

An Application of Risk Analysis in Liquid Cargo Terminals for Occupational Health and Safety Management

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Liquid cargo terminals present numerous risks related to occupational health and safety (OHS). These OHS risks may result from the cargo handled and the services provided. Risks must be eliminated or maintained at an acceptable level to ensure a safe working environment in liquid cargo terminals. This study aims to identify risks in liquid cargo terminals, conduct risk analysis using different methods for the identified risks, and determine which method is most suitable for liquid cargo terminals among those used in risk analysis. Analytic Hierarchy Process (AHP), fuzzy AHP, 5x5 L-type matrix, and Fine Kinney methods were used for risk analysis. The advantages and disadvantages of each method were identified and compared. According to the risk analysis, “environmental pollution and spatial problems,” a sub-criterion of the unloading operation, was calculated as the most important in the AHP method. In contrast, “damaged tanks, tank containers, or IBC tanks” was identified as the most important in the fuzzy AHP method. In both AHP and fuzzy AHP analyses, “liquid chemical cargoes” were the riskiest type of cargo. “Generation of static electricity” was calculated as the hazard with the highest risk score in the 5x5 L-type matrix and Fine Kinney methods. In these methods, “crude oil-oil derivatives” had more hazards at very high-risk levels than other types of cargo when compared by load type. A combination of the Fine Kinney and fuzzy AHP methods is recommended for liquid cargo terminals. The available literature reveals a significant lack of comprehensive and holistic risk analysis studies on liquid cargo terminals. Therefore, this study contributes to the literature by identifying liquid cargo terminal risks and comparing the risk analysis methods used.

KEY WORDS

- ~ Risk analysis
- ~ Liquid cargo terminal
- ~ Fine Kinney
- ~ AHP
- ~ Fuzzy logic

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doi: 10.7225/toms.v15.n02.w05

Received: 23 Apr 2024 / Revised: 27 Feb 2026 / Accepted: 18 May 2026 / Published: 20 May 2026

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1. INTRODUCTION

Ports, as frequent points of call in maritime transportation, play a critical role in the maritime logistics system by providing essential services for ships and cargo. By their nature, ports can serve various types of ships and cargo. However, to increase efficiency in terms of time and resources, it is preferable to provide services at terminals specialized in a single cargo type (Yuksekyildiz, 2014). Terminals can be classified according to the services they provide: liquid bulk cargo, dry bulk cargo, general cargo, container, Ro-Ro, and passenger terminals (Esmer, 2019). Among these, liquid cargo terminals, which handle crude oil and oil derivatives, chemicals, liquefied gases, and non-hazardous liquid cargo, require different expertise and equipment due to the nature of the cargo (Kadir et al., 2020a). Liquid cargo terminals, which follow specific cargo operations and procedures, prioritize safety measures to address potential occupational accidents and emergencies, such as death, injury, serious material damage, and marine or environmental pollution with long-term effects (Khan et al., 2021).

Risk management is defined as identifying risks that may cause occupational accidents and diseases, analyzing and evaluating these risks, eliminating them, and, when elimination is not possible, determining appropriate risk control measures to reduce the risk to a reasonable level (Ozkilic, 2005). Risk management actively prevents occupational accidents and diseases and ensures continuity in the working environment (Kadir et al., 2020a). This study aims to identify risks that may arise in liquid cargo terminals through a literature review, apply different analysis methods to the identified risks, and determine the most suitable risk analysis approach for liquid cargo terminals by comparing the findings. To this end, the analytic hierarchy process (AHP), one of the multi-criteria decision-making (MCDM) methods that can prioritize risks, was used based on expert opinion. Due to the subjectivity affecting the results, the outcomes of the AHP analysis were fuzzified. The 5x5 L-type matrix and Fine Kinney method, which are commonly used in risk analysis applications in the sector and literature, were also applied. A comparison was made by considering the results of the 5x5 L-type matrix, Fine Kinney, AHP, and fuzzy AHP methods applied to liquid cargo terminals.

1.1. Risks in Liquid Cargo Terminals

In maritime transportation, facilities where more than one type of cargo is handled are called ports. Terminals, on the other hand, are coastal facilities where only a single type of cargo is managed due to port specialization (Bal and Esmer, 2015). This distinction is made to improve the quality of service provided to ships, reduce their time in port, and thereby increase efficiency and profitability (Yuksekyildiz, 2014; Esmer, 2019).

According to statistics on cargo handled at Turkish ports over the past decade, liquid bulk cargo accounts for 31.5% of the total cargo handled, alongside categories such as dry bulk, general cargo, container, and Ro-Ro (Republic of Türkiye Ministry of Transport and Infrastructure, 2024). Handling, storage, and transportation operations in ports and terminals, where liquid bulk cargo plays a significant role, require specialized expertise. However, risks such as explosion, corrosion, environmental pollution, and harm to human health arise from these cargoes. While careful and professional work is essential to prevent these risks (Şenol et al., 2015), it is also crucial to establish standard procedures, provide regular employee training, and implement effective occupational health and safety (OHS) practices. In this context, OHS risks must first be systematically identified at ports and liquid cargo terminals. Examples of OHS risks and risk control measures that may be encountered in ports and liquid cargo terminals are provided in Table 1.

Hazard-Risk	Risk Control Measures
Inexperienced employees and insufficient training	Working with experienced employees with the required competencies and creating awareness among employees through training to be offered to them would make it possible to prevent or reduce the effects of occupational accidents (Khan et al., 2021; Unal and Alkan, 2023).
Hazard-Risk	Risk Control Measures
Defective cargo handling equipment and leakage caused by damage to storage areas	In order to prevent leaks and spills that the ship and terminal equipment may cause, it is necessary to check over equipment and to ensure that employees use personal protective equipment (PPE) suitable for operations (Grancharov, 2019; Sezer et al., 2023).
Exposure of employees to chemicals during the sampling process	It is essential that the procedure is followed during the sampling operations and that employees should use appropriate PPE (Saygi, 2018).
Oxygen level being insufficient in confined-space operations performed	It is possible to keep the risk under control by training employees about confined-space operations, conducting confined-space gas measurements, using PPE and having a lookout outside the confined space (Unal and Alkan, 2015).

Working at heights where necessary, such as tank maintenance and repair and loading and unloading operations	Employees must use PPE appropriate for operations involving working at heights (Nguyen et al., 2016).
Sparks, explosions and fire by static electricity	Grounding should be performed to prevent static electricity, the equipment used should be ex-proof, and the employees should use antistatic PPE (Elidolu et al., 2022).
Improper handling of liquid cargo due to non-compliance with the International Maritime Dangerous Goods (IMDG) Code and the Material Safety Data Sheet (MSDS), and cargo reactions resulting from violations of cargo segregation rules	It is not appropriate to store all dangerous cargo together within the port or terminal area (Khan et al., 2021). The rules of load separation specified in the IMDG code must be followed during the storage operation (Kucuksu et al., 2023).

