Construction and Application of a Safety Evaluation Index System for Customs Supervision Sites

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Abstract: Customs supervision sites, including airport cargo terminals, seaports, and railway stations, serve as critical nodes in the international logistics network. Their safety management is directly linked to national economic security and trade stability. As part of its mandate, customs authorities oversee inbound and outbound transportation vehicles, goods, and items, and establish supervision sites at designated locations for enforcement operations. This study, grounded in accident causation theory and customs supervision requirements, identifies five primary safety risks in customs supervision sites: physical security, information security, personnel safety, management risks, and compliance risks. Based on these risks, a comprehensive safety evaluation index system is developed. The Analytical Hierarchy Process (AHP) is employed to determine the weight of each evaluation index, and a systematic framework for risk assessment is constructed. A comprehensive safety risk assessment system is subsequently developed and tested using case studies of representative customs supervision sites to validate its applicability and effectiveness. The test results indicate that the proposed evaluation system accurately reflects the safety status of supervision sites and provides quantitative risk assessment results for decision-makers. The findings of this study offer theoretical support and practical guidance for the safety management of customs supervision sites, enhancing regulatory efficiency and risk prevention capabilities.

Keywords: Customs Supervision Sites; Safety Evaluation; Analytical Hierarchy Process; Risk Prevention

1. Introduction

As a port law enforcement agency, customs authorities are not the primary regulators of production safety for terminals, cargo depots, railway stations, or road stations[1]. However, due to the overlap in enforcement time and space, customs must also enhance the safety management of these sites[2].Customs supervision sites refer to facilities operated and managed by enterprises that accommodate inbound and outbound transport vehicles or domestic carriers transporting customs-supervised goods. These sites serve functions such as entry, docking, loading, unloading, storage, consolidation, and temporary holding of customs-regulated goods, in compliance with the Specifications for the Establishment of Customs Supervision Operation Sites[3]. According to these specifications, supervision sites can be categorized into five types: waterway transport, road transport, air transport, railway transport, and express delivery facilities[4].

In recent years, the safety landscape at domestic and international ports has become increasingly complex and severe, with several catastrophic incidents occurring, such as the Tianjin Port 8.12 explosion and the Beirut Port explosion[5].The researchers conducted a comprehensive analysis of the Beirut Port explosion, highlighting the critical importance of regular safety inspections and evaluations[6].Regarding other public spaces with high population density, it was noted that accidents on construction sites are unplanned events involving the movement of personnel, objects, or materials, potentially leading to injuries and property damage. They emphasized that most of these accidents result from unsafe behaviors and hazardous working conditions.[7].

With the rapid expansion of global trade, customs supervision sites are experiencing a significant increase in inbound, outbound, and transit operations, making the swift identification and mitigation of safety hazards a focal point across various sectors. However,

the current safety management mechanisms in customs supervision sites require further refinement, particularly in areas such as risk identification, early warning systems, and response protocols[8]. Therefore, this study integrates domestic and international research findings with the Specifications for the Establishment of Customs Supervision Operation Sites and routine inspection practices. It systematically extracts and refines the primary safety risk factors, constructs a detailed evaluation index system, and develops relevant applications for practical implementation.

2. Construction of a Safety Evaluation Index System for Customs Supervision Sites

2.1 Identification of Key Safety Risk Factors

In actual operations, site operators are responsible for multiple tasks, including cargo lifting, warehousing, consolidation, and short-distance transportation[9]. Due to the complexity and diversity of import and export goods — ranging from refrigerated cargo and hazardous materials to bulk and general cargo — the transportation and storage requirements vary significantly[10]. These goods are transported using multiple modes, including maritime, air, rail, and road transportation[11]. As a result, in addition to customs authorities, the operational entities of supervision sites are also subject to regulations from various governmental agencies, such as transportation committees, civil aviation administrations, railway authorities, and emergency management departments. The overlapping responsibilities among these agencies lead to challenges in coordinating safety management[12].

The investigation report on the Tianjin Port "8.12" explosion detailed multiple causes of the accident, including deficiencies in approval and supervision processes, intermediary agencies' failures, and the operational misconduct of Ruihai Logistics[13]. Domestic researchers have pointed out that unsafe operational behaviors, excessive storage, and improper cargo stacking, combined with insufficient safety knowledge, low safety awareness, and inadequate safety habits, were direct or indirect contributors to the disaster. Similarly, the 2020 Beirut Port explosion was directly caused by the improper storage of ammonium nitrate that had been impounded six years earlier[14]. The investigation report highlighted systemic safety negligence at all levels, from government officials to frontline workers. The presence of large quantities of highly hazardous materials, unsafe welding activities near storage areas, and a lack of transparency in information management led to a catastrophic explosion in a densely populated commercial district, resulting in significant casualties.

