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Başhan, Veysi
Demirel, Hakan
Gul, Muhammet

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A NOVEL RISK EVALUATION APPROACH FOR FREQUENTLY ENCOUNTERED RISKS IN SHIP ENGINE ROOMS

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Summary

The purpose of this study is to evaluate risks which are frequently encountered in the engine room on-board. In this context, twenty common risks are assessed using the neutrosophic analytic hierarchy process (N-AHP) and trapezoidal fuzzy technique for order preference by similarity to ideal solution (TrF-TOPSIS). In maritime risk evaluation, since it is frequently required the linguistic assessment of decision-makers to achieve a robust risk assessment tool, neutrosophic sets and fuzzy sets are used together in this study. Neutrosophic sets represent real-world problems effectively by considering all aspects of decision-making situations, (i.e. truthiness, indeterminacy, and falsity). Therefore, AHP is integrated with neutrosophic sets to assign weights of risk parameters initially. Then, the encountered risks are prioritized by TrF-TOPSIS. Finally, preventative actions for the risks have been discussed. In conclusion of the study, it is shown that skin exposure to the fuels/oils, exposure to chemicals and exposure to high pressure and temperature liquids are the most important risks through the engine room on-board. This study both emphasizes the importance of preventing damage to crew in the risk assessment of ship engine rooms and aims to increase the level of safety control and minimize the potential environmental impacts of a ship's damage.

Key words: *maritime risk evaluation; ship engine room; neutrosophic sets; AHP; fuzzy TOPSIS*

1. Introduction

Mostly, there is a great meaning relation among some concepts. Complexity may arise when using these terms. For example, concepts such as incident, accident, safety, hazard, risk, and consequence can create confusion in minds. Basically, incident can be defined as work-related events in which a personnel injury, damage to the environment, loss of property (regardless of severity) or fatality occurred. Accident is an unintended event involving fatality, injury or damage. Hazard is source, situation or acts with a potential for harm in terms of human injury. Furthermore, risk is defined as a situation involving exposure to any kind of danger or expose someone or something valued to danger, harm or loss. In this context, International Maritime Organization (IMO) –known as a mandatory rule-maker in maritime sector- describes

Formal Safety Assessment (FSA) as "*a rational and systematic process for assessing the risks associated with shipping activity and for evaluating the costs and benefits of IMO's options for reducing these risks*" [1]. However, Montewka et al. [2] indicate that there is an impression that the definition of risk does not fully reflect the way the risk is explained and that the components related to the definition of risk can change depending on the content. In this regard, Slovic [3] carried out comprehensive and pioneering work on risk perception research. He studied the people's judgments when they are asked to characterize and assess hazardous activities and technologies. In the literature, there are studies on risks in many different areas [4]–[6]. It can be seen that risk studies have been carried out mostly on land-based facilities or technologies. As in most of the terrestrial industrial facilities, the working environments in the ships have also many different risks and because a limited number of studies have been conducted in terms of ship and the maritime sector it needs to be examined in detail. As it is known, when public ship accidents occur resulting in extraordinary pollution in the seas, public conscience activates and encourages politicians to take more comprehensive measures. Taking this into consideration, Trbojevic and Carr [7] examined safety improvements in port with risk-based methodology. First, they carried out hazard identification and qualitative risk assessment to establish hazard barriers that must or should be present to prevent disclosure of hazards. Then, the controls for the management of these hazards are developed and integrated into the Safety Management System (SMS). Wang [8] applied a subjective modelling tool to formal ship safety assessment (SSA) by using fuzzy sets. Huntington et al. [9] carried out a study on ships and rules by considering several risks like ship strikes of whales, noise disturbance, pollution and oil spill in terms of ship traffic through Bering Strait. Hu et al. [10] examined numerical risk assessment and generic risk model in FSA, and also frequency and severity criteria in ship navigation are discussed. They presented a new model based on relative risk assessment (MRRA). Their models offer a risk-assessment approach based on fuzzy functions and take detailed information about the accident characteristics into account. Zhang et al. [11] applied Fuzzy Rule-Based Evidential Reasoning (FRBER) to an Inland Waterway Transportation System (IWTS) based on a hierarchical model for navigation risk. They have proven and confirmed the proposed method by analyzing the navigation risks of three different regions of the Yangtze River which is the longest river in Asia and the third-longest river in the world after the Amazon. They stated that their approach could be applied to model IWTS behaviours in other areas, such as America and Europe, to improve the safety of inland waterways. Mentes et al. [12] studied the FSA based approach combined with fuzzy set theory (FST), ordered weighted geometric averaging operator (OWGA) and decision making trial and evaluation laboratory technique (DEMATEL) for risk assessment of cargo ships at coasts and open seas of Turkey. Fu et al. [13] underlined the importance of the advantages of short sea routes which have recently forced ships to travel in such routes that are unfortunately challenging environments like Arctic waters. They indicated that in order to ensure safe operation in these areas, the potential risks of ship accidents should be systematically analyzed, evaluated and managed with the relevant uncertainties. In their study, the quantitative approach carried out in a four-stage study, including an event tree model, accident scenario modelling, probabilistic and dependency analysis of the associated intermediate events, and risk assessment for the resulting results. Akyildiz and Mentes [14] presented a risk assessment model for risk management and decision making. Through their analysis, the four main aspects of the uncertainty proposed by the authors: the level of understanding, the quality of information, the level of uncertainty of cargo ship accidents and the sensitivity levels of the model parameters, are integrated into the model parameters to analyze cargo ship accidents. Furthermore, Chauvin et al. [15] investigated collisions at sea by using Human Factor Analysis and Classification System (HFACS). In their results, it is indicated that unsafe acts are divided into two categories: decision and perception. Briefly, the authors stated that in open seas, the master's decisions should be investigated in case of incompatible with SMS. Kececi and Arslan [16] performed a Ship Accident Root Cause Evaluation (SHARE) analysis on a real ship accident case by the fuzzy Strengths, Weaknesses, Opportunities and Threats (SWOT) Analytic Hierarchy Process (AHP) method to demonstrate the causes of marine accidents and to implement appropriate corrective actions. Eliopoulou et al. [17] studied on a statistical analysis of ship accidents and showed that, although the frequency of ship accidents has increased in general over the last decade, the safety levels of various ship types have not changed significantly, because the results of the accidents remain at an average level. Akyuz and Celik [18] performed a study by using the Success Likelihood Index Method (SLIM) which is extended with fuzzy logic to understand the role of the human factor in maritime risk evaluation. They studied one of the specific operations of ships that is called Ballast Water Treatment (BWT). Consequently, they found that the riskiest phase is maintenance activities such as tank cleaning. Gul et al. [19] proposed a risk-based approach including the methods of Fine-Kinney method, FAHP, and fuzzy VIKOR. They applied it to ballast tank maintenance process in the maritime industry. Çakıroğlu et al. [20] performed a fuzzy AHP approach for choosing a suitable tugboat to be used at the port within the framework of design, operation and financial criteria. Demirel et al. [21] proposed a fuzzy AHP (Analytical Hierarchy Process) and ELECTRE (Elemination and Choice Translation Reality English) method to select the most effective roll stabilization system for a fishing vessel. Akdemir and Beskese [22] studied on a fuzzy AHP based decision model to provide practitioners with a decision support tool against further trade of a ship for the sale of demolition. Ding et al. [23] introduced an international shipping case and demonstrated that the proposed fuzzy MCDM model can be used to efficaciously select the best middle manager. KobylińSki [24] carried out a study on risks of ships which occur due to forces of the sea. When the above detailed literature is examined, it is clear that most of the studies give place to operational situations. However, the engine rooms on ships are like a large industrial factory. In engine rooms, there are many different machines that work on several different conditions and have many risky situations. Başhan and Demirel [25] evaluated the most common critical operational faults of marine diesel generator engines by using Decision Making Trial and Evaluation Laboratory (DEMATEL) method. Bashan and Ust [26] assessed super critical carbon dioxide Brayton power system which also can be used as a propulsion system of a ship by using fuzzy DEMATEL method. The diesel generator is one of the most important auxiliary engines in ships and it meets the power requirements of all auxiliary machinery on board, and most of its operations have many risks. Most of the ship machines operate at high temperature and pressure. Moreover, there are electric-electronic circuits in ship engine rooms and there are hazardous chemical risky liquids carried/used. Therefore, seafarers face many risks such as an explosion, fire, chemical exposure or inhalation of toxic/poison gaseous, etc.

Apart from prior studies, in this study twenty risks that are frequently encountered in the engine room are assessed by using N-AHP & TrF-TOPSIS methods. In this study, triangular Neutrosophic sets and trapezoidal fuzzy sets are combined with AHP and TOPSIS multi-criteria decision methods, respectively. Neutrosophic sets are a generalization of classical, fuzzy and intuitionistic fuzzy sets. It reflects uncertain, inconsistent, and incomplete information about real-world problems. In neutrosophic sets, decision-makers consider truth-membership, indeterminacy membership and falsity-membership functions. By integrating this aspect of neutrosophic sets with AHP, the preference judgment values of the decision-makers are described efficiently. On the other hand, the TOPSIS method is applied to risk assessment problems many times in the literature [27]–[30]. Mahdevari et al. [31] investigated risk associated with health and safety of coal miners by using fuzzy TOPSIS methods. Yazdi [32] proposed a new intuitionistic fuzzy hybrid TOPSIS approach for risk matrix aiming to improve effectiveness and reliability of approach. Collan et al. [33] carried out a study by introducing new closeness coefficients for fuzzy TOPSIS and numerically performed to a research and development project selection issue. It has several pluses as follows [29]: It allows the experts to assign judgments to the hazards and associated risks by means of linguistic terms, which are better interpreted by humans, fuzzy in nature and then transferred into trapezoidal fuzzy numbers. In this study, TrF-TOPSIS is applied to analyze the risks frequently encountered in the engine room, since it has more capability in handling uncertainties, simultaneous consideration of the positive and the negative ideal points, simple computation and logical concept.

