi-criteria decision-making problem. At this point, it is thought that the selection made by taking the opinions of experts in the field will respond more effectively to the expectations. However, there are no comprehensive studies based on multi-criteria decision-making methods in the maritime industry. Kafalı and Özkök [12] used a fuzzy AHP technique for the shipyard selection process and determined the most significant criteria/sub-criteria for this problem. Sellers and Martin [13] presented the comprehensive procedure for different roll stabilizing systems and evaluated the advantages and disadvantages of these systems. Demirel et al. [14] examined the different type of roll stabilizers for fishing vessels and suggested a fuzzy AHP and ELECTRE method for determination the most suitable one. In this study, the choice of stabilizer system for cruise ships is determined as a multi - criteria decision making problem. The relationship between the alternatives and the criteria was evaluated by experts. In addition to this perspective, the issue is evaluated by experts in different positions in the maritime sector and is important to decide with the data obtained interval-valued spherical fuzzy sets.

The continuation of this study is organized as follows: In Section 2, the methodology of spherical fuzzy sets is revealed. Section 3 describes the structure of TOPSIS method with interval-valued spherical fuzzy sets. Section 4 explains the assessments of the real case application for cruise ships using spherical fuzzy sets. Finally, evaluations of the results are expressed in Section 5.

2. Spherical Fuzzy sets

Intuitive and Pythagorean fuzzy functions comprise the parameters of membership, non-membership and hesitation. These parameters can be determined by $x_i = 1 - \mu_i - v_i$ and $\pi_{\tilde{p}} = \sqrt{1 - \mu_{\tilde{p}}^2 - v_{\tilde{p}}^2}$ formulas respectively. Truthiness, falsity and indeterminacy are expressed as three parameters of Neutrosophic membership functions. These parameters must be between 0 and 3 as the total value, as well as the value of each parameter should be independently between 0 and 1. In spherical fuzzy sets, the squared sum of membership, non-membership and hesitation parameters must be between 0 and also 1, while each independently defined between 0 and 1. As a result of these two conditions, the shape of the new fuzzy sets is formed. Using a spherical fuzzy set provides a wider decision-making environment as well as independent decision-making by decision-makers (Gong et al., 2016; Ullah et al., 2018; Gundogdu and Kahraman, 2019 a,b,c; Kahraman et al. 2019;). The positive aspects of other fuzzy set extensions show the advantage of spherical fuzzy sets as a unique theory.

The main purpose of the global fuzzy sets (SFS) is to allow decision makers to generalize the extensions of other fuzzy sets by defining a membership function on a spherical

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surface and assigning the parameters of this membership function independently to a larger domain. SFS is a synthesis of Pythagoras fuzzy sets (PFS) and Neutrosophic sets (NS) (Gündoğdu and Kahraman, 2019 a, b, c).

3. Extension of TOPSIS method with interval-valued spherical fuzzy sets

The TOPSIS method is firstly suggested by Hwang and Yoon (1981). The basic structure of this method is that the selected alternative should have the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution (Hwang and Yoon, 1981). A method has been proposed in which alternative TOPSIS, the weights of alternatives, criteria and ratings of alternatives are evaluated with linguistic variables represented by fuzzy numbers to deal with the deficiency in traditional TOPSIS (Ertuğrul and Karakaşoğlu, 2008). In this paper, an extension of the TOPSIS method is presented (Gündoğdu, and Kahraman, 2019 a).

This section refers to the use of distance measurement, arithmetic operations, aggregation and defuzzification operations (Peng, and Yang 2016a,b; Gong et al. 2016; Gundogdu and Kahraman, 2019a; Ashraf et al., 2018; Ashraf et al., 2019a,b,c,d). The related algorithm can be revealed as follows:

MCDM problems expressed as a decision matrix that specifies the values of all alternatives for each criterion under interval-valued spherical fuzzy environment. Allow $X = \{x_1, x_2, \ldots, x_m\} (m \geq 2)$ to be a discrete m applicable alternative set and $C = \{C_1, C_2, \ldots, C_n\}$ was a finite set of criteria, and $w = \{w_1, w_2, \ldots, w_n\}$ will be the weight vector of all criteria satisfying $0 \leq w_j \leq 1$ and $\sum_{j=1}^{n} w_j = 1$ (Gündoğdu, and Kahraman, 2019a).

