International Journal of Safety and Security Engineering
Vol. 16, No. 10, October, 2026, pp. 2337-2350
Journal homepage: http://iieta.org/journals/ijsse

Occupational Safety Risk Assessment in the Shipbuilding and Repair Industry in Vietnam Using a Combined AHP-DEMATEL Approach

Anh Tuan Nguyen[1*], Tan Dung Huynh[2]

[1] Faculty of Economics, Quang Ngai Campus, Industrial University of Ho Chi Minh City, Ho Chi Minh City 70000, Vietnam
[2] School of Finance and Accounting, Industrial University of Ho Chi Minh City, Ho Chi Minh City 70000, Vietnam

Corresponding Author Email: nguyenanhtuan.qn@iuh.edu.vn

Copyright: ©2026 The authors. This article is published by IIETA and is licensed under the CC BY 4.0 license (http://creativecommons.org/licenses/by/4.0/).

https://doi.org/10.18280/ijsse.161012

Received: 9 September 2026
Revised: 15 October 2026
Accepted: 23 October 2026
Available online: 31 October 2026

Keywords:
occupational safety risks, risk management, AHP–DEMATEL, shipbuilding and ship repair, shipyard safety, Vietnam

ABSTRACT

This study aims to assess occupational safety risks in Vietnam's shipbuilding and ship repair industry. A structured consultation involving 32 safety experts and 113 engineers and technical workers was conducted to identify and assess the relevant risks. Subsequently, the Analytic Hierarchy Process (AHP) and the Decision Making Trial and Evaluative Laboratory (DEMATEL) technique were sequentially applied to determine the comprehensive importance of the identified risks and examine their causal relationships. The five most important risks, ranked in descending order of comprehensive importance, are electrical safety risks, physical health-related risks, fire and explosion risks, fall risks, and asphyxiation risks, with comprehensive importance values ranging from 0.0631 to 0.2451. The causal analysis of the identified risks revealed that the physical health-related risk was classified as an "effect" risk, indicating that it was significantly influenced by other risks. Based on these findings, policy recommendations are proposed to mitigate occupational safety risks, protect workers' health, and improve risk management. The findings can also serve as supplementary material for occupational safety training in Vietnam's shipbuilding and repair industry.

1. INTRODUCTION

Vietnam has a lengthy coastline, measuring over 3,200 kilometers, and a geographical location that is advantageous for the development of its marine economy [1]. Vietnam is a country with a strategically significant maritime location, intersected by numerous shipping routes, making it an appealing destination for many nations. Therefore, the potential of the shipbuilding market is immense. Vietnam's shipbuilding capacity is approximately 3.5 million tons per year. Vietnam's shipbuilding industry is ranked 7th globally, holding a market share of 0.61% in the worldwide shipbuilding sector [2]. The estimated domestic demand for new shipbuilding by 2030 ranges from 95 to 245 vessels. This translates to approximately 16 to 41 vessels per year, with a total tonnage of 4 to 5 million tons [3]. This demand includes both new constructions and the replacement of the aging fleet. Currently, there are nearly 120 shipbuilding facilities of various sizes across the country, with annual production having increased tenfold compared to the previous decade. This growth is not limited to economically developed provinces and cities such as Hai Phong, Quang Ninh, Da Nang, Quang Ngai, and Ho Chi Minh City [4].

From 2020 to the present, many economic sectors have faced severe challenges due to the Covid-19 pandemic. However, Vietnam's shipbuilding industry has shown remarkable progress and is steadily establishing its presence in the international market. The shipbuilding industry has affirmed its mission and importance in the country's economic development, ensuring national security and defense, as well as participating deeply in international cooperation. To improve the competitiveness of its shipbuilding industry amid international economic integration, Vietnam must capitalize on the evolving trends in the global shipbuilding sector, leveraging the country's existing strengths. The Vietnam Marine Economic Sustainable Development Strategy, which outlines goals for 2030 and a vision for 2045, emphasizes the importance of developing the ship repair and shipbuilding industry in a rational manner [5, 6].

To develop the shipbuilding and ship repair industry in Vietnam sustainably and for the long term, one of the most crucial and essential issues is paying attention to the workforce, as they are the main factor determining this development. Workers in heavy industries in general, and in the shipbuilding and ship repair industry in Vietnam in particular, always face many risks in their work, such as exposure to hazardous materials, heavy machinery accidents, and ergonomic issues. Therefore, paying attention to safety, or in other words, addressing occupational safety and health risks, is essential and should be a top priority. Hazardous industries have faced serious work-related fatalities, workplace accidents, and worker injuries because of their high-risk processes [7, 8]. The primary purpose of risk assessment and analysis is to determine the importance of risks and thus prioritize them, giving them due attention [9, 10].

The Analytic Hierarchy Process (AHP) is a theory of

measurement that uses pairwise comparisons and expert judgments to establish preferred scales [11, 12]. The AHP has emerged as one of the most important research topics in the field of decision analysis [13]. The Decision Making Trial and Evaluative Laboratory (DEMATEL) was introduced by Fontela and Gabus in 1971 [14-16]. The DEMATEL method is used to create network relational designs that analyze the internal relationships among attributes [17, 18].

This study combines the AHP and DEMATEL methods to evaluate occupational safety risks in Vietnam's shipbuilding and ship repair industry. The application of a combination of these two methods aims to overcome the limitations of the AHP model, which can only address the prioritization of risks but cannot analyze the relationships and influences between them in the overall context. The research findings can assist risk managers and safety management departments in Vietnam's shipbuilding industry by enhancing the quality of their operations. Additionally, the findings propose policy implications that could serve as supplementary resources for occupational safety and health education and training in the shipbuilding and ship repair sectors.

2. LITERATURE REVIEW

Shipbuilding and repair are widely recognized as highly technical and complex industrial processes involving multiple interdependent production stages and requiring a diverse range of skilled trades and specialized expertise [19-21]. As a knowledge-intensive industry, shipbuilding and repair involve numerous interdependent technical processes that depend heavily on highly skilled personnel and specialized engineering expertise [19]. Ship repair activities generally encompass ship conversions, overhauls, scheduled maintenance, major structural repairs, and minor equipment maintenance. The primary raw materials used in shipbuilding and ship repair operations include steel and other metallic materials, paints and solvents, and abrasive blasting media, as well as lubricating and cutting oils [22, 23]. The shipbuilding industry relies heavily on a large and skilled workforce to undertake physically demanding production processes under hazardous working conditions. Occupational activities such as welding, painting, blasting, and composite material fabrication expose workers to multiple physical and chemical hazards that may negatively affect their health and safety [23].

Occupational health and safety risk assessment is central to safety management in shipbuilding and ship repair, where workers perform a range of hazardous tasks under complex working conditions. In Turkish shipyards, welding, painting, surface polishing, and hazardous waste handling have been identified as high-risk operations. These activities can expose workers to toxic dust and fumes and contribute to chronic illness and serious workplace accidents [23]. A health assessment at a shipbuilding and repair yard found a high prevalence of hypertension, hearing impairment, musculoskeletal disorders, and respiratory symptoms, highlighting the health burden associated with occupational exposures and adverse working conditions [24]. Among shipyard welders, occupational fatigue has also been associated with poorer work performance and greater occupational health and safety risks [25].

Previous research on occupational safety in shipbuilding and ship repair has primarily focused on hazard identification, risk classification, accident prevention, and the prioritization of safety measures. These studies have employed conventional risk assessment methods, including Failure Mode and Effects Analysis (FMEA), Hazard Identification, Risk Assessment, and Risk Control (HIRARC), and Hazard and Operability Study (HAZOP), to identify hazardous activities and determine appropriate control measures [26-28]. Despite differences in their analytical procedures, these approaches consistently highlight the importance of controlling unsafe work practices, improving protective equipment, and addressing hazards associated with welding, cutting, material handling, machinery operation, and work at height. For example, the FMEA-based assessment in ship repair identified 40 potential hazards, six of which were classified as extremely serious, while HIRARC and HAZOP applications highlighted the combined contributions of operational hazards, worker behavior, and equipment-related problems [27, 28]. Collectively, these findings demonstrate the practical value of conventional methods in identifying hazards and supporting preventive action. However, their emphasis on individual hazards and operational activities may limit their ability to explain how different risk factors interact and influence one another.

Beyond hazard identification, multi-criteria decision-making (MCDM) methods have been applied to establish risk priorities and investigate relationships among safety factors. AHP has been used to rank occupational accident causes based on expert judgments and accident-related evidence. In Turkish shipyards, the AHP-based analysis of 1,028 non-fatal occupational accidents identified inadequate safety equipment, improper use of machinery and tools, and non-compliance with safety procedures as important contributing factors [29]. This approach supports the prioritization of preventive measures but does not, by itself, establish the causal relationships among the identified factors. In contrast, the combination of DEMATEL and Grey System Theory has been used to examine occupational safety risks in the Turkish shipbuilding industry, distinguishing cause factors from effect factors and helping identify potential underlying influences on occupational accidents [30]. These applications illustrate the complementary strengths of AHP and DEMATEL: AHP supports the assessment of relative importance, whereas DEMATEL reveals the influence relationships among criteria. Nevertheless, the application of either method alone may provide only a partial understanding of occupational safety risks when both prioritization and causal analysis are required.