Table 1. Liquid cargo terminal risks

In addition to the OHS risks listed in Table 1, risks such as adverse weather conditions, lack of communication between the ship and the terminal, lack of risk assessment, insufficient knowledge of terminal employees about cargo, non-compliance with working hours, failure to use PPE appropriate for operations, and non-compliance with the terminal emergency plan can be considered general risk factors in liquid cargo terminals (Arslan et al., 2018). Moreover, the absence of an effective risk management system, inadequate written procedures, and insufficient employee training are managerial and organizational factors that can lead to additional risks at these terminals. Risk management in liquid cargo terminals, which involve many hazards, requires identifying the hazards and risks related to the working environment and operations, and determining and implementing risk control measures.

1.2. Literature Review

For the literature review, sources were searched in English and Turkish on online databases. The following keywords were used: “risk analysis,” “risk assessment,” “maritime risk assessment,” “liquid cargo terminal,” “AHP,” “fuzzy AHP,” “Fine Kinney,” “5x5 L-type matrix,” and “fuzzy logic.”

Among studies using the 5x5 L-type matrix and Fine Kinney methods in risk analysis, Okumus and Barlas (2016) compared these two methods for the shipbuilding sector; Aker (2019) did so for the metal sector; and Buturak and Yapici (2022) for the health sector. Although these risk analyses targeted different sectors, they reached similar conclusions. All of these studies argued that the Fine Kinney method, due to its method parameters, produces more precise and relevant results than the 5x5 L-type matrix method. In addition, Aker (2019) states that all risks identified by the 5x5 L-type matrix method and some risks identified by the Fine Kinney method can be reduced to a reasonable level with appropriate control measures. However, the decisive factor is not only the implementation of control measures; these methods also allow direct assessment and recalibration of the parameters that determine risk level (likelihood, consequences, and exposure factors). In this respect, the 5x5 L-type matrix and Fine Kinney methods can quantitatively reflect the effect of risk control measures. In contrast, since the AHP method does not involve direct calculations based on risk parameters, evaluating the effect of control measures requires a different modeling approach.

There is research in which the fuzzy logic approach is preferred to reduce the effects of uncertainty and subjectivity in risk analysis. Among these studies, Supciller and Abali (2015) used Fine Kinney and fuzzy Fine Kinney methods for a textile factory, and Gul and Celik (2018) applied them to rail transportation systems. These studies compared the fuzzy method with the classical method and similarly claimed that the subjectivity in expert assessments can be reduced through the fuzzy logic approach, that risk priorities change through the fuzzification process, and that fuzzy logic results are more realistic.

The fuzzy logic approach is also combined with risk analysis methods. Mokhtari et al. (2011) conducted risk analyses using the fuzzy bow-tie method on port and offshore terminals; Akyuz et al. (2020) examined the risk of liquefaction of dry cargo on ships using the same method; Arici et al. (2020) applied this method to collision and contact accidents in ship-to-ship cargo operations; and Sakar et al. (2022) conducted risk analysis for ship confined-space operations using the fuzzy bow-tie method. Andriani et al. (2019) focused on occupational accident risk reduction in green ports; Zaman et al. (2014) fuzzified the FMEA method for risk assessment of ship collisions in the Strait of Malacca; Senol et al. (2015) used the fuzzy fault tree method in their risk analysis for cargo contamination risk; Kuzu et al. (2019) for ship mooring operation risks; and Tuncel et al. (2023) for fire and explosion risks in bulk carriers. The studies mentioned above fuzzified the methods to eliminate the negative effects of risk analysis methods and used a single method.

Some studies conducted risk analyses using the fuzzy logic approach combined with various methods. For example, Akyuz and Celik (2015) analyzed the hazards of gas-free operations in crude oil tankers using the fuzzy decision-making trial and evaluation laboratory (DEMATEL) method. Ziquan et al. (2021) examined hazards in passenger ship construction with the fuzzy technique for order of preference by similarity to ideal solution (TOPSIS). Senol and Yasli (2021) analyzed tank cleaning operations, Aydin et al. (2021) assessed the risk of asphyxiation during gas inerting operations on chemical tankers, and Aydin et al. (2024) evaluated oil spills caused by human errors using the fuzzy Bayesian network method. Alyami et al. (2019) applied the FMEA method and the fuzzy Bayesian networks approach for risk analysis in container ports. In situations with uncertainty and limited access to historical data, these studies argued that the methods used are more suitable than classical risk analysis methods.

Some research utilized the AHP method, one of the MCDM methods, in risk analysis applications to rank and prioritize risks. Mabrouki et al. (2014) used brainstorming and the AHP method for risk analysis in Ro-Ro terminals. Caner (2020) developed a new method for risk analysis in three shipyards by integrating the 5x5 L-type matrix and the AHP method, comparing and ranking the shipyards with this new approach. In their risk analysis using the AHP and Fine Kinney methods in a manufacturing company, Kokangul et al. (2017) classified AHP scores according to Fine Kinney risk levels and found that the AHP method allows for determining risk levels. Yilmaz and Ozcan (2019) evaluated the hazards of lifting vehicles used on construction sites separately using the Fine Kinney and AHP methods. They created an integrated method by multiplying the AHP weights and Fine Kinney risk scores for the same hazards and ranked the hazards accordingly. Notably, there were differences in hazard rankings between the integrated method and the classical Fine Kinney method. Lamii et al. (2022) enabled easy analysis of port system risk factors using AHP, Fine Kinney, and Delphi techniques with input from decision-makers. Dogan and Keskin (2023) identified risks with the 5x5 L-type matrix method and weighted them with the AHP method in a risk assessment application in the mining sector.

Some studies employed the fuzzy AHP method to calculate risk weights due to the subjectivity of the AHP method, which relies on expert opinion. Hsu (2012) evaluated navigational safety of ships at the Port of Kaohsiung; John et al. (2014) examined port operation risks; Pak et al. (2015) investigated cruise safety in Korean ports; Kara et al. (2021) assessed risks of construction machinery used during port loading and unloading operations; and Unver et al. (2021) analyzed maintenance activities of marine diesel engines. Koulinas et al. (2019) examined construction site risks using the fuzzy AHP and Fine Kinney methods, while Tonoglu et al. (2022) used the same methods to analyze risks of collision, contact, grounding, and sinking that ships may face in the Turkish Straits. By combining these methods, they obtained a single risk value and ranked the risks. Tonoglu et al. (2022) argued that combining these methods reduces subjectivity from expert opinions and that results integrated with numerical data are more realistic. Gul and Guneri (2016) weighted probability and severity parameters in risk assessment with the fuzzy AHP method in aluminum plate production facilities, Acuner and Cebi (2016) did so in shipyards, and Gul (2020) in ports. Unlike these studies, Yavuz (2017) conducted risk analysis in the port sector using the Fine Kinney method, then applied the fuzzy logic approach to the risks identified by the Fine Kinney method. The researcher prioritized and ranked risks using the AHP method for operations with equal risk values based on fuzzy risk scores, demonstrating the co-usability of different methods. Li et al. (2020) used Bayesian network and fuzzy AHP methods for risk assessment in an underground coal mine.

