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Risk Analysis and Management of Occupational Accidents on Ships

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Abstract

Ships involved in maritime transportation are exposed to various occupational health and safety risks due to the complexity of onboard operations and the unpredictability of environmental conditions during navigation. This study aims to identify the factors leading to occupational accidents on merchant ships, to conduct a risk analysis, and to determine which types of ships are more frequently associated with such incidents. To achieve this, the Fine-Kinney method and the analytical hierarchy process (AHP) were employed. The Fine-Kinney analysis revealed that liquid cargo ships have more hazards classified as very high risk than other ship types, with management inefficiency identified as the primary hazard. The AHP analysis indicated that "insufficient sea experience" is a significant risk factor among the hazards, and that "liquid cargo ships" are at particularly high risk of occupational accidents. The findings suggest that the AHP method is advantageous for risk prioritization and that both methods should used complementarily to address methodological limitations in ship-based risk assessments.

Keywords: Shipping, ships, occupational accident, AHP, Fine-Kinney

1. Introduction

Shipping is one of the most hazardous lines of business due to its complex structure, working environment, and greater exposure to hazards than other land-based activities [1,2]. Maritime safety refers to the set of measures and practices aimed at preventing and managing both occupational accidents on ships and maritime incidents, such as fires, explosions, groundings, collisions, contacts, and capsizing [3]. Maritime safety is a shared concern among regulatory bodies, ship operators, researchers, and seafarers, given the significant human, environmental, and economic risks associated with accidents [4]. On ships, long working hours, isolation from daily life, and shift work increase employees' stress and fatigue [5,6]. Biological risk factors such as viruses, fungi, bacteria, and parasites; physical risk factors such as air, noise, radiation, and vibration; and psychosocial risk factors such as excessive and irregular working patterns, limited ship space, and poor sleep quality are frequently encountered on ships [7]. In addition, exposures to infectious diseases and hazardous substances are significant factors in the deterioration of ship workers' health [8]. Occupational accidents on ships may result from a range of factors, including confined spaces, work at heights, painting operations, mooring activities, and slippery floors or stairs [1,9]. Occupational accidents on ships are mainly caused by slips, trips, and falls [10]. The consequences of occupational accidents on board ships can be enormous owing to the lack of emergency response equipment, inadequate medical knowledge among the personnel, and limited direct and rapid access to hospitals during the voyage [6,9].

In workplaces, the provision of a safe working environment reflects the importance placed on employees. Failure to take the necessary precautions in the working environment and to provide personal protective equipment (PPE) to employees undermines a safe working environment, resulting in occupational accidents and lost working days [11]. Therefore, risk analysis must be conducted on a continuous and systematic basis to eliminate the risks of ship accidents or to reduce them to an acceptable level [10]. The Maritime Labour Convention [12], adopted by the International Labour Organization, sets comprehensive standards for the working and living conditions of seafarers and plays a critical role in

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promoting occupational health and safety (OHS) on board ships. In this context, improving working conditions is essential to ensure ship safety [13]; such improvements are achieved by identifying and implementing measures based on risk assessment [2]. In shipping, safety management procedures are implemented, but OHS in this sector still requires improvement [14]. Although occupational accidents on ships are widely addressed in studies, risk-analysis studies are less common. Studies on occupational accidents on ships generally fall into two categories: those that analyze past accident data and their causes [1,15-17], and those that investigate accidents and their causes through questionnaires and interviews with employees [3,18,19]. Although some studies have applied risk analysis methods to shipboard hazards [10,16,20], such applications remain relatively limited compared to the broader literature on accident data analysis and causal investigations.

The Fine-Kinney method is frequently preferred in risk analysis applications due to its ease of use [21], but it may be insufficient for risk prioritization [22]. Analytical hierarchy process (AHP), one of the multi-criteria decision-making (MCDM) methods, is a practical approach for determining the relative importance of risks and establishing their priority order [23]. In this study, the Fine-Kinney method was used to generate quantitative risk scores based on likelihood, consequence, and exposure factors. The AHP method was applied to prioritize these risks and, in particular, to distinguish among risks with the same score. Thus, the quantitative scores provided by the Fine-Kinney method are complemented by the multi-criteria evaluation capability of AHP, resulting in a more comprehensive risk analysis. Similar hybrid approaches in the literature have been shown to enhance risk analysis across different sectors [21,22]. However, studies examining the combined use of these methods in shipboard applications are limited. Therefore, this study aims to determine the causes of occupational accidents aboard commercial ships, to perform a risk analysis, and to assess the effect of ship type on these accidents. Consequently, this study contributes to the literature by examining the combined application of existing research methods to ship types. Furthermore, it expands the field's knowledge base by identifying which hazards should be prioritized when implementing risk control measures on ships. The study is organized into the following sections: introduction, literature review, materials and methods, findings, discussion, study limitations and conclusion.

2. Literature Review

To determine the hazards encountered on merchant ships and to perform risk analysis, the literature was reviewed and organized into four thematic sections. The first section includes studies examining data on occupational accidents on ships; the second contains studies based on questionnaires or interviews with ship workers; the third comprises studies applying risk analysis to these accidents; and the fourth includes studies applying risk analysis using the AHP and Fine-Kinney methods across different sectors.