Table 1 Linguistic terms and their corresponding interval-valued spherical fuzzy numbers (Gündoğdu, and Kahraman, 2019a)

Linguistic terms	$\left(\left[\mu_{ij}^L(u), \mu_{ij}^U(u) \right], \left[v_{ij}^L(u), v_{ij}^U(u) \right], \left[\pi_{ij}^L(u), \pi_{ij}^U(u) \right] \right)$
Absolutely more Importance (AMI)	([0.85,0.95],[0.1,0.15],[0.05,0.15])
Very High Importance (VHI)	([0.75,0.85],[0.15,0.2],[0.15,0.2])
High Importance (HI)	([0.65,0.75],[0.2,0.25],[0.2,0.25])
Slightly More Importance (SMI)	([0.55,0.65],[0.25,0.3],[0.25,0.3])
Equally Importance (EI)	([0.5,0.55],[0.45,0.55],[0.3,0.4])
Slightly Low Importance (SLI)	([0.25,0.35],[0.55,0.65],[0.25,0.3])
Low Importance (LI)	([0.2,0.25],[0.65,0.75],[0.2,0.25])
Very Low Importance (VLI)	([0.15,0.2],[0.75,0.85],[0.15,0.2])
Absolutely Low Importance (ALI)	([0.1,0.15],[0.85,0.95],[0.05,0.15])

Step 1: The scale shown in Table 1 used for data input. DMs can prefer intermediate values instead of given language terms. Therefore, DM assessments for weight criteria are summed, linguistic terms of DMs are used and decision matrices are filled.

Creating a decision matrix: let $C_j(X_i) = \left(\left[\mu_{ij}^L(u), \mu_{ij}^U(u) \right], \left[v_{ij}^L(u), v_{ij}^U(u) \right], \left[\pi_{ij}^L(u), \pi_{ij}^U(u) \right] \right)$ show the evaluation of each alternative $X_i (i = 1, 2, \ldots, m)$ with respect to each criterion

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$C_j (j = 1, 2, ..., n)$. Let $D = \left(C_j(X_i)\right)_{mxn}$ be a spherical fuzzy decision matrix. Then the decision matrix $D = \left(C_j(X_i)\right)_{mxn}$ created as in the following equation.

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$$D = \left(C_j(X_i)\right)_{mxn} = \begin{bmatrix} \left(\left[\mu_{11}^L(u),\mu_{11}^U(u)\right],\left[v_{11}^L(u),v_{11}^U(u)\right],\left[\pi_{11}^L(u),\pi_{11}^U(u)\right]\right) & .... & \left(\left[\mu_{1n}^L(u),\mu_{1n}^U(u)\right],\left[v_{1n}^L(u),v_{1n}^U(u)\right],\left[\pi_{1n}^L(u),\pi_{1n}^U(u)\right]\right) \\ \left(\left[\mu_{22}^L(u),\mu_{22}^U(u)\right],\left[v_{22}^L(u),v_{22}^U(u)\right],\left[\pi_{22}^L(u),\pi_{22}^U(u)\right]\right) & .... & \left(\left[\mu_{2n}^L(u),\mu_{2n}^U(u)\right],\left[v_{2n}^L(u),v_{2n}^U(u)\right],\left[\pi_{2n}^L(u),\pi_{2n}^U(u)\right]\right) \\ ..... & ..... & ..... \\ \left(\left[\mu_{m1}^L(u),\mu_{m1}^U(u)\right],\left[v_{m1}^L(u),v_{m1}^U(u)\right],\left[\pi_{m1}^L(u),\pi_{m1}^U(u)\right]\right) & ..... & \left(\left[\mu_{mn}^L(u),\mu_{mn}^U(u)\right],\left[v_{mn}^L(u),v_{mn}^U(u)\right],\left[\pi_{mn}^L(u),\pi_{mn}^U(u)\right]\right) \end{bmatrix} \quad (1)$$

Step 2: The Interval Valued Spherical Weighted Arithmetic Mean (IVSWAM) operator adopted to create the decision matrix.