Fuzzy DEMATEL and AHP have been combined to assess overall shipyard performance, using causal analysis to examine relationships among criteria and weighting to establish improvement priorities [31]. The assessment focused on overall performance, leaving specific occupational safety hazards outside its scope. In coal mining, an integrated AHP–DEMATEL analysis identified physical condition and fatigue as key factors associated with unsafe states among workers, alongside safety attitude, awareness, culture, and vigilance [32]. Together, these studies illustrate how criterion weighting and causal analysis can inform industrial assessments. Their findings provide a methodological basis for evaluating occupational safety risks in shipbuilding and ship repair, where the relationships among hazards need to be assessed under shipyard-specific working and exposure conditions.

Overall, the literature establishes a useful methodological foundation for occupational safety risk assessment but also reveals an important gap. Conventional methods such as FMEA, HIRARC, and HAZOP are valuable for identifying

hazards and determining risk-control measures, while AHP and DEMATEL provide complementary capabilities for prioritizing criteria and analyzing their interrelationships. However, the reviewed studies provide limited evidence of an integrated framework that simultaneously evaluates the relative importance of occupational safety risks and examines their cause-effect relationships in Vietnam's shipbuilding and ship repair industry. Addressing this gap is particularly relevant because shipyard operations involve diverse hazards whose effects may be interdependent. Accordingly, the present study combines AHP and DEMATEL to determine the relative importance of identified occupational safety risks and investigate their causal structure in the Vietnamese context. The combined approach is intended to provide a more comprehensive basis for risk prioritization and occupational safety management in Vietnam's shipbuilding and ship repair industry.

3. RESEARCH METHODOLOGY

3.1 Research data

The study reached out to 45 safety personnel. Among these, 32 of the safety personnel, including safety managers and experienced safety officers with over five years of experience in the shipbuilding and ship repair industry in Vietnam, were selected for consultation on risk criteria. To ensure the accuracy of the study, the remaining 13 staff members were eliminated because their years of experience were insufficient.

Based on the consultation results, this study has developed a list of 12 safety risk criteria pertinent to the shipbuilding industry in Vietnam. The research team classified the risk criteria into two categories: risks with immediate impacts on workers' health and long-term cumulative health risks that impact workers' health over time. The 12 risk criteria were compiled and further reviewed based on a survey conducted with 124 technical workers currently employed in shipbuilding and repair factories, along with 18 retired technical workers. A detailed list of safety risk criteria in the shipbuilding and ship repair industry in Vietnam is in Table 1.

Table 1. Occupational safety risks identified in Vietnam's shipbuilding industry

Goal	Criteria	Sub-Criteria
Safety risk assessment in the Vietnamese shipbuilding and ship repair industry	Immediate health impact risk (IIR)	Fire and explosion safety risk
		Electrical safety risk
		Transportation-related accident risk
		Noise risk
		Drowning risk
		Fall risk
		Falling object risk
		Asphyxiation risk
		X-ray radiation risk
		Environmental impact risk
	Long-term cumulative health risk (LCR)	Physical health-related disease risk
		Mental health-related disease risk

Table 2. Description of occupational safety risks in Vietnam's shipbuilding industry

Code	Sub-Criteria	Description	Ref.
IIR1	Fire and explosion safety risk	Gas leaks from pipelines that come into contact with welding sparks may cause explosions. Furthermore, improper installation or connection of gas and oxygen pipelines by workers may increase the risk of explosions.	[33, 34]
IIR2	Electrical safety risk	Electric shocks during welding and damaged or exposed electrical wiring can undermine workers' psychological well-being and confidence while posing serious risks to their safety and lives.	[35]
IIR3	Transportation-related accident risk	Workers may be injured by vehicles moving within the factory premises, such as cars, forklifts, and specialized vehicles.	[19, 36]
IIR4	Noise risk	Loud noises and sounds emanating from machinery can cause immediate earaches and headaches for workers.	[37]
IIR5	Drowning risk	Workers may drown while diving to adjust the ship's alignment when the ship is in dry dock for repairs, or they may fall while moving around in a water-filled dry dock, which can also lead to drowning.	[35]
IIR6	Fall risk	Workers may be exposed to fall hazards when working on slippery surfaces, at heights, or near open pits, potentially resulting in fractures, serious injuries, or fatalities.	[35, 38]
IIR7	Falling object risk	Objects placed high up in the factory can fall during work due to worker negligence or damaged crane cables, potentially causing immediate harm to the health and lives of workers.	[35]
IIR8	Asphyxiation risk	Toxic gas leaks or the buildup of hazardous fumes in confined spaces, such as ship holds and tanks, can expose workers to asphyxiation hazards, which may cause temporary unconsciousness or even death.	[22, 35]
IIR9	X-ray radiation risk	The process of inspecting and detecting welding defects can expose workers to X-rays for extended periods.	[29, 39]
IIR10	Environmental impact risk	The effects of sun exposure, cold winds, rainstorms, air pollution, and dust on workers in outdoor settings like docks or indoor environments such as factories can be detrimental to their health.	[29]
LCR1	Physical health-related disease risk	Workers experience a range of health issues, including cardiovascular, pulmonary, skin, and musculoskeletal problems, after spending extended periods dedicated to their jobs.	[40]
LCR2	Mental health-related disease risk	Workers can experience emotional and mental health impacts from the stressors associated with their jobs after extended periods of employment.	[40]

Note: IIR: immediate-impact risks, LCR: long-term cumulative risks.

This survey is important because technical workers, along with safety personnel, frequently face occupational risks. Of the 142 survey responses received, 29 were excluded because they were submitted by technical workers with fewer than three years of work experience. The remaining 113 responses showed 97.34% agreement with the list of 12 risks in the shipbuilding and ship repair industry in Vietnam. These 12 risk criteria were incorporated into the risk classification model.

Table 1 shows occupational safety risks identified in Vietnam's shipbuilding industry. The risks are described in Table 2.

The identified risk criteria represent different but related aspects of occupational safety, including hazardous events, exposure factors, and potential health outcomes. The classification into immediate-impact risks (IIR) and long-term cumulative risks (LCR) was adopted to structure the assessment according to the intended impact categories. However, these categories are not necessarily mutually exclusive, as some hazards, such as noise and radiation exposure, may have both immediate and cumulative health effects. In addition, physical health-related diseases may be associated with multiple occupational hazards and accident events. These interrelationships should therefore be considered when interpreting the AHP weights and DEMATEL results.

3.2 Analytic Hierarchy Process method

The AHP is a measurement theory that uses pairwise comparisons and expert judgment to establish a preferred scale. For comparison purposes, a numerical scale is needed to indicate how much more important or dominant one factor is compared to another in relation to the criteria or characteristics on which they are being compared [11]. The problem-solving process should first address the different types of scales by interpreting their meanings in the context of users' values. Finally, a balancing and aggregation process is applied to derive common priorities for the alternatives in relation to the overall goal [41]. The AHP involves three fundamental procedures: hierarchy construction, priority analysis, and consistency evaluation. The process begins by decomposing a complex decision problem into a hierarchical structure composed of multiple criteria and sub-criteria, with all elements systematically organized into different hierarchical levels based on their attributes. Pairwise comparisons are then conducted among elements at the same hierarchical level, allowing decision-makers to assign relative priorities based on their knowledge and professional experience [42]. Instead of directly identifying the optimal solution, these methods serve as decision-support tools by providing systematic information that enables decision-makers to evaluate and synthesize all relevant factors when selecting the most suitable alternative or establishing the priority ranking of multiple alternatives [43].

The AHP is a widely used decision-making process in management for setting priorities in MCDM problems. In the present research, AHP was used to determine the relative weights of occupational safety risk criteria based on expert judgments. The risk assessment problem was structured hierarchically, and pairwise comparisons were conducted among criteria at the same level using Saaty's nine-point scale. The resulting comparison matrices were used to derive priority weights and assess consistency. These weights were subsequently incorporated into the combined AHP–DEMATEL framework to determine the comprehensive importance of the identified risks.

To accommodate decision-making contexts involving multiple stakeholders, the conventional AHP has been adapted for group decision-making applications. By integrating the judgments of multiple experts, the approach improves the credibility and robustness of the evaluation process while mitigating the potential bias inherent in relying solely on the opinions of a single expert [44].

The first step in AHP analysis is to build a hierarchy for the decision. This is also called a decision model, and it simply involves constructing a hierarchy for decision analysis. The AHP builds the problem structure in a hierarchical form. The advantages of this hierarchical analysis are clear. By structuring the problem in this way, a better understanding can be gained of the decisions to be made, the criteria to be used, and the alternatives to be evaluated. This step is crucial, and this is where, in more complex problems, expert involvement may be required to ensure that all criteria and viable alternatives have been considered [45].