Lee et al. [15] examined accident data in the fishing industry. The most serious and common accident types were slips, entanglements, collisions, and capsizes. As a result of accidents, hand injuries were the most common. Bilir et al. [1] examined the medical records aboard container ships and obtained information on accidents. Sprains, open wounds, and foreign-body injuries were the most common on-deck injury types. Bowo and Furusho [24] used the Human Error Assessment and Reduction Technique and the 4M (man, machine, media, and management) method to analyze the causes of occupational accidents and examine accident data. Loading and unloading operations were associated with a high incidence of occupational accidents. Sagaro et al. [16] examined the prevalence of occupational accidents and occupational diseases on container ships, and changes in injury patterns by rank. Those working on deck were more likely to be injured than those working in the engine room. Injury and illness rates also varied inversely with rank. Nævestad et al. [25] analyzed accidents on cargo and cruise ships in different cultural contexts. It was determined that risk acceptance or violation varied by nationality and age and as a result, the risk of occupational accidents was affected by these factors. Çakır [26] analyzed reports of occupational accidents on merchant ships and determined their frequency and causes. Hazardous work practices and non-compliance with rules and instructions have been identified as the most critical hazards leading to occupational accidents. Ádám et al. [17] examined occupational accident records on merchant ships to analyze injury risk by nationality. The study results demonstrate that nationality significantly influences the occurrence of occupational accidents, owing to factors such as perceptions of safe behavior. Kim et al. [27] analyzed occupational accidents using past accident records from fishing vessels. The accidents were attributed to slips, trips, collisions with objects, and contact with equipment. Borch et al. [28] examined fatalities in the shipping fleet and compared the rate of fatal ship accidents with the rate in the working population. Although high risks persist, the shipping fleet has become a comparatively safer working environment in recent years. Orosa et al. [29] examined the working conditions on merchant ships and investigated occupational accidents by activity and work location. The results indicated no relationship between working hours and accidents, but the working environment influenced them. Hansen et al. [30] investigated the frequency and circumstances of occupational accidents on merchant ships.

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The results indicated that the most serious accidents occurred on deck and that age played a significant role in accidents resulting in permanent disability.

Radic [18] interviewed crew members to identify injuries sustained while working on cruise ships. According to the analysis, the causes of injuries included slips, trips, falls, physical pressure, body movements without pressure, and contact with liquids. Yılmaz and İlhan [19] developed a questionnaire to identify hazardous activities and OHS practices on ships; ship employees completed the questionnaire. It was found that as employees' education level increases, their perception of occupational accident risk increases associated with work tasks and the working environment. Nævestad [3] examined the impact of working conditions and safety culture on occupational accidents and on risk perception aboard ships. The study, which included a questionnaire, group meetings, and qualitative interviews, concluded that safety culture was weaker, and more accidents occurred on ships operating with insufficient manning levels, that is, below the required minimum. Jensen et al. [31], in a questionnaire-based study, reported injuries caused by slips, trips, and falls aboard ships. Based on the results obtained, this type of injury was found to account for 43% of all reported injuries. In addition, this type of injury has a high incidence among deck workers on passenger ships.

Demirci and Arıcan [32] conducted a two-stage risk assessment process to identify potential risks and preventive measures in marine tanker transportation. In this study, which applied failure mode and effects analysis (FMEA) and fuzzy AHP, management and maintenance were identified as high-risk areas. Ceylan [33] employed control theory and the fuzzy Fine-Kinney method to assess the risks of ship automation systems. The most significant hazard was identified as electrode failure. Park et al. [34] first administered a questionnaire and then applied a fuzzy Bayesian network to analyze accidents on fishing vessels. Na et al. [35] conducted a qualitative risk assessment to identify hazard scenarios for maritime autonomous surface ships, proposing a cognitive-model-based hazard identification method. Ceylan [36] evaluated the risks of ship bunkering operations using a rule-based fuzzy FMEA and identified the lack of an appropriate control mechanism as the most critical failure. Çamlıyurt et al. [37] used a machine learning approach to predict occupational accidents on ships. Workplace hazards cause more accidents than environmental hazards. Çamlıyurt et al. [2] examined the occupational accident records of naval pilots and performed a bow-tie risk analysis on these data. As a result of the analysis, the likelihood of an occupational accident was calculated to be 14%. Zhang et al. [14] devised a Bayesian network-based model to estimate the causes of occupational accidents caused by seafarers by examining contributing factors. PPE availability, age, and experience have been identified as the most significant factors influencing risk. Using the fuzzy AHP method, Özdemir et al. [38] identified the causes of occupational accidents on a ship. Human factors, inadequate management, ship-related technical failures, cargo handling and stowage issues, and environmental factors have been identified as key causes of occupational accidents. Uğurlu et al. [20] applied the AHP method to identify the occupational accidents that trainees on ships could potentially encounter. Decks, cargo areas, maneuvering areas, and accommodations are ranked by occupational accident risk from highest to lowest. Failure to use PPE, rashes, and presence in inappropriate locations have been the primary causes of occupational accidents. Song et al. [10] conducted a risk analysis of occupational accidents involving slips, trips, and falls from height using a Bayesian network based on the bow-tie method. In the study in which slip, trip, and fall accidents were systematically evaluated and environmental factors were considered, risks were assessed dynamically.