$$SWAM_w\left(\tilde{A}_{S1}, ..., \tilde{A}_{Sn}\right) = w_1\tilde{A}_{S1} + w_2\tilde{A}_{S2} + ... + w_n\tilde{A}_{Sn}$$

$$= \left\{\left[1 - \prod_{i=1}^{n}\left(1 - \mu_{\tilde{A}_{Si}}^2\right)^{w_i}\right]^{1/2}, \prod_{i=1}^{n}v_{\tilde{A}_{Si}}^{w_i}, \left[\prod_{i=1}^{n}\left(1 - \mu_{\tilde{A}_{Si}}^2\right)^{w_i} - \prod_{i=1}^{n}\left(1 - \mu_{\tilde{A}_{Si}}^2 - \pi_{\tilde{A}_{Si}}^2\right)^{w_i}\right]^{1/2}\right\} \quad (2)$$

Step 3: Generate the weighted interval-valued spherical fuzzy decision matrix.

After determining the weights of the criteria and the scores of the alternatives, the weighted interval-valued spherical fuzzy decision matrix formed using the $D = \left(C_j(X_{iw})\right)_{mxn}$ equation;

$$D = \left(C_j(X_{iw})\right)_{mxn} = \begin{bmatrix} \left(\left[\mu_{11w}^L(u),\mu_{11w}^U(u)\right],\left[v_{11w}^L(u),v_{11w}^U(u)\right],\left[\pi_{11w}^L(u),\pi_{11w}^U(u)\right]\right) & .... & \left(\left[\mu_{1nw}^L(u),\mu_{1nw}^U(u)\right],\left[v_{1nw}^L(u),v_{1nw}^U(u)\right],\left[\pi_{1nw}^L(u),\pi_{1nw}^U(u)\right]\right) \\ \left(\left[\mu_{22w}^L(u),\mu_{22w}^U(u)\right],\left[v_{22w}^L(u),v_{22w}^U(u)\right],\left[\pi_{22w}^L(u),\pi_{22w}^U(u)\right]\right) & .... & \left(\left[\mu_{2nw}^L(u),\mu_{2nw}^U(u)\right],\left[v_{2nw}^L(u),v_{2nw}^U(u)\right],\left[\pi_{2nw}^L(u),\pi_{2nw}^U(u)\right]\right) \\ ..... & ..... & ..... \\ \left(\left[\mu_{m1w}^L(u),\mu_{m1w}^U(u)\right],\left[v_{m1w}^L(u),v_{m1w}^U(u)\right],\left[\pi_{m1w}^L(u),\pi_{m1w}^U(u)\right]\right) & ..... & \left(\left[\mu_{mnw}^L(u),\mu_{mnw}^U(u)\right],\left[v_{mnw}^L(u),v_{mnw}^U(u)\right],\left[\pi_{mnw}^L(u),\pi_{mnw}^U(u)\right]\right) \end{bmatrix} \quad (3)$$

Step 4: Defuzzify the weighted interval-valued spherical fuzzy decision matrix generated using the $S\left(C_j(X_{iw})\right)$ equation;

$$S\left(C_j(X_{iw})\right) = \frac{\left(\mu_{ijw}^L(u)\right)^2 + \left(\mu_{ijw}^U(u)\right)^2 - \left(v_{ijw}^L(u)\right)^2 - \left(v_{ijw}^U(u)\right)^2 - \left(\frac{\pi_{ijw}^L(u)}{2}\right)^2 - \left(\frac{\pi_{ijw}^U(u)}{2}\right)^2}{2} \quad (4)$$

Step 5: The Interval-valued Spherical Fuzzy Positive Ideal Solution (IVSF-PIS) and the Interval-valued Spherical Fuzzy Negative Ideal Solution (IVSF-NIS) identified based on the values obtained in step 4.