The AHP is a reliable, rigorous, and robust method for capturing and quantifying subjective judgments in MCDM. Despite its many benefits, the complexity of the pairwise comparison process and limitations regarding consistency in AHP are challenges that have been the subject of extensive research [46]. According to Das et al. [47], the AHP method employs a systematic four-step analytical procedure to support decision-making and establish priorities among alternative criteria. Step 1: Define the decision problem and construct a hierarchical structure. Step 2: Pairwise comparisons are performed among elements at the same hierarchical level to determine their relative importance. Step 3: Priority weights are derived from the pairwise comparison matrices, followed by a consistency assessment to ensure the reliability of the judgments. Step 4: Synthesize the local priorities to obtain overall weights and rank the evaluated elements.

In this study, establishing the hierarchical structure and identifying the relevant safety risk criteria for Vietnam's shipbuilding and ship repair industry constitute the first step in the AHP procedure. Next, experts performed pairwise comparisons to assess the relative importance of the risk criteria, constituting the second step of the AHP procedure. Saaty's (2008) nine-point scale was used for the pairwise comparisons. The survey participants comprised 32 safety experts with professional experience in Vietnam's shipbuilding and ship repair industry. The authors aggregated the assessment scores provided by the 32 experts, processed the collected data, and subsequently constructed the pairwise comparison matrices. The pairwise comparison matrices were constructed based on the judgments of the 32 safety experts.

The aggregation procedure used to obtain the group comparison matrices is the geometric mean method. The resulting group matrices were then used to derive the priority weights of the risk criteria. The resulting pairwise comparison matrices are presented in Tables 3–5.

Table 3. Pairwise comparison matrix of risk criteria

Criteria	IIR	LCR
IIR	1	7
LCR	1/7	1

Note: IIR: immediate-impact risks, LCR: long-term cumulative risks.

Table 4. Pairwise comparison matrix of risk criteria: immediate-impact risks (IIR)

Code	IIR1	IIR2	IIR3	IIR4	IIR5	IIR6	IIR7	IIR8	IIR9	IIR10
IIR1	1	1/2	7	5	8	4	6	3	2	8
IIR2	2	1	8	6	9	5	7	4	3	9
IIR3	1/7	1/8	1	1/3	2	1/4	1/2	1/5	1/6	2
IIR4	1/5	1/6	3	1	4	1/2	2	1/3	1/4	4
IIR5	1/8	1/9	1/2	1/4	1	1/5	1/3	1/6	1/7	1
IIR6	1/4	1/5	4	2	5	1	3	1/2	1/3	5
IIR7	1/6	1/7	2	1/2	3	1/3	1	1/4	1/5	3
IIR8	1/3	1/4	5	3	6	2	4	1	1/2	6
IIR9	1/2	1/3	6	4	7	3	5	2	1	7
IIR10	1/8	1/9	1/2	1/4	1	1/5	1/3	1/6	1/7	1

Table 5. Pairwise comparison matrix of risk criteria: long-term cumulative risks (LCR)

Code	LCR1	LCR2
LCR1	1	5
LCR2	1/5	1

The experts assigned a strong preference to IIR over LCR, reflecting the potential for immediate-impact hazards in shipbuilding and repair operations to cause severe injuries, life-threatening incidents, or fatalities. Examples include electrical accidents, fires and explosions, falls from height, and gas asphyxiation in confined spaces. These consequences require immediate preventive and control measures. Accordingly, the pairwise comparison value of 7 on Saaty's fundamental scale represents the experts' very strong preference for IIR over LCR, as shown in Table 3.

As shown in Table 5, physical health-related risks (LCR1) were assessed as strongly more important than mental health-related risks (LCR2), with a pairwise comparison value of 5. This judgment reflects the relative priority assigned to physical health-related risks within the LCR category. The corresponding reciprocal values were entered into the comparison matrices in accordance with the AHP reciprocal property.

After constructing the pairwise comparison matrices, the authors calculated the priority vectors for the primary risk criteria (group weights) and secondary risk criteria (local weights), followed by a consistency check of the comparison matrices. The consistency ratio (CR) and consistency index (CI) are calculated using Eqs. (1) and (2), respectively.

$$CR = \frac{CI}{RI} \tag{1}$$

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{2}$$

where RI denotes the Random Consistency Index, as reported in Table 6; λ_{max} is the maximum eigenvalue of the pairwise comparison matrix; and n indicates the number of risk criteria included in the matrix.

Table 6. Random consistency index (CI) [48]

Order	1	2	3	4	5	6	7	8	9	10	11
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.53

If the CR > 0.10, the pairwise comparison judgments should be reviewed and revised through further consultation with the experts. If the consistency criterion is satisfied (CR ≤ 0.10), the composite weights are calculated. The consistency of aggregated group matrices should be distinguished from that of individual experts' matrices. Individual-level consistency can only be assessed when the original pairwise comparison matrices for each expert are available. Accordingly, the consistency results are interpreted based on the level of data actually assessed.

The derivation of the composite weights marks the completion of Step 3 in the AHP procedure. In this study, we perform the final step of the AHP method, namely the determination of criterion priorities, following the DEMATEL analysis. The equation for calculating the overall weights, as proposed by Saaty (2008), is presented in Eq. (3).

$$W_i = W_{i,local} \times W_{global} \tag{3}$$

3.3 Decision Making Trial and Evaluative Laboratory method

The DEMATEL method provides an effective framework for analyzing complex systems by elucidating the cause–effect relationships among their constituent factors. It enables the assessment of interdependencies and the identification of critical relationships through the development of a visual structural model [49]. The DEMATEL method has been widely applied to identify key factors of simple systems across various fields. Despite various efforts to improve the DEMATEL method, it remains more suitable for relatively simple systems and may be inadequate for addressing decision-making problems involving complex structures [50]. The DEMATEL method is employed to establish a network relationship structure that facilitates the identification and analysis of the interrelationships among attributes [14]. The advantage of the DEMATEL method is that it distinguishes between the groups that exert influence and those that receive it within the problem and identifies the relationships between criteria based on graph theory [51].

The DEMATEL method is an evaluation tool used to analyze cause-and-effect relationships among evaluation criteria and sub-criteria. Its outputs include clarifying the interdependencies between criteria and constructing diagrams that reflect these connections [52]. Among its various application domains, the DEMATEL method has been extensively employed to address issues related to risk management and safety [53].

According to Das et al. [47] the procedure for implementing the DEMATEL method consists of six steps:

Step 1: Construction of the direct-influence matrix and average direct-relation matrix: The direct-influence matrix is first constructed based on the assessments provided by a panel of experts. Assume that (H) experts participate in evaluating the mutual influence relationships among (n) risks. The degree of influence exerted by risk (i) on risk (j) is denoted by x_{ij} and the degree of influence is assessed using a five-point scale ranging from 0 to 4, where 0 indicates no influence, 1 indicates low influence, 2 indicates moderate influence, 3 indicates high influence, and 4 indicates very high influence.

The direct-relation matrix obtained from the assessment of the k[th] expert is expressed as an $n \times n$ matrix, as shown in Eq. (4).

$$\begin{bmatrix} 0 & x_{12}^k & x_{13}^k & \cdots & x_{1n}^k \\ x_{21}^k & 0 & x_{23}^k & \cdots & x_{2n}^k \\ x_{31}^k & x_{32}^k & 0 & \cdots & x_{3n}^k \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ x_{n1}^k & x_{n2}^k & x_{n3}^k & \cdots & 0 \end{bmatrix} k = 1,2,3 \ldots H \tag{4}$$

Step 2: The average direct-relation matrix A is determined as shown in Eq. (5).

$$A = \begin{bmatrix} 0 & \frac{1}{H}\sum_{k=1}^{H} x_{12}^k & \frac{1}{H}\sum_{k=1}^{H} x_{13}^k & \cdots & \frac{1}{H}\sum_{k=1}^{H} x_{1n}^k \\ \frac{1}{H}\sum_{k=1}^{H} x_{21}^k & 0 & \frac{1}{H}\sum_{k=1}^{H} x_{23}^k & \cdots & \frac{1}{H}\sum_{k=1}^{H} x_{2n}^k \\ \frac{1}{H}\sum_{k=1}^{H} x_{31}^k & \frac{1}{H}\sum_{k=1}^{H} x_{32}^k & 0 & \cdots & \frac{1}{H}\sum_{k=1}^{H} x_{3n}^k \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \frac{1}{H}\sum_{k=1}^{H} x_{n1}^k & \frac{1}{H}\sum_{k=1}^{H} x_{n2}^k & \frac{1}{H}\sum_{k=1}^{H} x_{n3}^k & \cdots & 0 \end{bmatrix} \tag{5}$$

Step 3: Determine the normalized direct-relation matrix D. The average direct-relation matrix A is normalized to obtain the normalized direct-relation matrix D, as presented in Eq. (6).

$$D = \frac{A}{s} \tag{6}$$

where, $s = max\left\{\frac{max}{i}\sum_{j=1}^{n} a_{ij}, \frac{max}{j}\sum_{i=1}^{n} a_{ij}\right\}$

Step 4: Determination of the total relation matrix T. The matrix T is calculated using the Eq. (7).

$$T = D \times (I - D)^{-1} \tag{7}$$

where, I = is a $n \times n$ identity matrix

Step 5: Determination of sums of the rows and columns of total relation matrix T

Let r and c denote the $n \times 1$ column vector containing the row sums and the $1 \times n$ row vector containing the column sums of the total relation matrix T, respectively.