By analyzing classic domestic and international accident cases and integrating modern accident causation chain theories with the regulatory hardware requirements outlined by the General Administration of Customs, researchers have identified key safety risk factors for customs supervision sites. These risk factors include, but are not limited to, physical safety (building security, boundary security, checkpoint security, facility safety), personnel safety (access control, safety awareness and training, safety supervision personnel), information security (digitalization level, data network security, real-time monitoring and early warning systems), management (emergency plans and drills, equipment maintenance and calibration), and compliance (site planning regulations, environmental and safety permits, inspection and supervision).

Physical Safety Risks: Physical safety risks primarily relate to the site’s infrastructure and protective measures. Customs supervision sites are often located near major transportation hubs such as ports and airports, where cargo handling involves hazardous materials, bulk goods, and specialized commodities. Poorly designed building structures and inadequate internal traffic planning can create operational hazards. Insufficient emergency exits and fire passage configurations increase the risk of disaster escalation in the event of a fire. Aging storage facilities, lifting equipment, checkpoint systems, and firefighting infrastructure that lack proper maintenance are prone to malfunctions, elevating the likelihood of accidents. Improper storage arrangements, particularly for hazardous goods, can lead to catastrophic chain reactions. The improper storage of ammonium nitrate in both the Tianjin Port "8.12" explosion and the Beirut

Port explosion exemplifies the critical risks associated with the mismanagement of dangerous goods.

Information Security Risks: As customs supervision sites adopt increasingly digitalized and intelligent management systems, information security risks have become a crucial factor affecting site stability. The reliance on digital platforms for data transmission, system monitoring, and remote supervision makes these sites vulnerable to cyber threats. Major information security risks include data leaks and tampering, where customs-related data involving import/export details and trade secrets are at risk of exposure or manipulation, potentially leading to financial and reputational losses. System failures and downtime pose another significant threat, as real-time data transmission and surveillance systems are integral to regulatory operations. A system outage or hacking incident could disrupt regulatory activities. Network security and maintenance deficiencies can also contribute to operational risks. For example, failures in signal transmission can lead to misinformation and operational errors, as seen in the Wenzhou "7.23" train collision, where an information system flaw played a critical role.

Personnel Safety Risks: Personnel safety is a central concern in customs supervision sites, given the high volume and fluidity of personnel, especially when hazardous cargo is involved. Common personnel safety risks include low safety awareness, where workers lack adequate training on hazardous material handling, emergency evacuation, and incident response. Violation of operational procedures and unlicensed employment are also serious concerns, as unqualified individuals engaging in high-risk operations increase the likelihood of mishaps. Poor personnel control measures, such as unauthorized welding near hazardous cargo storage areas without proper protective measures, significantly heighten the risk of fires and explosions.

Management Safety Risks: Management safety risks stem from deficiencies in the implementation of safety policies and interdepartmental coordination. An effective management system must cover the entire process from daily operations to emergency response. Poorly managed sites often exhibit incomplete safety policies, where regulatory frameworks are either absent or inconsistently enforced, leading to gaps in daily inspections, hazard identification, and emergency preparedness. Unclear departmental responsibilities and regulatory blind spots result from overlapping jurisdictional roles among customs, emergency management, transportation authorities, and private operators, leading to inefficient coordination. Additionally, inadequate safety drills and emergency response mechanisms often reduce response efficiency during crises, as safety exercises may be conducted in a superficial manner without practical enforcement of emergency protocols.

Compliance Risks: Compliance risks pertain to the adherence of supervision sites to regulatory requirements and customs supervision guidelines. Key compliance risks include non-compliance with site planning regulations, as seen in the Tianjin Port case, where Ruihai Logistics illegally constructed hazardous material storage areas without proper authorization. Irregular customs approval procedures are another common issue, where sites operate without conforming to the *Specifications for the Establishment of Customs Supervision Operation Sites*, including unauthorized modifications to site usage, area expansion without reporting, or changes in operating entities that are not officially registered. Furthermore, lack of environmental and safety permits is a critical issue, with some sites bypassing necessary approvals for facility construction and modifications, potentially leading to severe legal and operational consequences.