Several studies have benefited from the formal safety assessment (FSA) method, developed to ensure maritime safety in risk analysis. Pallis (2017) and Budiyo and Fernanda (2020) applied the FSA method for risk analysis in container terminals. Budiyo and Fernanda (2020) also used fault tree analysis alongside the FSA method. These studies conducted benefit-cost calculations based on risk control measures, as required by the FSA method. Measures were selected by considering the cost-benefit analysis. Some researchers used additional methods: Bellsola et al. (2020) applied the Analytic Network Process (ANP) to analyze navigation risks in ports; Ech-Cheikh et al. (2021) examined risks in container terminal handling operations using the risk matrix; Emovon et al. (2015) assessed risks in marine machinery systems with FMEA, VIKOR, and consensus programming methods; Zhang et al. (2016) evaluated risks in Tianjin Port from 2008 to 2013 using the Bayesian network method based on accident data and expert opinions. Hou and Zhao (2016) performed risk assessments for oil handling using Bayesian networks and fuzzy ANP methods.

A literature review reveals that OHS risks in industrial settings have been widely studied. However, detailed and structured risk analysis specific to liquid cargo terminals remains limited. Furthermore, unlike most studies that focus on a single risk assessment method, this study compares four risk analysis methods (AHP, fuzzy AHP, 5x5 L-type matrix, and Fine Kinney) according to their advantages and limitations. It provides information on the most suitable method or combination for liquid cargo terminal risk management.

2. MATERIAL AND METHOD

Figure 1 shows the workflow diagram of this study, which seeks to conduct the risk analysis of liquid cargo terminals and determine the appropriate method.

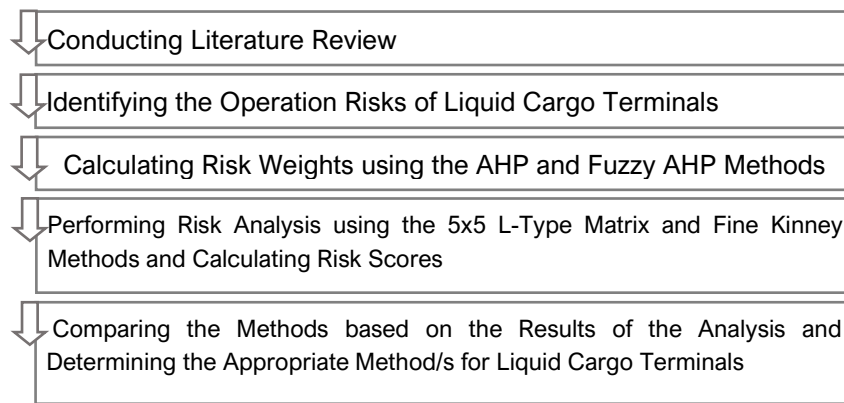


Figure 1. Workflow Diagram of the Study

As shown in the workflow diagram in Figure 1, a comprehensive literature review was first conducted on OHS risks in port operations and industrial environments. This review determined that, although liquid cargo terminals pose high risks, detailed and structured risk analyses specific to these terminals are limited. Therefore, liquid cargo terminals were selected as the focus of the study. The study is based on a generalized liquid cargo terminal model derived from sectoral practices, regulatory frameworks, and existing literature. The model reflects typical operational processes observed in terminals handling liquid chemical cargoes, crude oil and oil derivatives, and liquefied gases. Within this framework, the main criteria represent standard cargo handling operations commonly performed at liquid cargo terminals, including loading (transfer of cargo to the ship), unloading (transfer of cargo from the ship to the terminal or other transport systems), storage (tank storage operations), and transfer (such as tank-to-tank or pipeline transfers within the terminal). In this model, cargo handling operations are assumed to be performed using standard industrial technologies commonly employed in liquid cargo terminals (such as ship and shore pumping systems and pipeline transfers), without focusing on specific equipment configurations. Based on this operational framework, the hierarchical structure of the study was developed. The sub-criteria (risks) included in the hierarchical structure were identified through a critical review of the available literature and aligned with the defined operational processes of the terminal model. The hierarchical structure created based on the identified risks was evaluated by a group of experts comprising port operators and academics for content and scope, and then finalized. After approval from the Ethics Committee of Science and Engineering Sciences of Kocaeli University, dated 26.08.2022 and numbered 277851, the finalized hierarchical structure was provided to the participants as the reference framework, and the AHP and fuzzy AHP survey, including pairwise comparison matrices, was prepared accordingly. The experts were asked to evaluate the defined main criteria, sub-criteria, and alternatives through pairwise comparisons. After this process, risks were weighted for each method based on survey responses. Nine experts working at liquid cargo terminals completed the survey, and Table 2 presents information on the survey participants.

	Age	Educational Status	Work Period in Sector	Occupation
Expert 1	51	Master	27	OHS Specialist
Expert 2	42	Master	20	Operation Manager
Expert 3	50	Master	28	Operation Manager
Expert 4	50	Master	25	Technical Manager
Expert 5	43	Master	17	Operation Manager
Expert 6	38	PhD	12	OHS Specialist
Expert 7	45	PhD	20	OHS Specialist
Expert 8	38	Master	13	OHS Specialist
Expert 9	32	Master	8	OHS Specialist

Table 2. Experts profile in AHP-fuzzy AHP survey

Table 2 shows that the average age of the experts is 43.2 years, and their average industry experience is 18.9 years. The participating experts include operations managers, technical managers, and OHS specialists working at liquid cargo terminals. Although not all experts worked at terminals handling every type of cargo analyzed in this study, each expert had direct operational or safety management experience with at least one of the examined liquid cargo categories (liquid

chemical cargoes, crude oil and oil derivatives, and liquefied gases). This diversity of professional experience contributed to the evaluation process. The completed surveys were analyzed using Microsoft Excel to calculate pairwise comparison matrices and weight values. After the AHP and fuzzy AHP analyses, the research team conducted risk assessments using a 5x5 L-type matrix and the Fine Kinney method. The parameter values were determined according to the standard scoring frameworks of the respective methods and were based on national and international literature, past accident reports, and relevant regulatory documents. Finally, a comparison was made based on the analysis results.

2.1. Analytical Hierarchy Process (AHP)

The AHP method is one of the MCDM methods developed by Thomas L. Saaty in 1980. It is designed to solve complex problems. The method involves modeling the problem using a hierarchy of criteria and alternatives, making both qualitative and quantitative evaluations, and incorporating expert opinion in decision-making (Dagdeviren et al., 2004). In the AHP method, the decision problem is first defined and structured within a hierarchy consisting of objectives, criteria, sub-criteria, and alternatives (Saaty, 2008). The decision elements at each level of the hierarchy are then evaluated through pairwise comparisons using the 1–9 scale in Table 3, based on the judgments of the decision-makers (Saaty and Ozdemir, 2003).