The total impact, comprising both direct and indirect effects of the i^{th} factor, is denoted by r_i and expressed by Eq. (8) as follows:

$$r = (r_i) = \left[\sum_{j=0}^{n} t_{ij}\right]_{n\times 1} \tag{8}$$

The total impact exerted by other risks on risk j^{th}, including both direct and indirect effects, is denoted by c_j and determined by Eq. (9) as follows:

$$c = (c_j) = \left[\sum_{i=0}^{n} t_{ij}\right]_{1\times n} \tag{9}$$

When $i = j$, the sum $(r_i + c_i)$ represents the overall importance of the i[th] risk in the system. The difference $(r_i - c_i)$ indicates the net influence of the i[th] risk on the system. Specifically, if $(r_i - c_i) > 0$, the i[th] risk belongs to the causal group, whereas if $(r_i - c_i) < 0$, it belongs to the effect group.

Step 6: Determine the threshold value and construct the causal diagram

The threshold value α is determined to filter out insignificant relationships among the identified safety risks from the total-relation matrix T. Specifically, only relationships with influence values greater than or equal to the threshold value are retained, whereas those below this value are excluded from further analysis. This filtering process facilitates the identification of the most significant cause-and-effect relationships among safety risks in the shipbuilding industry and provides the basis for constructing the causal diagram. The threshold value $\alpha$is calculated as the average of all elements in the total-relation matrix T, as expressed in Eq. (10).

$$\alpha = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}[t_{ij}]}{N} \tag{10}$$

where, N is the total number of elements in the total-relation matrix T. Before constructing the causal diagram, a threshold value must be defined to eliminate negligible interactions. This threshold, α, is determined as the arithmetic mean of all elements in the total-relation matrix T. The prominence degree, represented by $(r_i + c_i)$, measures the central importance of risk i. Risks characterized by small $(r_i + c_i)$ values are relatively isolated and independent within the network. In contrast, those with large $(r_i + c_i)$ values are key risk factors that exert and receive substantial influence.

In this study, after determining the sum of $(r_i + c_i)$ as the importance level of the i^{th} risk within the system, the comprehensive importance of each influencing criterion is determined by combining this with the overall weight W_i derived from the AHP analysis using Eq. (11).

$$P_i = \frac{(r_i + c_i) \times W_i}{\sum_{i=1}^{n}((r_i + c_i) \times W_i)} \tag{11}$$

Following the DEMATEL procedure, the total-relation matrix was used to calculate the prominence and net influence of each risk criterion. The prominence values were subsequently combined with the overall AHP weights to calculate the comprehensive importance of the identified risks. These results were used to prioritize the risks and examine their cause–effect relationships, as presented in Section 4.

4. RESULTS

4.1 Analytic Hierarchy Process analysis results

Based on the responses received from various experts, the consistent pairwise comparison results, and the local and global weights, the overall weights of the identified safety risks were determined. The results are presented in Table 7.

The AHP results provide a clear prioritization of the safety risks considered in the study based on their overall weights. As shown in Table 7, the global weight assigned to the IIR category is 0.8750, whereas the LCR category accounts for only 0.1250. This indicates a substantial difference in the relative importance assigned to the two categories within the overall risk assessment framework.

Among the identified risks, electrical safety risk (IIR2) has the highest overall weight, with a value of 0.2594, making it the most important risk in the AHP assessment. Its local weight within the IIR category is 0.2964, which is the highest among the ten IIR sub-criteria. Given the global weight of 0.8750 assigned to the IIR category, this local priority results in an overall weight of 0.2594. Fire and explosion safety risk (IIR1) ranks second, with an overall weight of 0.1881 and a local weight of 0.2150 within the IIR category. The relatively high weight assigned to this risk places it substantially above most of the remaining IIR risks. X-ray radiation risk (IIR9) ranks third overall, with an overall weight of 0.1342 and a local weight of 0.1533. Together, IIR2, IIR1, and IIR9 account for approximately 57.1% of the total overall weight. The next group of risks has considerably lower overall weights. Gas asphyxiation risk (IIR8) has an overall weight of 0.0947, followed by physical health-related diseases (LCR1) with 0.1042 and fall risk (IIR6) with 0.0663. Although LCR1 belongs to the LCR category, its overall weight is higher than that of most IIR sub-criteria, ranking fourth among all identified risks. Its local weight within the LCR category is 0.8333, compared with 0.1667 for mental health-related diseases (LCR2). The remaining risks receive relatively smaller overall weights. Noise risk (IIR4) has an overall weight of 0.0462, while falling-object risk (IIR7) and transportation-related accident risk (IIR3) have overall weights of 0.0321 and 0.0224, respectively.

A comparison of the local weights within each category further highlights the degree of prioritization. Within the IIR category, the local weights range from 0.2964 for electrical safety risk (IIR2) to 0.0181 for both drowning risk (IIR5) and environmental impact risk (IIR10). This demonstrates a pronounced differentiation in the perceived relative importance of IIR. In the LCR category, the difference is even more pronounced: physical health-related diseases (LCR1) have a local weight of 0.8333, compared with 0.1667 for mental health-related diseases (LCR2).

The AHP results should be interpreted as reflecting the relative priority of individual risks, rather than the causal influence among them. In particular, the high overall weight of electrical safety risk (IIR2) indicates its high relative priority in the AHP hierarchy, but it does not by itself establish that IIR2 causes or influences other risks. Therefore, the AHP results provide the weighting structure for the identified risks, while the subsequent DEMATEL analysis is required to examine the cause-and-effect relationships among these risks.

Table 7. Overall weight of risks

Risks	Code	Local Weight	Global Weight	Overall Weight
Fire and explosion safety risk	IIR1	0.2150	0.8750	0.1881
Electrical safety risk	IIR2	0.2964	0.8750	0.2594
Transportation-related accident risk	IIR3	0.0256	0.8750	0.0224
Noise risk	IIR4	0.0528	0.8750	0.0462
Drowning risk	IIR5	0.0181	0.8750	0.0158
Fall risk	IIR6	0.0758	0.8750	0.0663
Falling object risk	IIR7	0.0367	0.8750	0.0321
Asphyxiation risk	IIR8	0.1082	0.8750	0.0947
X-ray radiation risk	IIR9	0.1533	0.8750	0.1342
Environmental impact risk	IIR10	0.0181	0.8750	0.0158
Physical health-related disease risk	LCR1	0.8333	0.1250	0.1042
Mental health-related disease risk	LCR2	0.1667	0.1250	0.0208

Note: IIR: immediate-impact risks, LCR: long-term cumulative risks.

4.2 Decision Making Trial and Evaluative Laboratory analysis results

Use the DEMATEL method to categorize the factors into cause and effect groups based on their relative significance. The expert panel comprised 32 safety experts from Vietnam's shipbuilding and ship repair industry, who assessed the interrelationships and influence among the 12 identified safety risks. After collecting the direct-relation matrices from the 32 experts, the individual matrices were aggregated by averaging the experts' assessments to obtain the average direct-relation matrix, as shown in Eq. (5). The results of the average direct-relation matrix A are presented in Table 8.

The normalized direct-relation matrix D is calculated using Eq. (6) and is presented in Table 9.

The total-relation matrix T is calculated using Eq. (7) and is presented in Table 10.

The threshold value was determined using Eq. (10), yielding a value of $\alpha = 0.0267$. This result indicates that all relationships with influence values greater than the threshold value are considered significant and are therefore taken into account. The results regarding the importance, influence, and causal relationships of each criterion are presented in Table 11.

The DEMATEL analysis results presented in Table 11 reveal a distinct cause-and-effect structure among the safety risk criteria in Vietnam's shipbuilding and ship repair industry. IIR1, IIR2, IIR3, IIR4, IIR7, IIR8, IIR9, and IIR10 are classified as causal criteria, whereas IIR5, IIR6, LCR1, and LCR2 belong to the effect group. This distribution indicates that safety risks in shipbuilding and ship repair are not isolated phenomena but are characterized by interconnected relationships in which changes in causal risk criteria may propagate through the system and contribute to subsequent safety outcomes.

Table 8. Direct-relation matrix A

	IIR1	IIR2	IIR3	IIR4	IIR5	IIR6	IIR7	IIR8	IIR9	IIR10	LCR1	LCR2
IIR1	0.00	2.50	0.00	0.00	0.00	0.00	0.00	4.00	0.00	0.00	3.50	3.00
IIR2	3.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00	2.00
IIR3	0.00	0.00	0.00	0.00	0.00	3.00	1.00	0.00	0.00	0.00	4.00	2.00
IIR4	0.00	0.00	3.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.00	2.50
IIR5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	3.00
IIR6	0.00	0.00	0.00	0.00	2.00	0.00	0.00	0.00	0.00	0.00	4.00	2.00
IIR7	0.00	0.50	0.00	1.00	0.00	2.00	0.00	0.00	0.00	0.00	4.00	2.00
IIR8	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	4.00	3.50
IIR9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.00	2.50
IIR10	1.00	4.00	2.00	2.00	2.00	4.00	3.50	0.00	0.00	0.00	3.00	1.00
LCR1	0.00	0.00	0.00	0.00	0.00	2.00	0.00	0.00	0.00	0.00	0.00	3.00
LCR2	1.50	1.50	0.00	0.00	2.00	1.00	0.00	0.00	0.00	0.00	1.00	0.00

Note: IIR: immediate-impact risks, LCR: long-term cumulative risks.