Yorulmaz and Avcı [39] analyzed the risks associated with ship engine-room operations using the Fine-Kinney and AHP methods. Both methods identified fire risk the most critical. Tosik et al. [40] used the Fine-Kinney method to identify critical risks and their levels, and the AHP method to perform a hierarchical assessment of these risks. Güney and Kahraman [41] conducted a risk analysis in an environmental research laboratory using the AHP and Fine-Kinney methods. Measures have been established with due consideration of safety and economic factors. Yılmaz and Özcan [42] conducted a risk analysis of lifting equipment used in the construction sector, employing a combination of the Fine-Kinney and AHP methods. Kokangül et al. [43] performed a risk analysis by integrating the Fine-Kinney and AHP methods in a production area.

According to the literature, occupational accidents on ships are commonly studied in the context of complex operations and exposure to dynamic risk factors. Most studies have analyzed past occupational accident data to identify common accidents and their causes or have identified these causes through questionnaires and interviews with ship personnel. When examining studies that apply risk analysis, it is evident that those using the Fine-Kinney and AHP methods together are limited in number. Yorulmaz and Avcı [39] provided an important example in the maritime context by applying both methods to ship engine-room operations. Moreover, studies have primarily focused on different sectors. For example, Tosik et al. [40] (textile sector), Güney and Kahraman [41] (environmental research laboratories), Yılmaz and Özcan [42] (construction sector), and Kokangül et al. [43] (manufacturing sector) have performed risk

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analyses using a combination of the Fine-Kinney and AHP methods. These studies show that AHP can be used as a complementary approach to address the limitations of the Fine-Kinney method in risk prioritization. However, studies of this hybrid approach in the maritime context are limited. Therefore, the present study aims to fill this gap in the literature by identifying the causes of occupational accidents on commercial ships, analyzing the associated risks, and highlighting differences by ship type.

3. Materials and Methods

Potential hazards causing occupational accidents on ships were initially identified through a comprehensive literature review of academic and industry sources [2,14,24,26,38]. These hazards were compiled from the findings of studies. Following the identification process, each hazard was assessed using the Fine-Kinney method, which assigns risk scores based on likelihood, consequence, and exposure factors. The research team performed the Fine-Kinney assessment. The assessment values were based on data obtained from national and international literature, past accident reports, and regulations. Thus, sectoral experience and previous findings were used as the basis for determining risk scores, while the standard structure of the method was maintained. However, the Fine-Kinney method alone may be insufficient for determining the detailed priority order of risks. Therefore, the AHP method was used in this study to complement the Fine-Kinney results. First, the potential hazards identified through the literature review were converted into sub-criteria in accordance with the hierarchical structure required by the AHP method. The AHP hierarchy was grouped into four main criteria, reflecting the most fundamental risk sources related to occupational accidents: seafarers (human factor), environment, machinery and equipment, and management. Subsequently, expert assessments were collected from captains, chief engineers, and safety and quality managers through structured interviews and pairwise comparison matrices. Risks were prioritized through comparative evaluation across criteria. Similar hybrid approaches have been applied across different engineering fields, as reported in the literature. For example, in their study, Ayvaz et al. [21] performed risk prioritization by integrating Fine-Kinney scores with fuzzy AHP, whereas Wang et al. [22] integrated Fine-Kinney-based risk assessment with the multi-objective optimization by ratio analysis method. These examples demonstrate that Fine-Kinney's ability to generate risk scores, when supported by MCDM methods, provides more comprehensive and reliable prioritization. In the current study, this approach is applied to the risk analysis and prioritization of occupational accidents on commercial ships, offering a unique contribution to maritime literature. The study also enables the differentiation of hazards with the same risk score and the determination of ship-specific risk priorities.

The AHP questionnaire was conducted with the permission of the İstanbul Beykent University Science and Engineering Sciences Scientific Research and Publication Ethics Committee (decision no: 185296, date: 15.04.2025).

3.1. Fine-Kinney Method

The risk analysis method proposed by Fine [44] and developed by Kinney and Wiruth [45] consists of three parameters: likelihood, consequence, and exposure factor. In the Fine-Kinney method, the risk score is obtained by multiplying the likelihood (L), consequence (C), and exposure factor (E) values. The risk score is calculated as presented in Equation (1):

$$R = \mathrm{L} \times \mathrm{E} \times \mathrm{C} \quad (1)$$

According to the risk score, resources are allocated to risk-control measures and risks are prioritized [46]. Table 1 presents the scales of the likelihood, consequence, and exposure-factor parameters, and Table 2 presents the risk scores and decision levels obtained by multiplying these three parameters.

In the Fine-Kinney method, the likelihood, consequence, and exposure-factor scores range from 0.2 to 10, 1 to 100, and 0.5 to 10, respectively. The calculated risk score is expressed in five levels of risk: very high, high, substantial, possible, and reasonable. Risk control measures are decided, and actions are taken according to the determined risk levels.