Intensity of importance on an absolute scale	Definition
1	Equal importance
3	Moderate importance of one over another
5	Essential or strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values between the two adjacent judgments

Table 3. The fundamental scale of AHP (Saaty, 1990)

Relative weights are derived from pairwise comparison matrices obtained through pairwise comparisons (Saaty, 1990). In the final stage, the consistency of decision-makers' evaluations is tested using the consistency ratio (CR) (Saaty and Ozdemir, 2003). If the CR value is less than 0.10, the results are considered consistent (Saaty, 1990). In this study, the AHP method was applied to prioritize OHS risks in liquid cargo terminals. First, a literature review was conducted and current legal requirements were examined to ensure OHS compliance in port operations. Based on these findings, a preliminary hierarchical structure was developed. The proposed AHP hierarchy was then evaluated and refined through expert consultation with port operators and academics to ensure content validity and sectoral relevance. After this evaluation process, the hierarchical structure was finalized, consisting of four main criteria, 32 sub-criteria, and three alternatives. The main and sub-criteria were defined to identify operational risks in liquid cargo terminals and determine the most critical operation, while the alternatives were selected to identify the most risky type of liquid cargo. Table 4 presents the coding of the main and sub-criteria, and Figure 2 illustrates the finalized hierarchical structure.

Main Criteria	Sub-Criteria	Coding
LOADING	Adverse Weather Conditions	Y1
	Defective Cargo Handling Equipment	Y2
	Exceeding the Loading Limit/Overloading	Y3
	Contact with Chemical Liquid Substance	Y4
	Failure to Check the Cargo through Sampling	Y5
	Noise and Vibration Caused by Equipment	Y6
	Employees Not Using PPE	Y7
	Environmental Pollution and Spatial Problems	Y8
UNLOADING	Damaged Tanks, Tank Containers or IBC Tanks	B1
	Intensive Work/Shift Work	B2
	Insufficient Lighting	B3
	Insufficient Communication Between Ship and Terminal	B4
	Employees Not Using PPE	B5
	Lack of Appropriate Instructions Provided to Employees During Operations	B6
	Environmental Pollution and Spatial Problems	B7
STORAGE	Inappropriate Storage Space and Cargoes	D1
	Unlabeling or Mislabeling Cargoes	D2
	Cargo Segregation Not in Conformity with IMDG Code and MSDS Rules	D3
	Inappropriate or Inactive Fire Suppression Systems	D4
	Performing Hot Work in Unsuitable Conditions	D5
	Generation of Static Electricity	D6
	Non-Compliance with Rules on Confined-Space Entry	D7
	Insufficient Oxygen Level	D8
	Lack of or Insufficient Ventilation	D9
	Employees Not Using PPE	D10
	Environmental Pollution and Spatial Problems	D11
TRANSFER	Loading and Transferring the Cargo on Vehicles Not Conforming to ADR	T1
	Using Vehicles Not Having Gone under Inspection	T2
	Exceeding the Maximum Loading Capacity	T3
	Working At Heights On a Land Tanker	T4
	Employees Not Using PPE	T5
	Environmental Pollution and Spatial Problems	T6

Table 4. Problem coding main criteria and sub-criteria

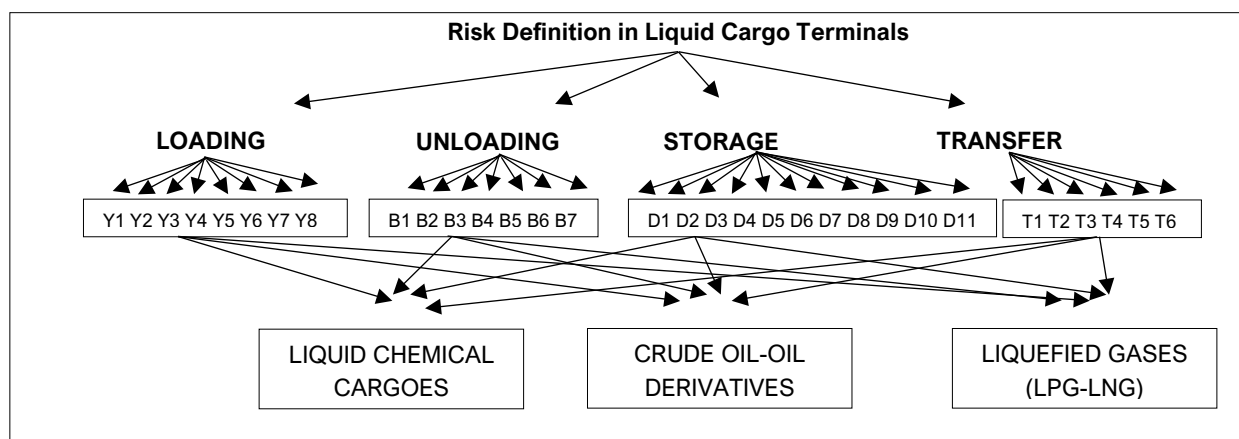


Figure 2. Problem hierarchy

Following the establishment of the hierarchical structure, pairwise comparison matrices were constructed based on the defined main criteria, sub-criteria, and alternatives. Based on this hierarchical structure, pairwise comparison matrices were constructed and analyzed to derive relative weights and establish priority rankings for the criteria and alternatives.

2.2. The Fuzzy AHP Approach

The AHP method enables the comparison of criteria and alternatives and has a flexible structure that can be integrated with various methods. However, the classical AHP method assumes that decision-makers' judgments are definite and clear, which contradicts the uncertainty present in real-world problems (Gupta et al., 2023). To address this, the fuzzy AHP approach emerged by integrating fuzzy set theory, developed by Zadeh (1965), into the AHP method. Pioneering work on the fuzzy AHP approach was conducted by Van Laarhoven and Pedrycz (1983), followed by Buckley (1985) and Chang (1996), who proposed different fuzzy AHP models. The Buckley approach used in this study analyzes the AHP method through trapezoidal membership functions and employs the geometric mean method to calculate fuzzy weights (Buckley, 1985; Buyukozkan et al., 2004). The fuzzy AHP method follows the same steps as the AHP method: creating the hierarchy, constructing the comparison matrices, and clarifying the fuzzy weights (Liu et al., 2020). The rating scale in Table 5 is used for bilateral comparisons in the fuzzy AHP method.

Linguistic Scale	Fuzzy Scale	Reciprocal Fuzzy Scale
Equal importance	(1, 1, 3)	(1/3, 1, 1)
Moderate importance of one over another	(1, 3, 5)	(1/5, 1/3, 1)
Essential or strong importance	(3, 5, 7)	(1/7, 1/5, 1/3)
Very strong importance	(5, 7, 9)	(1/9, 1/7, 1/5)
Extreme importance	(7, 9, 9)	(1/9, 1/9, 1/7)

Table 5. The fundamental scale of fuzzy AHP (Chang, 1996)

The fuzzy AHP ranking scale offered in Table 5 is applied to the survey data to fuzzify the values, and an analysis is conducted using the resulting binary comparison matrices.

2.2. The 5x5 L-Type Matrix Method

The 5x5 L-type matrix method intends to analyze hazards and evaluate the cause-and-effect relationship in simple tasks or cases where quick results are desired (Ozkilic, 2005). In this method, risk analysis is achieved by choosing the likelihood (L) and possible consequence (C) parameters given in Table 6, considering the given hazard.