In the view of mentioned works, although a wide range of AHP and TOPSIS-based works have been performed to assess the risks, there is no practical approach using extended AHP with neutrosophic sets and TOPSIS with trapezoidal fuzzy sets applied to maritime risk evaluation. To remedy the gap, this paper aims at proposing a new risk evaluation approach for prioritizing risks in the maritime industry.

2. Methodology

In this section, the followed methodology is described in the lights of preliminaries of neutrosophic sets, the AHP based on neutrosophic sets named N-AHP, and trapezoidal fuzzy numbers-based TOPSIS techniques.

2.1 Neutrosophic analytic hierarchy process (N-AHP)

2.1.1 Preliminaries on neutrosophic sets

Neutrosophic set is a general version of classical, fuzzy and intuitionistic fuzzy sets [34]. They were first developed by Smaradache [35]. These sets reflect uncertainty, inconsistency and real-world problems better than classical fuzzy sets [34], [36], [37]. A single-valued triangular neutrosophic number is as follows: $\tilde{n} = \langle (n_1, n_2, n_3); \alpha_{\tilde{n}}, \beta_{\tilde{n}}, \theta_{\tilde{n}} \rangle$. Where n_1, n_2, n_3 are the lower, median and upper value of neutrosophic number and $\alpha_{\tilde{n}}, \beta_{\tilde{n}}, \theta_{\tilde{n}}$ are the truth-membership, indeterminacy-membership and falsity-membership functions, respectively. These functions are defined as follows:

The truth–membership function indicated as Eq. (1)

$$T_{\tilde{n}}(x) = \begin{cases} \alpha_{\tilde{n}}\left(\frac{x-n_1}{n_2-n_1}\right) & (n_1 \le x \le n_2) \\ \alpha_{\tilde{n}} & (x = n_2) \\ \alpha_{\tilde{n}}\left(\frac{n_3-x}{n_3-n_2}\right) & (n_2 \le x \le n_3) \\ 0 & otherwise \end{cases} \quad (1)$$

The indeterminacy-membership function as Eq. (2)

$$I_{\tilde{n}}(x) = \begin{cases} \frac{(n_{2} - x+\beta_{\tilde{n}}(x-n_1))}{(n_2-n_1)} & (n_1 \le x \le n_2) \\ \beta_{\tilde{n}} & (x = n_2) \\ \frac{(x-n_2+\beta_{\tilde{n}}(n_3-x))}{(n_3-n_2)} & (n_2 \le x \le n_3) \\ 1 & otherwise \end{cases} \quad (2)$$

The falsity-membership function as indicated Eq. (3)

$$F_{\tilde{n}}(x) = \begin{cases} \frac{(n_{2} - x+\theta_{\tilde{n}}(x-n_1))}{(n_2-n_1)} & (n_1 \le x \le n_2) \\ \theta_{\tilde{n}} & (x = n_2) \\ \frac{(x-n_2+\theta_{\tilde{n}}(n_3-x))}{(n_3-n_2)} & (n_2 \le x \le n_3) \\ 1 & otherwise \end{cases} \quad (3)$$

Here, $\alpha_{\tilde{n}}, \beta_{\tilde{n}}, \theta_{\tilde{n}}$ demonstrate the maximum truth-membership degree, minimum indeterminacy-membership degree and minimum falsity-membership degree, respectively. Some mathematical operations related to the neutrosophic sets are defined as in the following:

Definition 1 [34], [36], [37]: Addition of two triangular neutrosophic numbers.

Let $\tilde{n} = \langle (n_1, n_2, n_3); \alpha_{\tilde{n}}, \beta_{\tilde{n}}, \theta_{\tilde{n}} \rangle$ and $\tilde{s} = \langle (s_1, s_2, s_3); \alpha_{\tilde{s}}, \beta_{\tilde{s}}, \theta_{\tilde{s}} \rangle$ be two single valued triangular neutrosophic numbers. Then addition of these two numbers can be computed as in Eq. (4):

$$\tilde{n} + \tilde{s} = \langle (n_1 + s_1, n_2 + s_2, n_3 + s_3); \alpha_{\tilde{n}} \wedge \alpha_{\tilde{s}}, \beta_{\tilde{n}} \vee \beta_{\tilde{s}}, \theta_{\tilde{n}} \vee \theta_{\tilde{s}} \rangle \quad (4)$$

Definition 2 [34], [36], [37]: Subtraction of two triangular neutrosophic numbers. This can be computed as in Eq. (5):

$$\tilde{n} - \tilde{s} = \langle (n_1 - s_3, n_2 - s_2, n_3 - s_1); \alpha_{\tilde{n}} \wedge \alpha_{\tilde{s}}, \beta_{\tilde{n}} \vee \beta_{\tilde{s}}, \theta_{\tilde{n}} \vee \theta_{\tilde{s}} \rangle \quad (5)$$

Definition 3 [34], [36], [37]: Inverse of a triangular neutrosophic number. Let $\tilde{n} = \langle (n_1, n_2, n_3); \alpha_{\tilde{n}}, \beta_{\tilde{n}}, \theta_{\tilde{n}} \rangle$ be a single valued triangular neutrosophic number. Then inverse of this number can be computed as in Eq. (6):

$$\tilde{n}^{-1} = \langle \left(\frac{1}{n_3}, \frac{1}{n_2}, \frac{1}{n_1} \right); \alpha_{\tilde{n}}, \beta_{\tilde{n}}, \theta_{\tilde{n}} \rangle \text{ where } \tilde{n} \neq 0 \quad (6)$$

Definition 4 [34], [36], [37]: Division of two triangular neutrosophic numbers

Let $\tilde{n} = \langle (n_1, n_2, n_3); \alpha_{\tilde{n}}, \beta_{\tilde{n}}, \theta_{\tilde{n}} \rangle$ and $\tilde{s} = \langle (s_1, s_2, s_3); \alpha_{\tilde{s}}, \beta_{\tilde{s}}, \theta_{\tilde{s}} \rangle$ be two single valued triangular neutrosophic numbers. Then division of these two numbers can be computed as in Eq. (7):

$$\tilde{n}/\tilde{s} = \begin{cases} \langle \left(\frac{n_1}{s_3}, \frac{n_2}{s_2}, \frac{n_3}{s_1} \right); \alpha_{\tilde{n}} \wedge \alpha_{\tilde{s}}, \beta_{\tilde{n}} \vee \beta_{\tilde{s}}, \theta_{\tilde{n}} \vee \theta_{\tilde{s}} \rangle & if\ n_3 > 0, s_3 > 0 \\ \langle \left(\frac{n_3}{s_3}, \frac{n_2}{s_2}, \frac{n_1}{s_1} \right); \alpha_{\tilde{n}} \wedge \alpha_{\tilde{s}}, \beta_{\tilde{n}} \vee \beta_{\tilde{s}}, \theta_{\tilde{n}} \vee \theta_{\tilde{s}} \rangle & if\ n_3 < 0, s_3 > 0 \\ \langle \left(\frac{n_3}{s_1}, \frac{n_2}{s_2}, \frac{n_1}{s_3} \right); \alpha_{\tilde{n}} \wedge \alpha_{\tilde{s}}, \beta_{\tilde{n}} \vee \beta_{\tilde{s}}, \theta_{\tilde{n}} \vee \theta_{\tilde{s}} \rangle & if\ n_3 < 0, s_3 < 0 \end{cases} \quad (7)$$

Definition 5 [34], [36], [37]: Multiplication of two triangular neutrosophic numbers

Let $\tilde{n} = \langle (n_1, n_2, n_3); \alpha_{\tilde{n}}, \beta_{\tilde{n}}, \theta_{\tilde{n}} \rangle$ and $\tilde{s} = \langle (s_1, s_2, s_3); \alpha_{\tilde{s}}, \beta_{\tilde{s}}, \theta_{\tilde{s}} \rangle$ be two single valued triangular neutrosophic numbers. Then multiplication of these two numbers can be computed as in Eq. (8):

$$\tilde{n} * \tilde{s} = \begin{cases} \langle (n_1 * s_1, n_2 * s_2, n_3 * s_3); \alpha_{\tilde{n}} \wedge \alpha_{\tilde{s}}, \beta_{\tilde{n}} \vee \beta_{\tilde{s}}, \theta_{\tilde{n}} \vee \theta_{\tilde{s}} \rangle\ if\ n_3 > 0, s_3 > 0 \\ \langle (n_1 * s_3, n_2 * s_2, n_3 * s_1); \alpha_{\tilde{n}} \wedge \alpha_{\tilde{s}}, \beta_{\tilde{n}} \vee \beta_{\tilde{s}}, \theta_{\tilde{n}} \vee \theta_{\tilde{s}} \rangle\ if\ n_3 < 0, s_3 > 0 \\ \langle (n_3 * s_3, n_2 * s_2, n_1 * s_1); \alpha_{\tilde{n}} \wedge \alpha_{\tilde{s}}, \beta_{\tilde{n}} \vee \beta_{\tilde{s}}, \theta_{\tilde{n}} \vee \theta_{\tilde{s}} \rangle\ if\ n_3 < 0, s_3 < 0 \end{cases} \quad (8)$$

2.1.2 Steps of N-AHP

The AHP method originally was proposed by Saaty [38]. Later, Saaty [39] wrote several books about the AHP method and proposed the Analytic Network Process (ANP) method [40], [41]. Saaty's AHP and ANP was integrated with fuzzy sets and its extensions such as fuzzy extent analysis [42], neutrosophic sets [35], interval type-2 fuzzy sets [43], hesitant fuzzy sets [44], intuitionistic fuzzy sets [45] and Pythagorean fuzzy sets [27], [30], [46]–[48]. As in *the* classical AHP method, N-AHP has the following main steps: decomposition, pair-wise comparison, and synthesis of priorities. The detailed procedural flow of N-AHP is provided with details below in five steps.