In summary, customs supervision sites face multifaceted safety challenges that span infrastructure, personnel management, digital security, administrative oversight, and regulatory compliance. The integration of systematic safety evaluation methods can help mitigate these risks, enhance operational security, and ensure compliance with customs and governmental regulations.

2.2 Construction of a Safety Evaluation Index System

The development of a safety evaluation index system for customs supervision sites heavily relies on expert opinions. To ensure the system's scientific validity, objectivity, and comprehensiveness, it is essential to engage

experts with extensive professional knowledge and practical experience in customs supervision and safety management. The weight assignment process should be conducted meticulously to reflect the real-world operational and safety conditions of these sites.

Based on factors influencing the safety status of customs supervision sites, and in alignment with safety evaluation theories, the study categorizes key risk factors into five primary dimensions: physical safety, information security, personnel safety, compliance, and management. These five primary indicators serve as the foundation for constructing the safety evaluation index system. The details of this classification and the specific evaluation criteria are presented in Table 1.

Table 1. Safety Evaluation Index System for Customs Supervision Sites

Overall Index	Primary Indicators (Ki)	Secondary Indicators (Kii)
Safety of Customs Supervision Sites	Physical Safety Factors (K1)	Distance between site boundaries and residential areas/chemical enterprises (K11)
		Frequency of extreme weather and geological disasters at the site location (K12)
		Traffic capacity of internal and surrounding roads (K13)
		Planning of fire safety and evacuation routes (K14)
		Complexity and number of functional zones within the site (K15)
		Presence of designated storage areas for hazardous goods (K16)
		Availability and variety of personal protective equipment for operational staff (K17)
		Structural safety and routine maintenance of buildings (K18)
		Firefighting equipment and emergency evacuation routes in office areas (K19)
		Placement of guidance, safety warning, and cautionary signage (K110)
		Coverage and functionality of video surveillance systems (K111)
	Information Security Factors (K2)	Degree of digitalization in operational management (K21)
		Accuracy and timeliness of cargo inflow, outflow, and storage data (K22)
		Compliance with customs data transmission and exchange requirements (K23)
		Accessibility of operational data to customs authorities (K24)
		Wireless network coverage and stability (K25)
		Network security management status (K26)
	Personnel Safety Factors (K3)	Registration and management of personnel entering and exiting the site (K31)
		Level of human intervention required in operational processes (K32)
		Implementation of safety training for site operators (K33)
		Average education level of site management personnel (K34)
		Average education level of site operational personnel (K35)
		Designation of safety supervisors or equivalent roles (K36)
		Customs officers' supervision and enforcement effectiveness (K37)
	Compliance Factors (K4)	Legal compliance of site land-use planning (K41)
		Compliance with environmental assessment regulations (K42)
		Qualification and licensing of hazardous storage areas (K43)
		Alignment of functional zoning with business operation needs (K44)
		Conformity of customs administrative approval procedures (K45)
		Customs authorities' routine inspection evaluation of site safety (K46)
		Evaluation of site safety by other regulatory bodies (e.g., transportation, emergency management, civil aviation) (K47)
	Management Factors (K5)	Completeness of site safety management regulations (K51)
		Adequacy of emergency response mechanisms (K52)
		Effectiveness of emergency response plans (K53)
		Implementation of emergency drills (K54)
		Routine safety inspections conducted by the operating entity (K55)
		Routine safety inspections conducted by regulatory agencies (e.g., emergency management, fire, transportation, civil aviation) (K56)
		Routine safety inspections conducted by the supervising customs authority (K57)

This comprehensive evaluation system integrates multiple dimensions of safety management, ensuring that customs supervision sites meet regulatory requirements while effectively mitigating risks. By adopting a structured and data-driven approach, this

system enhances the ability to identify, assess, and respond to safety hazards, thereby improving overall site security and operational efficiency.

2.3 Expert Evaluation and Weight Assignment

In the development of a safety evaluation index system for customs supervision sites, expert opinion plays a crucial role in ensuring the scientific rigor, objectivity, and comprehensiveness of the assessment framework. To achieve an accurate and representative weight assignment, experts with extensive professional knowledge and practical experience in customs supervision and safety management must be selected.