L		C	
5	Very High	5	Very Serious
4	High	4	Serious
3	Medium	3	Medium
2	Low	2	Minor
1	Very Low	1	Negligible

Table 6. L and C scale (Ozkilic, 2005)

Table 6 shows that the L and C scales are rated on a scale of 1 to 5. Accordingly, the L scale includes very low, low, medium, high, and very high levels, while the C scale is defined as negligible, minor, medium, serious, and very serious. The risk score is obtained by multiplying the L and C parameters and varies between 1-25. Quantitative assessment of hazards involves sorting the risk scores from high to low (Celiktaş and Unlu, 2018). Table 7 includes the decision-making step based on risk scores.

Risk Level	Risk Score	Explanation
1	25	Not Tolerated Risk
2	15-16-20	Critical Risk
3	8-9-10-12	Moderate Risk
4	2-3-4-5-6	Minor Risk
5	1	Negligible Risk

Table 7. Decision based on risk score (Ozkilic, 2005)

The risk scores in Table 7 are grouped under five levels: not tolerated risks, critical risks, moderate risks, minor risks, and negligible risks. The decision-making process involves considering the importance level of the risk and taking the necessary risk control measures.

2.4. The Fine Kinney Method

The Fine Kinney method was first proposed by Fine (1971) and then discussed by Kinney and Wiruth. The technical report by Kinney and Wiruth (1976) made this method a more elaborate risk analysis method. The Fine Kinney method benefits from the L, C and the exposure factor (E) parameter for method analysis. The Fine Kinney method is a quantitative risk analysis approach based on numerical data. In this method, the hazard is evaluated using the parameters of L, C, and E presented in Table 8 and the risk score is calculated as the product of these three parameters.

L			C		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)	

Table 8. L, C and E parameters (Kinney and Wiruth, 1976)

The resulting risk score determines the level of risk, and control measures are taken considering the level of risk. The decision-making process based on the risk score in the Fine Kinney method follows Table 9.

Risk Level	Risk Score	Decision	Action
1	$R > 400$	Very High Risk	Consider discontinuing operation
2	$200 < R < 400$	High Risk	Immediate correction required
3	$70 < R < 200$	Substantial Risk	Correction needed
4	$20 < R < 70$	Possible Risk	Attention indicated
5	$R < 20$	Reasonable Risk	Perhaps reasonable

Table 9. Decision and action by risk score (Kinney and Wiruth, 1976)

The risk scores given in Table 9 are classified into five different risk levels: very high risk, high risk, substantial risk, possible risk, and reasonable risk. The ranking is built on the level of risk, from high to low, and risk control measures are determined.

3. FINDINGS

In this section, the findings obtained from the applied risk assessment analyses are presented. First, the importance levels of the main criteria, sub-criteria, and alternatives were calculated using the AHP and fuzzy AHP methods, and the results are presented in Tables 10, 11, and 12.

AHP			CR	Fuzzy AHP	
Main Criteria	Weight Values	Sorting		Weight Values	Sorting
Loading	0.3538	1	0.0134	0.3534	1
Unloading	0.3390	2		0.3312	2
Storage	0.1529	4		0.1594	3
Transfer	0.1543	3		0.1558	4

Table 10. Comparison of AHP and fuzzy AHP for the main criteria weights

Based on the weights of the main criteria given in Table 10, the “loading” operation was considered the most risky main criterion in the AHP (35.4%) method and the fuzzy AHP (35.3%) method. The analysis yielded that the risk ranking of “storage” and “transfer” operations differed for the two methods. CR calculated for the main criteria was found to be below 0.10, indicating that the expert judgments were consistent. The overall weight values were calculated by multiplying the main criteria and sub-criteria weights for each method, and all 32 sub-criteria were ranked based on these values. Table 11 presents the overall weight and ranking of the sub-criteria.

Sub-Criteria	AHP		CR	Fuzzy AHP	
	General Weight	Sorting		General Weight	Sorting
Y1	0.0191	19	0.0226	0.0188	20
Y2	0.0494	6		0.0479	6
Y3	0.0678	3		0.0653	3
Y4	0.0811	2		0.0797	2
Y5	0.0269	15		0.0283	15
Y6	0.0211	17		0.0232	17
Y7	0.0595	4		0.0588	4
Y8	0.0285	14		0.0308	12
B1	0.0234	16	0.0162	0.0967	1
B2	0.0297	13		0.0364	10
B3	0.0367	10		0.0240	16
B4	0.0448	8		0.0437	8
B5	0.0480	7		0.0473	7
B6	0.0543	5		0.0531	5
B7	0.1018	1		0.0295	14
D1	0.0151	25	0.0156	0.0154	26
D2	0.0152	24		0.0159	23
D3	0.0150	27		0.0159	24
D4	0.0153	23		0.0163	22
D5	0.0203	18		0.0202	18
D6	0.0161	22		0.0157	25
D7	0.0108	31		0.0121	31
D8	0.0129	29		0.0140	28
D9	0.0122	30		0.0131	30
D10	0.0136	28		0.0140	29
D11	0.0062	32		0.0061	32
T1	0.0362	11	0.0222	0.0356	11
T2	0.0303	12		0.0297	13
T3	0.0374	9		0.0378	9
T4	0.0151	26		0.0154	27
T5	0.0184	20		0.0198	19
T6	0.0166	21		0.0171	21

Table 11. Comparison of AHP and fuzzy AHP for the sub-criteria general weights

Table 11 also shows that in the AHP method analysis, “environmental pollution and spatial problems,” a sub-criterion of the unloading operation, was identified as the riskiest (0.1018) sub-criterion, while “environmental pollution and spatial problems,” a sub-criterion of the storage operation, was determined to be the least risky (0.0062) sub-criterion. In contrast, the fuzzy AHP method found “damaged tanks, tank containers, or IBC tanks,” a sub-criterion of the unloading operation, to be the riskiest (0.0967) sub-criterion, and determined “environmental pollution and spatial problems,” a sub-criterion of the storage operation, as the least risky (0.0061) sub-criterion. The CRs calculated for the sub-criteria were below 0.10, indicating that the expert judgments were consistent. While the two methods differed in identifying the most risky sub-criterion, they agreed on the least risky sub-criterion. The overall ranking of the sub-criteria followed a similar pattern in both methods, but two notable sub-criteria changed significantly. The sub-criterion “damaged tanks, tank containers, or IBC

tanks” ranked first in the fuzzy AHP method (0.0967) but 16th in the AHP method (0.0234). Conversely, the sub-criterion “environmental pollution and spatial problems” ranked first in the AHP method (0.1018) but was 14th in the fuzzy AHP method (0.0295).

In the AHP and fuzzy AHP analyses, the importance levels of the alternatives were evaluated based on the sub-criteria, and the results for the alternatives were finalized. Table 12 presents the alternative weights and rankings for both methods.

Alternatives	AHP		CR	Fuzzy AHP	
	General Weight	Sorting		General Weight	Sorting
Liquid Chemical Cargoes	0.3973	1	0.0102	0.3920	1
Crude Oil-Oil Derivatives	0.2268	3		0.2294	3
Liquefied Gases (LPG-LNG)	0.3759	2		0.3784	2

Table 12. Comparison of AHP and fuzzy AHP for the alternatives

The results of the analysis, presented in Table 12, show that the alternative weights were similar for both methods and that the alternative ranking remained unchanged. For both methods, “liquid chemical cargoes” were identified as the most risky type of cargo. The CR calculated for the alternatives was below 0.10, indicating that the expert judgments were consistent.

