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Hazard Identification and Risk Assessment for Sustainable Shipyard Floating Dock Operations: An Integrated Spherical Fuzzy Analytical Hierarchy Process and Fuzzy CoCoSo Approach

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Abstract: Background: This study investigated the process of selecting sustainable safety protocols for floating dock operations in shipyards by identifying potential workplace risks in emergency situations. Thirteen occupational hazards for shipyard floating dock operations were identified through a literature review and expert discussions. Methods: We incorporated four risk elements (consequence: C, frequency: F, probability: P, and number of people at risk: NP) from the Fine–Kinney and Hazard Rating Number System (HRNS) approaches as the risk assessment criteria. We obtained the importance weights of the risk assessment criteria via the Spherical Fuzzy Analytical Hierarchy Process (SF-AHP) and extended the Combined Compromise Solution (CoCoSo) method within the fuzzy framework to prioritize occupational hazards. This study demonstrated the practicality and efficiency of the proposed emergency risk assessment model for shipyard floating dock operations through a case example of occupational risk assessment. Results: The analysis results show that H4 is the occupational hazard with the highest priority, with a score of 3.553. H4 represents the hazard associated with insufficient access to the entire pool area. The second and third most important hazards are the inability of cranes to move freely in and out of the berthing dock and the inability to dispatch emergency teams. These hazards, denoted H1 and H12, follow closely behind with scores of 3.391 and 3.344, respectively. H10 is deemed the least concerning hazard, with a score of 1.802. Conclusions: Professionals can handle complex and uncertain risk assessment data more flexibly using the proposed system, which excels in accurately organizing occupational hazards.

Keywords: risk management; multi-criteria decision-making (MCDM) model; SF-AHP; F-CoCoSo; health; safety; sustainability

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1. Introduction

Research on occupational health and safety in developing countries has increased in the last decade, especially within the shipyard industry. Various methods have been suggested for identifying hazards, evaluating risks, and establishing controls [1]. These studies are crucial for swift action in response to hazards during emergencies, which is crucial for minimizing potential impacts [2].

Risk assessment identifies the causes of risks and recommends control measures that should be implemented before any damage or loss occurs. The risk analysis procedure consists of the following steps:

1. Hazard identification: recognize all potential hazards and situations that may cause any harm or loss.

2. Identify people at risk and how they may be harmed: determine who may be affected and how they may be harmed by each hazard.
3. Document findings and implement control measures: incorporate the results of the risk assessment into training and practice.
4. Continuously observe the risk assessment and update it as necessary: review the implemented measures and revise them if the process unfolds differently than planned.

Continuous monitoring and adjustment of risk assessment is essential for sustainable occupational health and safety management [3].

The primary goal of disaster management is to minimize various risks. In other words, it aims to reduce the negative impacts of disasters. Disaster management involves four stages: mitigation/avoidance, preparedness, response, and recovery. Conducting an effective risk analysis is the most crucial factor in the intervention and improvement phase. Sustainable disaster management requires a transformation in workplace culture. This will ensure sustainability by reducing disaster damages. However, to achieve these goals, disaster must be included in risk assessment, and communication and coordination must be maintained across all workplace units. Ensuring sustainable disaster management involves focusing on four key areas: legislation, internal coordination, technology that is responsive and sustainable, and knowledge of the latest disaster risk research [4].

This study aimed to develop innovative and sector-specific techniques by adding a different dimension to traditional risk assessment methods and transforming the disadvantages of these methods into advantages. Multi-criteria decision-making methodologies can address these limitations. Additionally, we opted to utilize linguistic variables because experts' assessments of occupational hazards and risks associated with weighted risk parameters often encompass both bias and objectivity [5].

We incorporated risk elements (consequence: C, frequency: F, probability: P, and number of people at risk: NP) from the Fine–Kinney and Hazard Rating Number System (HRNS) approaches as our risk assessment criteria. The human factor is the most crucial aspect of disasters. This is why the number of people at risk was included in the risk assessment criteria. The importance of these criteria was assessed using a spherical fuzzy set-based AHP. An extension of the CoCoSo method with fuzzy sets allowed us to introduce an innovative approach for prioritizing risks in our study. The unique contributions of this method to the existing literature are outlined in Figure 1.

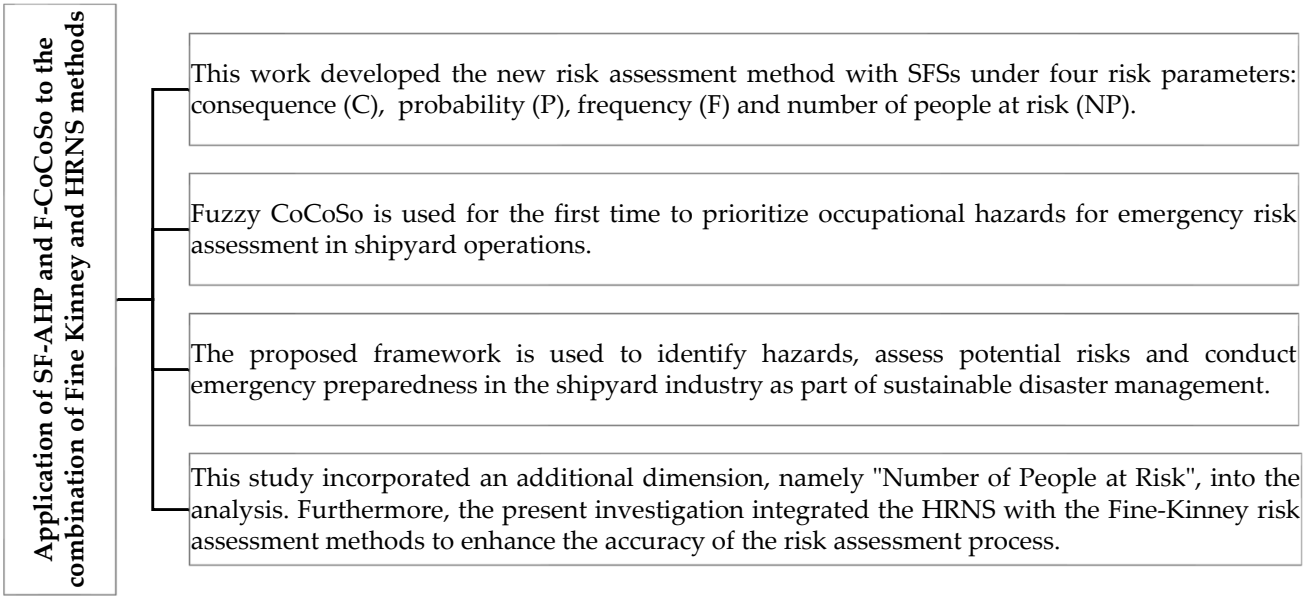


Figure 1. Contributions of the study.

The rest of the article is structured as follows: Section 2 provides a concise overview of past emergency occupational hazard risk assessment (EOHRA) studies, focusing on the fundamental principles and definitions of spherical fuzzy sets (SFSs). A new risk assessment method is presented by incorporating SF-AHP and F-CoCoSo. Section 3 presents a case study including the implementation outcomes, comparative analysis, and sensitivity analysis using approaches found in the existing literature. Lastly, Section 4 presents the conclusions and proposes potential areas for future research based on this study.

2. Literature Review

2.1. Fuzzy MCDM in the Context of Risk Assessment

In this study, the importance of a prompt and appropriate response to occupational hazards during emergencies in ship maintenance and repair is highlighted. A new comprehensive risk assessment approach is suggested to identify occupational hazards, aiming to enhance employee safety, particularly in emergency scenarios. This study utilized the Web of Science (WOS) database, which is known for its high-quality articles, to access relevant scientific literature [6].