The IVSF-PIS given by X^*:

$$X^* = \left\{C_j, \max_i < S(C_j(X_{iw})) > j = 1, 2......n\right\} \quad (5)$$

or

$$X^* = \left\{\left\langle C_1, \left(\left[\mu_1^{L*},\mu_1^{U*}\right],\left[v_1^{L*},v_1^{U*}\right],\left[\pi_1^{L*},\pi_1^{U*}\right]\right)\right\rangle, \left\langle C_2, \left(\left[\mu_2^{L*},\mu_2^{U*}\right],\left[v_2^{L*},v_2^{U*}\right],\left[\pi_2^{L*},\pi_2^{U*}\right]\right)\right\rangle .... \left\langle C_n, \left(\left[\mu_n^{L*},\mu_n^{U*}\right],\left[v_n^{L*},v_n^{U*}\right],\left[\pi_n^{L*},\pi_n^{U*}\right]\right)\right\rangle\right\} \quad (6)$$

The IVSF-NIS given by X^-:

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$$X^- = \left\{ C_j, \min_i < S(C_j(X_{iw})) > j = 1, 2......n \right\} \tag{7}$$

or

$$X^- = \left\{ \left\langle C_1, \left(\left[\mu_1^{L-}, \mu_1^{U-} \right], \left[v_1^{L-}, v_1^{U-} \right], \left[\pi_1^{L-}, \pi_1^{U-} \right] \right) \right\rangle, \left\langle C_2, \left(\left[\mu_2^{L-}, \mu_2^{U-} \right], \left[v_2^{L-}, v_2^{U-} \right], \left[\pi_2^{L-}, \pi_2^{U-} \right] \right) \right\rangle .... \left\langle C_n, \left(\left[\mu_n^{L-}, \mu_n^{U-} \right], \left[v_n^{L-}, v_n^{U-} \right], \left[\pi_n^{L-}, \pi_n^{U-} \right] \right) \right\rangle \right\} \tag{8}$$

Step 6: To determine the distance between alternative Xi, IVSF-PIS and IVSF-NIS used, respectively. The normalized distance formula of Peng and Yang (2016a, 2016b) used in this step.

Distance to IVSF-PIS:

$$d(X_{ij}, X_j^+) = \frac{1}{4n} \sum_{j=1}^n \left(\left| \left(u_{ij}^L \right)^2 - \left(u_j^+ \right)^2 \right| + \left| \left(u_{ij}^U \right)^2 - \left(u_j^+ \right)^2 \right| + \left| \left(v_{ij}^L \right)^2 - \left(v_j^+ \right)^2 \right| + \left| \left(v_{ij}^U \right)^2 - \left(v_j^+ \right)^2 \right| + \left| \left(\pi_{ij}^L \right)^2 - \left(\pi_j^+ \right)^2 \right| + \left| \left(\pi_{ij}^U \right)^2 - \left(\pi_j^+ \right)^2 \right| \right) \forall_i \tag{9}$$

Distance to IVSF-NIS:

$$d(X_{ij}, X_j^-) = \frac{1}{4n} \sum_{j=1}^n \left(\left| \left(u_{ij}^L \right)^2 - \left(u_j^- \right)^2 \right| + \left| \left(u_{ij}^U \right)^2 - \left(u_j^- \right)^2 \right| + \left| \left(v_{ij}^L \right)^2 - \left(v_j^- \right)^2 \right| + \left| \left(v_{ij}^U \right)^2 - \left(v_j^- \right)^2 \right| + \left| \left(\pi_{ij}^L \right)^2 - \left(\pi_j^- \right)^2 \right| + \left| \left(\pi_{ij}^U \right)^2 - \left(\pi_j^- \right)^2 \right| \right) \forall_i \tag{10}$$

Step 7: Calculating the closeness ratio:

$$ClosenessRatio_i = \frac{d\left(X_{ij}, X_j^- \right)}{d\left(X_{ij}, X_j^- \right) + d\left(X_{ij}, X_j^+ \right)} \tag{11}$$

Step 8: Determine the optimal order of alternatives and determine the most appropriate alternative.