The selection criteria for experts prioritize industry relevance, ensuring that selected individuals possess an in-depth understanding of site establishment regulations, risk factors, and management requirements specific to customs supervision locations. Experts are chosen from key domains, including but not limited to, Customs Administration: Professionals well-versed in customs supervision, law enforcement requirements, and risk management policies, capable of providing insights into regulatory frameworks and operational standards. Site Safety Management: Practitioners with extensive experience in facility management, capable of identifying potential safety hazards and contributing to the formulation of risk assessment methodologies. Hazardous Materials Management: Specialists in the storage and transportation of hazardous materials, offering expertise in evaluating the risks associated with high-risk cargo handling and management.

In addition to industry relevance, practical experience is another critical factor in expert selection. Experts must have substantial hands-on experience, particularly in the planning, operation, management, or safety assessment of customs supervision sites. To ensure that expert evaluations are based on practical insights, selected professionals must have a minimum of five years of experience in relevant roles.

Following these selection principles, a total of ten experts were invited to participate in the evaluation process. These experts were drawn from various institutions, including the General Administration of Customs (GAC) headquarters, functional departments of directly affiliated customs offices, on-site regulatory divisions of subordinate customs units, and operational entities managing customs supervision sites. Their combined expertise ensures a well-rounded and authoritative weight assignment process, enhancing the reliability and applicability of the proposed safety evaluation index system.

2.4 Weight Calculation Results

The experts participating in the evaluation process are denoted as Zi. Each expert assesses the secondary indicators, and the weight coefficient Kii for each secondary indicator is calculated based on the assigned evaluation scores Pi, where the score range is set between 1 and 5. The calculation formula for Kii is expressed as follows:

$$K_{ii}=\frac{\sum(Z_iK_i\times P_i)}{\sum(Z_iK_i\times 5)} \quad (1)$$

To ensure the consistency and comparability of the weight assignments across different secondary indicators, a normalization process is applied. The total sum of all weight coefficients is standardized to 1, ensuring that the final weight distribution is proportionally balanced. The normalization process follows the equation:

$$K_{ii}=\frac{K_{ii}}{\sum(K_{ii})} \quad (2)$$

This weight standardization approach guarantees that the evaluation system remains statistically valid and methodologically robust, allowing for an objective and structured assessment of the safety risks associated with customs supervision sites. The finalized weight values serve as the basis for constructing a comprehensive and scalable evaluation framework, facilitating accurate risk quantification and decision-making.

To quantitatively assess the relative importance of various safety indicators in customs supervision sites, a weight assignment process was conducted based on expert evaluations. The final weight standardization scores were determined through Analytic Hierarchy Process (AHP) and normalization methods to ensure a scientifically rigorous assessment framework. The weight calculation results for each indicator are summarized in Table 2.

Table 2. Standardized Weight Scores of Safety Evaluation Indicators

No.	Indicator Name	Standardized Weight Score
1	Distance between site boundary and residential/chemical enterprise zones	0.0344
2	Frequency of extreme weather and geological disasters at site location	0.0363
3	Traffic capacity of internal and surrounding roads	0.0136
4	Planning of fire safety and evacuation routes	0.0225
5	Complexity and number of functional zones within the site	0.0148
6	Presence of designated storage areas for hazardous goods	0.0369
7	Availability and variety of personal protective equipment	0.0221
8	Structural safety and routine maintenance of buildings	0.0148
9	Firefighting equipment and emergency evacuation routes in office areas	0.0221
10	Placement of guidance, safety warning, and cautionary signage	0.0148
11	Coverage and functionality of video surveillance systems	0.0148
12	Degree of digitalization in operational management	0.0148
13	Accuracy and timeliness of cargo inflow, outflow, and storage data	0.0369
14	Compliance with customs data transmission and exchange requirements	0.0221
15	Accessibility of operational data to customs authorities	0.0221
16	Wireless network coverage and stability	0.0148
17	Network security management status	0.0148
18	Registration and management of personnel entering and exiting the site	0.0295
19	Level of human intervention required in operational processes	0.0369
20	Implementation of safety training for site operators	0.0369
21	Average education level of site management personnel	0.0295
22	Average education level of site operational personnel	0.0369
23	Designation of safety supervisors or equivalent roles	0.0221
24	Customs officers' supervision and enforcement effectiveness	0.0148
25	Legal compliance of site land-use planning	0.0369
26	Compliance with environmental assessment regulations	0.0148
27	Qualification and licensing of hazardous storage areas	0.0369
28	Alignment of functional zoning with business operation needs	0.0221
29	Conformity of customs administrative approval procedures	0.0148
30	Customs authorities' routine inspection evaluation of site safety	0.0295
31	Evaluation of site safety by other regulatory bodies (e.g., transportation, emergency management, civil aviation)	0.0369
32	Completeness of site safety management regulations	0.0295
33	Adequacy of emergency response mechanisms	0.0295
34	Effectiveness of emergency response plans	0.0369
35	Implementation of emergency drills	0.0295
36	Routine safety inspections conducted by the operating entity	0.0369
37	Routine safety inspections conducted by regulatory agencies (e.g., emergency management, fire, transportation, civil aviation)	0.0369
38	Routine safety inspections conducted by the supervising customs authority	0.0295