A systematic review of scientific research conducted between 2004 and 2024 is presented in this section, and new models and approaches are proposed for assessing occupational hazard risks (Table 1). The aim of the literature review was to examine the limitations of traditional risk assessment approaches and suggest alternative methods for prioritizing risks. The 27 studies that were analyzed employed diverse approaches to tackle risk assessment issues, using a range of value and benefit methodologies. Papadakis et al. introduced a hybrid approach for risk analysis by integrating the gradual weight assessment ratio analysis and complex proportional assessment methods [7]. The Best–Worst Method (BWM) was used to prioritize options and reach a compromise within a type-2 fuzzy framework to address risk issues in dam construction [8]. The emphasis of one study was on utilizing the Hazard Identification, Risk Assessment, and Risk Control (HIRARC) model to recognize, evaluate, and manage safety and health hazards at a hydroelectric power production facility [9]. Another study integrated the Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH) approach with a Choquet integral to address the limitations of conventional risk matrices by introducing the Impact and Risk Integrated by Similarity (IRIS) methodology [10]. The fuzzy AHP method was used to assess the severity of the main risk factors in hospitals, and fuzzy VIKOR was applied to prioritize the types of hazards [11]. The AHP method was used to prioritize hazards based on their importance levels, and the Fine–Kinney method was applied to assess the hazards and determine their risk class [12]. Another study used a method that combined SWOT analysis with Unstable Fuzzy Linguistic Term Sets to evaluate occupational safety risks in the life cycle of a wind turbine [13]. Other scholars used a hybrid approach combining the fuzzy extended AHP with the Proportional Risk Assessment (PRA) technique [14]. In another study, the authors developed a practical hybrid risk analysis and ranking method that integrates the Fine–Kinney risk assessment method with the analytical hierarchy process for lifting tools used in the construction industry [15]. The D-SWOT method, which combines the strengths–weaknesses–opportunities–threats analysis with the D number theory, was used to evaluate safety risks in the life cycle of a wind turbine [16]. The Pythagorean fuzzy AHP was employed to detect and prioritize the hazards linked with the operations of hydroelectric power plants [17]. The integration of the FMEA approach with the Interval-Valued Intuitionistic Fuzzy (IVIF)-based MABAC method was carried out to overcome the substantial drawbacks found in conventional methods [18]. To eliminate all risks related to driverless vehicles, AHP, TOPSIS, and VIKOR methods were used with Pythagorean fuzzy (PF) sets [19]. An ELECTRE-I approach under the hesitant Pythagorean fuzzy (HPF) environment was proposed for the prevention of infant abduction and risk assessment of healthcare failure modes during blood transfusion [20]. Another study developed an innovative risk assessment method for natural gas pipeline construction using spherical fuzzy sets (SFSs) [21]. A hybrid approach integrating probabilistic hesitant

fuzzy (PHF)-based BWM and TOPSIS methods was used to evaluate the risks in gear grinding machine systems [22]. A comprehensive framework for FMEA was developed by integrating the evidentiary BWM and SMAA-MARCOS methods, along with the BWM, Dempster–Shafer theory, and stochastic methods [23].

Table 1. Literature on fuzzy MCDM for risk assessment.

References	Methods	Applications	Advantages
[7]	TFN, BWM, AHP	LPG storage	A new method using four variables in the probability function is presented to improve safety decision-making measures and assess risks when working with hazardous substances.
[8]	IT2F, BWM MARCOS	Dam construction	The value and benefit methodologies used in this study address the OSHRA issues in dam construction.
[9]	HIRAC model	Hydroelectric power	This approach enhances the safety protocols for occupational risks and their management.
[10]	IRIS, MACBETH	-	The IRIS method refines risk matrices by integrating decision analysis to address their limitations.
[11]	Buckley's FAHP, FVIKOR	Hospitals	This approach identifies and prioritizes potential dangers in healthcare settings.
[12]	AHP, Fine–Kinney	Machine manufacturing	This approach enables a thorough risk assessment by evaluating hazard significance and identifying those requiring immediate intervention based on their categories.
[13]	HF, SWOT	Wind turbine	This study used a comprehensive methodology that combines qualitative analysis, expert judgment, and fuzzy logic to enhance risk assessment tools for improving OHS practices.
[14]	FE, AHP	Construction	This approach enables the prioritization of risks on worksites based on expert opinions and actual accident data.
[15]	Fine–Kinney, AHP	Construction	An approach to risk analysis is suggested, combining the constraints of the Fine–Kinney method with the AHP method.
[16]	D number theory, SWOT	Wind turbine	This approach provides a way to simplify information processing and offers a more intuitive and concise alternative to previous methods.
[17]	PF, AHP	Hydroelectric power	This study found that improving occupational safety in hydroelectric power plants led to reduced financial losses and enhanced risk management.
[18]	FMEA, IVIF, MABAC	Radiation therapy	A new FMEA approach is proposed, which offers a linear programming model to determine the optimal weights for risk factors.
[19]	PF, AHP, TOPSIS, VIKOR	Automated driving	This approach fully considers all risks associated with driverless vehicles.
[20]	HPF, ELECTRE-I	Health	An ELECTRE-I approach was developed for healthcare risk assessment under HPF environment.
[21]	Fine–Kinney Complex SF, Risk prioritization CRADIS	Pipeline construction	This study proposed an innovative risk assessment method using complex spherical fuzzy sets in the context of natural gas pipeline construction.
[22]	FMEA, PHF, BWM, TOPSIS	Gear grinding machine	This model combines subjective and objective risk factor weights and uses a hybrid MCDM approach to enhance risk priority ranking in FMEA.
[23]	FMEA, BWM, SMAA-MARCOS	Industry 4.0	This approach reduces uncertainties in risk assessment for Industry 4.0 and smart manufacturing failure modes.

TFN: Triangular Fuzzy Numbers; IVIF: Interval-Valued Intuitionistic Fuzzy; SF: Spherical Fuzzy; IT2F: Interval Type-2 Fuzzy Set; HF; Hesitant Fuzzy; HPF: Hesitant Pythagorean Fuzzy; IHF: Intuitionistic and Hesitant Fuzzy; PF: Pythagorean Fuzzy; IVDHF: Interval-Valued Dual Hesitant Fuzzy; PHF: Proportional Hesitant Fuzzy.

2.2. Fuzzy MCDM in the Context of Risk Assessment for Shipyard Floating Dock Operations

We also reviewed research studies in the marine and shipbuilding industry (Table 2). In one study, an approach called HFACS-SIBCI that combines the HFA and classification system framework with Fault Tree Analysis (FTA) was developed to assess risk factors associated with collision between icebreakers and ships in icy waters [24]. In another study, spherical fuzzy Critical Impact Analysis (CIA) techniques tailored to the shipbuilding industry were utilized [25]. Other scholars used FMEA methods combined with evidential reasoning and a rule-based Bayesian network to assess the risk levels of the identified hazards for Maritime Autonomous Surface Ships (MASSs) [26]. Ballast tank maintenance is crucial for the safety of personnel during cargo ship operations, especially when a cargo ship is loaded or in a dry dock. Methods such as Fine–Kinney, interval type-2 fuzzy (IT2F)-based TODIM, and BWM are used to prioritize risk assessment and ensure safety [27]. The IF-TOPSIS method was used to better assess and manage the complex risks linked to the construction of cruise ships [28]. Another study used Lempel–Ziv complexity enhancement and the Order Preference Technique by Similarity to Ideal Solution to analyze ship travel time and traffic regime to improve traffic safety management [29]. The authors of [30] used Event Tree Analysis (ETA) and Bayesian networks for onboard safety decision making during emergencies.

Table 2. Literature on fuzzy MCDM for risk assessment for shipyards.