4. A real case application using extension of TOPSIS method with interval-valued spherical fuzzy sets

In the present study, the selection of roll stabilization system is evaluated around different alternatives and criteria. There are technical studies in the literature on the applicability and efficiency of alternative stabilizing systems for cruise ships. Therefore, in addition to technical evaluations, a different perspective is created for the problem with many criteria determined. The criteria were evaluated through a two-stage questionnaire containing comparative questions by a group of three decision-makers (DM1, DM2, DM3) including captain, academician and designer. The weights of these decision-makers having different experience levels were determined as 0.3, 0.2 and 0.5, respectively. The identified criteria are clearly stated in Table 2 together with their explanations. Based on these criteria, four types of roll motion stabilization system (A1 Active Anti-roll tanks, A2 Activated Fins, A3 Gyroscopic Roll Stabilizer and A4 Bilge Keels) were evaluated. Figure 1 shows the relationship between criteria and alternatives according to the TOPSIS method.

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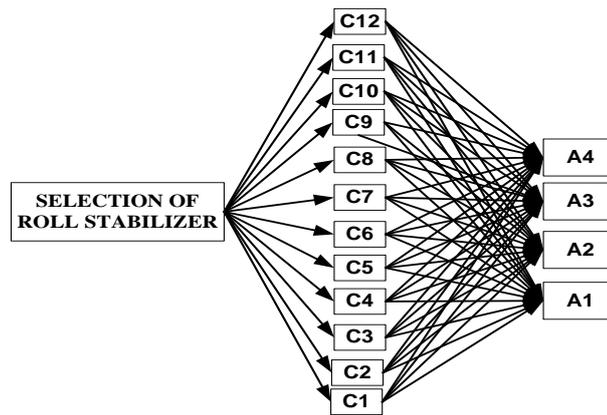
Fig 1. Hierarchical structure for selection of roll stabilizer systems

Table 2 Definitions of defined criteria for roll stabilizer selection problem (Sellars and Martin, 1992; Balin, 2020)

No	Criteria	Definition
C1	Initial cost	Required investment cost for stabilizer system
C2	Maintenance cost	The total value of the costs such as required auxiliary equipment and workmanship in maintenance work
C3	Maintenance Requirements	Standards, certification works and approval processes to be used in maintenance and repair works
C4	Effect on Hull Resistance and Speed	The status on the performance of the ship
C5	Effect of Crew Performance and Passenger Comfort	The comfort of the crew in operational activities and the mobility of passengers
C6	Ease of Repair	Complexity of the structure of the stabilizer system
C7	Underwater Noise	Effect of noise and vibration level generated by stabilizer system
C8	Roll Reduction	Percentage of minimizing amplitude of roll motion
C9	Working on Wide Speed Range	Ability to operate at different speeds of stabilizer system
C10	Installation Requirements	Ease of placement and positioning of the stabilizer system
C11	Reaction Time	Speed of effect and response of stabilizer system
C12	Risk of Damage	Damage to activities such as berthing due to the position of the stabilizer system

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All evaluations given in Table 3 in the form of a decision matrix, which collected and combined using the IVSWAM operator shown in the equation 2, taking into consideration the weight of the decision-makers.

Table 3 Aggregated decision matrix.