In the second step, this study conducted a risk analysis in which terminals handling liquid chemical cargo, crude oil and oil derivatives, and liquefied gases were individually evaluated using the 5x5 L-type matrix and the Fine Kinney method. Table 13 presents the analyses from these two methods, including risk scores, risk levels, and post-risk control scores. The risk control measures considered at this stage were defined based on the literature review and established sectoral safety practices, and the post-risk control scores were recalculated under the assumption that these corrective actions were effectively implemented.

No	1		2																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																		
	LOADING		LOADING																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																		
	Y1		Y2																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																		
	5x5 L-Type Matrix	Fine Kinney	5x5 L-Type Matrix	Fine Kinney																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																	
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No	8		7		6		5		4		3	
	LOADING		LOADING		LOADING		LOADING		LOADING		LOADING	
	Y8		Y7		Y6		Y5		Y4		Y3	
	5x5 L-Type Matrix	Fine Kinney	5x5 L-Type Matrix	Fine Kinney	5x5 L-Type Matrix	Fine Kinney	5x5 L-Type Matrix	Fine Kinney	5x5 L-Type Matrix	Fine Kinney	5x5 L-Type Matrix	Fine Kinney
3		3	4	3	4	6	5	6	3	3	5	6
		2		3		3		3		2		2
5		100	4	15	4	15	2	7	4	15	5	40
15		600	16	135	16	270	10	126	12	90	25	480
2		1	2	3	2	2	3	3	3	3	1	1
6		90	6	42	4	6	3	9	4	21	3	45
3		3	4	3	4	6	3	3	3	3	3	3
		2		3		3		2		2		2
5		100	4	15	4	15	2	7	3	7	4	15
15		600	16	135	16	270	6	42	9	42	12	90
2		1	2	3	2	2	4	4	3	4	3	3
6		90	6	42	4	18	2	9	2	9	2	7
3		3	4	3	4	6	2	3	3	3	3	3
		2		3		3		2		2		2
3		100	4	15	3	7	2	7	4	15	3	7
15		600	16	135	12	126	4	42	12	90	9	42
2		1	2	3	3	3	4	4	3	3	3	4
6		90	6	42	4	9	2	9	4	21	2	7

13		12		11		10		9		No
UNLOADING		UNLOADING		UNLOADING		UNLOADING		UNLOADING		Hazard
B5		B4		B3		B2		B1		Risk
5x5 L-Type Matrix	Fine Kinney	5x5 L-Type Matrix	Fine Kinney	5x5 L-Type Matrix	Fine Kinney	5x5 L-Type Matrix	Fine Kinney	5x5 L-Type Matrix	Fine Kinney	Method
4	3	3	3	3	3	4	3	3	3	L
	3		2		3		3		3	E
4	15	5	100	3	15	4	40	4	40	C
16	135	15	600	9	135	16	360	12	360	Risk Score
2	3	2	1	3	3	2	2	3	2	Risk Level
6	42	6	14	4	6	9	42	6	14	After Risk Control
4	3	3	3	3	3	4	3	3	3	L
	3		2		3		3		3	E
4	15	5	100	3	15	4	40	4	40	C
16	135	15	600	9	135	16	360	12	360	Risk Score
2	3	2	1	3	3	2	2	3	2	Risk Level
6	42	6	14	4	6	9	42	6	14	After Risk Control
4	3	3	3	3	3	4	3	3	3	L
	3		2		3		3		3	E
4	15	5	100	3	15	4	40	4	40	C
16	135	15	600	9	135	16	360	12	360	Risk Score
2	3	2	1	3	3	2	2	3	2	Risk Level
6	42	6	14	4	6	9	42	6	14	After Risk Control
4	3	3	3	3	3	4	3	3	3	L
	3		2		3		3		3	E
4	15	5	100	3	15	4	40	4	40	C
16	135	15	600	9	135	16	360	12	360	Risk Score
2	3	2	1	3	3	2	2	3	2	Risk Level
6	42	6	14	4	6	9	42	6	14	After Risk Control

20		19		18		17		16		15		14		No	
STORAGE		STORAGE		STORAGE		STORAGE		STORAGE		UNLOADING		UNLOADING		Hazard	
D5		D4		D3		D2		D1		B7		B6		Risk	
5x5 L-Type	Fine Kinney	5x5 L-Type	Fine Kinney	5x5 L-Type Matrix	Fine Kinney	5x5 L-Type	Fine Kinney	5x5 L-Type	Fine Kinney	5x5 L-Type Matrix	Fine Kinney	5x5 L-Type	Fine Kinney	Method	
4	6	4	3	3	3	4	3	3	3	3	3	3	3		
	3		2		2		3		2				3		
5	100	5	100	5	100	3	15	5	100	5	100	4	40		
20	1800	20	600	15	600	12	135	15	600	15	600	12	360		
2	1	2	1	2	1	3	3	2	1	2	1	3	2	Risk Rating	
6	90	12	45	4	30	6	14	6	30	6	90	6	14	Liquid Chemical Cargoes	
5	10	4	3	3	3	4	3	3	3	3	3	3	3	Risk Rating	
	6		2		2		3		2		2		3	Crude Oil-Oil Derivatives	
5	100	5	100	5	100	4	15	4	40	5	100	4	40	Risk Rating	
25	6000	20	600	15	600	16	135	12	240	15	600	12	360	Risk Rating	
1	1	2	1	2	1	2	3	3	2	2	1	3	2	Risk Rating	
9	63	6	15	4	30	6	27	3	14	6	90	6	14	After Risk Control	
4	6	4	3	3	3	3	1	2	3	3	3	3	3	Liquefied Gases	
	3		2		2		3		2		2		3	Risk Rating	
5	100	5	100	5	100	3	15	4	40	5	100	4	40	Risk Rating	
20	1800	20	600	15	600	9	45	8	240	15	600	12	360	Risk Rating	
2	1	2	1	2	1	3	4	3	2	2	1	3	2	Risk Rating	
12	135	9	15	4	30	4	14	3	14	6	90	6	14	After Risk Control	

26		25		24		23		22		21		No
STORAGE		STORAGE		STORAGE		STORAGE		STORAGE		STORAGE		Hazard
D11		D10		D9		D8		D7		D6		Risk
5x5 L-Type Matrix	Fine Kinney	5x5 L-Type Matrix	Fine Kinney	5x5 L-Type Matrix	Fine Kinney	5x5 L-Type Matrix	Fine Kinney	5x5 L-Type Matrix	Fine Kinney	5x5 L-Type Matrix	Fine Kinney	Method
	3		3		3		4		4		5	
	2		3		2							
	100		15		40		4		5		5	
	600		135		240		16		20		25	
2	1	2	3	2	2	2	2	2	1	1	1	Risk Score
6	90	6	42	6	45	6	6	6	90	9	135	Risk Level
												After Risk Control
3	3	4	3	5	6	4	4	4	6	5	10	L
	2		3		3				6		10	E
5	100	4	15	5	40	5	5	5	40	5	100	C
15	600	16	135	20	720	20	20	20	1440	25	10000	Risk Score
2	1	2	3	1	1	2	2	2	1	1	1	Risk Level
6	42	6	42	6	42	4	4	12	30	9	63	After Risk Control
3	3	4	3	3	6	4	4	4	3	5	6	L
	2		3		3				6		3	E
5	100	4	15	5	40	5	5	5	40	5	100	C
15	600	16	135	20	720	20	20	20	720	25	1800	Risk Score
2	1	2	3	2	1	2	2	2	1	1	1	Risk Level
6	90	6	42	2	45	4	4	4	60	12	42	After Risk Control