References	Methods	Applications	Advantages
[24]	HFACS-FTA	Maritime	This study identified and categorized collision risk factors in icebreaker-assisted navigation operations, offering insight into risk control strategies in this sector.
[25]	Fine–Kinney, FMEA, SF, AHP, VIKOR	Shipyard	Spherical fuzzy safety and Critical Impact Analysis was used to provide occupational risk assessment specifically for shipyards in Turkey.
[26]	FMEA, Bayesian	Maritime	This study provides important information about significant hazards and contributes to MASS's overall safety assurance.
[27]	Fine–Kinney, IT2F, TODIM, BWM	Shipyard	Maintenance of ballast tanks is crucial when a cargo ship is loaded or in a dry dock. This approach helps prioritize risk assessment to ensure the safety and health of personnel during operations.
[28]	IF, TOPSIS	Maritime	This study aimed to improve the ability to assess and manage complex risks associated with cruise ship construction environments by addressing uncertainty in the decision-making process.
[29]	Artificial intelligence Lempel–Ziv algorithm, TOPSIS	Maritime	This study developed a method to estimate the complexity of maritime traffic on inland waterways using predictive analytics.
[30]	ETA, Bayesian	Maritime	This approach simplifies the analysis of various dangerous situations, ranging from shipboard emergencies to survival at sea.

3. Materials and Methods

3.1. Definition of Criteria

This section summarizes the procedural steps and theoretical understanding of the Fine–Kinney and HRNS approaches. It aims to facilitate a better understanding of the criteria (C, F, P, NP) used in the proposed method. The Fine–Kinney approach is used to assess and address workplace accidents and hazards. It assesses the effectiveness of measures using risk ranking and informs budget allocation for corrective actions [31]. The severity of consequences for an employee in the event of a threat or danger is determined based on the potential outcome of the accident. The risk score is calculated using Equation (1):

$$\text{Risk Score} = C \times F \times P \quad (1)$$

Chris Steel's article published in *SHP* advocates the Hazard Rating Number System (HRNS) method for estimating the significance of risks, which can be customized to specific industries [32]. In the HRNS method, the risk score is calculated using 4 factors: "Probability of Occurrence", "Frequency of Exposure", "Possible Degree of Damage", and "Number of People at Risk". These factors are evaluated at specific intervals and Equation (2) is used to calculate the risk scores [33]:

$$\text{HRNS} = LO \times FE \times DPH \times NP \quad (2)$$

This study incorporated an additional dimension, namely "Number of People at Risk", into the analysis. Furthermore, the present investigation integrated the HRNS method with the Fine–Kinney risk assessment method to enhance the accuracy of the risk assessment process [25]. This work developed a new risk assessment method with SFSs using four risk factors:

1. Consequence (C): the severity of the consequences for an employee in the event of threats or hazards is the primary factor in determining the likelihood of a potential accident.
2. Frequency (F): this factor describes the rate at which hazardous events occur.
3. Probability (P): this factor refers to the probability of a dangerous event occurring.
4. Number of people at risk (NP): the number of people at risk indicates the density of employees in the work area.

3.2. The Proposed Emergency Occupational Hazard Risk Assessment (EOHRA) Model

Before applying the SF-AHP and F-CoCoSo methodologies, the weights of the risk parameters were calculated and used to prioritize hazards. The flow of the stages for occupational risk assessment in emergency situations is illustrated in Figure 2.

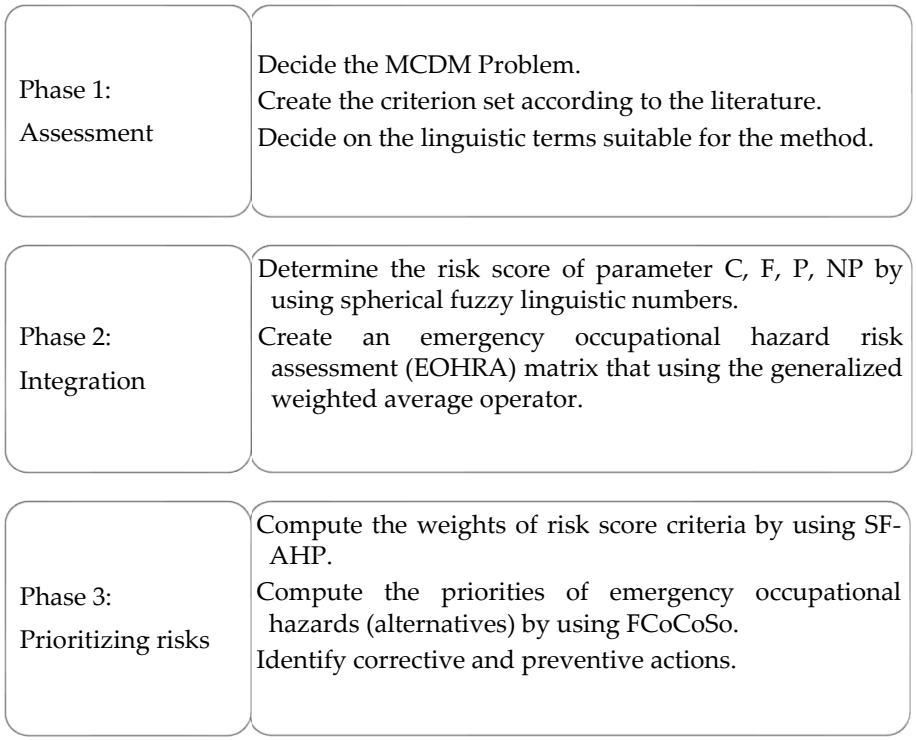


Figure 2. The proposed EOHRA framework.

3.3. Spherical Fuzzy Analytic Hierarchy Process (SF-AHP)

SF-AHP was developed by Gündoğdu and Kahraman. It was applied in this study to calculate the weights of the risk score parameters. SF-AHP involves five stages:

Stage 1. Creating a hierarchical structure.
A linguistic comparative decision matrix is built for fuzzy analysis, with the criteria (i, j = 1, 2, . . ., n), hazards (h = 1, 2, . . ., m), experts (k = 1, 2, . . . p), and pairwise comparison matrices (s = 1, 2, . . . o).
Stage 2. Pairwise comparison matrices of the criteria are created using spherical fuzzy expressions and linguistic terms (Table 3) [34].
Equations (3) and (4) are used to calculate the score indices for each criterion:

$$SI = \sqrt{\left|100 \times \left[\left(\mu_{\widetilde{A}_s} - \pi_{\widetilde{A}_s}\right)^2 - \left(\vartheta_{\widetilde{A}_s} - \pi_{\widetilde{A}_s}\right)^2\right]\right|} \quad (3)$$

for AMI, VHI, HI, SMI, and EI;

$$\frac{1}{SI} = 1/\sqrt{\left|100 \times \left[\left(\mu_{\widetilde{A}_s} - \pi_{\widetilde{A}_s}\right)^2 - \left(\vartheta_{\widetilde{A}_s} - \pi_{\widetilde{A}_s}\right)^2\right]\right|} \quad (4)$$

for SLI, LI, VLI, and ALI.
Stage 3. Checking the consistency of all pairwise comparison matrices.
The consistency calculation is performed using a 10% Consistency Ratio (CR) threshold as follows:

$$CR = CI/CR \quad (5)$$

The Consistency Index (CI) is calculated according to Equation (6):

$$CI = (\lambda_{max} - n)/(n - 1) \quad (6)$$

where λ_{max} is the max eigenvalue of the matrix and n represents the number of criteria [35].
Stage 4. Obtaining fuzzy criterion weights.
The relative weight of each criterion is calculated using Equations (7) and (8).

$$Score\left(\widetilde{A}_S\right) = \left(\mu_{\widetilde{A}_s} - \pi_{\widetilde{A}_s}\right)^2 - \left(\vartheta_{\widetilde{A}_s} - \pi_{\widetilde{A}_s}\right)^2 \quad (7)$$

$$Accuracy\left(\widetilde{A}_S\right) = \mu^2_{\widetilde{A}_s} + \vartheta^2_{\widetilde{A}_s} + \pi^2_{\widetilde{A}_s} \quad (8)$$

Stage 5. Computing the overall weights using hierarchical layer sorting.
The final order is determined by adding up the spherical weights at each hierarchical level. Equation (9) is used to smooth out the criterion weights.

$$S\left(\widetilde{w}_j^S\right) = \sqrt{\left|100 \times \left[\left(3\mu_{\widetilde{A}_s} - \frac{\pi_{\widetilde{A}_s}}{2}\right)^2 - \left(\frac{\vartheta_{\widetilde{A}_s}}{2} - \pi_{\widetilde{A}_s}\right)^2\right]\right|} \quad (9)$$

The criterion weights are normalized and then used in the spherical fuzzy product (Equations (10) and (11)).

$$\overline{w}_j^S = \frac{S\left(\widetilde{w}_j^S\right)}{\sum_{j=1}^{n} S\left(\widetilde{w}_j^S\right)} \quad (10)$$

$$\widetilde{A}_{S_{ij}} = \overline{w}_j^S \times \widetilde{A}_{S_i} \quad (11)$$

Table 3. Spherical fuzzy linguistic terms.