	A1	A2	A3	A4
C1	([0.12,0.17],[0.82,0.92],[0.09,0.171])	([0.32,0.41],[0.53,0.63],[0.26,0.335])	([0.84,0.94],[0.11,0.16],[0.07,0.156])	([0.74,0.84],[0.16,0.21],[0.156,0.206])
C2	([0.7,0.8],[0.18,0.23],[0.18,0.227])	([0.84,0.94],[0.11,0.16],[0.07,0.156])	([0.67,0.76],[0.23,0.28],[0.2,0.262])	([0.15,0.2],[0.74,0.84],[0.155,0.205])
C3	([0.31,0.36],[0.58,0.69],[0.24,0.315])	([0.15,0.2],[0.76,0.88],[0.14,0.203])	([0.65,0.75],[0.2,0.25],[0.2,0.251])	([0.58,0.65],[0.33,0.41],[0.255,0.339])
C4	([0.16,0.23],[0.75,0.87],[0.15,0.215])	([0.32,0.38],[0.56,0.66],[0.25,0.327])	([0.77,0.86],[0.19,0.25],[0.15,0.224])	([0.7,0.8],[0.18,0.23],[0.177,0.227])
C5	([0.13,0.18],[0.79,0.91],[0.11,0.187])	([0.36,0.46],[0.45,0.54],[0.25,0.299])	([0.79,0.89],[0.13,0.18],[0.12,0.182])	([0.72,0.82],[0.17,0.22],[0.166,0.218])
C6	([0.24,0.34],[0.56,0.66],[0.24,0.295])	([0.48,0.56],[0.4,0.49],[0.28,0.362])	([0.85,0.95],[0.1,0.15],[0.05,0.15])	([0.65,0.75],[0.2,0.25],[0.202,0.251])
C7	([0.12,0.17],[0.82,0.92],[0.09,0.171])	([0.12,0.17],[0.82,0.92],[0.09,0.171])	([0.72,0.82],[0.17,0.22],[0.16,0.217])	([0.65,0.72],[0.33,0.42],[0.23,0.331])
C8	([0.14,0.19],[0.76,0.87],[0.14,0.196])	([0.22,0.29],[0.61,0.71],[0.22,0.269])	([0.81,0.91],[0.12,0.17],[0.1,0.172])	([0.65,0.75],[0.2,0.25],[0.202,0.251])
C9	([0.35,0.43],[0.51,0.6],[0.21,0.263])	([0.57,0.64],[0.35,0.44],[0.26,0.351])	([0.12,0.17],[0.81,0.91],[0.1,0.176])	([0.62,0.71],[0.25,0.31],[0.226,0.287])
C10	([0.74,0.84],[0.16,0.21],[0.16,0.206])	([0.65,0.74],[0.24,0.3],[0.21,0.276])	([0.84,0.94],[0.11,0.16],[0.07,0.156])	([0.69,0.79],[0.18,0.23],[0.184,0.233])
C11	([0.71,0.81],[0.17,0.22],[0.17,0.222])	([0.17,0.25],[0.72,0.85],[0.17,0.23])	([0.81,0.91],[0.12,0.17],[0.1,0.172])	([0.65,0.76],[0.2,0.25],[0.199,0.255])
C12	([0.53,0.61],[0.35,0.43],[0.27,0.354])	([0.4,0.48],[0.47,0.56],[0.21,0.264])	([0.79,0.89],[0.13,0.18],[0.12,0.182])	([0.79,0.89],[0.13,0.18],[0.12,0.184])

The weight of each criteria obtained using the IVSWAM operator shown in the equation 2, expressing the importance of the criteria determined by the DMs, is given in Table 4.

Table 4 Aggregated criteria weight.

Criteria	Weight
C1	([0.2,0.26],[0.64,0.74],[0.2,0.25])
C2	([0.1,0.15],[0.84,0.94],[0.06,0.16])
C3	([0.8,0.9],[0.13,0.18],[0.11,0.18])
C4	([0.53,0.61],[0.35,0.43],[0.27,0.35])
C5	([0.2,0.26],[0.64,0.74],[0.2,0.25])
C6	([0.85,0.95],[0.1,0.15],[0.05,0.15])
C7	([0.21,0.27],[0.73,0.86],[0.17,0.24])
C8	([0.12,0.17],[0.81,0.91],[0.1,0.18])
C9	([0.36,0.43],[0.51,0.6],[0.2,0.26])
C10	([0.4,0.5],[0.42,0.51],[0.26,0.32])
C11	([0.76,0.86],[0.15,0.2],[0.14,0.2])
C12	([0.84,0.94],[0.11,0.16],[0.07,0.16])

After determining the weights of the criteria and the rating of the alternatives, the spherical fuzzy decision matrix with the weighted range-value given in Table 5 was formed using equation 3.

Table 5 Weighted decision matrix.