Table 1. *Fine-Kinney parameters [45]*

Likelihood (L)		Consequence (C)		Exposure factor (E)	
10	Might well be expected	100	Catastrophe (many fatalities)	10	Continuous
6	Quite possible	40	Disaster (few fatalities)	6	Frequent (daily)
3	Unusual but possible	15	Very serious (fatality)	3	Occasional (weekly)
1	Only remotely possible	7	Serious (serious injury)	2	Unusual (monthly)
0.5	Conceivable but very unlikely	3	Important (disability)	1	Rare (a few per year)
0.2	Practically impossible	1	Noticeable (minor first aid accident)	0.5	Very rare (yearly)

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Table 2. Decision phase according to risk score [45,47]

Risk score	Decision
R≥400	Very high risk
200≤R<400	High risk
70≤R<200	Substantial risk
20≤R<70	Possible risk
R<20	Reasonable risk

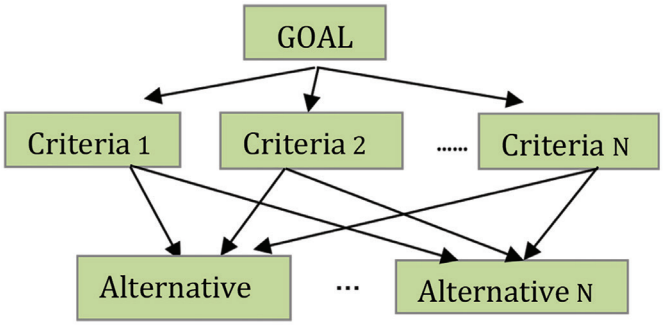

Figure 1. AHP hierarchy structure [48]

AHP: Analytical hierarchy process

3.2. AHP Method

The AHP method, developed by Saaty [48], is one of the most popular MCDM methods across various fields. The method, designed to solve complex problems, helps structure the problem and assign weights to criteria and alternatives [49]. The AHP method was applied using the following steps [48,50].

Step 1: Defining the problem and creating the hierarchical structure. First, the problem is defined and a hierarchical structure comprising criteria and alternatives is designed to solve the problem. The hierarchical structure of the AHP model is presented in Figure 1.

The hierarchy illustrated in Figure 1 comprises three levels: the problem goal at the first level, the criteria for achieving this goal at the second level, and the decision-making alternatives at the third level.

Step 2: Creation of pairwise comparison matrices. Matrices of appropriate size nxn are created to compare levels pairwise. The value n denotes the number of criteria. For each level, the evaluation scale developed by Saaty [48] (Table 3) is used to make pairwise comparisons.

Step 3: Determining the importance levels of criteria and alternatives: relative weights are calculated according to the pairwise comparison matrices. The final result among the alternatives is calculated, and the most appropriate alternative is selected.

Step 4: Determining the consistency ratio (CR). The calculated importance levels need to be checked for consistency. The consistency check should be conducted for each criterion and each alternative. Equations 2 and 3 were used to perform a consistency check [51].

$$CI = (\lambda max - n)/(n-1) \quad (2)$$

$$CR = CI/RI \quad (3)$$

The consistency index (CI) in Equation 1 is calculated, and the random index (RI) in Equation 2 is determined using the n values in Table 4. Once the CI and RI values are specified, the CR is obtained.

The CR calculated to assess the acceptability of the importance levels for criteria and alternatives should be below 0.1 [48,51].

4. Findings

In this study, the Fine-Kinney and AHP methods were used to analyze occupational accidents occurring onboard ships. In this context, 13 hazards that may pose a risk of occupational accidents in the ship environment were identified and included in the analysis.

4.1. Risk Analysis with Fine-Kinney Method

Table 5 presents the results of the Fine-Kinney analysis. Values for likelihood, consequence, and exposure factor were determined separately for liquid-cargo ships, container ships, and dry-cargo ships; hazard risk scores were then calculated from these values.

According to Fine-Kinney risk scores, the hazard of "management inefficiency" ranks first in liquid cargo ships. This hazard was followed by "failure to comply with International Safety Management (ISM) code requirements," "machine-equipment failure," and "lack of role training" hazards with the same risk score (1200). The hazard with the lowest risk score calculated for the liquid cargo ship was "physical conditions of the working environment." According to the risk scores on the container ship, the hazard of "cargo operations" ranked first. This hazard was followed

Table 3. Evaluation scale [48]

Degree of importance	Explanation
1	Equal importance
3	Moderate importance of one over another
5	Strong or essential importance
7	Very strong or demonstrated importance
9	Extreme importance
2,4,6,8	Intermediate values

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Table 4. *Random index values [51]*

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.52	1.54	1.56	1.58	1.59

Table 5. *Fine-Kinney analysis results*

			Liquid cargo ship risk rating				Container ship risk rating				Dry cargo ship risk rating			
No	**Hazard/hazard source**	**Risk**	**Likelihood**	**Exposure factor**	**Consequence**	**Risk score**	**Likelihood**	**Exposure factor**	**Consequence**	**Risk score**	**Likelihood**	**Exposure factor**	**Consequence**	**Risk score**
1	Management inefficiency	Occupational accident	6	3	100	1800	3	2	100	600	3	1	100	300
2	Failure to comply with International Safety Management (ISM) Code requirements		6	2	100	1200	3	2	100	600	3	2	100	600
3	Machine-equipment failure		6	2	100	1200	3	2	100	600	3	1	100	300
4	Lack of role training		6	2	100	1200	6	1	100	600	3	1	100	300
5	Insufficient sea experience		6	3	40	720	3	1	40	120	3	2	40	240
6	Lack of periodic control of machine-equipment		3	2	100	600	3	1	100	300	3	1	100	300
7	Lack of training		6	2	40	480	3	2	40	240	3	1	40	120
8	Structural damage to the ship		6	0.5	100	300	3	0.5	100	150	3	0.5	100	150
9	Not using PPE		3	2	40	240	3	2	15	90	3	2	15	90
10	Cargo operations		1	2	100	200	3	3	100	900	1	2	40	80
11	Intensive work		3	3	15	135	3	3	40	360	3	2	15	90
12	Meteorological conditions		3	3	15	135	3	3	40	360	3	3	15	135
13	Physical conditions of the working environment		3	1	40	120	3	1	40	120	3	1	40	120