Step 1: This step is about problem conceptualization in terms of hierarchical manner. It means that the problem is dealt with goals, alternatives, criteria, and sub-criteria.

Step 2: This step is related to the construction of pairwise comparison matrix, in other words, the neutrosophic decision matrix. The vagueness of decision-makers is characterized by triangular neutrosophic numbers $\tilde{n}_{ij}$. This matrix is shown in Eq. (9) below:

$$\tilde{n} = \begin{bmatrix} 1 & \cdots & \tilde{n}_{1m} \\ \vdots & \ddots & \vdots \\ \tilde{n}_{m1} & \cdots & 1 \end{bmatrix} \text{where } \tilde{n}_{ji} = \tilde{n}_{ij}^{-1}. \tag{9}$$

Step 3 [34], [36], [37]: This step is regarding determination of the weight of each criterion from corresponding neutrosophic decision matrix. To do this, neutrosophic decision matrix is initially transformed to deterministic decision matrix, using the Eqs. (10-11). Let $\tilde{n} = \langle (n_1, n_2, n_3); \alpha_{\tilde{n}}, \beta_{\tilde{n}}, \theta_{\tilde{n}} \rangle$ be a single valued triangular neutrosophic number, then,

$$S(\tilde{n}_{ij}) = \frac{1}{16}[n_1 + n_2 + n_3]x(2 + \alpha_{\tilde{n}} - \beta_{\tilde{n}} - \theta_{\tilde{n}}) \tag{10}$$

$$A(\tilde{n}_{ij}) = \frac{1}{16}[n_1 + n_2 + n_3]x(2 + \alpha_{\tilde{n}} - \beta_{\tilde{n}} - \theta_{\tilde{n}}) \tag{11}$$

These two terms are score and accuracy degrees of $\tilde{n}_{ij}$, respectively. After this transformation, the matrix is turned into a deterministic decision matrix. Using the deterministic decision matric, the eigen vector calculation can be performed. From this step, the calculations are the same as the calculations in the classical AHP method.

Step 4: In this step, the consistency ratio (CR) is calculated. If the obtained CR value is lower than 0.1, it can be said that the evaluation of expert's judgment is consistent. The steps of CR computation are as follows:

Step 4.1: Multiply the pairwise comparison matrix by the relative priorities

Step 4.2: Divide the weighted sum vector elements by the associated priority value

Step 4.3: Compute the average (denoted λ_{max}) of the values from Step 4.2

Step 4.4: Compute the consistency index (CI) ($CI = \frac{\lambda_{max} - n}{n-1}$), where *n* is the number of items being compared.

Step 4.5: Compute the consistency ratio CR = CI/RI, where RI is the random index (CI of the randomly generated pairwise comparison matrix) as shown in [49], [50].

Step 5: In the last step, overall priority of each criterion is calculated, and final rankings are determined.

2.2 Trapezoidal fuzzy numbers-based technique for order preference by similarity to ideal solution (TrF-TOPSIS)

2.2.1 Trapezoidal fuzzy numbers and related linguistic terms

The TOPSIS method was firstly proposed by Hwang and Yoon [51]. It is based on the compromise solution concept which selects the solution with the shortest distance from the ideal solution, and the farthest distance from the negative ideal solution. In the literature, TOPSIS is extended by using various versions of fuzzy numbers [49], [52]. A single-valued trapezoidal fuzzy number *A* is demonstrated with its membership function as follows in Eqs (12-13):

$$\tilde{A} = (a_1, a_2, a_3, a_4), \quad a_1 \le a_2 \le a_3 \le a_4 \tag{12}$$

$$\mu_{\tilde{A}}(x) = \begin{cases} 0, & x < a_1) \\ \left(\frac{x-a_1}{a_2-a_1}\right), & (a_1 \le x \le a_2) \\ \left(\frac{a_3-x}{a_3-a_2}\right), & (a_2 \le x \le a_3) \\ 1, & x > a_3 \end{cases} \tag{13}$$

Mathematical operations of two trapezoidal fuzzy numbers can be found at Cheng and Lin [53]. For the current study, linguistic variables and corresponding fuzzy numbers in trapezoidal format in the study of Samantra [54] are utilized. The seven-point scale is represented as in Table 1 below.

Table 1 Seven-point fuzzy linguistic scale [54].

Linguistic term	Fuzzy number
Absolutely certain (AC)	(0.8,0.9,1,1)
Very frequent (VF)	(0.7,0.8,0.8,0.9)
Frequent (F)	(0.5,0.6,0.7,0.8)
Probable (P)	(0.4,0.5,0.5,0.6)
Occasional (O)	(0.2,0.3,0.4,0.5)
Rare (R)	(0.1,0.2,0.2,0.3)
Very rare (VR)	(0,0,0.1,0.2)

2.2.2 Steps of TrF-TOPSIS

The procedure used in Chen's [55] TrF-TOPSIS method was followed for the hazard prioritization aim in the case study presented in this paper. The steps are as follows [29], [49], [56], [57]:

Step 1: The scores of alternatives with respect to each criterion are obtained considering a decision-making group with K experts by this formula: $\tilde{x}_{ij} = \frac{1}{K}[\tilde{x}_{ij}^1(+)\tilde{x}_{ij}^1(+)....(+)\tilde{x}_{ij}^K]$. While $A = \{A_i | i = 1,...., m\}$ shows the set of alternatives, $C = \{C_j \mid j = 1,...., n\}$ represents the criteria set. $X = \{X_{ij} | i = 1,...., m;\ j = 1,...., n\}$ denotes the set of fuzzy ratings, and $\tilde{w} = \{\tilde{w}_j \mid j = 1,...., n\}$ is the set of fuzzy weights. The linguistic variables are described by trapezoidal fuzzy number as follows: $\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij}, d_{ij})$.

Step 2: Normalized ratings are determined by Eq. (14).

$$\tilde{r}_{ij} = \begin{cases} (\frac{a_{ij}}{d_j^*}, \frac{b_{ij}}{d_j^*}, \frac{c_{ij}}{d_j^*}, \frac{d_{ij}}{d_j^*}), \text{ where } d_j^* = \max_i d_{ij} \text{ if } j \in \text{benefit criteria} \\ (\frac{a_j^-}{d_{ij}}, \frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}), \text{ where } a_j^- = \min_i a_{ij} \text{ if } j \in \text{cost criteria} \end{cases} \tag{14}$$

Step 3: Weighted normalized ratings are obtained by Eq. (12).

$$\tilde{v}_{ij} = w_j(x)\tilde{r}_{ij}, \quad i = 1,...., m;\ j = 1,...., n \tag{15}$$

Step 4: The fuzzy positive ideal point (FPIS,A*) and the fuzzy negative ideal point (FNIS,A$^-$) are derived as in Eq. (16-17). Where J_1 and J_2 are the benefit and the cost attributes, respectively.

$$\text{FPIS}=\text{A}^* = \{\tilde{v}_1^*, \tilde{v}_2^*, ..., \tilde{v}_n^*\} \text{ where } \tilde{v}_j^* = (1,1,1,1) \tag{16}$$

$$\text{FNIS}=\text{A}^- = \{\tilde{v}_1^-, \tilde{v}_2^-, ..., \tilde{v}_n^-\} \text{ where } \tilde{v}_j^- = (0,0,0,0) \tag{17}$$

Step 5: The next step is about calculating the separation between the FPIS and the FNIS among the alternatives. The separation values can also be obtained by means of the vertex method as in Eq. (18-19):

$$\tilde{S}_i^* = \sqrt{\frac{1}{4}\sum_{j=1}^{n}[\tilde{v}_{ij} - \tilde{v}_j^*]^2}, \quad i = 1, ..., m \tag{18}$$

$$\tilde{S}_i^- = \sqrt{\frac{1}{4}\sum_{j=1}^{n}[\tilde{v}_{ij} - \tilde{v}_j^-]^2}, \quad i = 1, ..., m \tag{19}$$

Step 6: Then, the defuzzified separation values are derived using the CoA (center of area) defuzzification method to calculate the similarities to the ideal solution. Next, the similarities to the ideal solution are given as Eq. (20).

$$C_i^* = \tilde{S}_j^- / (\tilde{S}_j^* + \tilde{S}_j^-), \quad i = 1, ..., m \tag{20}$$

The preferred orders are ranked according to C_i^* in descending order to select the best final alternatives. Thus, referring to the proposed analysis, and according to the obtained C_i^* values, the ranking order of all hazards can be determined.

2.3 The overall picture of proposed methodology

In this section, the proposed methodology is presented to prioritize hazards and analyze associated risks by N-AHP and TrF-TOPSIS methods. Figure 1 shows flow chart of the proposed methodology. Initially, problem description and risk identification are performed by meetings and snowball method. Then, in the second phase, experts assign weights of risk parameters by using N-AHP method. The risk parameters are as follows: severity, probability, sensitivity to personal protective equipment non-utilization (SPPENU), and undetectability. Finally, maritime risks related to the machinery are prioritized by using TrF-TOPSIS method.