3. Development and Testing of the Safety Evaluation Platform

3.1 Platform Development and Application

To enhance the usability and manageability of the safety evaluation system, an integrated Customs Supervision Site Safety Risk Assessment Platform was developed using information visualization technologies. This platform, based on the established evaluation model, provides a user-friendly tool for experts and frontline customs officers to efficiently assess safety risks in real-world operations.

The platform consists of three main functional modules: (1) Expert Evaluation Module, which includes weight assignment, historical

evaluation records, and expert assessment functions; (2) Frontline Officer Scoring Module, which allows customs officers to input and review safety scores; and (3) Data Monitoring and Early Warning Module, which features weight distribution visualization, threshold-based risk alerts, and site evaluation tracking. The structured functionality of the platform ensures systematic and data-driven risk assessment, facilitating the identification and mitigation of potential hazards in customs supervision sites.

3.2 Case Study Testing

To validate the effectiveness of the developed safety evaluation system, two major port-related safety incidents were selected as case studies: the Tianjin Port 8.12 explosion and the Beirut Port 8.4 explosion. A retrospective safety assessment was conducted using the platform, analyzing pre-incident conditions to identify safety management deficiencies and evaluate the system's applicability and accuracy.

Case Study: Tianjin Port 8.12 Explosion

Incident Background: On August 12, 2015, a catastrophic fire and explosion occurred at the Tianjin Port Ruihai Logistics hazardous goods warehouse, resulting in 165 fatalities, over 800 injuries, and direct economic losses exceeding 7 billion CNY. According to the investigation report, the direct cause of the explosion was the self-combustion of nitrocellulose due to moisture loss, which led to prolonged burning and heat accumulation, eventually triggering the detonation of ammonium nitrate and other hazardous chemicals stored in the facility. The warehouse was an officially approved customs supervision site under Tianjin Customs jurisdiction.

The report highlighted severe violations of safety regulations, attributing responsibility to Ruihai Logistics for illegal facility construction, unauthorized hazardous goods operations, non-compliant storage practices, and systematic safety mismanagement. Furthermore, multiple government agencies, including transportation, port management, customs, safety supervision, planning, environmental protection, and public security departments, were cited for regulatory failures, inadequate enforcement, and negligence in overseeing hazardous material operations. Additionally, third-party safety inspection agencies were found to have falsified assessments, further exacerbating risks.

Based on the investigation findings, key safety deficiencies at the Ruihai warehouse were identified: Physical Safety: The warehouse was located at an unsafe proximity to residential areas, violating national standards. The facility was approved for general cargo storage, but actual blueprints included hazardous materials zones. Unauthorized ammonium nitrate storage and excessive hazardous goods stockpiling created critical risks. Information Security: The lack of digitalized inventory management and failure to disclose real-time hazardous material data to regulatory authorities resulted in severe information gaps during the crisis. Personnel Safety: Employees lacked proper safety training and emergency response knowledge. Unqualified personnel operated forklifts and handled dangerous goods without certification. Regulatory Compliance: The facility operated without proper permits for 11 months, violating customs and safety regulations. Unauthorized modifications and failure to obtain hazardous material storage licenses further increased risks. Management Deficiencies: Regulatory bodies exhibited ineffective enforcement, allowing unsafe operations to continue unchecked. The customs authority did not revoke the warehouse's supervision site registration despite its non-compliance.

To ensure an objective evaluation, criteria not explicitly mentioned in the investigation report were assigned the maximum safety score. The safety assessment results for the Ruihai warehouse before the accident are presented in Table 3.

After inputting all safety indicators into the evaluation platform, the overall pre-incident safety score was calculated as 40.23 out of 100. This significantly lower-than-standard score indicates that the evaluation model effectively identified pre-existing safety vulnerabilities, demonstrating its applicability in risk prediction and mitigation.