by "management inefficiency," "failure to comply with ISM Code requirements," "machine-equipment failure," and "lack of role training" with the same risk score (600). The hazard with the lowest risk score calculated on the container ship was "not using PPE." According to the risk scores of the dry cargo ship, the hazard of "failure to comply with ISM code requirements" ranked first. This hazard was followed by "management inefficiency," "machine-equipment failure," "lack of role training," and "lack of periodic control of machine-equipment" with the same risk score (300). The hazard with the lowest risk score calculated on the dry cargo ship was "cargo operations." Risk levels were determined from the risk scores for the three cargo types, and the distribution of these levels is shown in Figure 2.

When the classification is made according to the risk levels in Figure 2, most of the hazards for liquid cargo and container

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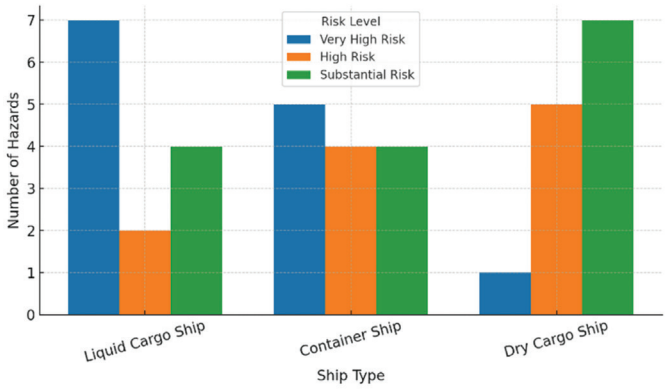

Figure 2. *Risk levels by ship types*

ships are calculated at the "very high risk" level. For dry cargo ships, most of the hazards were calculated at the "substantial risk" level, and only one hazard was identified at the very high risk level. Although the Fine-Kinney method defines five risk levels, hazards are classified as very high, high, or substantial across all three cargo types. When the ship types are compared, it is concluded that "liquid cargo ship" has a high percentage (54%) of hazards at a very high risk level.

The interpretation of risk ratings in this study aligns with the risk acceptance principles outlined in the International Maritime Organization guidelines on maritime risk assessment [52] and is further supported by industry practices, such as Det Norske Veritas-Germanischer Lloyd's risk matrices [53], which provide structured thresholds for evaluating risk tolerability in maritime contexts.

4.2. Risk Analysis with AHP Method

The AHP method, which enables the elicitation of expert opinion, has been used to determine the causes of occupational accidents on ships. The causes of occupational accidents on ships are analyzed under four main criteria: seafarer-related causes, environmental causes, machinery- and equipment-related causes, and management-related causes. Figure 3 presents the hierarchical structure consisting of main criteria, sub-criteria, and alternatives.

Ten experts answered the AHP questionnaires, which were developed based on the hierarchical structure in Figure 3. The experts' educational status, durations of experience, and job titles are presented in Table 6.

Most of the experts listed in Table 6 have postgraduate education and hold direct operational and managerial responsibilities in the maritime sector, such as captains, chief engineers, and safety and quality managers. The experts' professional experience has been classified into 0-5 years, 6-10 years, and 11 years and above, rather than recorded as individual annual values. The vast majority of experts are highly experienced, which contributes to assessments drawing on strong professional knowledge and sectoral experience. In this regard, all experts were given equal weight, based on the assumption that they have similar levels of education, professional qualifications, and sectoral experience. The experts' questionnaires were analyzed using the Super Decisions program. The weights for the main criteria, sub-criteria, and alternatives were calculated using the Super Decisions program. Table 7 presents the weights, CRs, and rankings for the main criteria and sub-criteria. Table 8 presents the final weights and CRs for the alternatives.

Based on the results in Table 7, the main criteria are ranked from high to low as follows: seafarer-related causes (0.53), management-related causes (0.23), environment-related causes (0.15), and machinery- and equipment-related causes (0.15), and machinery— and equipment— related causes (0.09). The most significant hazard leading to occupational accidents on ships has been identified as "seafarer-related causes." Among the sub-criteria, "insufficient sea experience" (0.23), "not using PPE" (0.148), and "lack of training" (0.147) rank in the top three based on their overall weights. According to overall weights, the least significant hazard is "cargo operations".

Based on the ship types in Table 8, the importance ranking was determined to be liquid cargo ship (0.55), container ship (0.24), and dry cargo ship (0.21). Based on the CR calculated for the main criteria, sub-criteria, and alternatives, the experts' decisions were considered consistent because all values were below 0.1.