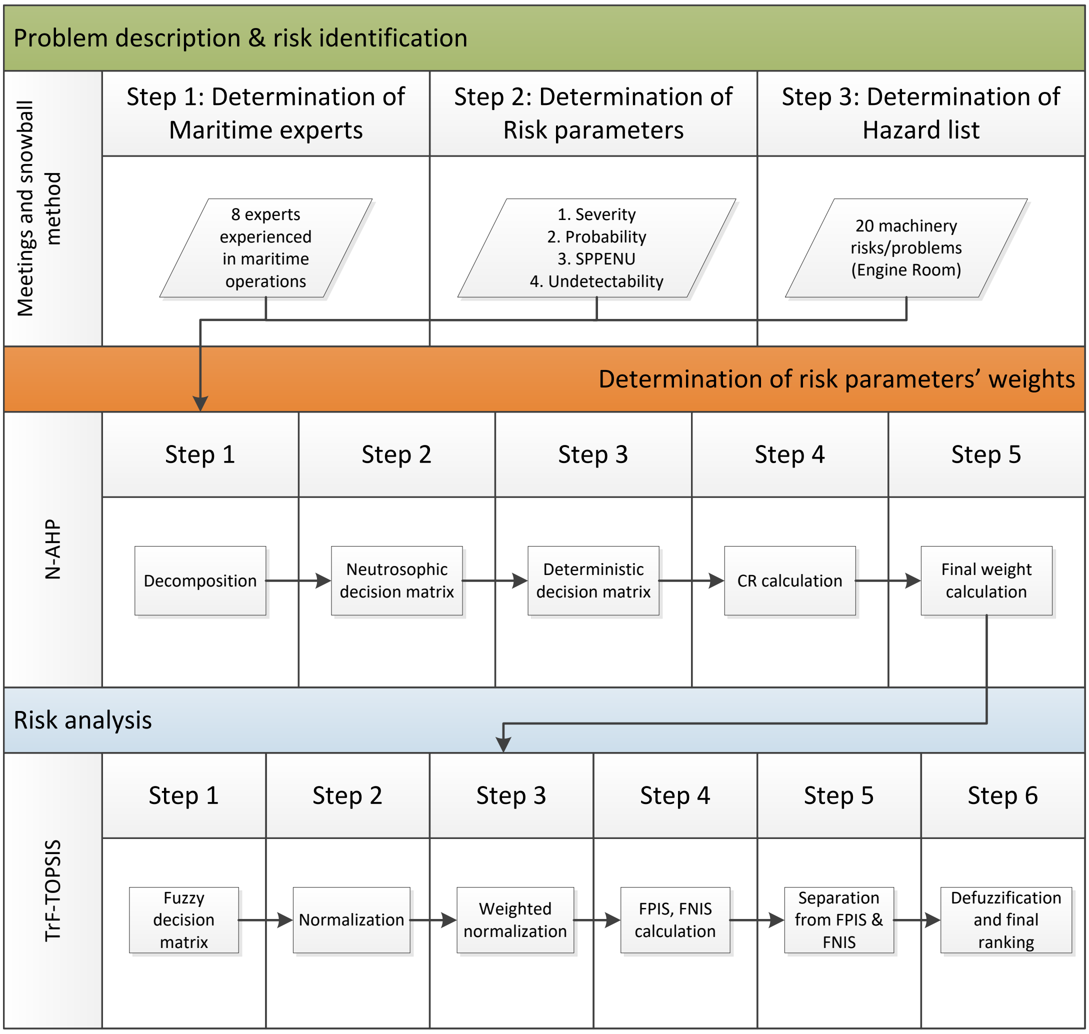

Fig. 1 Systematic procedural steps of the proposed methodology

3. Case study: Evaluation of risks in ship engine room

3.1 Problem description and risk identification

Regarding the first step of the application of the proposed methodology, determination of maritime experts who filled the questionnaires, determination of risk parameters and determination of hazard list were performed. Table 2 shows the detailed information about the expert group and their corresponding working experience. For reasons of anonymity, the identity of the experts is not revealed in this study. In the current study, eight experts participated in rating and analyzing occupational hazard risks. All members have experience in maritime industry with different levels. Since, the DPA and the two Machinery Superintendents have the highest experience level, they take participate the first phase of the approach (N-AHP implementation to determine importance levels of four risk parameters). Compared to the TrF-TOPSIS phase, N-AHP phase requires a strategic assessment viewpoint rather than an operational assessment viewpoint. In the second phase of the approach, all the eight experts take participation in evaluating occupational hazard risks. We have assumed equal importance degree to the experts in both phases. In the literature, there exits some novel methods for expertise coefficient determination [58], [59].

Secondly, four risk parameters were considered within the scope of this study. Certainly, according to the ISO definition, risk is defined as combination of severity and probability.

However, we believe that other two parameters named as SPPENU and undetectability represent the most important aspects of human behavior and working environment interaction in an industrial field. They are described as follows: (1) Severity addresses the evaluation of the severity of the more consistent injury that can be caused by an accident during the execution of hazardous activity. (2) Probability considers the combination of the occurrence probability of the accident and the probability that injuries to operators occur. (3) SPPENU considers the potential negative effect on the operator's health resulting from a failure to wear personal protective equipment (PPE) together with the expectation that the operator may not wear it. Sensitivity to PPE non-utilization considers the potential negative effect on the operator's health resulting from a failure to wear PPE together with the expectation that the operator may not wear it. (4) Undetectability is related to the interaction between the operator and the working environment such as machines and equipment.

The experts identified twenty hazards frequently encountered risks in ship engine rooms. The detailed information about the hazard list is provided in Table 3.

Table 2 Expert profile details

Expert	Title and Years of experience in maritime
Expert-1	DPA (Designated Person Ashore) -CE (Chief Engineer) – MSc - Technical Manager of Shipping Company -32 years' experience
Expert-2	Machinery Superintendent -CE (Chief Engineer) – MSc - 25 years' experience
Expert-3	Machinery Superintendent -CE (Chief Engineer) -19 years' experience
Expert-4	CE (Chief Engineer) - Oceangoing watch keeping engineer –Ph.D- 18 years' experience
Expert-5	CE (Chief Engineer) - Oceangoing watch keeping engineer -MSc- 17 years' experience
Expert-6	2nd Engineer -Oceangoing watch keeping engineer -MSc- 17 years' experience
Expert-7	2nd Engineer -Oceangoing watch keeping engineer -MSc -15 years' experience
Expert-8	Naval Architecture and Marine Engineer -Shipyard -MSc- 15 years' experience

Table 3 Identified hazards

Hazard No.	Hazard and/or occurring of risk
Hazard-1	Falling from high spaces
Hazard-2	Struck by falling objects
Hazard-3	Personal injury
Hazard-4	Oil spill
Hazard-5	Skin exposure to fuels/oils
Hazard-6	Pipe line burst due to excess pressure
Hazard-7	Fire
Hazard-8	Inhalation of poison/toxic gaseous
Hazard-9	Electrocution
Hazard-10	Exposure to high pressure and high temperature liquids
Hazard-11	Lifting heavy objects
Hazard-12	Excessive stress to ship structure

Hazard-13	Exposure to chemicals
Hazard-14	Interruption of power loss onboard
Hazard-15	Explosion
Hazard-16	Drop of crane or grab because of break off wire
Hazard-17	Explosion on auxiliary machinery components
Hazard-18	Loose floor plating
Hazard-19	Engine room lightning damage
Hazard-20	Involuntary explosion of carbon dioxide extinguishing system

3.2 Determination of risk parameters' weights by N-AHP

In this step, the neutrosophic pair-wise comparison matrix is initially constructed following the Step 2 of sub-section 2.1.2. In this step, lower, median and upper values of neutrosophic numbers and the truth- membership, indeterminacy membership and falsity-membership functions are adapted from Abdel-Basset et al. 's [34] study. The matrix is given in Table 4.

Table 4 The neutrosophic pair-wise comparison matrix

		C1 (a,b,c)(α,β,θ)						C2 (a,b,c)(α,β,θ)						C3 (a,b,c)(α,β,θ)						C4 (a,b,c)(α,β,θ)					
C1	E1	0.5	1	3	0.9	0.2	0.3	3	5	15	0.9	0.5	0.1	3	7	14	0.7	0.4	0.3	0	3	9	0.6	0.3	0.2
	E2	0.5	1	3	0.9	0.2	0.3	0.5	1	3	0.9	0.2	0.3	3	5	15	0.9	0.5	0.1	3	7	14	0.7	0.4	0.3
	E3	0.5	1	3	0.9	0.2	0.3	0	3	9	0.6	0.3	0.2	3	5	15	0.9	0.5	0.1	3	5	15	0.9	0.5	0.1
C2	E1							0.5	1	3	0.9	0.2	0.3	3	5	15	0.9	0.5	0.1	3	5	15	0.9	0.5	0.1
	E2							0.5	1	3	0.9	0.2	0.3	0	3	9	0.6	0.3	0.2	3	5	15	0.9	0.5	0.1
	E3							0.5	1	3	0.9	0.2	0.3	3	5	15	0.9	0.5	0.1	0	3	9	0.6	0.3	0.2
C3	E1													0.5	1	3	0.9	0.2	0.3	3	7	14	0.7	0.4	0.3
	E2													0.5	1	3	0.9	0.2	0.3	0.5	1	3	0.9	0.2	0.3
	E3													0.5	1	3	0.9	0.2	0.3	3	5	15	0.9	0.5	0.1
C4	E1																			0.5	1	3	0.9	0.2	0.3
	E2																			0.5	1	3	0.9	0.2	0.3
	E3																			0.5	1	3	0.9	0.2	0.3

Note: C1: Severity; C2: Probability; C3: SPPENU; C4: Undetectability; (a,b,c) refers to the lower, median and upper of neutrosophic number; (α,β,θ) refers to the truth- membership, indeterminacy membership and falsity-membership functions; E1: Expert-1; E2: Expert-2; E3: Expert-3.