Table 9. Normalized direct-relation matrix D

	IIR1	IIR2	IIR3	IIR4	IIR5	IIR6	IIR7	IIR8	IIR9	IIR10	LCR1	LCR2
IIR1	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.10	0.08
IIR2	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.05
IIR3	0.00	0.00	0.00	0.00	0.00	0.08	0.03	0.00	0.00	0.00	0.11	0.05
IIR4	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.07
IIR5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.08
IIR6	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.11	0.05
IIR7	0.00	0.01	0.00	0.03	0.00	0.05	0.00	0.00	0.00	0.00	0.11	0.05
IIR8	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.11	0.10
IIR9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.07
IIR10	0.03	0.11	0.05	0.05	0.05	0.11	0.10	0.00	0.00	0.00	0.08	0.03
LCR1	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.08
LCR2	0.04	0.04	0.00	0.00	0.05	0.03	0.00	0.00	0.00	0.00	0.03	0.00

Note: IIR: immediate-impact risks, LCR: long-term cumulative risks.

Table 10. Total-relation matrix

	IIR1	IIR2	IIR3	IIR4	IIR5	IIR6	IIR7	IIR8	IIR9	IIR10	LCR1	LCR2
IIR1	0.01	0.07	0.00	0.00	0.01	0.01	0.00	0.11	0.00	0.00	0.12	0.11
IIR2	0.10	0.01	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.10	0.07
IIR3	0.00	0.00	0.00	0.00	0.01	0.09	0.03	0.00	0.00	0.00	0.13	0.07
IIR4	0.00	0.00	0.08	0.00	0.01	0.02	0.00	0.00	0.00	0.00	0.12	0.09
IIR5	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.06	0.09
IIR6	0.00	0.00	0.00	0.00	0.06	0.01	0.00	0.00	0.00	0.00	0.12	0.07
IIR7	0.00	0.02	0.00	0.03	0.01	0.06	0.00	0.00	0.00	0.00	0.12	0.07
IIR8	0.00	0.00	0.00	0.00	0.01	0.04	0.00	0.00	0.00	0.00	0.12	0.11
IIR9	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.11	0.08
IIR10	0.04	0.12	0.06	0.06	0.07	0.13	0.10	0.00	0.00	0.00	0.14	0.07
LCR1	0.00	0.00	0.00	0.00	0.01	0.06	0.00	0.00	0.00	0.00	0.01	0.09
LCR2	0.05	0.04	0.00	0.00	0.06	0.03	0.00	0.01	0.00	0.00	0.04	0.02

Note: IIR: immediate-impact risks, LCR: long-term cumulative risks.

Table 11. Cause-and-effect analysis of the criteria based on r and c values

Code	r	c	r + c	r - c	Cause or Effect
IIR1	0.4443	0.2306	0.6749	0.2136	Cause
IIR2	0.3029	0.2890	0.5919	0.0139	Cause
IIR3	0.3362	0.1440	0.4803	0.1922	Cause
IIR4	0.3234	0.0857	0.4090	0.2377	Cause
IIR5	0.1664	0.2415	0.4079	−0.0751	Effect
IIR6	0.2604	0.4696	0.7300	−0.2092	Effect
IIR7	0.3197	0.1272	0.4469	0.1924	Cause
IIR8	0.2821	0.1349	0.4170	0.1473	Cause
IIR9	0.2135	0.0000	0.2135	0.2135	Cause
IIR10	0.7870	0.0000	0.7870	0.7870	Cause
LCR1	0.1713	1.1902	1.3614	−1.0189	Effect
LCR2	0.2434	0.9379	1.1813	−0.6945	Effect

Note: IIR: immediate-impact risks, LCR: long-term cumulative risks.

In terms of overall importance, LCR1 has the highest $(r + c)$ value (1.3614), followed by LCR2 (1.1813), IIR10 (0.7870), IIR6 (0.7300), and IIR1 (0.6749). The particularly high $(r + c)$ values of LCR1 and LCR2 indicate that these

criteria have strong overall connectivity within the safety risk system. Nevertheless, their negative $(r - c)$ values of -1.0189 and -0.6945, respectively, show that they are predominantly affected by other risk criteria rather than acting as primary sources of influence. In the context of shipbuilding and ship repair safety, this finding suggests that these outcome-oriented risks should be considered as important manifestations of the cumulative effects of other interconnected risk factors.

Among the causal criteria, IIR10 demonstrates the strongest net influence $(r - c = 0.7870)$, followed by IIR4 (0.2377), IIR1 (0.2136), IIR7 (0.1924), and IIR3 (0.1922). The positive $(r - c)$ values indicate that these criteria exert greater influence on the safety risk system than they receive from other criteria. Therefore, within the DEMATEL structure, they represent potential leverage points for safety risk management. In particular, the prominent position of IIR10, characterized by $(r = 0.7870)$ and $(c = 0)$, suggests that changes associated with this criterion may have a comparatively strong outward influence on the overall risk structure.

IIR2 presents a different pattern, with $(r + c = 0.5919)$ and $(r - c = 0.0139)$. Its near-zero net influence indicates a relatively balanced role between influencing and being influenced. This suggests that IIR2 occupies an intermediate position within the safety-risk network rather than functioning as a strongly dominant cause or effect. By contrast, IIR6, with $(r + c = 0.7300)$ and $(r - c = -0.2092)$, is more strongly positioned as an effect criterion, indicating that its condition is more substantially shaped by other risks within the system.

Overall, the DEMATEL findings suggest that safety risk management in Vietnam's shipbuilding and ship repair industry should not focus solely on the criteria with the highest overall importance. Rather, the causal structure indicates that greater attention should be given to criteria with positive $(r - c)$ values, particularly IIR10, IIR4, IIR1, IIR7, and IIR3, because they function primarily as sources of influence within the system. At the same time, LCR1 and LCR2, despite being classified as effect criteria, exhibit the highest levels of overall importance and therefore represent critical outcomes of the interconnected risk structure. Accordingly, the DEMATEL results provide a basis for distinguishing between risk factors that should be addressed as potential drivers and those that should be managed as consequences of the broader safety risk system.

5. DISCUSSION

The overall importance of each risk criterion is determined based on the AHP–DEMATEL approach using Eq. (11). The resulting importance weights are presented in Table 12. Table 12 presents the comprehensive importance values and final priority ranking of the safety risk criteria in the Vietnamese shipbuilding and repair industry. The results indicate substantial differences in the relative importance of the 12 identified risk criteria, with comprehensive importance values ranging from 0.0103 to 0.2451. This variation demonstrates that the criteria do not contribute equally to the overall safety risk structure.

Electrical safety risk (IIR2) ranks first, with the highest comprehensive importance value of 0.2451. This result highlights the critical importance of electrical safety in the Vietnamese shipbuilding and repair industry. Electric shock accidents involving high currents and voltages are predominantly fatal. During welding operations, body sweat can increase electrical conductivity, thereby creating a high risk of electric shock upon contact with energized components. Factors that increase the risk of electric shock accidents include exposed electrical distribution panels, the absence of grounding systems or residual current devices, scattered cables, and inadequate cable insulation [35].

Ranked second is the physical health-related disease risk (LCR1), with 0.2264. Although this risk does not manifest immediately, it represents a serious and difficult-to-avoid threat to workers' health. Over time, exposure to occupational hazards can accumulate within the body, eventually contributing to the development of diseases that severely affect workers' lives. Such pathological conditions may affect major internal organs, particularly the lungs and heart, as well as the musculoskeletal system, including the limbs. As shown in Tables 8 and 11, the risk criterion LCR1 is influenced by multiple other risk criteria. With an $(r - c)$ value of -1.0189, LCR1 is classified as an "effect" criterion, indicating that it receives greater influence from other criteria than it exerts on them.

The high prominence of physical health-related disease risk (LCR1) should be interpreted in the context of the interdependencies among the defined risk criteria. Because physical health outcomes may be associated with several occupational hazards and accident events, the prominence of LCR1 may partly reflect its broad outcome-oriented definition and its connections with other criteria. Therefore, its high prominence indicates a central position within the constructed influence network rather than necessarily demonstrating a higher absolute level of occupational risk.