	A1	A2	A3	A4
C1	([0.02,0.04],[0.9,0.97],[0.14,0.14])	([0.07,0.1],[0.76,0.85],[0.26,0.29])	([0.17,0.24],[0.65,0.75],[0.21,0.27])	([0.15,0.22],[0.65,0.75],[0.23,0.28])
C2	([0.07,0.12],[0.85,0.95],[0.11,0.16])	([0.09,0.15],[0.84,0.95],[0.07,0.16])	([0.07,0.12],[0.85,0.95],[0.12,0.17])	([0.02,0.03],[0.93,0.98],[0.09,0.1])
C3	([0.25,0.33],[0.59,0.7],[0.26,0.33])	([0.12,0.18],[0.77,0.88],[0.15,0.21])	([0.52,0.68],[0.24,0.3],[0.23,0.3])	([0.46,0.59],[0.35,0.44],[0.27,0.37])
C4	([0.08,0.14],[0.78,0.9],[0.23,0.25])	([0.17,0.23],[0.63,0.73],[0.32,0.38])	([0.41,0.52],[0.39,0.48],[0.3,0.39])	([0.37,0.49],[0.39,0.47],[0.31,0.39])
C5	([0.03,0.05],[0.88,0.96],[0.15,0.16])	([0.07,0.12],[0.73,0.83],[0.26,0.28])	([0.16,0.23],[0.65,0.75],[0.22,0.27])	([0.15,0.21],[0.65,0.76],[0.24,0.28])
C6	([0.21,0.32],[0.57,0.67],[0.25,0.31])	([0.41,0.53],[0.41,0.51],[0.28,0.38])	([0.72,0.9],[0.14,0.21],[0.07,0.21])	([0.56,0.72],[0.22,0.29],[0.21,0.29])
C7	([0.02,0.05],[0.92,0.98],[0.11,0.12])	([0.02,0.05],[0.92,0.98],[0.11,0.12])	([0.15,0.23],[0.74,0.87],[0.2,0.25])	([0.14,0.2],[0.77,0.89],[0.22,0.26])
C8	([0.02,0.03],[0.92,0.98],[0.11,0.11])	([0.03,0.05],[0.88,0.96],[0.15,0.16])	([0.1,0.16],[0.81,0.92],[0.12,0.18])	([0.08,0.13],[0.82,0.92],[0.15,0.19])
C9	([0.13,0.18],[0.67,0.77],[0.25,0.29])	([0.21,0.28],[0.59,0.69],[0.29,0.35])	([0.04,0.08],[0.86,0.95],[0.15,0.17])	([0.22,0.31],[0.55,0.65],[0.27,0.33])
C10	([0.29,0.42],[0.45,0.54],[0.29,0.35])	([0.26,0.37],[0.48,0.57],[0.31,0.37])	([0.33,0.47],[0.44,0.53],[0.26,0.34])	([0.27,0.39],[0.46,0.55],[0.3,0.36])
C11	([0.54,0.69],[0.22,0.29],[0.22,0.29])	([0.13,0.21],[0.73,0.85],[0.19,0.24])	([0.61,0.78],[0.19,0.26],[0.17,0.25])	([0.5,0.65],[0.25,0.32],[0.24,0.31])
C12	([0.44,0.57],[0.36,0.45],[0.28,0.37])	([0.33,0.45],[0.48,0.57],[0.21,0.29])	([0.66,0.83],[0.17,0.24],[0.14,0.23])	([0.66,0.83],[0.17,0.24],[0.14,0.24])

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Score function values according to Table 5 are obtained as in Table 6 using equation 4. The highest values represent PIS and the lowest values represent NIS.

Table 6 Score function values.

Criteria	A1	A2	A3	A4
C1	0.89	0.73	0.59	0.60
C2	0.84	0.83	0.84	0.93
C3	0.59	0.74	0.51	0.54
C4	0.78	0.63	0.53	0.50
C5	0.88	0.69	0.60	0.60
C6	0.54	0.55	0.72	0.54
C7	0.92	0.92	0.74	0.78
C8	0.92	0.88	0.79	0.80
C9	0.62	0.58	0.85	0.52
C10	0.48	0.50	0.49	0.48
C11	0.52	0.71	0.59	0.49
C12	0.54	0.50	0.65	0.65

Table 7 shows the Interval-valued Spherical Fuzzy Positive Ideal Solution and Interval-valued Spherical Fuzzy Negative Ideal Solution corresponding to the best and worst scores obtained in Table 6 using equation 5 to 10 respectively.

Table 7 IVSF-PIS and IVSF-NIS.