By using Equations (7) and (8), the previous neutrosophic pair-wise comparison matrix transformed to deterministic pair-wise comparison matrix as in Table 5.

Table 5 The deterministic pair-wise comparison matrix

	C1	C2	C3	C4
C1	0.675	1.852	3.204	2.627
C2	0.806	0.675	2.729	2.729
C3	0.313	0.413	0.675	2.327
C4	0.424	0.413	0.706	0.675

To ensure that all inputs of experts are consistent we made a CR test. From equations of Step 4 in sub-section 2.1.2, λ_{max}=average{1.688/0.402, 1.306/0.316, 0.650/0.159, 0.496/0.123}=4.115 and CI = (λ_{ma}x−n)/n−1 = (4.115–4)/(4–1) = 0.038. CR=CI/RI = 0.038/0.9= 0.042.

Using the eigenvector, the weights of four risk parameters are determined as in Figure 2. According to the results, the most important risk parameter is severity with a weight value of 0.402. It is followed by probability, SPPENU and undetectability with the weight values of 0.316, 0.159 and 0.123, respectively.

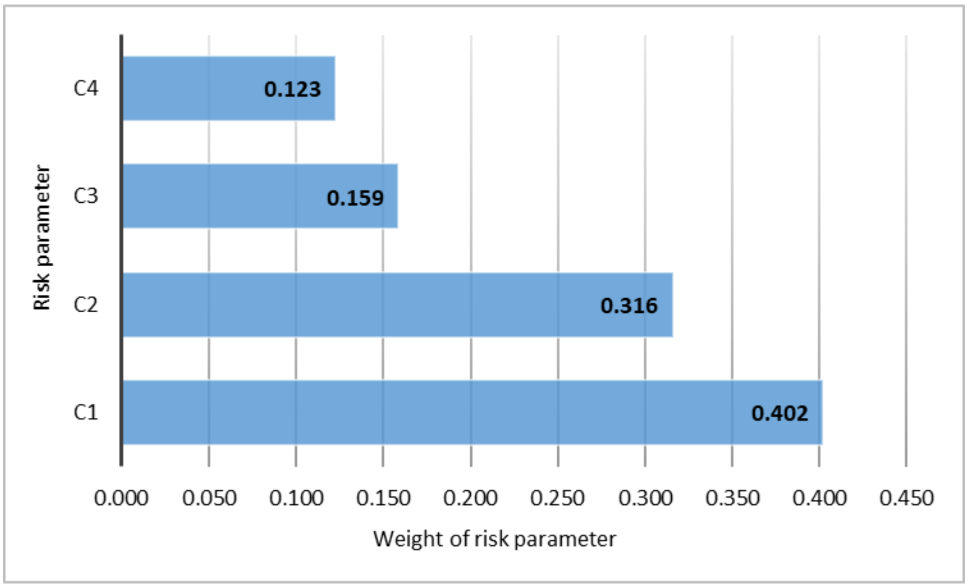

Fig. 2 Risk parameters' weights

3.3 Risk analysis and prioritization by TrF-TOPSIS

The last step of the proposed methodology is about risk analysis and prioritization by TrF-TOPSIS. Utilizing the risk parameters' weights from N-AHP step, and the fuzzy evaluations of hazards with respect to four risk parameter, TrF-TOPSIS is applied. In the study, all eight maritime experts the maritime experts make the evaluation of twenty hazards using linguistic variables as shown in Table 1. The fuzzy linguistic variables in Table 1 is then transformed into fuzzy trapezoidal numbers as shown in Table 6. This is the first stage of the TrF-TOPSIS analysis.

Table 6 Trapezoidal fuzzy decision matrix in TrF-TOPSIS step

Hazard	C1				C2				C3				C4			
Hazard-1	0.725	0.825	0.850	0.925	0.363	0.463	0.500	0.600	0.338	0.425	0.500	0.588	0.475	0.563	0.588	0.688
Hazard-2	0.575	0.675	0.700	0.788	0.45	0.55	0.600	0.700	0.300	0.388	0.425	0.525	0.438	0.538	0.575	0.675
Hazard-3	0.413	0.513	0.563	0.650	0.438	0.538	0.613	0.713	0.413	0.513	0.563	0.663	0.375	0.463	0.500	0.600
Hazard-4	0.300	0.388	0.463	0.563	0.338	0.438	0.488	0.588	0.375	0.475	0.488	0.588	0.400	0.488	0.550	0.650
Hazard-5	0.438	0.538	0.575	0.675	0.475	0.575	0.613	0.713	0.563	0.663	0.713	0.788	0.438	0.525	0.588	0.688
Hazard-6	0.550	0.650	0.688	0.775	0.275	0.363	0.450	0.550	0.325	0.413	0.475	0.575	0.288	0.388	0.425	0.525
Hazard-7	0.700	0.800	0.838	0.913	0.413	0.513	0.563	0.663	0.288	0.388	0.425	0.525	0.313	0.413	0.438	0.538
Hazard-8	0.650	0.750	0.775	0.863	0.338	0.438	0.488	0.588	0.338	0.425	0.463	0.563	0.425	0.525	0.588	0.688
Hazard-9	0.650	0.750	0.813	0.875	0.313	0.413	0.438	0.538	0.388	0.488	0.513	0.600	0.475	0.575	0.613	0.713
Hazard-10	0.625	0.725	0.800	0.875	0.350	0.450	0.513	0.613	0.388	0.488	0.513	0.613	0.400	0.500	0.538	0.638
Hazard-11	0.438	0.538	0.575	0.663	0.500	0.600	0.625	0.725	0.350	0.450	0.513	0.613	0.413	0.488	0.550	0.638
Hazard-12	0.488	0.588	0.638	0.738	0.250	0.325	0.375	0.475	0.213	0.288	0.338	0.438	0.238	0.313	0.350	0.450
Hazard-13	0.675	0.775	0.825	0.900	0.338	0.438	0.488	0.588	0.450	0.550	0.563	0.663	0.388	0.488	0.550	0.650
Hazard-14	0.513	0.613	0.650	0.738	0.263	0.350	0.388	0.488	0.088	0.138	0.225	0.325	0.213	0.300	0.363	0.463
Hazard-15	0.725	0.825	0.888	0.925	0.213	0.288	0.338	0.438	0.213	0.300	0.363	0.463	0.163	0.238	0.275	0.375
Hazard-16	0.775	0.875	0.950	0.975	0.150	0.238	0.275	0.375	0.213	0.275	0.313	0.413	0.325	0.413	0.438	0.538
Hazard-17	0.663	0.763	0.800	0.875	0.188	0.275	0.313	0.413	0.288	0.388	0.425	0.525	0.388	0.488	0.513	0.613
Hazard-18	0.475	0.575	0.613	0.713	0.325	0.425	0.500	0.600	0.300	0.400	0.450	0.550	0.175	0.250	0.300	0.400
Hazard-19	0.413	0.513	0.563	0.663	0.238	0.325	0.413	0.513	0.363	0.450	0.513	0.613	0.175	0.238	0.275	0.375
Hazard-20	0.650	0.750	0.775	0.863	0.088	0.138	0.188	0.288	0.238	0.325	0.375	0.475	0.188	0.263	0.325	0.413

Then these values are normalized using Eq. (14) in step 2 of Section 2.2.2. Table 7 provides the normalized fuzzy decision matrix.

Table 7 Normalized fuzzy decision matrix in TrF-TOPSIS step

Hazard	C1				C2				C3				C4			
Hazard-1	0.744	0.846	0.872	0.949	0.500	0.638	0.690	0.828	0.429	0.540	0.635	0.746	0.667	0.789	0.825	0.965
Hazard-2	0.590	0.692	0.718	0.808	0.621	0.759	0.828	0.966	0.381	0.492	0.540	0.667	0.614	0.754	0.807	0.947
Hazard-3	0.423	0.526	0.577	0.667	0.603	0.741	0.845	0.983	0.524	0.651	0.714	0.841	0.526	0.649	0.702	0.842
Hazard-4	0.308	0.397	0.474	0.577	0.466	0.603	0.672	0.810	0.476	0.603	0.619	0.746	0.561	0.684	0.772	0.912
Hazard-5	0.449	0.551	0.590	0.692	0.655	0.793	0.845	0.983	0.714	0.841	0.905	1.000	0.614	0.737	0.825	0.965
Hazard-6	0.564	0.667	0.705	0.795	0.379	0.500	0.621	0.759	0.413	0.524	0.603	0.730	0.404	0.544	0.596	0.737
Hazard-7	0.718	0.821	0.859	0.936	0.569	0.707	0.776	0.914	0.365	0.492	0.540	0.667	0.439	0.579	0.614	0.754
Hazard-8	0.667	0.769	0.795	0.885	0.466	0.603	0.672	0.810	0.429	0.540	0.587	0.714	0.596	0.737	0.825	0.965
Hazard-9	0.667	0.769	0.833	0.897	0.431	0.569	0.603	0.741	0.492	0.619	0.651	0.762	0.667	0.807	0.860	1.000
Hazard-10	0.641	0.744	0.821	0.897	0.483	0.621	0.707	0.845	0.492	0.619	0.651	0.778	0.561	0.702	0.754	0.895
Hazard-11	0.449	0.551	0.590	0.679	0.690	0.828	0.862	1.000	0.444	0.571	0.651	0.778	0.579	0.684	0.772	0.895
Hazard-12	0.500	0.603	0.654	0.756	0.345	0.448	0.517	0.655	0.270	0.365	0.429	0.556	0.333	0.439	0.491	0.632
Hazard-13	0.692	0.795	0.846	0.923	0.466	0.603	0.672	0.810	0.571	0.698	0.714	0.841	0.544	0.684	0.772	0.912
Hazard-14	0.526	0.628	0.667	0.756	0.362	0.483	0.534	0.672	0.111	0.175	0.286	0.413	0.298	0.421	0.509	0.649
Hazard-15	0.744	0.846	0.910	0.949	0.293	0.397	0.466	0.603	0.270	0.381	0.460	0.587	0.228	0.333	0.386	0.526
Hazard-16	0.795	0.897	0.974	1.000	0.207	0.328	0.379	0.517	0.270	0.349	0.397	0.524	0.456	0.579	0.614	0.754
Hazard-17	0.679	0.782	0.821	0.897	0.259	0.379	0.431	0.569	0.365	0.492	0.540	0.667	0.544	0.684	0.719	0.860
Hazard-18	0.487	0.590	0.628	0.731	0.448	0.586	0.690	0.828	0.381	0.508	0.571	0.698	0.246	0.351	0.421	0.561
Hazard-19	0.423	0.526	0.577	0.679	0.328	0.448	0.569	0.707	0.460	0.571	0.651	0.778	0.246	0.333	0.386	0.526
Hazard-20	0.667	0.769	0.795	0.885	0.121	0.190	0.259	0.397	0.302	0.413	0.476	0.603	0.263	0.368	0.456	0.579