No	Hazard	Risk	Method	Liquid Chemical Cargoes			Crude Oil-Oil Derivatives			Liquefied Gases		
				Risk Rating			Risk Rating			Risk Rating		
				L	E	C	L	E	C	L	E	C
				Risk Score	Risk Level	After Risk Control	Risk Score	Risk Level	After Risk Control	Risk Score	Risk Level	After Risk Control
27	TRANSFER	T1	Fine Kinney	5x5 L-Type	5	6	5x5 L-Type	5	6	5x5 L-Type	5	6
28	TRANSFER	T2	Fine Kinney	5x5 L-Type	3	3	5x5 L-Type	3	3	5x5 L-Type	3	3
29	TRANSFER	T3	Fine Kinney	5x5 L-Type	5	6	5x5 L-Type	5	6	5x5 L-Type	5	6
30	TRANSFER	T4	Fine Kinney	5x5 L-Type Matrix	5	6	5x5 L-Type Matrix	5	6	5x5 L-Type Matrix	5	6
31	TRANSFER	T5	Fine Kinney	5x5 L-Type	4	3	5x5 L-Type	4	3	5x5 L-Type	4	3
32	TRANSFER	T6	Fine Kinney	5x5 L-Type	3	3	5x5 L-Type	3	3	5x5 L-Type	3	3

Table 13. Risk analysis in Fine Kinney and 5x5 L-type matrix methods

According to the results of the risk analysis using the Fine Kinney method, for liquid chemical cargo, “generation of static electricity” at storage had the highest risk (6000), while “adverse weather conditions” at loading had the lowest risk (42). After risk control measures, 25% of the initial risk scores were reduced to reasonable risks (5th risk level). The 5x5 L-type matrix analysis for liquid chemical cargo showed that “exceeding the loading limit/overloading” at loading and “generation of static electricity” at storage were the highest risk items (25), while “adverse weather conditions” at loading and “insufficient lighting” at unloading had the lowest risk (9). After risk control measures, 84.4% of the initial risk scores were reduced to reasonable risks.

For crude oil and oil derivatives, the Fine Kinney method identified “generation of static electricity” at storage as the highest risk (1000), and “adverse weather conditions,” “contact with chemical liquid substance,” and “failure to check the cargo through sampling” at loading as the lowest risk (42). After risk control measures, 37.5% of the initial risk scores were reduced to reasonable risks (5th risk level). The 5x5 L-type matrix analysis for crude oil and oil derivatives showed that

“generation of static electricity,” “performing hot work in unsuitable conditions,” and “lack of or insufficient ventilation” at storage, as well as “loading and transferring the cargo on vehicles not conforming to ADR” and “using vehicles not inspected” at transfer, had the highest risk (25). “Failure to check the cargo through sampling” at loading had the lowest risk (6). After risk control measures, 87.5% of the initial risk scores were reduced to reasonable risks.

For liquefied gases, the Fine Kinney method found that “generation of static electricity” and “performing hot work in unsuitable conditions” at storage had the highest risk (1800), while “adverse weather conditions,” “exceeding the loading limit/overloading,” and “failure to check the cargo through sampling” at loading had the lowest risk (42). After risk control measures, 34.4% of the initial risk scores were reduced to reasonable risks (5th risk level). The 5x5 L-type matrix analysis for liquefied gases indicated that “generation of static electricity” at storage had the highest risk (25), and “failure to check the cargo through sampling” at loading had the lowest risk (4). After risk control measures, 90.6% of the initial risk scores were reduced to reasonable risks.

The results of the Fine Kinney and 5x5 L-type matrix methods were classified by cargo type and risk level. Table 14 presents a comparison of the risk levels.

Cargo Type	Method	Risk Level			
		1	2	3	4
Liquid Chemical Cargoes	5x5 L-Type Matrix	2 Risk 6%	22 Risk 69%	8 Risk 25%	
	Fine Kinney	16 Risk 50%	7 Risk 22%	8 Risk 25%	1 Risk 3%
Crude Oil-Oil Derivatives	5x5 L-Type Matrix	5 Risk 16%	19 Risk 59%	7 Risk 22%	1 Risk 3%
	Fine Kinney	17 Risk 53%	5 Risk 16%	7 Risk 22%	3 Risk 9%
Liquefied Gases	5x5 L-Type Matrix	1 Risk 3%	19 Risk 60%	11 Risk 34%	1 Risk 3%
	Fine Kinney	15 Risk 47%	4 Risk 12%	9 Risk 28%	4 Risk 13%

Table 14. Comparison of Fine Kinney and 5x5 L-type matrix for the risk level

According to the 5x5 L-type matrix method results given in Table 14, the critical risks (2nd risk level) and moderate risks (3rd risk level) were predominant. There were only a few risks in the category of not tolerated risks (1st risk level). In the Fine Kinney method, the category of very high risks (1st risk level) was predominant. “Crude oil-oil derivatives” were the type of cargo with the highest risk in the 1st risk level according to the results of the risk analyses through the 5x5 L-type matrix and Fine Kinney methods.

4. DISCUSSION AND CONCLUSION

Cargoes such as crude oil and oil derivatives, chemicals, and liquefied gases handled in ports are classified as dangerous goods, and their logistics inherently involve significant operational risks (Liu et al., 2019). As noted by Khan et al. (2021), accidents related to dangerous cargoes frequently occur during loading and unloading, temporary storage, and port entry and exit operations. By evaluating different cargo types and operational stages through multiple risk assessment techniques, this study provides a comparative perspective on how methodological approaches may influence risk prioritization in liquid cargo terminals. The defined sub-criteria were structured according to the operational logic of the loading, unloading, storage, and transfer processes within the adopted generalized terminal model. Accordingly, the inclusion and placement of certain risks were determined based on their direct relevance to specific cargo handling stages. For example, risks were positioned under the operational interfaces in which they are most likely to manifest within standard terminal practices. In this context, the terminology used reflects a process-oriented hazard classification rather than a cargo-type-specific or site-specific categorization.

In the risk analysis conducted using the AHP method, the importance levels of the risks were determined by weighting the main criteria, sub-criteria, and alternatives. The results showed that “loading” was the riskiest operation, that “environmental pollution and spatial problems,” a sub-criterion of the unloading operation, had the highest level of importance, and that “liquid chemical cargoes” were the riskiest cargo. Another notable finding in the AHP analysis is that the sub-criterion “environmental pollution and spatial problems” had the highest risk in the unloading operation and the lowest risk in the storage operation. This supports the conclusion that the impact of the same risk varies across different

types of operations. In this context, the term “spatial problems” broadly refers to operational constraints associated with the physical configuration and spatial characteristics of terminal facilities.