4.3. Interpreting Fine-Kinney and AHP Analyses Together

In the Fine-Kinney method, risk scores for three ship types—liquid, container, and dry cargo—were examined. Each ship type was ranked by its risk score. Furthermore, ships with the same risk score were assigned the same rank number. This approach aimed to directly reflect the priority order of operational conditions and risk dynamics specific to each ship type. This approach allowed the Fine-Kinney structure to account for operational differences between ship types. Consequently, the Fine-Kinney results produced three distinct sets of priorities, each ranking the risks for a different ship type. In contrast, the AHP method ranked the ships based on overall weights derived from expert opinion. Since AHP allows evaluation of relative importance among criteria, it reflects experts' holistic perception of risk independently of ship type. As both methods operate on different scales, the comparison was made based on rankings rather than scores and weights. Table 9 shows the Fine-Kinney rankings by ship type and the AHP rankings.

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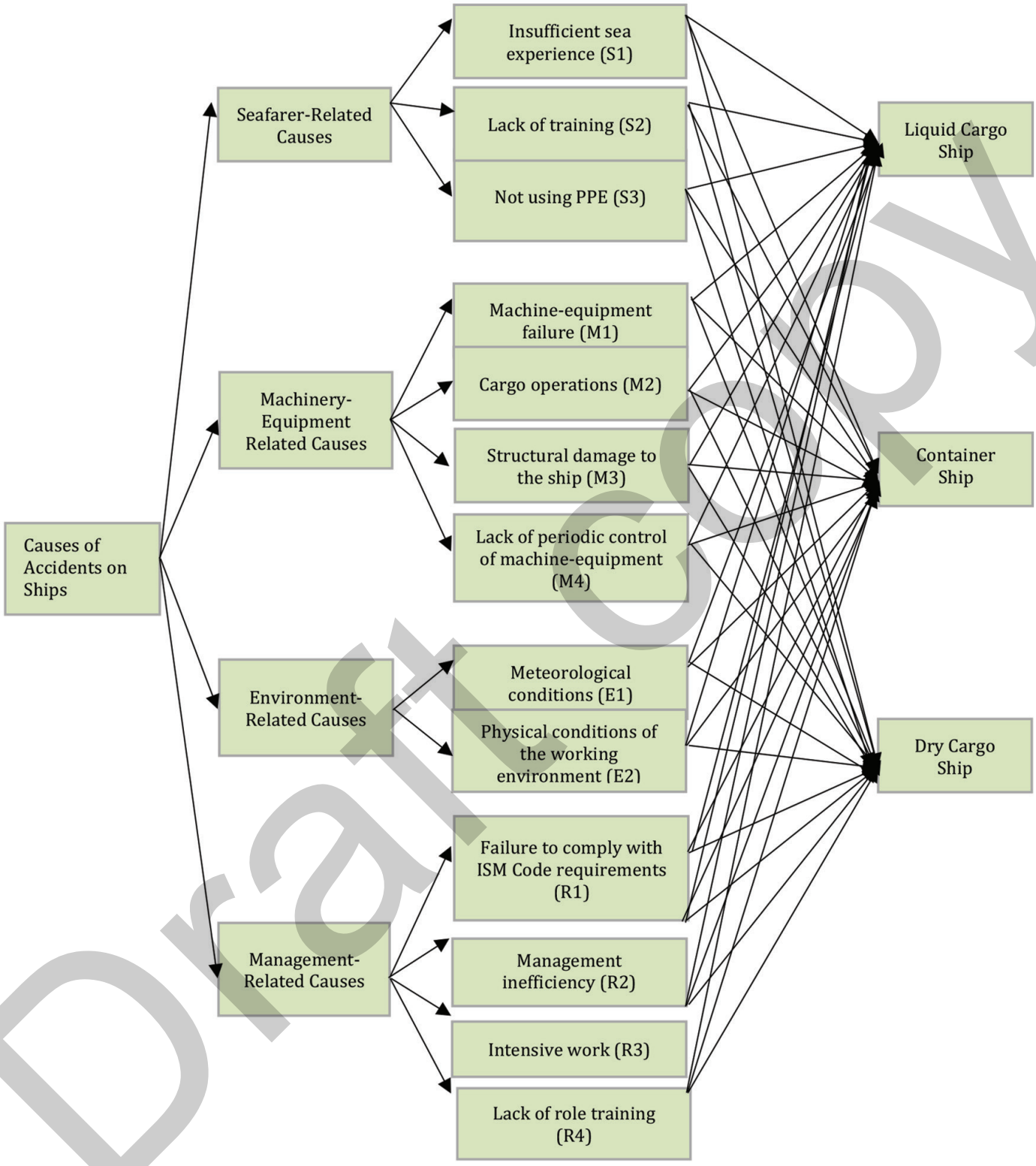

Figure 3. *Hierarchy structure*

According to the rankings in Table 9, significant differences were observed between the Fine-Kinney and AHP results. For example, while "cargo operations" stood out as one of the most critical risks in Fine-Kinney, particularly for container ships, it was assessed as the lowest-priority risk in AHP. This situation may stem from Fine-Kinney highlighting technical and operational risks by considering ship-type-specific parameters. At the

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Table 6. *Expert information*

Expert	Educational status	Experience	Job
Expert 1	Postgraduate	11+	Chief engineer
Expert 2	Postgraduate	11+	Safety manager
Expert 3	Postgraduate	11+	Captain
Expert 4	Postgraduate	11+	Chief engineer
Expert 5	License	0-5	Quality manager
Expert 6	Postgraduate	11+	Chief engineer
Expert 7	License	11+	Safety manager
Expert 8	Postgraduate	6-10	Quality manager
Expert 9	Postgraduate	6-10	Captain
Expert 10	Postgraduate	11+	Captain