The fuzzy risk parameter weights are added into the calculation in FTOPSIS analysis. The next step is to generate the weighted fuzzy decision matrix using. Using Eq. (15) fuzzy weighted decision matrix is obtained as in Table 8.

Table 8 Weighted normalized fuzzy decision matrix in TrF-TOPSIS step

Hazard	C1				C2				C3				C4			
Hazard-1	0.299	0.340	0.351	0.382	0.158	0.202	0.218	0.262	0.068	0.086	0.101	0.118	0.082	0.097	0.101	0.119
Hazard-2	0.237	0.278	0.289	0.325	0.196	0.305	0.333	0.388	0.060	0.198	0.217	0.268	0.075	0.093	0.099	0.116
Hazard-3	0.170	0.211	0.232	0.268	0.191	0.298	0.340	0.395	0.083	0.262	0.287	0.338	0.065	0.080	0.086	0.103
Hazard-4	0.124	0.160	0.191	0.232	0.147	0.243	0.270	0.326	0.076	0.243	0.249	0.300	0.069	0.084	0.095	0.112
Hazard-5	0.181	0.222	0.237	0.278	0.207	0.319	0.340	0.395	0.113	0.338	0.364	0.402	0.075	0.091	0.101	0.119
Hazard-6	0.227	0.268	0.284	0.320	0.120	0.201	0.250	0.305	0.066	0.211	0.243	0.294	0.050	0.067	0.073	0.091
Hazard-7	0.289	0.330	0.346	0.376	0.180	0.284	0.312	0.368	0.058	0.198	0.217	0.268	0.054	0.071	0.075	0.093
Hazard-8	0.268	0.309	0.320	0.356	0.147	0.243	0.270	0.326	0.068	0.217	0.236	0.287	0.073	0.091	0.101	0.119
Hazard-9	0.268	0.309	0.335	0.361	0.136	0.229	0.243	0.298	0.078	0.249	0.262	0.306	0.082	0.099	0.106	0.123
Hazard-10	0.258	0.299	0.330	0.361	0.153	0.250	0.284	0.340	0.078	0.249	0.262	0.313	0.069	0.086	0.093	0.110
Hazard-11	0.181	0.222	0.237	0.273	0.218	0.333	0.347	0.402	0.071	0.230	0.262	0.313	0.071	0.084	0.095	0.110
Hazard-12	0.201	0.242	0.263	0.304	0.109	0.180	0.208	0.264	0.043	0.147	0.172	0.223	0.041	0.054	0.060	0.078
Hazard-13	0.278	0.320	0.340	0.371	0.147	0.243	0.270	0.326	0.091	0.281	0.287	0.338	0.067	0.084	0.095	0.112
Hazard-14	0.211	0.253	0.268	0.304	0.114	0.194	0.215	0.270	0.018	0.070	0.115	0.166	0.037	0.052	0.063	0.080
Hazard-15	0.299	0.340	0.366	0.382	0.093	0.160	0.187	0.243	0.043	0.153	0.185	0.236	0.028	0.041	0.047	0.065
Hazard-16	0.320	0.361	0.392	0.402	0.065	0.132	0.153	0.208	0.043	0.140	0.160	0.211	0.056	0.071	0.075	0.093
Hazard-17	0.273	0.315	0.330	0.361	0.082	0.153	0.173	0.229	0.058	0.198	0.217	0.268	0.067	0.084	0.088	0.106
Hazard-18	0.196	0.237	0.253	0.294	0.142	0.236	0.277	0.333	0.060	0.204	0.230	0.281	0.030	0.043	0.052	0.069
Hazard-19	0.170	0.211	0.232	0.273	0.104	0.180	0.229	0.284	0.073	0.230	0.262	0.313	0.030	0.041	0.047	0.065
Hazard-20	0.268	0.309	0.320	0.356	0.038	0.076	0.104	0.160	0.048	0.166	0.192	0.243	0.032	0.045	0.056	0.071

We set the FPIS and the FNIS values as: (1, 1, 1, 1) and (0, 0, 0, 0). For the next step, the distance of each alternative from FPIS and FNIS are calculated using Eqs. (18) and (19). The next step presents the similarities to an ideal solution by Eq. (20). The resulting closeness coefficients values of are reported in Table 9.

Table 9 TrF-TOPSIS C_i^* values

Hazard	S_i^+	S_i^-	C_i^*
Hazard-1	5.811	1.410	0.195
Hazard-2	5.526	1.715	0.237
Hazard-3	5.541	1.707	0.235
Hazard-4	5.772	1.473	0.203
Hazard-5	5.364	1.883	0.260
Hazard-6	5.711	1.537	0.212
Hazard-7	5.508	1.733	0.239
Hazard-8	5.547	1.695	0.234
Hazard-9	5.520	1.719	0.237
Hazard-10	5.492	1.753	0.242
Hazard-11	5.532	1.711	0.236
Hazard-12	5.944	1.298	0.179
Hazard-13	5.437	1.806	0.249
Hazard-14	6.027	1.219	0.168
Hazard-15	5.819	1.424	0.197
Hazard-16	5.819	1.420	0.196
Hazard-17	5.752	1.489	0.206
Hazard-18	5.768	1.479	0.204
Hazard-19	5.854	1.396	0.193
Hazard-20	5.999	1.246	0.172

According to the TrF-TOPSIS results, the most crucial hazard is the one which has the shortest distance from the fuzzy positive ideal solution and farthest distance from the fuzzy negative ideal solution. When hazards are ordered by giving Ci* value closest to 1 is ranked highest risk, while risks having Ci* value farthest from 1 is ranked lowest risk.

It has been observed that amongst 20 hazards studied herein, skin exposure to fuels/oils (Hazard-5), exposure to chemicals (Hazard-13), exposure to high pressure and high temperature liquids (Hazard-10), fire (Hazard-9) and electrocution (Hazard-9) have appeared the as the hazards processing relatively high-risk ratings. Figure 3 also shows the first five ranking order of hazards with a dashed circle inside the radar chart.