Linguistic Variables	Spherical Fuzzy Numbers		
	μ	ϑ	π
Absolutely more important (AMI)	0.9	0.1	0.1
Very high important (VHI)	0.8	0.2	0.2
High important (HI)	0.7	0.3	0.3
Slightly more important (SMI)	0.6	0.4	0.4
Equally important (EI)	0.5	0.5	0.5
Slightly low important (SLI)	0.4	0.6	0.4
Low important (LI)	0.3	0.7	0.3
Very low important (VLI)	0.2	0.8	0.2
Absolutely low important (ALI)	0.1	0.9	0.1

3.4. Fuzzy Combined Compromise Solution (F-CoCoSo)

The CoCoSo method combines simple additive weighting and the exponential weighted product, providing experts with effective decision-making opportunities due to its stability and reliability compared to other methods [35]. CoCoSo faces data precision issues like AHP. Therefore, the CoCoSo method is extended as F-CoCoSo (Table 4). The steps of the recommended F-CoCoSo method are as follows [36]:

Step 1. Achieving a fuzzy decision matrix ($\tilde{Z}$)
Creating a decision matrix $D = \{d_1, d_2, \ldots, d_p\}$ based on expert opinions is the initial step in MCDM. This set of default criteria is $C = \{C_1, C_2, \ldots C_J \ldots, C_q\}$, and for $C_j \in C$, $w_j \in [0, 1]$ is the criterion weight. $\tilde{Z} = [\tilde{Z}_{ij}]_{pxq}$ represents the assessment of m selections using a matrix formed based on the linguistic terms related to the n criteria selected by experts [37].

$$\tilde{Z} = \left[\tilde{Z}_{ij}\right]_{pxq} = \begin{bmatrix} \tilde{z}_{11} & \cdots & \tilde{z}_{1q} \\ \vdots & \ddots & \vdots \\ \tilde{z}_{p1} & \cdots & \tilde{z}_{pq} \end{bmatrix}, c = 1, 2, \ldots p; d = 1, 2, \ldots q \quad (12)$$

Step 2. Transforming the linguistic variables into fuzzy numbers
The decision matrix in Step 1 is transformed into fuzzy numbers using the linguistic variables (Table 4), and a decision matrix is obtained based on Equation (13) $\left(\tilde{Z}_{ij} = (z^l_{ij}, z^m_{ij}, z^u_{ij})\right)$, where i denotes an alternative, and j denotes a criterion).

$$\left[\tilde{Z}_{ij}\right]_{pxq} = \begin{bmatrix} l_{11}m_{11}u_{11} & \cdots & l_{1q}m_{1q}u_{1q} \\ \vdots & \ddots & \vdots \\ l_{p1}m_{p1}u_{p1} & \cdots & l_{pq}m_{pq}u_{pq} \end{bmatrix} \quad (13)$$

Step 3. Creating an integrated decision matrix
An integrated decision matrix is created by using Spherical Weighted Arithmetic Mean (SWAM) and Spherical Weighted Geometric Mean (SWGM) operators, considering the weights assigned to each criterion and the opinions of dm experts according to Equations (7) and (8).
Step 4. Achieving a normalized fuzzy decision matrix ($\widetilde{R}$)
The decision matrix is normalized based on the benefit and harm criteria (Equations (14) and (15)).

$$\widetilde{R} = \left[\tilde{r}_{ij}\right]_{pxq} = \tilde{r}_{ij} = (r^l_{ij}, r^m_{ij}, r^u_{ij}) = \frac{\max(\tilde{z}_{ij}) - \tilde{z}_{ij}}{\max(\tilde{z}_{ij}) - \min(\tilde{z}_{ij})} = \left(\frac{\max(z^u_{ij}) - z^u_{ij}}{\max(z^u_{ij}) - \min(z^l_{ij})}, \frac{\max(z^u_{ij}) - z^m_{ij}}{\max(z^u_{ij}) - \min(z^l_{ij})}, \frac{\max(z^u_{ij}) - z^l_{ij}}{\max(z^u_{ij}) - \min(z^l_{ij})}\right) \quad (14)$$

$$\widetilde{R} = \left[\tilde{r}_{ij}\right]_{pxq} = \tilde{r}_{ij} = \left(r^{l}_{ij}, r^{m}_{ij}, r^{u}_{ij}\right) = \frac{\tilde{z}_{ij} - \min(\tilde{z}_{ij})}{\max(\tilde{z}_{ij}) - \min(\tilde{z}_{ij})} = \left(\frac{z^{l}_{ij} - \min(z^{l}_{ij})}{\max(z^{u}_{ij}) - \min(z^{l}_{ij})}, \frac{z^{m}_{ij} - \min(z^{l}_{ij})}{\max(z^{u}_{ij}) - \min(z^{l}_{ij})}, \frac{z^{u}_{ij} - \min(z^{l}_{ij})}{\max(z^{u}_{ij}) - \min(z^{l}_{ij})}\right) \quad (15)$$

Step 5. The power weight of comparability ($\widetilde{P}_i$) and the sum of weighted comparability ($\widetilde{S}_i$) sequences for each alternative are calculated as follows [38]:

$$\widetilde{S}_i = \left(S^{l}_i, S^{m}_i, S^{u}_i\right) = \sum_{j=1}^{n} \widetilde{\omega}_{jc}\tilde{r}_{ij} = \left(\sum_{j=1}^{n} \omega^{l}_{jc} r^{l}_{ij}, \sum_{j=1}^{n} \omega^{m}_{jc} r^{m}_{ij}, \sum_{j=1}^{n} \omega^{u}_{jc} r^{u}_{ij}\right) \quad (16)$$

$$\widetilde{P}_i = \left(P^{l}_i, P^{m}_i, P^{u}_i\right) = \sum_{j=1}^{n} \left(\tilde{r}_{ij}\right)^{\tilde{\omega}_{jc}} = \left(\sum_{j=1}^{n} \left(r^{l}_{ij}\right)^{\omega^{u}_{jc}}, \sum_{j=1}^{n} \left(r^{m}_{ij}\right)^{\omega^{m}_{jc}}, \sum_{j=1}^{n} \left(r^{u}_{ij}\right)^{\omega^{l}_{jc}}\right) \quad (17)$$

Step 6. Calculating evaluation scores for three different strategies

The comparative scores of WSM and WPM are calculated using Equations (18) and (19). Equation (20) is used to balance WSM and WPM [39].