Ranked third is fire and explosion safety risk (IIR1), with 0.2027. This finding indicates that fire and explosion risk represents a highly critical safety concern in the Vietnamese shipbuilding and repair industry, as its occurrence can have an immediate and severe impact on workers' lives. Fires in shipyards pose significant safety hazards and are associated with high fatality rates, particularly in small and medium-sized shipyards. Consequently, strict management of flammable materials and facilities, together with the implementation of effective fire prevention measures during welding operations, is essential [34]. Shipyards also frequently face fire and explosion hazards from flammable and explosive gases. Gases such as LPG, LNG, oxygen, hydrogen, and acetylene can contribute to such incidents. Explosions may occur when gases accumulate due to inadequate ventilation in confined spaces. During welding operations, uncontrolled oxygen and acetylene gas hoses, together with improper storage of flammable materials, may further increase the likelihood of fires and explosions [35].

Fall risk (IIR6) ranks fourth among the identified safety risk criteria, with 0.0773. Falls, particularly falls from heights, are a leading cause of fatalities and injuries in shipyards and similar construction industries. Accordingly, comprehensively investigating the causes of occupational falls in shipyards is essential for understanding and addressing this safety risk [38].

Asphyxiation risk (IIR8) ranks fifth, with a comprehensive importance value of 0.0631. Working in confined or narrow spaces, such as ship holds or tanks, can expose workers to a risk of asphyxiation because these environments may have insufficient ventilation and may be contaminated with industrial dust [22].

The remaining risks, ranked from sixth to twelfth, have comprehensive importance values ranging from 0.0457 to 0.0103. Specifically, X-ray radiation risk (IIR9) ranks sixth

with a value of 0.0457, mental health-related disease risk (LCR2) ranks seventh with a value of 0.0393, noise risk (IIR4) at 0.0302, falling-object risk (IIR7) at 0.0229, environmental-impact risk (IIR10) at 0.0199, transportation-related accident risk (IIR3) at 0.0172, and drowning risk (IIR5) at 0.0103. Although these risks do not occupy the highest positions in the overall ranking, each represents a distinct component of the broader safety risk structure in Vietnam's shipbuilding and ship repair industry.

The analysis of Table 11 also identifies four risk criteria belonging to the "Effect" group: drowning risk (IIR5), fall risk (IIR6), physical health-related disease risk (LCR1), and mental health-related disease risk (LCR2). These criteria are more strongly influenced by other risk criteria within the system. In other words, their occurrence or development may be associated with the influence of other risk criteria when causal relationships exist among them. Therefore, the "Effect" group can be considered to represent risk outcomes that are more likely to emerge or intensify because of interactions with other risks within the safety risk system.

Table 12. Comprehensive importance and priority ranking of safety risk criteria

Risks	Code	$r_i + c_i$	W_i	$(r_i + c_i) \times W_i$	$\frac{(r_i + c_i) \times W_i}{\sum_{i=1}^{n}((r_i + c_i) \times W_i)}$	Rank
Fire and explosion safety risk	IIR1	0.6749	0.1881	0.126949	0.2027	3
Electrical safety risk	IIR2	0.5919	0.2594	0.153539	0.2451	1
Transportation-related accident risk	IIR3	0.4803	0.0224	0.010759	0.0172	11
Noise risk	IIR4	0.4090	0.0462	0.018896	0.0302	8
Drowning risk	IIR5	0.4079	0.0158	0.006445	0.0103	12
Fall risk	IIR6	0.7300	0.0663	0.048399	0.0773	4
Falling object risk	IIR7	0.4469	0.0321	0.014345	0.0229	9
Asphyxiation risk	IIR8	0.4170	0.0947	0.03949	0.0631	5
X-ray radiation risk	IIR9	0.2135	0.1342	0.028652	0.0457	6
Environmental impact risk	IIR10	0.7870	0.0158	0.012435	0.0199	10
Physical health-related disease risk	LCR1	1.3614	0.1042	0.141858	0.2264	2
Mental health-related disease risk	LCR2	1.1813	0.0208	0.024571	0.0393	7

Figure 1 illustrates the cause-and-effect relationships among safety risks in Vietnam's shipbuilding and ship repair industry, which may be either unidirectional or bidirectional. This finding highlights the advantage of integrating the DEMATEL and AHP methods, as DEMATEL identifies mutual influences and causal relationships among risks, whereas AHP determines their relative importance.

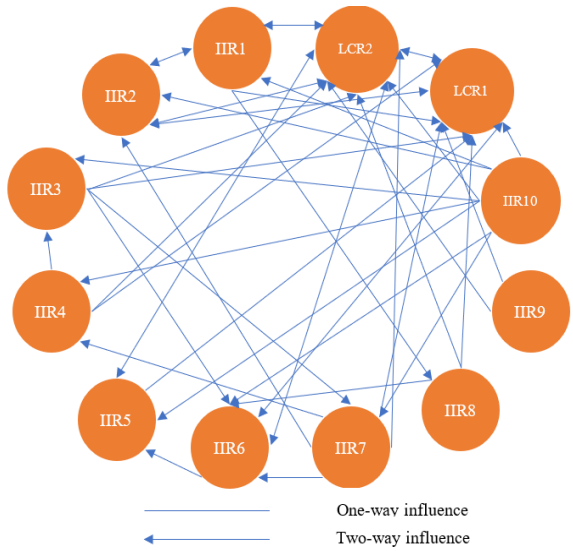


Figure 1. Cause-and-effect relationships among safety risk criteria

The comparison in Figure 2 demonstrates that integrating DEMATEL with AHP substantially modifies the relative weights of several safety risk criteria compared with AHP alone. The most notable change occurs for LCR1, whose weight increases markedly under the AHP–DEMATEL approach, while IIR9 experiences a pronounced reduction. Other criteria, including IIR1, IIR6, and LCR2, also receive higher comprehensive weights, while IIR3, IIR4, IIR7, and IIR8 are assigned lower weights.

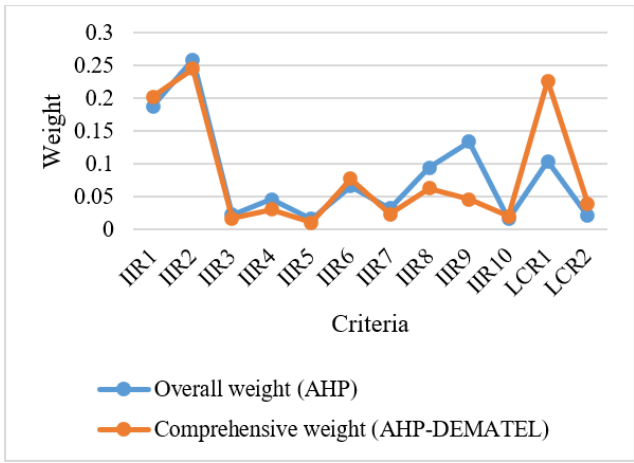


Figure 2. Risk criteria weights obtained using AHP and AHP–DEMATEL

Note: AHP: Analytic Hierarchy Process, DEMATEL: Decision Making Trial and Evaluative Laboratory.

Overall, these differences indicate that the AHP–DEMATEL approach does not merely reproduce the priority structure obtained from AHP; rather, it reallocates the weights according to the interrelationships among risk criteria. Thus, incorporating DEMATEL provides a more differentiated prioritization of safety risks by accounting for their systemic influence relationships, which are not reflected in the AHP weights alone.

6. SAFETY RISK MANAGEMENT RECOMMENDATIONS

(1) Recommendations for safety management

Strict adherence to established principles, discipline, and

proper procedures is essential when carrying out work. Regular occupational safety training should be provided to engineers and workers to enhance safety awareness and reduce the risk of workplace accidents. Strict enforcement of penalties for violations of occupational safety regulations should be implemented to strengthen safety compliance and reduce workplace safety risks.

(2) Recommendations for engineers and workers

Engineers and workers should fully and regularly participate in occupational safety training programs organized by the enterprise to enhance safety awareness and strengthen risk prevention. Strictly adhere to occupational safety regulations and procedures before, during, and after work, prioritizing safety to protect workers' lives and the well-being of their families.

(3) Recommendations for safety risk prevention and control

Regarding electrical safety risks, the electrical system should be inspected weekly. Before commencing work, power lines, switches, and electrical outlets should be inspected to identify and promptly address potential problems. Upon completion of the work, all electrical devices should be switched off.

Regarding health-related medical risks, these risks are difficult to avoid because long-term exposure to various hazards at work may gradually lead to adverse physical changes and the development of health conditions. To mitigate these risks, workers should exercise caution when performing their duties to minimize exposure to occupational hazards. Regular health check-ups are also essential for the early detection and timely treatment of potential health problems.

Regarding fire and explosion risks, workers, particularly new employees, should receive proper training on the correct connection of oxygen and gas lines to prevent incorrect connections. Oxygen must not be used for purposes apart from its intended application. Particular caution should be exercised when working near flammable materials or in areas where primer has recently been applied, and work areas must be adequately ventilated. Fire safety equipment and systems must be maintained in a state of readiness for immediate use in the event of an emergency.

Regarding fall risks, specialized equipment should be properly organized before, during, and after work, while entryways and narrow passages within the workshop should be kept clear. Particular caution should be exercised when working in areas where floors or surfaces are slippery due to oil or grease. When working at heights, workers should remain vigilant and properly use safety harnesses to enhance protection against falls.