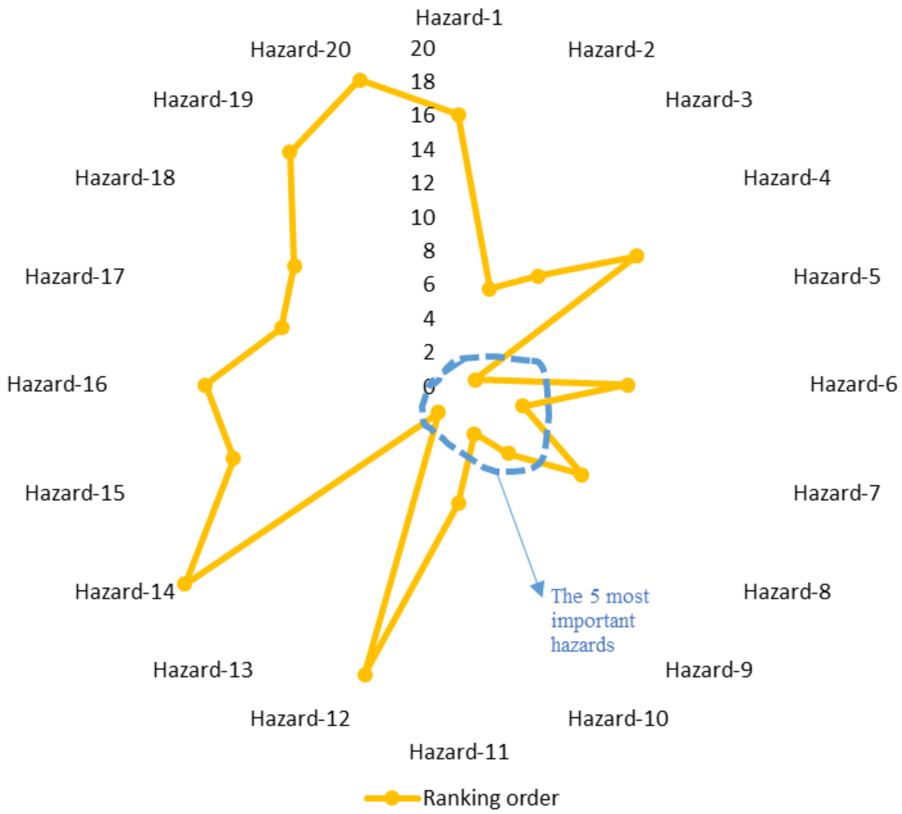

Fig. 3 Ranking order of hazards

3.4 Control measures

Risk assessments on ships are classified. These classifications can be listed as follows: Minor (trivial) risks, tolerable risks, controllable severe risks (moderate), major risks (substantial) and unacceptable major risks (intolerable). There is no need to take any further action than the maintenance of the controls while facing minor risks. These risks are considered acceptable. In tolerable risks, additional checks are not required as long as they cannot be implemented at a low cost (in terms of time, money and effort). To further reduce these risks, actions to be taken are given low priority. Like minor risks, the necessary arrangements must be made to maintain the controls in a complete manner. In controllable severe risks, risks could be reduced to a tolerable level and preferably to an acceptable level, but the costs of additional risk should also be taken into account. Risk mitigation measures should be applied within a defined period of time. In particular, if risk levels are associated with harmful consequences, the necessary arrangements must be made to ensure that control measures are maintained. In major risks, significant efforts should be made to reduce the risk. Risk mitigation measures should be urgently implemented within a certain period of time, and it may be necessary to consider the suspension or restriction of activities or the implementation of interim risk control measures until the completion of this procedure. It may need to allocate considerable resources to additional control measures. Especially with the level of risk is associated with extremely harmful and very harmful consequences result, all necessary arrangements to ensure sustainable control measures should be made. In this risk level, the master should inform the DPA about risk and measures. In the most important and unacceptable major risks, significant improvements in risk are required so that the risk is reduced to a tolerable or acceptable level. If the risk controls applied will not reduce the risk, the operation activity should be stopped. If it is not possible to reduce the risk, it may be necessary to keep the job prohibited. In this risk level, the master should inform the DPA about risk and measures, and also DPA should approve these measures or identify additional ones. Besides, in table 10 in many parts, PPE has many risk prevention features. Many PPEs are available. For example, special helmets to protect the head, special goggles to protect the eyes, headphones for protecting the hearing, protection of the respiratory organs, dressing, gloves, work shoes, hygiene-related equipment are the main ones. After giving place to these general approaches, preventive actions related to the 20 risks included in this study are presented below in Table 10. Due to the insufficiency of the studies on the risks in the ship's engine rooms, we could not compare all the risks we have encountered with the literature. However, the results of our study coincides with the results of the Eide et al. [60] which is focused on oil spill. Besides, many years ago Bloor et al. [61] studied the maritime industry-related health problems which is also matched with the results of our study. In addition, the problems used in Cicek et al. [62] study on fuel systems also support the risks that we presented in our study.

Table 10 Preventive measures for each risk

Hazard	Description of hazard and/or occurring of risk	Preventative measures
Hazard-1	Falling from high spaces	• Personal safety equipment should be used.
Hazard-2	Struck by falling objects	• PPE should always be used • Crew should be informed about current work
Hazard-3	Personal injury	• PPE should always be used • Especially on moving machineries safety signs must be placed properly
Hazard-4	Oil spill	• Bunkering plan should be prepared properly • All scuppers should be closed on deck and oil trays • Portable firefighting equipment should be prepared • Tank soundings should be checked frequently during operations • Oil spill kit should be kept ready
Hazard-5	Skin exposure to fuels/oils	• Appropriate protective gloves should be worn, especially when cleaning filters or adding chemicals to anywhere • Work wears must be worn properly • PPE should always be used
Hazard-7	Fire	• Calibration of pressure gauges must be checked • Checks of pressure safety valves must be carried out at appropriate times • Fire sensors must be checked • General fire extinguisher systems must be checked • Expiry dates of fire extinguisher tubes should be up to date • No smoking in the engine room • Self-closing doors must be kept closed all time
Hazard-8	Inhalation of poison/toxic gaseous	• Fresh air/ventilation should be supplied • Before entering enclosed spaces, gas measurements should be carried out
Hazard-9	Electrocution	• Power supply should be cut off immediately • Warnings should be putted to the all power switches • PPE should always be used • Megger insulation tests should be done properly
Hazard-10		• Involved crew should be warned about danger

	Exposure to high pressure and high temperature liquids	• PPE should always be used
Hazard-11	Lifting heavy objects	• Suitable lifting devices should be used
Hazard-12	Excessive stress to ship structure	• Top bracing systems should be in use
Hazard-13	Exposure to chemicals	• While filter cleaning or adding chemicals masks should be used • PPE should always be used
Hazard-14	Interruption of power loss onboard	• Emergency generator should be at automatic mode in case of power loss • It should be ensured that the lightings used in emergency situations are operational.
Hazard-15	Explosion	• The pressure and temperature sensors must be checked, and the alarms monitored • In the case of any high pressure the relevant equipment should be stopped • Self-closing doors must be kept closed all time
Hazard-16	Drop of crane or grab because of break off wire	• Never stand under hanging loads, • Wires of the relevant device must be checked • Warning signal of crane must be working
Hazard-17	Explosion on auxiliary machinery components	• Periodic maintenance and repairs of auxiliary machines should be carried out.
Hazard-18	Loose floor plating	• Plating must be fixed properly • Personal safety equipment should be used
Hazard-19	Engine room lightning damage	• Intermittently interrupted lamps must be replaced immediately • All maintenance of the diesel generator (DG) providing lighting should be carried out. Because ship provide it is electricity from DG.
Hazard-20	Involuntary explosion of carbon dioxide extinguishing system	• Emergency escape breathing devices (EEBD) should be present • System alarm must be working properly

After the risk analysis phase, which is based on the numerical calculation of the risk, there is another phase where the risk is evaluated and controlled within certain periods. Evaluation of the risk is of course dynamic and its effect varies depending on the workplace, employer / worker and process conditions that change over time. However, it is valid for a long time unless there is a significant change and there is no reason to suspect validity. The risk assessment should be renewed according to the hazard class of the activity. In some countries (such as Turkey), there are three different hazard classes which are very hazardous, hazardous and less hazardous workplaces. These workplaces should renew their risk assessments in two-year, four-year and six-year period, respectively. Yazdi et al. [63] presented a systematic approach to update the risk analysis results in a dynamic environment. While doing this, they benefited from two important well-known MCDM methods of DEMATEL and Best and Worst Method (BWM), as well as Bayesian Network concept.

Our proposed approach has more advantages than traditional risk analysis methods. That is, the maritime experts involved in the study are aware of the classical methods classifying risks at different levels according to their final risk scores. Opinions of these experts have been asked to differentiate the reliability of the proposed approach. With the review of these experts, it has been re-examined whether the ranking is realized in a reasonable and realistic way. In the risk categorization of the previous studies in the literature (also pointed in the literature review of this study), a categorization has been made under a certain number of risk levels (for example, very high risk, high risk, sustainable risk, possible risk and no action requiring risk). For this study, it has been stated by the participated experts that a categorization similar to that of five classes can be beneficial for the proposed preventive action plan in order to effectively control the emerged risks. Various risks at each level and their corresponding control action plan will enhance successful management and mitigation.

3.5 Validation study on the results

In this sub-section, some validation tests of the obtained results are provided. As a first validation study, we made a comparative study between the results of the current approach (integrated N-AHP & TrF-TOPSIS approach) and another popular MCDM-based method F-VIKOR [40]. In this comparative study, we used the weight values computed by N-AHP and follow the procedure of Gul [40]'s study in ranking hazards. In the computational process of F-VIKOR, we benefited trapezoidal fuzzy numbers as in current approach. The defuzzification method we follow in the F-VIKOR is *Circumference of Centroids* method [22]. We then observe the variations in both final scores and hazard ranks. The results are shown in Fig. 4.

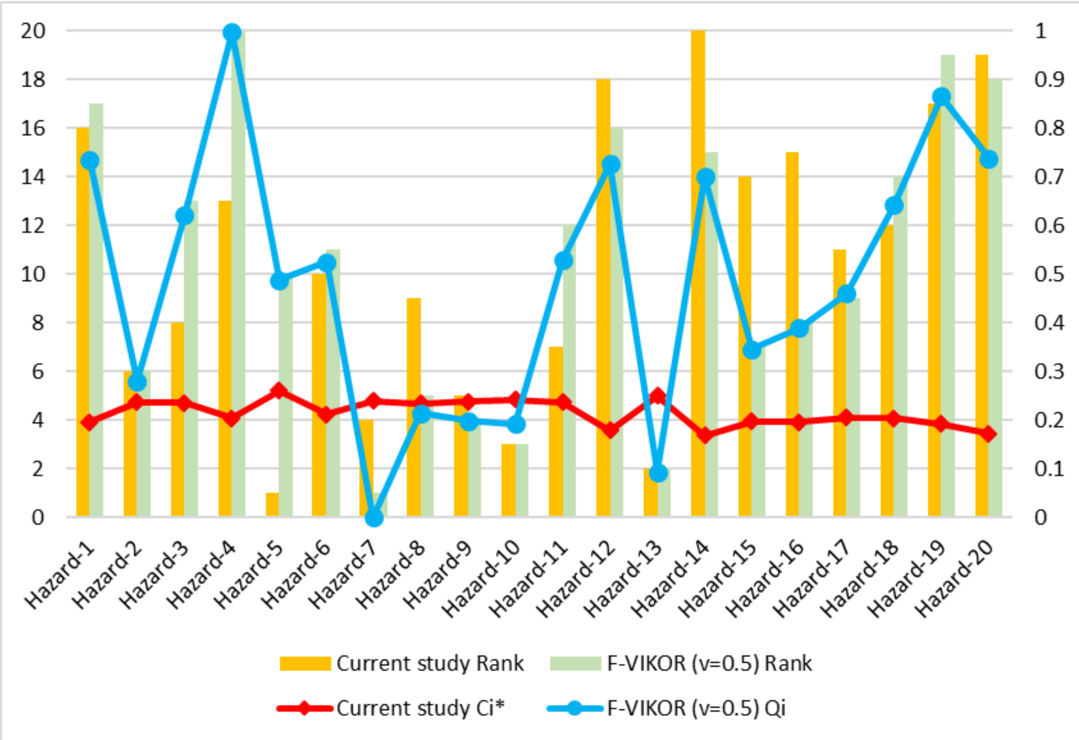

Fig. 4 First validation results: Comparison of final scores & ranks by two approaches