$$\tilde{f}_{ia} = \left(f^{l}_{ia}, f^{m}_{ia}, f^{u}_{ia}\right) = \frac{\tilde{P}_{i+}\tilde{S}_i}{\sum_{i=1}^{k}\left(\tilde{P}_{i+}\tilde{S}_i\right)} = \left(\frac{P^{l}_i + S^{l}_i}{\sum_{i=1}^{k}\left(P^{u}_i + S^{u}_i\right)}, \frac{P^{m}_i + S^{m}_i}{\sum_{i=1}^{k}\left(P^{m}_i + S^{m}_i\right)}, \frac{P^{u}_i + S^{u}_i}{\sum_{i=1}^{k}\left(P^{l}_i + S^{l}_i\right)}\right) \quad (18)$$

$$\tilde{f}_{ib} = \left(f^{l}_{ib}, f^{m}_{ib}, f^{u}_{ib}\right) = \frac{\tilde{S}_i}{\min(\tilde{S}_i)} + \frac{\tilde{P}_i}{\min(\tilde{P}_i)} = \left(\frac{S^{l}_i}{\min(S^{l}_i)} + \frac{P^{l}_i}{\min(P^{l}_i)}, \frac{S^{m}_i}{\min(S^{l}_i)} + \frac{P^{m}_i}{\min(P^{l}_i)}, \frac{S^{u}_i}{\min(S^{l}_i)} + \frac{P^{u}_i}{\min(P^{l}_i)}\right) \quad (19)$$

$$\tilde{f}_{ic} = \left(f^{l}_{ic}, f^{m}_{ic}, f^{u}_{ic}\right) = \frac{\lambda(\tilde{S}_i) + (1-\lambda)\tilde{P}_i}{\lambda\max(\tilde{S}_i) + (1-\lambda)\max(\tilde{P}_i)} = \left(\frac{\lambda\left(S^{l}_i\right) + (1-\lambda)(P^{l}_i)}{\lambda\max(S^{u}_i) + (1-\lambda)\max(P^{u}_i)}, \frac{\lambda(S^{m}_i) + (1-\lambda)(P^{m}_i)}{\lambda\max(S^{u}_i) + (1-\lambda)\max(P^{u}_i)}, \frac{\lambda(S^{u}_i) + (1-\lambda)(P^{u}_i)}{\lambda\max(S^{u}_i) + (1-\lambda)\max(P^{u}_i)}\right) \quad (20)$$

The value λ in Equation (18) is accepted as $\lambda = 0.5$.

Step 7. Obtaining evaluation scores

The fuzzy evaluation scores are converted into net results using Equations (21) and (23) [38,39] as follows:

$$f_{ia} = \frac{f^{l}_{ia}, f^{m}_{ia}, f^{u}_{ia}}{3} \quad (21)$$

$$f_{ib} = \frac{f^{l}_{ib}, f^{m}_{ib}, f^{u}_{ib}}{3} \quad (22)$$

$$f_{ic} = \frac{f^{l}_{ic}, f^{m}_{ic}, f^{u}_{ic}}{3} \quad (23)$$

Step 8. Computing crisp scores

The final scores are determined using Equation (24). These determined scores represent the sum of the arithmetic mean and the geometric mean of the three calculated strategies. Therefore, the alternative is the one with the highest score [39].

$$f_i = \sqrt[3]{f_{ia} f_{ib} f_{ic}} + \frac{f_{ia} + f_{ib} + f_{ic}}{3} \quad (24)$$

Table 4. Fuzzy linguistic scale.

Linguistic Scale	Triangle Fuzzy Number
Very High (VH)	(0.9, 1.0, 1.0)
High (H)	(0.7, 0.9, 1.0)
Medium High (MH)	(0.5, 0.7, 0.9)
Medium (M)	(0.3, 0.5, 0.7)
Medium Low (ML)	(0.1, 0.3, 0.5)
Low (L)	(0.0, 0.1, 0.3)
Very Low (VL)	(0.0, 0.0, 0.1)

4. Results

This study evaluated potential risks in emergency situations to demonstrate the effectiveness of the proposed risk analysis model. It aimed to develop response strategies for occupational hazards for a company operating shipyards in Tuzla, Istanbul, including comparing the findings and conducting sensitivity analysis. The method combined risk parameters from the Fine–Kinney and HRNS approaches, namely, P, F, C, and NP. The criterion weights were determined using SF-AHP to reduce uncertainty in decision makers' opinions when determining criterion weights.

This risk analysis examined occupational hazards during shipyard floating dock operations. The occupational hazards are listed in Table 5.

Table 5. Occupational hazards in the case study.

Alternatives	Emergency Occupational Hazards in Shipyard Floating Dock Operations
H1	Cranes are unable to move while entering and exiting the docking pool.
H2	Failure to offer ladder and transit services for embarking and disembarking from ships during diving operations.
H3	The docks and ramps to the pool areas are congested with supplies and gear.
H4	When the cat bridge is accessible and the pool float is in the water, there is no suitable pathway to access the entire pool area.
H5	Failure to transfer stretchers during an emergency.
H6	Failure to dispatch emergency crews.
H7	During shipyard maneuvers, vessels may collide with each other or with the berths in the shipyard.
H8	Incapability to intervene or restricted intervention during maneuvering, functioning, and docking procedures in the event of an emergency.
H9	Inability to intervene or limited intervention in the warehouses and working areas remaining at sea in cases where a ship overflows from the pier.
H10	Inability to intervene or limited intervention as a result of operations that completely close the floating docks or crossings to traffic.
H11	Intervention failure or delayed and limited intervention in areas such as living quarters, crane cabins, machine rooms, and poles at heights that are unreachable even with a crane.
H12	Docking vessels for maintenance at shipyards with inappropriate or insufficient facilities and environments, or neglecting to address emergencies that may arise during voyages.
H13	When the floating dock cover is dry (i.e., while operating on the floating dock), the control of a vessel is compromised, leading to collisions with the cover during maneuvers. Adverse weather conditions may also cause a ship to strike the cover when mooring at a pier, or damage to the cover could occur as a result of an earthquake.

Information on the professional experience of the expert team is shown in Table 6. Table 7 presents the comprehensive spherical fuzzy-based evaluations of the risk criteria by the team of experts, including occupational safety experts and engineers.

Table 6. Information on the professional experience of the expert team.

Expert Team	Position	Years of Experience
Expert 1	Project Planning Manager	20 years
Expert 2	Health and Safety Manager	20 years
Expert 3	Shipyard Berth and Dock Operation Captain	15 years
Expert 4	Leader in Operational Excellence	10 years

Table 7. Decision matrix of the expert team regarding the risk criteria.

Risk criteria									
Expert 1	C	F	P	NP	Expert 3	C	F	P	NP
C	EL	AMI	LI	ALI	C	EL	HI	SMI	SLI
F	ALI	EL	HI	SLI	F	LI	EL	VHI	LI
P	HI	LI	EL	SMI	P	SLI	VLI	EL	AMI
NP	AMI	SMI	SLI	EL	NP	SMI	HI	ALI	EL
Expert 2	C	F	P	NP	Expert 4	C	F	P	NP
C	EL	AMI	HI	LI	C	EL	SLI	VLI	HI
F	ALI	EL	AMI	HI	F	SMI	EL	SLI	VLI
P	LI	ALI	EL	VHI	P	VHI	SMI	EL	LI
NP	HI	LI	VLI	EL	NP	LI	VHI	HI	EL

4.1. Application of the Framework

The section discusses the findings of this study in assessing occupational risks in ship maintenance and repair during emergencies. This study introduced an original approach utilizing advanced MCDM techniques within an unpredictable setting.

In the first phase of the proposed approach, the expert team used Table 3 to explain the linguistic significance of the criteria listed in Table 7. The linguistic variables in Table 6 were transformed into the general fuzzy numbers shown in Table 8.

Table 8. Integrated spherical fuzzy comparison matrix.

	C			**F**			**P**			**NP**		
C	0.500	0.400	0.400	0.690	0.362	0.204	0.398	0.623	0.199	0.303	0.716	0.181
F	0.206	0.805	0.130	0.500	0.400	0.400	0.670	0.371	0.209	0.360	0.654	0.205
P	0.509	0.519	0.226	0.245	0.766	0.150	0.500	0.400	0.400	0.600	0.449	0.200
NP	0.580	0.460	0.214	0.563	0.467	0.218	0.274	0.744	0.156	0.500	0.400	0.400

The crisp values of the criterion weights obtained from the analysis are presented in Table 9.