Table 7. *Sub-criteria overall weights and rankings*

Main criteria	Main criteria weights	Consistency ratio (CR)	Sub-criteria	Sub-criteria weights	CR	Overall weights	Rankings
Seafarer-related causes	0.52704	0.0925	S1	0.43945	0.0565	0.23160	1
			S2	0.27917		0.14713	3
			S3	0.28137		0.14829	2
Machinery-equipment related causes	0.08818		M1	0.22113	0.0905	0.01949	12
			M2	0.14788		0.01304	13
			M3	0.25000		0.02205	11
			M4	0.38100		0.03359	10
Environment-related causes	0.15493		E1	0.35897	0	0.05562	7
			E2	0.64103		0.09931	4
Management-related causes	0.22985		R1	0.18138	0.0439	0.04169	8
			R2	0.27337		0.06283	6
			R3	0.38877		0.08935	5
			R4	0.15647		0.03596	9

Table 8. *Final conclusion for alternatives*

Ship type	Weight	Consistency ratio
Liquid cargo ship	0.553118	0.0781
Container ship	0.235590	
Dry cargo ship	0.211291	

same time, AHP considers human factors and managerial elements more critical, based on expert opinion. Similarly, while "insufficient sea experience" ranks in the middle in Fine-Kinney, it is the highest priority risk in AHP; this difference can be explained by experts who evaluate lack of experience as a decisive factor in risks in general. Conversely, although "machinery-equipment failure" is defined as high risk in Fine-Kinney, it is considered to be of low importance in AHP. These findings indicate potential differences in rankings arising from the differing prioritization logics of the AHP and Fine-Kinney methods. While the Fine-Kinney method prioritizes operational parameters such as likelihood, exposure factor, and consequence for some risks, the AHP method, due to its multi-criteria structure, more clearly reflects the human factor and relative importance levels. This can lead to different rankings for the same risks, which is a limitation of the method. However, combining both methods yields a more comprehensive and balanced risk assessment than either method alone.

5. Discussion

The study's findings indicate that, in the Fine-Kinney analysis, liquid cargo ships have higher "very high" risk levels than other ship types, and that management inefficiency is one of the most critical hazards on these

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Table 9. *Comparative risk prioritization*

Hazard/hazard source	Liquid cargo ship	Container ship	Dry cargo ship	AHP rank	Hazard/hazard source	Liquid cargo ship	Container ship	Dry Cargo ship	AHP rank
Management inefficiency	1	2	2	6	Structural damage to the ship	6	6	4	11
Failure to comply with ISM code requirements	2	2	1	8	Not using PPE	7	9	7	2
Machine-equipment failure	2	2	2	12	Cargo operations	8	1	8	13
Lack of role training	2	2	2	9	Intensive work	9	3	7	5
Insufficient sea experience	3	7	3	1	Meteorological conditions	9	3	5	7
Lack of periodic control of machine-equipment	4	4	2	10	Physical conditions of the working environment	10	8	6	4
Lack of training	5	5	6	3					

AHP: Analytical hierarchy process ISM: International Safety Management, PPE: Personal protective equipment

ships. From an OHS perspective, liquid cargo ships have a substantially higher risk level than other ship types. They pose serious threats to both the crew and the environment. The transportation of flammable, explosive, or toxic materials increases the risk of fire and explosion. At the same time, working in closed tanks poses life-threatening risks, including exposure to hazardous gases and oxygen deprivation. This finding reveals that liquid cargo ships require stricter safety measures than other vessels, and that tanker operations demand a distinct safety culture and specialized training programs. This is consistent with the study by Ünal and Arıcan [54], which emphasizes that fires, explosions, and major gas leaks are among the most serious threats in tanker operations. Another point highlighted in the results is the existence of hazards with the same risk score. The findings of another study, which emphasize the inadequacy of the Fine-Kinney method for risk prioritization, are consistent with this result [21].

According to the AHP analysis, the reasons related to seafarers, management, the environment, and machinery and equipment are ranked in descending order. Similarly, Özdemir et al. [38] listed the causes of occupational accidents on ships as human factors, lack of management, ship-related problems, cargo problems, and environmental factors. These findings reveal that the human and managerial dimensions predominate among the root causes of occupational accidents aboard ships. The study‘s findings indicate that liquid cargo ships play a major role in occupational accidents and that the most significant factor causing such accidents is insufficient maritime experience. This result is consistent with the literature [14] and points to the critical role of recruitment, training, and experience transfer mechanisms in the maritime sector. This situation demonstrates that not only technical measures but also human resource management and training strategies play a central role in strengthening safety culture. Second, the most important criterion the non-use of PPE. Similarly, Zhang et al. [14] identified age, experience, and failure to use PPE as risk factors. Uğurlu et al. [20] identified failure to use PPE, rushing, and being in inappropriate places as significant reasons for occupational accidents. Individual behavior and safety culture are critical to risk management. Moreover, Sagaro et al. [16] demonstrated that, on container ships, the likelihood of injuries is higher among deck workers than among the engine crew, while Hansen et al. [30] highlighted that the most severe accidents typically occur on deck and that age plays a significant role in permanent disabilities. These findings reinforce the view that both human and organizational dimensions must be considered when addressing occupational accidents at sea.