Regarding the asphyxiation risk, workers should work in teams of two or three to ensure mutual assistance when necessary. Gas concentrations should be carefully measured before entering confined spaces, such as cargo holds or tanks, and adequate ventilation should be maintained using ventilation fans.

7. CONCLUSIONS

Workers in Vietnam's shipbuilding and repair industry face numerous occupational risks. A structured consultation involving 32 safety experts and 113 engineers and technical workers in the sector was conducted, resulting in the identification of 12 specific risks. The AHP and DEMATEL methods are applied sequentially to determine the overall importance of the identified risks and to examine the causal relationships among them. The five most important risks, ranked in descending order of importance, are electrical safety risks, physical health-related risks, fire and explosion risks, fall risks, and asphyxiation risks. The overall importance values range from 0.0631 to 0.2451. The remaining seven risks have overall importance values ranging from 0.0103 to 0.0457. Although these risks do not fall within the five most critical, each exerts a distinct influence and contributes to the overall safety risk profile of Vietnam's shipbuilding and repair industry. Furthermore, an analysis of the causal relationships among the risks based on the $r - c$ values reveals that physical health-related risk is classified as an "Effect" risk, indicating that it is strongly influenced by other risks.

Limitations and future research: The study sample comprised 32 safety experts and 113 engineers and workers. Given the moderate sample size, future studies could consider expanding the sample size to enhance the robustness and generalizability of the findings. An additional limitation of this study is that a sensitivity analysis was not conducted to examine the robustness of the AHP-derived weights and the resulting risk rankings under changes in expert judgments or comparison values. Consequently, the extent to which variations in the input judgments could affect the relative importance of the risk criteria and the final prioritization results remains uncertain. Future research should incorporate sensitivity analysis to assess the stability of the results and determine whether the identified priority risks remain consistent under alternative weighting scenarios. In addition, this study focused exclusively on the shipbuilding and repair industry. Future research could extend the proposed assessment approach to other industrial sectors to examine its applicability across different occupational contexts.

ACKNOWLEDGMENT

This research was financially supported by the Industrial University of Ho Chi Minh City (IUH) under research project No. 25BPHQN01. The authors gratefully acknowledge the University's financial support for this study.

REFERENCES

[1] Senturk, O.U. (2011). The shipbuilding industry in Viet Nam. OECD Journal. General Papers, 2010(3): 71-103. https://doi.org/10.1787/gen_papers-2010-5kg6z7tg35kf

[2] Vietnamplus. (2025). Vietnam sails with competitive advantages in global shipbuilding industry. https://en.vietnamplus.vn/vietnam-sails-with-competitive-advantages-in-global-shipbuilding-industry-post317655.vnp.

[3] Nguyen, P.Q.P., Tran, V.T. (2017). Vietnamese shipbuilding industry: Opportunities and challenges. International Journal of Recent Engineering Research and Development, 2(9): 11-15. http://www.ijrerd.com/papers/v2-i9/3-IJRERD-B459.pdf.

[4] Nguyen, D.T., Nguyen, D.C. (2019). A short communication for shipbuilding industry in Vietnam.

European Journal of Engineering and Technology Research, 4(4): 90-94. https://doi.org/10.24018/ejeng.2019.4.4.1255

[5] Yen, V.T.H. (2022). Capital solutions to promote fleet investment in shipping in countries such as Vietnam. International Journal of Professional Business Review, 7(5): e0738. https://doi.org/10.26668/businessreview/2022.v7i5.e738

[6] Nguyen, H. (2022). Vietnam and the shift towards maritime security cooperation. In Maritime Cooperation and Security in the Indo-Pacific Region: Essays in Honour of Sam Bateman, Brill, Leiden, pp. 341-363. https://doi.org/10.1163/9789004532847_019

[7] Gul, M., Ak, M.F. (2018). A comparative outline for quantifying risk ratings in occupational health and safety risk assessment. Journal of Cleaner Production, 196: 653-664. https://doi.org/10.1016/j.jclepro.2018.06.106

[8] Raja, U., Iqbal, N. (2019). Ensuring worker safety in Lahore's large industries: A study on occupational health, safety, and risk management. Journal of Energy and Environmental Policy Options, 2(4): 117-124. https://resdojournals.com/index.php/JEEPO/article/view/100.

[9] Sharma, S.K., Bhat, A. (2012). Identification and assessment of supply chain risk: Development of AHP model for supply chain risk prioritisation. International Journal of Agile Systems and Management, 5(4): 350-369. https://doi.org/10.1504/IJASM.2012.050155

[10] Chandani, P., Gupta, C. (2018). Requirement risk prioritization using analytic hierarchy process: A gateway to identify risky requirements. In 2018 Eleventh International Conference on Contemporary Computing (IC3), Noida, India, pp. 1-6. https://doi.org/10.1109/IC3.2018.8530569

[11] Saaty, T.L. (2008). Decision making with the analytic hierarchy process. International Journal of Services Sciences, 1(1): 83-98. https://doi.org/10.1504/IJSSCI.2008.017590

[12] Goepel, K.D. (2019). Comparison of judgment scales of the analytical hierarchy process—A new approach. International Journal of Information Technology & Decision Making, 18(2): 445-463. https://doi.org/10.1142/S0219622019500044

[13] Sipahi, S., Timor, M. (2010). The analytic hierarchy process and analytic network process: An overview of applications. Management Decision, 48(5): 775-808. https://doi.org/10.1108/00251741011043920

[14] Alinezhad, A., Khalili, J. (2019). DEMATEL method. In New Methods and Applications in Multiple Attribute Decision Making (MADM), Springer International Publishing, Cham, pp. 103-108. https://doi.org/10.1007/978-3-030-15009-9_15

[15] Devi, S.A., Felix, A., Narayanamoorthy, S., Ahmadian, A., Balaenu, D., Kang, D. (2022). An intuitionistic fuzzy decision support system for COVID-19 lockdown relaxation protocols in India. Computers and Electrical Engineering, 102: 108166. https://doi.org/10.1016/j.compeleceng.2022.108166

[16] Liu, P., Xu, Y., Li, Y. (2023). An improved failure mode and effect analysis model for automatic transmission risk assessment considering the risk interaction. IEEE Transactions on Reliability, 72(3): 1107-1122. https://doi.org/10.1109/TR.2022.3215110

[17] Ho, W.R.J., Tsai, C.L., Tzeng, G.H., Fang, S.K. (2011). Combined DEMATEL technique with a novel MCDM model for exploring portfolio selection based on CAPM. Expert Systems with Applications, 38(1): 16-25. https://doi.org/10.1016/j.eswa.2010.05.058

[18] Zou, T., Jin, Y., Chuang, Y.C., Chien, C.W., Tung, T.H. (2022). The DEMATEL method explores the interdependent relationship structure and weights for diagnosis-related groups system. Frontiers in Public Health, 10: 872434. https://doi.org/10.3389/fpubh.2022.872434

[19] Tsoukalas, V.D., Fragiadakis, N.G. (2016). Prediction of occupational risk in the shipbuilding industry using multivariable linear regression and genetic algorithm analysis. Safety Science, 83: 12-22. https://doi.org/10.1016/j.ssci.2015.11.010

[20] Brandon, P., Dondorp, M. (2023). Nodes of knowledge, managing transfer: Shipbuilding and repair during the transformation from sail to steam. History of Science, 61(1): 19-39. https://doi.org/10.1177/0073275320971100

[21] Wang, Z., Ma, J., Zhu, Y., Fan, S., Han, Z. (2026). A process-based and data-driven framework for carbon emission evaluation in integrated shipbuilding and repair in a typical small-to-medium sized shipyard. Journal of Cleaner Production, 559: 148327. https://doi.org/10.1016/j.jclepro.2026.148327

[22] Islam, A.H.M.R., Sarah, U.T., Zakaria, N.M.G., Begum, S. (2025). A review on assessment and management of occupational and health risks in the shipbuilding sector of Bangladesh. MIST International Journal of Science and Technology, 13(1): 37-47. https://banglajol.info/index.php/MIJST/article/view/82783.

[23] Celebi, U.B., Ekinci, S., Alarcin, F., Unsalan, D. (2010). The risk of occupational safety and health in shipbuilding industry in Turkey. In Proceedings of the 3rd International Conference Maritime and Naval Science and Engineering, pp. 178-184.