Table 9. Weights of risk parameters based on SF-AHP.

	Spherical Fuzzy Weights			CRISP Weights
C	0.510	0.504	0.268	0.258
F	0.484	0.529	0.267	0.243
P	0.490	0.517	0.269	0.246
NP	0.501	0.503	0.270	0.253

The weights of the criteria were determined using Equations (10) and (11). The obtained CRISP values are 0.258, 0.243, 0.246, and 0.253. The criterion consequence takes precedence, with a value of 0.258. Afterwards, fuzzy CoCoSo was then used to rank the occupational hazards. The linguistic evaluation of thirteen alternatives, created by taking the opinions of the expert team, for each criterion is presented in Table 10. The normalized decision matrix R was obtained based on Equations (14) and (15) (Table 11). The power of total weighted comparability was computed for each occupational hazard using Equations (16) and (17) (Tables 12 and 13).

Table 10. Linguistic evaluation of the thirteen alternatives for each criterion.

Expert 1	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12	H13
C	VL	L	L	VL	H	L	ML	L	ML	L	L	ML	H
F	ML	L	VL	L	VL	L	VL	L	ML	VL	L	L	VL
P	VH	VH	ML	VH	ML	L	VL	L	VH	VH	VH	VH	VL
NP	L	L	L	L	L	L	L	L	L	L	L	L	VH
Expert 2	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12	H13
C	VH	H	H	H	H	VH	VH	VH	H	H	H	VH	VH
F	H	H	M	ML	VL	VL	L	VL	ML	VL	L	L	VL
P	L	VL	VL	L	VL	VL	L	L	VL	L	L	VL	VL
NP	H	H	VH	H	VH	VH	MH	H	H	VH	H	VH	H
Expert 3	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12	H13
C	VL	L	L	VL	H	L	ML	L	ML	H	L	ML	VH
F	VL	L	VL	L	MH	ML	L	M	M	H	VH	L	VL
P	L	M	ML	ML	ML	L	M	VL	ML	MH	ML	VL	VL
NP	H	MH	MH	VH	H	MH	VH	MH	VH	H	ML	MH	VH
Expert 4	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12	H13
C	M	H	MH	H	MH	VH	H	MH	M	H	MH	MH	VH
F	L	M	H	VL	L	L	MH	H	L	MH	H	L	MH
P	VL	L	MH	VL	L	L	M	VL	ML	MH	L	VL	H
NP	M	H	H	MH	H	VH	MH	H	M	VH	H	MH	VH

Table 11. Normalized matrix.

Alternatives	C			F			P			NP		
H1	0.745	0.891	0.982	0.243	0.541	0.784	0.489	0.681	0.787	0.450	0.700	0.950
H2	0.655	0.855	1.000	0.243	0.568	0.811	0.255	0.426	0.553	0.400	0.650	0.900
H3	0.527	0.764	0.945	0.297	0.541	0.703	0.340	0.596	0.809	0.400	0.600	0.800
H4	0.764	0.909	1.000	0.486	0.811	1.000	0.404	0.638	0.787	0.400	0.625	0.850
H5	0.018	0.182	0.436	0.622	0.865	1.000	0.383	0.660	0.872	0.225	0.425	0.675
H6	0.364	0.509	0.673	0.486	0.811	1.000	0.000	0.894	1.000	0.200	0.400	0.625
H7	0.436	0.636	0.873	0.135	0.432	0.649	0.383	0.638	0.809	0.400	0.700	0.950
H8	0.527	0.745	0.909	0.243	0.541	0.757	0.000	0.915	1.000	0.350	0.600	0.850
H9	0.327	0.527	0.764	0.162	0.514	0.811	0.255	0.426	0.574	0.250	0.475	0.725
H10	0.218	0.382	0.618	0.135	0.405	0.622	0.000	0.213	0.404	0.175	0.350	0.575
H11	0.509	0.727	0.909	0.000	0.297	0.541	0.213	0.426	0.596	0.450	0.725	1.000
H12	0.545	0.745	0.964	0.432	0.784	0.973	0.426	0.553	0.617	0.450	0.675	0.900
H13	0.000	0.091	0.291	0.324	0.595	0.757	0.574	0.766	0.851	0.000	0.150	0.400

Table 12. The fuzzy weighted comparability sequence and Si.

Alternatives	C			F			P			NP			**Si**		
H1	0.380	0.449	0.263	0.118	0.286	0.209	0.245	0.342	0.127	0.221	0.362	0.256	0.964	1.439	0.855
H2	0.334	0.431	0.268	0.118	0.300	0.216	0.128	0.214	0.089	0.196	0.336	0.242	0.775	1.281	0.816
H3	0.269	0.385	0.253	0.144	0.286	0.188	0.171	0.300	0.130	0.196	0.310	0.215	0.779	1.281	0.786
H4	0.389	0.458	0.268	0.235	0.429	0.267	0.203	0.321	0.127	0.196	0.323	0.229	1.023	1.531	0.890
H5	0.009	0.092	0.117	0.301	0.458	0.267	0.192	0.332	0.140	0.110	0.220	0.182	0.612	1.101	0.706
H6	0.185	0.257	0.180	0.235	0.429	0.267	0.000	0.449	0.161	0.098	0.207	0.168	0.519	1.342	0.776
H7	0.223	0.321	0.234	0.065	0.229	0.173	0.192	0.321	0.130	0.196	0.362	0.256	0.676	1.232	0.793
H8	0.269	0.376	0.244	0.118	0.286	0.202	0.000	0.460	0.161	0.172	0.310	0.229	0.558	1.432	0.835
H9	0.167	0.266	0.205	0.078	0.272	0.216	0.128	0.214	0.092	0.123	0.246	0.195	0.496	0.997	0.709
H10	0.111	0.192	0.166	0.065	0.214	0.166	0.000	0.107	0.065	0.086	0.181	0.155	0.262	0.695	0.551
H11	0.260	0.367	0.244	0.000	0.157	0.144	0.107	0.214	0.096	0.221	0.375	0.269	0.587	1.113	0.753
H12	0.278	0.376	0.258	0.209	0.415	0.260	0.213	0.278	0.099	0.221	0.349	0.242	0.921	1.418	0.859
H13	0.000	0.046	0.078	0.157	0.315	0.202	0.288	0.385	0.137	0.000	0.078	0.108	0.445	0.823	0.525

Table 13. The fuzzy exponentially weighted comparability sequence and Pi.

Alternatives	C			F			P			NP			**Pi**		
H1	0.924	0.943	0.991	0.686	0.722	0.889	0.891	0.824	0.887	0.807	0.832	0.975	3.308	3.321	3.742
H2	0.893	0.924	1.000	0.686	0.741	0.903	0.803	0.651	0.743	0.782	0.800	0.950	3.162	3.116	3.596
H3	0.842	0.873	0.972	0.723	0.722	0.843	0.841	0.771	0.899	0.782	0.768	0.896	3.188	3.134	3.610
H4	0.930	0.953	1.000	0.825	0.895	1.000	0.864	0.798	0.887	0.782	0.784	0.923	3.401	3.430	3.811
H5	0.342	0.424	0.655	0.881	0.926	1.000	0.857	0.811	0.934	0.669	0.643	0.825	2.749	2.803	3.414
H6	0.763	0.712	0.817	0.825	0.895	1.000	0.000	0.945	1.000	0.649	0.623	0.794	2.236	3.174	3.611
H7	0.801	0.796	0.933	0.586	0.642	0.811	0.857	0.798	0.899	0.782	0.832	0.975	3.025	3.068	3.618
H8	0.842	0.862	0.953	0.686	0.722	0.874	0.000	0.956	1.000	0.754	0.768	0.923	2.282	3.309	3.750
H9	0.741	0.724	0.872	0.615	0.703	0.903	0.803	0.651	0.758	0.689	0.681	0.854	2.848	2.758	3.387
H10	0.665	0.616	0.782	0.586	0.620	0.794	0.000	0.459	0.635	0.626	0.581	0.762	1.877	2.276	2.975
H11	0.834	0.852	0.953	0.000	0.526	0.742	0.779	0.651	0.771	0.807	0.847	1.000	2.421	2.876	3.466
H12	0.850	0.862	0.981	0.799	0.879	0.987	0.871	0.742	0.785	0.807	0.816	0.950	3.328	3.300	3.703
H13	0.000	0.299	0.533	0.740	0.760	0.874	0.915	0.874	0.922	0.000	0.375	0.638	1.655	2.308	2.967

Finally, $\tilde{f}_{ia}, \tilde{f}_{ib}, \tilde{f}_{ic}$ were calculated using Equations (21) and (23). In these equations, the λ value is accepted as 0.5. Using these three values, the final score for each occupational hazard was calculated based on Equation (24), and $\tilde{f}_i$ was obtained (Table 14).