According to the results obtained from Table 11, by both approaches, Hazard-13, Hazard-10 and Hazard-2 have the same ranks. When compared the results in terms of final scores and ranks, we observe some variations between them. The Spearman rank correlation (RHO) between two approaches is obtained as 0.74. That means there exists a close correlation that can be considered high between the ranking orders of two approaches. Moreover, we calculated the Pearson correlation between the final scores of both approaches. It has been obtained as -0.66. That means an intermediate opposite correlation between two approaches. Although there are some variations between both approaches, some close results are also observed. Therefore, the proposed approach is applicable for occupational risk assessment in the marine systems domain.

As a second validation study, we analyze the difference between rank of hazards in times of changing of risk parameters' weights. This is mostly called sensitivity analysis in the literature. Therefore, we apply four different weight vectors as given in Table 11. The rankings of hazards with respect to four different weight vectors are demonstrated in Fig. 5.

Table 11. The weight vectors designed for the sensitivity analysis

Weight vector	Parameter	Weight value	Weight vector	Parameter	Weight value
Weight vector-1 (WV-1)	C1	0.402	Weight vector-3 (WV-3)	C1	0.200
	C2	0.316		C2	0.200
	C3	0.159		C3	0.300
	C4	0.123		C4	0.300
Weight vector-2 (WV-2)	C1	0.250	Weight vector-4 (WV-4)	C1	0.316
	C2	0.250		C2	0.402
	C3	0.250		C3	0.123
	C4	0.250		C4	0.159

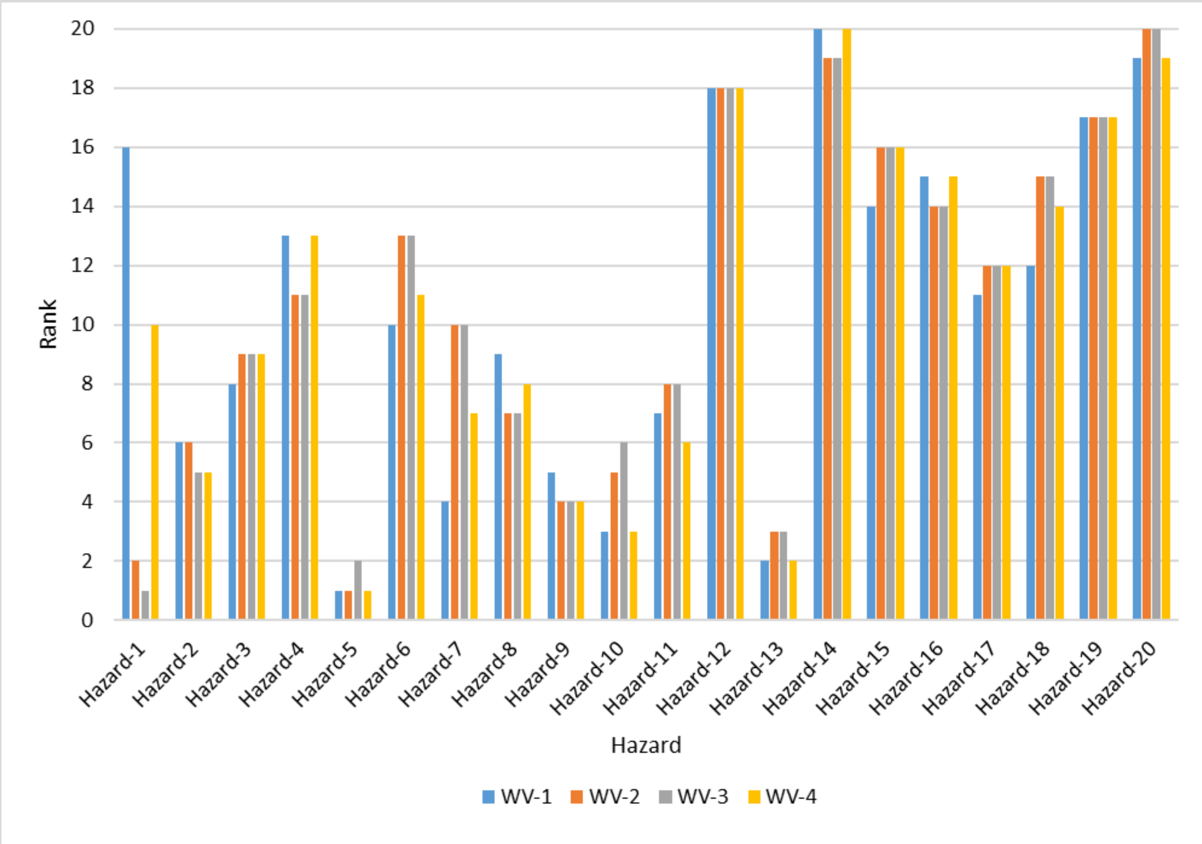

Fig. 5 Second validation results: Ranking changes in times of parameters' weights changes

It can be observed from Fig. 5 that when the weights change, it exists variations in the ranking of hazards. Therefore, our proposed approach is sensitive to risk parameters' weights. Hazard-5 is ranked as the most critical hazard according to the three weight vectors (WV-1, WV-2, WV-4). There is no change in the rankings of Hazard-12 and Hazard-19 under four weight vector combinations. They lie on the 18th and 17th places among the rankings. When compared to the results with the ones similar to this study from the literature, we can say that the ranking result obtained by our proposed approach is credible and applicable.

We also calculated the RHO values between weight vectors by an online calculator. The obtained results are given in Table 12. Results show that there exist high correlations between the ranking orders obtained by four different weight vectors. Since all values are close to 1. To this end, we can be claimed that this proposed approach is sensitive to the changing of the weight values. It is an expected output when considered the similar attempts from the literature.

Table 12. Results of Spearman's RHO between weight vectors

	WV-1	WV-2	WV-3	WV-4
WV-1	-	0.793	0.766	0.954
WV-2		-	0.996	0.927
WV-3			-	0.911
WV-4				-

4. Conclusion and future agenda

The working environments like engine rooms in the ships have faced several kinds of risks. Risk analysis in marine systems requires a great level of expert opinions and subjective judgment. Therefore, frequently encountered risks in the engine room are considered by using N-AHP & TrF-TOPSIS methods. In maritime risk analysis, linguistic assessment of decision-makers in evaluating risks is aided to the robustness of risk assessment tools, neutrosophic sets and fuzzy sets are used together in this study. Neutrosophic sets represent real-world problems effectively by considering all aspects of decision-making situations, (i.e. truthiness, indeterminacy, and falsity). Therefore, AHP is integrated with neutrosophic sets to assign weights of risk parameters initially. Then, the encountered risks are prioritized by TrF-TOPSIS. Finally, preventative actions for the risks have been discussed. In conclusion of the study, it is shown that skin exposure to the fuels/oils, exposure to chemicals and exposure to high pressure and temperature liquids are the most important risks through the engine room on-board. This study contributes to the literature in some aspects as follows:

(i) Neutrosophic sets integrated with AHP is adapted to maritime risk evaluation for the first time.

(ii) The second contribution of the study is regarding the proposal of a new integrated risk assessment methodology in quantifying the risk ratings. The N-AHP and TrF-TOPSIS, which are vital multi-criteria methods with neutrosophic sets and fuzzy sets, are applied integrally to the assessment of risks. By doing this, an improved approach using linguistic terms with neutrosophic set and the trapezoidal fuzzy set has been implemented. This integration successfully managed the uncertainty and vagueness of the expert teams' perceptions, simultaneous consideration of the positive and the negative ideal points, simple computation and logical concept during the subjective judgment process.

(iii) The third contribution concerns the implementation and the sector. Providing control measures can increase the level of safety control and minimize the potential environmental impacts of a ship's damage.

For future works, authors intend to further improve and adapt the methodology to evaluate navigation risks on board. From a methodological point of view, novel methods that integrate with various versions of fuzzy set theory (i.e. intuitionistic fuzzy sets, Pythagorean fuzzy sets, interval type-2 fuzzy sets, hesitant fuzzy sets, spherical fuzzy sets) can be proposed to compare the current work.

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Veysi Başhan, (*corresponding author) veysibashan@gmail.com
Yildiz Technical University, Naval Architecture and Maritime Faculty, 34349, Besiktas, Istanbul, Turkey.
Phone: +90 212 3832936, Fax: +90 2123833021
Hakan Demirel, demirelhakan60@gmail.com
Zonguldak Bülent Ecevit University, Department of Marine Engineering Operations, 67300, Zonguldak, Turkey.
Muhammet Gul, muhammetgul@munzur.edu.tr
Munzur University, Department of Industrial Engineering, 62000, Tunceli, Turkey.