In the fuzzy AHP analysis, “loading” was again the riskiest operation; “damaged tanks, tank containers, or IBC tanks,” a sub-criterion of the unloading operation, had the highest level of importance, and “liquid chemical cargoes” were the riskiest cargo. When the results of the AHP and fuzzy AHP analyses are compared, there are slight changes in the rankings of the sub-criteria, although the most risky operation and cargo type remain unchanged. As stated by Li and Zou (2011), AHP and fuzzy AHP results do not differ significantly. The reduction of subjectivity with the fuzzy AHP method and the resulting increase in analysis accuracy support the study's results. Despite this, a significant change was observed in the ranking of two sub-criteria in the study.

In the risk analysis using the 5x5 L-type matrix, the risks of “exceeding the loading limit/overloading” during loading and “generation of static electricity” during storage had the highest risk scores for liquid chemical cargoes. For crude oil and oil derivatives, the risks of “generation of static electricity,” “performing hot work in unsuitable conditions,” and “lack of insufficient ventilation” had the highest scores during storage, while “loading and transferring the cargo on vehicles not conforming to ADR” and “using vehicles not having undergone inspection” had the highest scores during transfer. For liquefied gases, the risk of “generation of static electricity” had the highest risk score during storage. The analysis using the 5x5 L-type matrix confirmed that “generation of static electricity” had the highest risk score during storage for each of the three cargo types.

The Fine Kinney analysis identified the risk of “generation of static electricity” at storage as the source of hazard with the highest risk score for liquid chemical cargoes and crude oil-oil derivatives. For liquefied gases, the risks of “generation of static electricity” and “performing hot work in unsuitable conditions” at storage as the source of hazard had the highest risk scores. In the Fine Kinney analysis, the risk of “generation of static electricity” at storage as the source of hazard had the highest risk score for each of the three cargo types. In both the Fine Kinney and 5x5 L-type matrix analysis results, generation of static electricity was found to have the highest risk for all three cargo types. In a study evaluating risks in a container terminal, operator errors and defects, communication misunderstandings, and human negligence and error were identified as high risk (Ding and Tseng, 2013). A study conducted in ports determined that the most important hazards were working without a helmet, working at height, and standing under load (Gul, 2020). In another study evaluating port cargo handling risks, communication misunderstandings were calculated to have the highest risk (Kadir et al., 2020b).

The results of the risk analyses using the 5x5 L-type matrix and Fine Kinney methods further showed that some risks received the same risk score in both methods. This presents a challenge for implementing risk control measures. Since prioritizing equal risk scores exceeds the capabilities of these two methods, they fall short in this regard. Similarly, the risk analysis conducted by Yavuz (2017) calculated the same risk scores for different risks using the Fine Kinney method. To address this, Yavuz (2017) integrated the fuzzy logic approach and AHP methods into the analysis.

The risks assessed through the Fine Kinney method were predominantly in the first risk level, while those evaluated through the 5x5 L-type matrix method were mostly in the second risk level. This indicates that the Fine Kinney method evaluates risks at a higher level, confirming its greater precision and justifying its widespread use in risk analyses. Usanmaz and Köse (2020) and Buturak and Yapici (2022), who performed risk analysis using both the 5x5 L-type matrix and Fine Kinney methods, reached different risk priorities for the same hazards. In common, they concluded that the Fine Kinney method identifies a higher risk level than the 5x5 L-type matrix method. In the 5x5 L-type matrix method, risk scores were considerably reduced to a tolerable level after risk control measures were implemented, but the Fine Kinney method did not achieve the same level of reduction. Similarly, in the risk analysis performed by Aker (2019), more risks were reduced to a reasonable level through the 5x5 L-type matrix method compared to the Fine Kinney method. This can be explained by the absence of the exposure factor parameter in the 5x5 L-type matrix analyses calculation.

The risk analysis results are derived from the generalized terminal model adopted in this study. Variations in operational conditions and cargo distribution structures across different terminals may influence the relative importance of certain risks and operational stages. Therefore, the findings should be interpreted as reflecting a model-based assessment framework rather than a context-specific or site-specific evaluation. Within this methodological context, the comparative performance of the applied risk assessment techniques becomes particularly relevant. For risk analyses at liquid cargo terminals, it may be more reasonable to employ the Fine Kinney method because it evaluates risks at a higher level than the 5x5 L-type matrix method. The Fine Kinney method may assign the same risk score to different combinations of likelihood, exposure factor, and possible consequences. As Kokangul et al. (2017) found, the AHP method can enhance risk analysis by calculating risk weights and ranking risks. However, the AHP method does not determine risk levels as the Fine Kinney method does and does not require the determination of risk control measures. For this reason, it is more advantageous to use the Fine Kinney and AHP methods together. To reduce subjectivity and uncertainty in the AHP method, the fuzzy AHP

method is preferable. In conclusion, this study recommends combining the Fine Kinney and fuzzy AHP methods in the risk analysis of liquid cargo terminals.

Based on the risk analyses performed, this study offers the following suggestion to reduce risks in liquid cargo terminals:

- Risk analysis primarily determines whether risks can be reduced, and using a single method is often insufficient. Therefore, methods appropriate for the sector should be identified before any analysis is performed.
- For effective risk analysis, the risk control measures identified in the final step should be implemented and monitored.
- Risk effects may vary depending on the operation; therefore, each identified risk must be evaluated individually based on the specific operation.

The literature review indicates that there are insufficient risk analyses focused on liquid cargo terminals. Given the lack of comprehensive risk analysis practices in these terminals, this study provides a structured framework that occupational safety professionals, policymakers, and terminal operators can use to improve workplace safety. In conclusion, a new hybrid approach is proposed that combines the Fine Kinney and fuzzy AHP methods, which have not previously been applied to liquid cargo terminals. This integrated methodology enhances the accuracy and reliability of risk assessment by leveraging the quantitative strengths of Fine Kinney and the expert-driven weighting capabilities of fuzzy AHP.

The limitations of this study include evaluating risks in liquid cargo terminals only in terms of the identified risks and excluding tank containers, which are commonly used for transporting liquid cargoes, from the analysis of terminal handling equipment and operations. Additionally, the identified risks were structured within a generalized terminal model and may not fully capture all site-specific organizational factors or operational variations. The parameter estimations in the 5x5 L-type matrix and Fine Kinney methods were conducted by the research team, which may limit the incorporation of broader expert-based variability in these assessments.

For future studies, it is recommended to include the HAZOP method, an effective tool for chemical risk analysis, in risk analyses of liquid cargo terminals; to integrate the fuzzy Fine Kinney method into the Fine Kinney method used in risk analyses; and to use different MCDM methods for comparing results and ranking risks to demonstrate the suitability of alternative approaches.

CONFLICT OF INTEREST

The authors declared no potential conflicts of interest with respect to the research, authorship and publication of this article.

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