Table 14. The fuzzy evaluation scores and ranking.

Alternatives	**Fuzzy F_{ia}**			**Crisp F_{ia}**	**Fuzzy F_{ib}**			**Crisp F_{ib}**	**Fuzzy F_{ic}**			**Crisp F_{ic}**	**Final Score F_i**	**Final Ranking**
H1	0.077	0.087	0.104	0.089	5.671	7.492	5.518	6.227	1.082	1.617	0.960	1.220	3.391	2
H2	0.071	0.081	0.100	0.084	4.866	6.764	5.281	5.637	0.871	1.439	0.916	1.075	3.063	4
H3	0.071	0.081	0.100	0.084	4.896	6.774	5.178	5.616	0.875	1.438	0.883	1.066	3.050	5
H4	0.080	0.091	0.107	0.092	5.955	7.908	5.695	6.519	1.149	1.720	1.000	1.290	3.553	1
H5	0.061	0.072	0.093	0.075	3.994	5.888	4.753	4.878	0.688	1.236	0.793	0.906	2.645	10
H6	0.050	0.083	0.099	0.077	3.329	7.031	5.141	5.167	0.583	1.507	0.872	0.987	2.810	8
H7	0.067	0.079	0.100	0.082	4.403	6.550	5.207	5.387	0.759	1.384	0.890	1.011	2.924	7
H8	0.051	0.087	0.104	0.081	3.506	7.456	5.449	5.470	0.627	1.608	0.938	1.058	2.979	6
H9	0.060	0.069	0.093	0.074	3.610	5.466	4.747	4.608	0.557	1.120	0.796	0.824	2.490	11
H10	0.039	0.054	0.080	0.058	2.134	4.023	3.899	3.352	0.295	0.780	0.619	0.565	1.803	13
H11	0.054	0.073	0.096	0.074	3.698	5.978	4.963	4.880	0.659	1.250	0.846	0.918	2.651	9
H12	0.077	0.086	0.103	0.089	5.521	7.396	5.513	6.143	1.035	1.592	0.965	1.197	3.344	3
H13	0.038	0.057	0.079	0.058	2.695	4.531	3.792	3.673	0.500	0.925	0.589	0.671	1.991	12

Ranking was conducted according to the final scores. As shown in Table 14, the findings indicate that H4 is the priority among the occupational hazards, scoring 3.553. This is followed closely by H1 and H12, with scores of 3.391 and 3.344, respectively, while H10 is deemed the least concerning hazard, with a score of 1.803.

4.2. Sensibility Analysis

Sensibility analysis was conducted to validate the outcomes of the proposed approach. To ensure accuracy, adjustments were made to the main criterion weights obtained using SF-AHP. Six scenarios were considered for this purpose (Table 15).

Upon examining the sensitivity analysis results shown in Figure 3, it was found that changes in the risk criterion weights did not significantly impact the occupational hazards' ranking. This indicates that the model's reliability remains robust regarding the risk criterion weights.

Sensibility analysis was conducted by adjusting the threshold parameter (λ) in the CoCoSo process. Figure 4 depicts the impact of λ on the scores for each occupational hazard using the SF-AHP and F-CoCoSo methods.

Table 15. Six different scenario scripts for the sensibility analysis of criterion weights.

Scripts	(C)	(F)	(P)	(NP)
Current	0.258	0.243	0.246	0.253
S 1	0.243	0.258	0.246	0.253
S 2	0.246	0.243	0.258	0.253
S 3	0.253	0.243	0.246	0.258
S 4	0.258	0.246	0.243	0.253
S 5	0.258	0.253	0.246	0.243
S 6	0.258	0.243	0.253	0.246

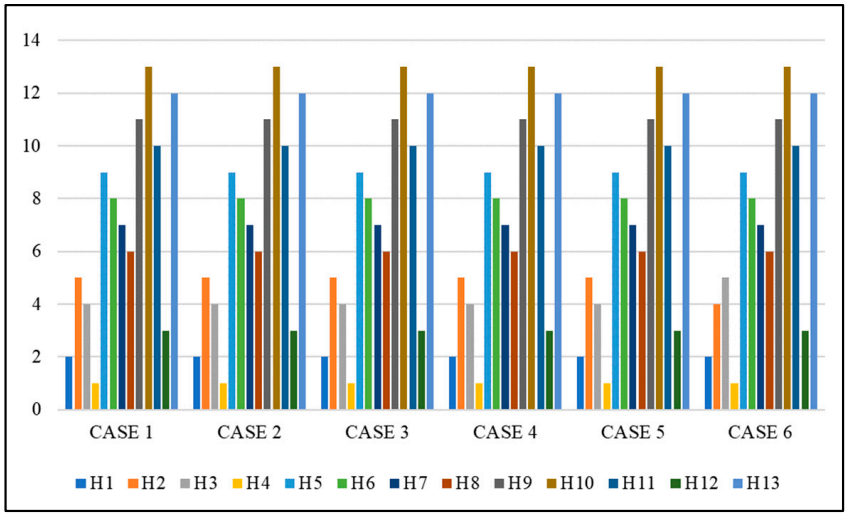


Figure 3. Sensitivity analysis results.

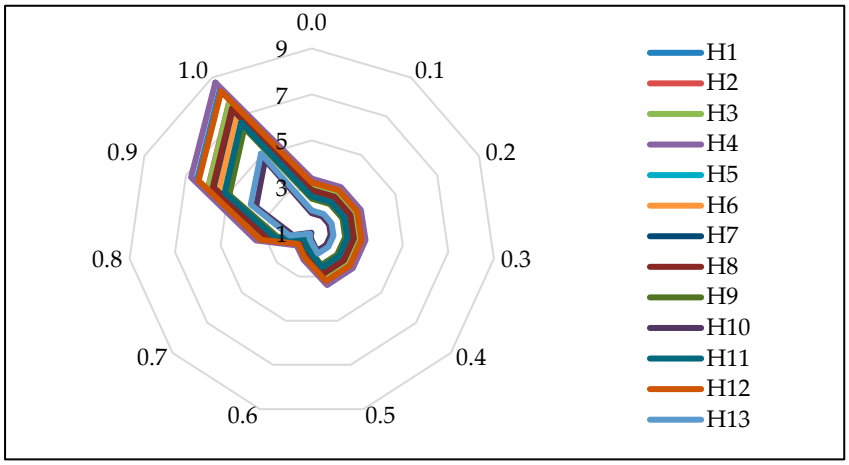


Figure 4. Final scores with different λ values.

4.3. Comparison with Existing Methods

A comparative analysis was performed to further demonstrate the effectiveness of the proposed EOHRA approach. FMABAC [40], FTOPSIS [41], FVIKOR [42], and FCOPRAS [43] were selected and applied to the case study for comparison. The results of the risk ranking of occupational hazards obtained using the five methods are shown in Figure 5.