[24] Lokhande, V.R. (2014). Health profile of workers in a ship building and repair industry. Indian Journal of Occupational and Environmental Medicine, 18(2): 89-94. https://doi.org/10.4103/0019-5278.146898

[25] Okumus, D., Fariya, S., Tamer, S., et al. (2023). The impact of fatigue on shipyard welding workers' occupational health and safety and performance. Ocean Engineering, 285: 115296. https://doi.org/10.1016/j.oceaneng.2023.115296

[26] Sudrajat, I., Purwangka, F., Iskandar, B.H. (2024). Assessment of occupational safety risks in ship repairs at the fisheries service employees cooperative shipyard (FSECS). International Journal of Marine Engineering Innovation and Research, 9(1): 20-29. https://doi.org/10.12962/j25481479.v9i1.20084

[27] Zaman, M.B., Pitana, T., Prastowo, H., et al. (2023). Occupational health and safety risk assessment of shipyard using HIRARC method. AIP Conference Proceedings, 2562: 130005. https://doi.org/10.1063/5.0117107

[28] Winarno, Priadi, A.A., Wulandari, R.S. (2024). Shipbuilding risk assessment: Legal frameworks and practical challenges in Indonesian shipyards. International Journal of Safety & Security Engineering, 14(4): 1061-1072. https://doi.org/10.18280/ijsse.140405

[29] Izci, F.B., Gökyay, O., Barlas, B. (2024). Investigation

of non-fatal occupational accidents and their causes in Turkish shipyards. International Journal of Occupational Safety and Ergonomics, 30(1): 33-40. https://doi.org/10.1080/10803548.2022.2157545
[30] Seker, S., Recal, F., Basligil, H. (2017). A combined DEMATEL and grey system theory approach for analyzing occupational risks: A case study in Turkish shipbuilding industry. Human and Ecological Risk Assessment: An International Journal, 23(6): 1340-1372. https://doi.org/10.1080/10807039.2017.1308815
[31] Baihaqi, I., Lazakis, I., Supomo, H. (2023). Integrated value engineering and risk assessment performance measurement framework in ship-manufacturing industry towards net zero emissions using fuzzy DEMATEL-AHP. Machines, 11(8): 799. https://doi.org/10.3390/machines11080799
[32] Chen, L., Li, H., Tian, S. (2022). Application of AHP and DEMATEL for identifying factors influencing coal mine practitioners' unsafe state. Sustainability, 14(21): 14511. https://doi.org/10.3390/su142114511
[33] Tuncel, A.L., Beşikçi, E.B., Akyuz, E., Arslan, O. (2023). Safety analysis of fire and explosion (F&E) accidents risk in bulk carrier ships under fuzzy fault tree approach. Safety Science, 158: 105972. https://doi.org/10.1016/j.ssci.2022.105972
[34] Fu, S., Sun, Z., Jiang, C., Hao, Y., Mao, W. (2026). An integrated risk assessment framework for fire accidents on passenger ships. Ocean Engineering, 343: 123290. https://doi.org/10.1016/j.oceaneng.2025.123290
[35] Barlas, B., Izci, F.B. (2018). Individual and workplace factors related to fatal occupational accidents among shipyard workers in Turkey. Safety Science, 101: 173-179. https://doi.org/10.1016/j.ssci.2017.09.012
[36] Wang, N., Yin, J., Khan, R.U. (2024). Risk coupling assessment of vehicle scheduling for shipyard in a complicated road environment. Journal of Marine Science and Engineering, 12(4): 685. https://doi.org/10.3390/jmse12040685
[37] Shin, J., Lee, S., Lee, K., Kim, H. (2021). Effect of unmeasured time hours on occupational noise exposure assessment in the shipbuilding process in Korea. International Journal of Environmental Research and Public Health, 18(16): 8847. https://doi.org/10.3390/ijerph18168847
[38] Türk, A., Özkök, M. (2022). Comprehensive risk assessment analysis of accidental falls in shipyards using the gaussian fuzzy AHP model. Journal of ETA Maritime Science, 10(4): 211-222. https://doi.org/10.4274/jems.2022.04695
[39] Daniels, R.D., Taulbee, T.D., Chen, P. (2004). Radiation exposure assessment for portsmouth naval shipyard health studies. Radiation Protection Dosimetry, 111(2): 139-150. https://doi.org/10.1093/rpd/nch332
[40] Kim, K.W., Park, S.J., Lim, H.S., Cho, H.H. (2017). Safety climate and occupational stress according to occupational accidents experience and employment type in shipbuilding industry of Korea. Safety and Health at Work, 8(3): 290-295. https://doi.org/10.1016/j.shaw.2017.08.002
[41] Saaty, T.L. (2001). Fundamentals of the analytic hierarchy process. In the Analytic Hierarchy Process in Natural Resource and Environmental Decision Making, Springer Netherlands, Dordrecht, pp. 15-35. https://doi.org/10.1007/978-94-015-9799-9_2
[42] Ho, W. (2008). Integrated analytic hierarchy process and its applications–A literature review. European Journal of Operational Research, 186(1): 211-228. https://doi.org/10.1016/j.ejor.2007.01.004
[43] Bodin, L., Gass, S.I. (2003). On teaching the analytic hierarchy process. Computers & Operations Research, 30(10): 1487-1497. https://doi.org/10.1016/S0305-0548(02)00188-0
[44] Bernasconi, M., Choirat, C., Seri, R. (2010). The analytic hierarchy process and the theory of measurement. Management Science, 56(4): 699-711. https://doi.org/10.1287/mnsc.1090.1123
[45] Mu, E., Pereyra-Rojas, M. (2017). Understanding the analytic hierarchy process. In Practical Decision Making: An Introduction to the Analytic Hierarchy Process (AHP) Using Super Decisions V2, Springer International Publishing, Cham, pp. 7-22. https://doi.org/10.1007/978-3-319-33861-3_2
[46] Tavana, M., Soltanifar, M., Santos-Arteaga, F.J. (2023). Analytical hierarchy process: Revolution and evolution. Annals of Operations Research, 326(2): 879-907. https://doi.org/10.1007/s10479-021-04432-2
[47] Das, D., Datta, A., Kumar, P., Kazancoglu, Y., Ram, M. (2022). Building supply chain resilience in the era of COVID-19: An AHP-DEMATEL approach. Operations Management Research, 15(1-2): 249-267. https://doi.org/10.1007/s12063-021-00200-4
[48] Saaty, T.L. (2008). The analytic hierarchy and analytic network measurement processes: Applications to decisions under risk. European Journal of Pure and Applied Mathematics, 1(1): 122-196. https://doi.org/10.29020/nybg.ejpam.v1i1.6
[49] Si, S.L., You, X.Y., Liu, H.C., Zhang, P. (2018). DEMATEL technique: A systematic review of the state-of-the-art literature on methodologies and applications. Mathematical Problems in Engineering, 2018(1): 3696457. https://doi.org/10.1155/2018/3696457
[50] Du, Y.W., Li, X.X. (2021). Hierarchical DEMATEL method for complex systems. Expert Systems with Applications, 167: 113871. https://doi.org/10.1016/j.eswa.2020.113871
[51] Lin, C.L., Tzeng, G.H. (2009). A value-created system of science (technology) park by using DEMATEL. Expert Systems with Applications, 36(6): 9683-9697. https://doi.org/10.1016/j.eswa.2008.11.040
[52] Braga, I.F., Ferreira, F.A., Ferreira, J.J., Correia, R.J., Pereira, L.F., Falcão, P.F. (2021). A DEMATEL analysis of smart city determinants. Technology in Society, 66: 101687. https://doi.org/10.1016/j.techsoc.2021.101687
[53] Yazdi, M., Khan, F., Abbassi, R., Rusli, R. (2020). Improved DEMATEL methodology for effective safety management decision-making. Safety Science, 127: 104705. https://doi.org/10.1016/j.ssci.2020.104705

APPENDIX

This appendix presents the detailed calculations used to derive the AHP priority weights and assess the consistency of the pairwise comparison matrices. The calculations follow the corrected matrices reported in Tables 3–5 and the overall weighting procedure described in Section 3.2.

- Priority weights of the main risk categories:

The corrected pairwise comparison matrix for the

immediate health impact risk (IIR) and long-term cumulative health risk (LCR) categories is:

Priority vector for risk criteria: $\begin{bmatrix}0.8750\\0.1250\end{bmatrix}$

With $n = 2$ the decision is obviously consistent. (a)

- Priority weights of the ten IIR sub-criteria:

The pairwise comparison matrix for the ten immediate health impact risk sub-criteria is shown in Table 4. The priority vector is derived from the principal eigenvector of the comparison matrix.

Priority vector for sub-criteria risk- IIR: $\begin{bmatrix}0.2150\\0.2964\\0.0256\\0.0528\\0.0181\\0.0758\\0.0367\\0.1082\\0.1533\\0.0181\end{bmatrix}$

With $n = 10$; $\lambda max = 10.4649$

$$\text{CI} = \frac{\lambda max - n}{n-1} = \frac{10.4649-10}{10-1} = 0.0517$$

$$\text{CR} = \frac{\text{CI}}{\text{RI}} = \frac{0{,}0517}{1.49} = 0.0347$$

Since CR = 0.0347 < 0.10, the pairwise comparison matrix for the ten IIR sub-criteria satisfies the conventional AHP consistency criterion. (b)

- Priority weights of the LCR sub-criteria:

Priority vector for risk sub-criteria - LCR: $\begin{bmatrix}0.8333\\0.1667\end{bmatrix}$

With $n = 2$ the decision is obviously consistent. (c)

The overall AHP weights of the twelve risk criteria were subsequently derived by synthesizing the results obtained in (a), (b), and (c), as presented in Table 7.