	IVSF-PIS	IVSF-NIS
C1	([0.02,0.04],[0.9,0.97],[0.14,0.14])	([0.07,0.1],[0.76,0.85],[0.26,0.29])
C2	([0.02,0.03],[0.93,0.98],[0.09,0.1])	([0.09,0.15],[0.84,0.95],[0.07,0.16])
C3	([0.12,0.18],[0.77,0.88],[0.15,0.21])	([0.52,0.68],[0.24,0.3],[0.23,0.3])
C4	([0.08,0.14],[0.78,0.9],[0.23,0.25])	([0.37,0.49],[0.39,0.47],[0.31,0.39])
C5	([0.03,0.05],[0.88,0.96],[0.15,0.16])	([0.16,0.23],[0.65,0.75],[0.22,0.27])
C6	([0.72,0.9],[0.14,0.21],[0.07,0.21])	([0.21,0.32],[0.57,0.67],[0.25,0.31])
C7	([0.02,0.05],[0.92,0.98],[0.11,0.12])	([0.15,0.23],[0.74,0.87],[0.2,0.25])
C8	([0.02,0.03],[0.92,0.98],[0.11,0.11])	([0.1,0.16],[0.81,0.92],[0.12,0.18])
C9	([0.04,0.08],[0.86,0.95],[0.15,0.17])	([0.22,0.31],[0.55,0.65],[0.27,0.33])
C10	([0.26,0.37],[0.48,0.57],[0.31,0.37])	([0.27,0.39],[0.46,0.55],[0.3,0.36])
C11	([0.13,0.21],[0.73,0.85],[0.19,0.24])	([0.5,0.65],[0.25,0.32],[0.24,0.31])
C12	([0.66,0.83],[0.17,0.24],[0.14,0.23])	([0.33,0.45],[0.48,0.57],[0.21,0.29])

As the next step of the methodology, the values giving the distances between alternative X_i and the IVSF-PIS as well as IVSF-NIS and the closeness ratios values were calculated and ranked in Table 8 and Table 9, respectively using equation 11. Table 8 and Table 9 demonstrated that Activated Fins chosen as the most appropriate alternatives with the 0.690 CR value as the common opinion of all subject-matter-experts, where Bilge Keels determined as the last option with the 0.451 CR value. Gyroscopic Roll Stabilizer and Active Anti-roll tanks ranked as the second and third alternative with 0.560 and 0.489 CR value, respectively.

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Table 8 Distances to interval-valued positive and negative ideal solutions and Closeness ratio of each alternative.

Alternatives	A1	A2	A3	A4
PIS	0.141	0.127	0.187	0.200
NIS	0.135	0.282	0.238	0.164
CR	0.489	0.690	0.560	0.451

Table 9 Ranking to interval-valued positive and negative ideal solutions and closeness ratio of each alternative.

Alternatives	A1	A2	A3	A4
IV-PIS	2	1	3	4
IV-NIS	4	1	2	3
CR	3	1	2	4

IVSF-TOPSIS provides decision makers with a wider range of definitions to make their decisions. Considering the proximity ratio values of the proposed method, the best alternative is A2 and the overall ranking is A2> A3> A1> A4.

5. CONCLUSION

On cruising ships, the comfort and safety of passengers and crews is of critical importance. In this context, roll stabilization systems play an active role. While selecting these systems, it is decided by making evaluations on different alternatives. Alternative stabilization systems have advantages and disadvantages against each other. At this point, it is necessary to determine which criteria will be in the foreground while making a choice.

In this study, in order to determine the most effective stabilization system for cruise ships, a multi-criteria decision-making method such as interval-valued spherical fuzzy TOPSIS, based on the new theory, had been proposed. IVSF-TOPSIS offers decision makers a wider range of definitions in terms of making their decisions. In this context, experts evaluated in detail the active and passive roll stabilizer systems, which are alternatives to each other, taking into account many parameters from different perspectives. To this end, the proposed IVSF-TOPSIS methodology is considered to be functional because it is realistic and reliable.

Among the alternative stabilizing systems evaluated by experts based on certain criteria, Activated fin system was identified as the most effective one. In addition to these assessments, it should be noted that the differentiation of experts and criteria, which is an important part of the problem, may change the outcome.

In future studies, alternatives and criteria evaluated in this study can be used for different types of ships, and comparisons can be made with different multi-criteria decision making methods (such as AHP and VIKOR) by changing the number of criteria, alternatives and experts.

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