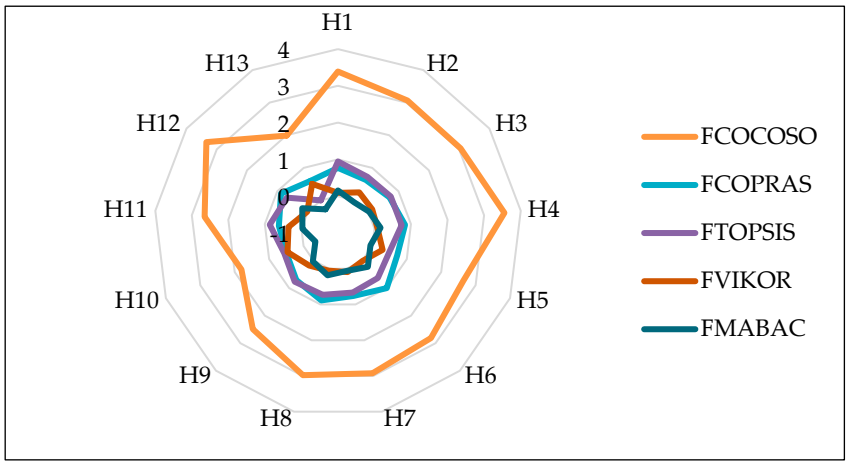


Figure 5. Comparison of risk ranking results.

As illustrated in Figure 5, the top three occupational hazards determined using different methods are consistent with the results of our approach. A Spearman correlation test was conducted to examine the relationship between the risk assessment results of the four existing methods and our proposed method. The Spearman's correlation coefficients (p-values) for the risk rankings of occupational hazards obtained using our method and the fuzzy MABAC, fuzzy TOPSIS, fuzzy VIKOR, and fuzzy COPRAS methodologies are 1, 1, 0.9999, and 0.6389, respectively. These results indicate strong relationships between our proposed model and the four methodologies. Additionally, the hazard rankings obtained using our EOHRA technique align closely with those obtained using the fuzzy COPRAS and fuzzy MABAC approaches. This further validates the effectiveness of our proposed EOHRA model.

Based on the outcomes regarding the priority of the occupational hazards using our EOHRA model, discrepancies are evident between the results obtained using the fuzzy VIKOR (H2 and H6) and fuzzy TOPSIS (H9 and H11) techniques. These variations can be attributed to several factors. Firstly, there are differences in how professionals assess fuzzy linguistic terms. Secondly, the compared methods have limited analytical ability in distinguishing occupational hazards. In contrast, our EOHRA method based on the CoCoSo approach produces a practical and reliable conclusion for risk assessment [44].

5. Discussion

This study investigated thirteen potential hazard alternatives that may arise during emergency situations during shipyard floating dock operations. These alternatives were assessed based on the following risk criteria: consequence, frequency, probability, and the number of individuals at risk. Experts with at least a decade of shipyard experience were consulted to assist in prioritizing the alternatives efficiently and effectively. The occupational hazards in emergency scenarios were categorized into thirteen alternatives by these experts.

Identifying occupational hazards and assessing their associated risks are critical components of occupational health and safety studies. Accordingly, proactive planning for the prioritized hazards and systematically addressing them are both essential functions. The proposed risk assessment model has the potential to be applied in various operations within the shipyard industry in the future.

The comparative assessment confirms the reliability and strength of the risk prioritization of occupational hazards achieved using our proposed EOHRA method. In comparison with existing approaches, the benefits of the proposed EOHRA method include the following: The AHP method introduces a spherical fuzzy set for determining the weights of the risk criteria. As a result, the spherical fuzzy method generates more robust results by producing different values for the weights of the risk criteria. Triangular linguistic fuzzy

numbers (TLFNs) are utilized to conduct intricate risk assessments of the uncertainties of occupational hazards. The proposed model, with a broad spectrum of TLFN membership levels, enables the attainment of more efficient outcomes in prioritizing risks. The proposed method for evaluating the ranking of occupational hazards in a fuzzy linguistic environment is the extended CoCoSo approach. This model aims to enhance the reliability of the EOHRA technique and offers strong analytical capability for prioritizing occupational hazards during emergencies.

The EOHRA model identified the lack of a suitable means for accessing the entire pool area as the first serious emergency occupational risk. The recommended corrective and preventive actions for this risk correspond to alternative H4 in Table 16. The second most significant risk identified is the inability of cranes to move freely when entering and exiting the docking pool. The EOHRA model results are presented in Table 16, which ranks occupational hazards based on their severity and provides corresponding corrective and preventative action recommendations for each hazard.

Table 16. Corrective and preventive action plans.

Rank	Alternatives	Corrective and Preventive Actions
1	H4	The docks and ramps leading to the pool must always remain open, except in cases where closures are necessary for disaster and emergency services.
2	H1	The operations manager evaluates the safe slope and trim for cranes to prevent movement during diving and ascending.
3	H12	Ensuring ongoing communication, prohibiting hot work on offshore vessels, and providing emergency training for ship personnel are essential. Other actions include implementing a systematic external shipyard communication process and sharing it with relevant departments. Compiling a list of missing tools, equipment, and supplies for emergencies in outer shipyards and arranging their transfer in potential situations are needed.
4	H2	It is ensured that there is always a barrier surrounding the pools. All scenarios are predetermined.
5	H3	When transition ladder and crane services are unavailable, work on the ships is halted. In ship-related emergencies, a cross or side ladder is used for intervention with attention to access and opening conditions.
6	H8	The work is stopped immediately. Evacuation takes place. Security measures are provided in the area. Necessary conditions are provided for the response teams to carry out their work.
7	H7	Tugboats intervene when there are fires during navigation until the ship stops moving.
8	H6	All operations are halted, and slope trim is inspected. Cranes are utilized for the rescue operations.
9	H11	Inaccessible areas are determined for unforeseen situations and mountaineering, and rescue and first aid training is given to the teams that will intervene in these areas. Periodic examinations of these teams are carried out in more detail.
10	H5	The marine vehicle is kept in reserve at all times.
11	H9	The accessible ship area for the dock's seaside cranes is marked and passages are opened to reach the remaining working areas beyond this. Stretchers and intervention equipment are then positioned in these areas.
12	H13	Floating docks are subjected to regular technical inspections by authorized institutions. Maintenance and repairs should be performed by docking the ships in a different pool every five years.
13	H10	The health cabinet is informed. Alternative transportation routes are determined instantly. In cases where no action can be taken, the operation is stopped.

6. Conclusions

The proposed occupational health and safety management system aims to improve working conditions and employee health, especially in industries such as shipyards where workplace accidents can have a significant impact. This study used the spherical fuzzy

AHP method to determine criterion weights for assessing risks in a fuzzy environment. Additionally, an extended CoCoSo technique was developed using a fuzzy approach to prioritize occupational hazards that may arise during emergencies or disasters. To demonstrate the applicability and effectiveness of the proposed EOHRA model, a case study involving risk assessment of occupational hazards in shipyard floating dock operations and emergency management was conducted at a ship maintenance and repair company located in the İstanbul Tuzla shipyard region. The simulation results show that this model provides a practical and effective approach for analyzing complex risk assessment issues.

The limitation of this study is that the effective utilization of the proposed model for occupational hazard risk assessment necessitates specialized expertise. The EOHRA model requires further refinement to mitigate the challenges associated with obtaining information from subject matter experts. Future research should explore the integration of the CoCoSo method with decomposed fuzzy sets to address uncertainties in the data. Additionally, alternative decision-making approaches, such as the Ordered Priority Approach, can be employed to determine the criterion weights within the proposed framework.

In future investigations, the range of choices and criteria used in this study could be expanded and diversified to enhance the study's adaptability. Furthermore, the selection of the expert team, which was solely based on professional experience in this study, may benefit from increased diversity. While this research focused on emergency risk assessment for floating dock operations on ships, analogous investigations could be carried out for other activities within the shipyard sector.

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