In this study, the methodological approach combining Fine-Kinney and AHP strengthens the robustness of maritime risk assessments. Although there are examples from different sectors in which Fine-Kinney and AHP are used together (e.g., Yılmaz and Özcan [42] in the construction sector; Kokangül et al. [43] in production environments), these hybrid applications remain relatively limited in the maritime context. Indeed, Yorulmaz and Avcı [39] contributed to the literature by applying both methods to ship engine-room operations. However, the current study addresses this gap more comprehensively by presenting a comparative analysis of occupational accidents across commercial ship types. Furthermore, AHP has corroborated the shortcomings of the Fine-Kinney method in prioritizing risks and has differentiated hazards with identical risk scores. Thus, the study offers a

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unique contribution to a better understanding of risks in the maritime sector, both methodologically and practically.

6. Study Limitations

Although occupational accident cases are presented across multiple dimensions, the study has certain limitations. In the AHP method, the reliance on expert opinions carries the risk of subjectivity, as assessments depend on individual perspectives and professional backgrounds. The predominance of highly experienced participants limits the representation of perspectives from less-experienced experts. Similarly, the concentration of experts in a limited set of professional roles (e.g., captain, chief engineer, and safety-quality manager) restricts contributions from personnel in other operational roles. Furthermore, assigning equal weight to all experts constitutes a limitation that may introduce bias, since differences in operational familiarity across ship types are not reflected in the evaluation results. Using the Fine-Kinney method, the research team conducted the assessment and assigned the likelihood, consequence, and exposure parameters based on the literature, accident reports, and regulations. However, failing to directly incorporate the experts' ship-type-specific practical experience at this stage has resulted in a limited field-based perspective.

7. Conclusion

The maritime sector is considered a high-risk industry due to its complex operations and variable environmental conditions. The effectiveness of OHS practices directly affects the prevention of occupational accidents on merchant ships. In this context, it is essential to determine the causes of occupational accidents, evaluate risk levels, and develop strategies to prevent them. This study presents a comprehensive assessment using the Fine-Kinney and AHP methods to analyze the causes of occupational accidents on merchant ships and prioritize risks. The findings of the research show that effective risk control measures need to be implemented for risk levels that vary according to ship type. The following risk control measures are recommended to maintain acceptable risk levels:

- To mitigate the hazards of poor management and non-compliance with ISM code requirements, periodic management training should be organized for ship managers and crew, and regular audits should be conducted to ensure that the ISM code is effectively implemented in all operations.
- To address insufficient sea experience, simulation-based training programs should be implemented to increase the maritime expertise of new personnel. Simulation-based training provides hands-on learning experiences that enhance skill acquisition and readiness of new personnel [55].
- To prevent occupational accidents due to machinery and equipment failures, onboard equipment should undergo more frequent maintenance, and procedures should be established to ensure that spare equipment can be activated quickly in an emergency. Although most ships are already equipped with planned maintenance programs and systems for managing critical spare parts, deficiencies may occur in practice, particularly regarding maintenance frequency, compliance monitoring, and readiness of essential spares. Therefore, it is recommended not only that such systems exist but also that they be implemented more stringently and monitored more closely.
- Cargo operations have been identified as one of the highest-risk factors on container ships. Therefore, the use of automation and remote control systems in loading and unloading operations should be increased, and special training on loading safety should be provided for employees.
- Crew training and regular inspections must be conducted to prevent hazards arising from failure to use PPE. In addition, the use of PPE should be encouraged by ensuring that it is ergonomic and functional.
- Lack of role-specific training causes personnel to react inadequately in emergencies. Therefore, mandatory emergency drills should be conducted regularly aboard ships.
- To prevent occupational accidents caused by meteorological conditions, special procedures should be developed for operations during bad weather, and the crew should be trained in precautionary measures.
- Since structural damage poses a serious risk, especially in liquid-cargo ships, ship hulls and tanks should be periodically inspected using ultrasonic testing and other structural analysis methods to maintain structural integrity.

Future studies should utilize more diverse and balanced expert groups, support Fine-Kinney assessments with expert opinions, and integrate weighting methods such as Delphi, entropy, or fuzzy AHP. Furthermore, examining different ship types and operational contexts and using advanced analytical techniques such as fuzzy logic and machine learning will yield more comprehensive and dynamic results by reducing subjectivity. However, the use of root cause analysis frameworks, such as marine systematic cause analysis technique and human factors analysis and classification system, to systematically analyze not only the risk levels of accidents but also their root causes can significantly contribute to the development of more holistic and effective safety strategies for accident prevention. In this respect, the present study provides a theoretical and practical foundation that can guide subsequent research and

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support the development of more robust and adaptive risk management strategies in the maritime sector.

Ethics

Ethics Committee Approval: The AHP questionnaire was conducted with the permission of the İstanbul Beykent University Science and Engineering Sciences Scientific Research and Publication Ethics Committee (decision no: 185296, date: 15.04.2025).

Footnotes

Authorship Contributions

Concept design: M. Yorulmaz, Data Collection or Processing: M. Yorulmaz, and K. Sezen Erküvün, Analysis or Interpretation: M. Yorulmaz, and K. Sezen Erküvün, Literature Review: K. Sezen Erküvün, Writing, Reviewing and Editing: M. Yorulmaz, and K. Sezen Erküvün.

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