Case Study: Beirut Port 8.4 Explosion

On August 4, 2020, a catastrophic explosion occurred at Beirut Port, Lebanon, caused by 2,750 tons of improperly stored ammonium nitrate. The blast resulted in over 200 fatalities, thousands of injuries, and extensive property damage, leading to severe economic and

infrastructural losses. While the direct cause of the explosion was the improper storage of hazardous materials, the lack of safety management and regulatory oversight played a crucial role in escalating the disaster. However, due to political and economic complexities, no comprehensive investigation report has been officially released by Lebanese authorities.

Table 3. Pre-Incident Safety Evaluation Scores for Tianjin Ruihai Warehouse

Evaluation Criteria	Score (Scale: 1-5)
Distance to residential/chemical zones	1
Extreme weather and geological hazard frequency	5
Traffic capacity of internal and surrounding roads	5
Fire safety and evacuation route planning	1
Complexity and number of functional zones	1
Presence of designated hazardous goods storage areas	1
Availability of personal protective equipment	5
Structural safety and routine maintenance	5
Firefighting and emergency evacuation facilities	1
Placement of safety warning signage	5
Surveillance system coverage	5
Level of digitalization in management	1
Accuracy of cargo inflow, outflow, and storage data	1
Compliance with customs data transmission requirements	5
Accessibility of operational data to customs	5
Wireless network coverage and stability	5
Network security management	5
Registration and management of personnel access	5
Human intervention required in operations	3
Implementation of worker safety training	1
Average education level of management staff	1
Average education level of operational staff	1
Appointment of safety supervisors	1
Customs law enforcement supervision	1
Land-use planning compliance	1
Environmental assessment compliance	1
Qualification for hazardous material storage	1
Functional zoning compliance with operational needs	1
Compliance with customs administrative approval processes	1
Routine customs safety inspection evaluation	1
Safety evaluation by other regulatory agencies	1
Completeness of safety management regulations	1
Adequacy of emergency response mechanisms	1
Effectiveness of emergency response plans	1
Implementation of emergency drills	1
Routine safety inspections by operating entity	5
Routine safety inspections by external regulatory agencies	1
Routine safety inspections by customs authority	1

The safety deficiencies at Beirut Port were analyzed based on available reports and documented evidence. In terms of physical safety, the warehouse storing hazardous materials was located at an adequate distance from residential areas, meeting most international industry standards. However, Lebanon's geographical position at the intersection of the Arabian and African tectonic plates makes it prone to seismic activity. Beirut experiences approximately five minor earthquakes per year, though most are of low intensity. Despite this, the long-term storage of ammonium nitrate without appropriate safety measures, combined with the presence of fireworks in the same facility,

indicated significant deficiencies in hazardous material management and zoning.

Regarding information security, Beirut Port relied heavily on traditional warehouse management methods, with limited digitization and automation. The lack of an integrated hazardous material tracking system meant that the storage conditions and associated risks were not effectively communicated to authorities or the public, delaying necessary interventions.

From a personnel safety perspective, reports indicate that three workers left the warehouse shortly before the explosion, suggesting that operational errors or unsafe handling of materials may have directly contributed to the incident. Additionally, the absence of structured safety training meant that warehouse staff and surrounding personnel were not adequately prepared for hazardous material management or emergency response.

In terms of regulatory compliance, no specific Lebanese laws governing hazardous material storage at the port were identified in public records. However, considering that Beirut Port is the country's largest logistics hub, it is reasonable to assume that its management practices should align with international safety standards. Given the lack of verifiable regulatory compliance data, relevant safety indicators were assigned mid-range scores to reflect potential adherence to global practices.

Regarding safety management, multiple reports indicated that Lebanese authorities had received repeated warnings about the presence of hazardous materials at the port but failed to take corrective action. The customs authority's prolonged detention of high-risk goods without proper safety measures ultimately contributed to the disaster. Both the port operators and government agencies exhibited long-term negligence in implementing effective risk management strategies, significantly increasing the likelihood of a catastrophic event.

To ensure objectivity, when specific safety deficiencies were not explicitly mentioned in available reports, the maximum possible score was assigned. For infrastructure and legal compliance indicators where precise information was unavailable, mid-range values were used. The pre-incident safety assessment for Beirut Port is summarized in Table 4.

After inputting these safety indicators into the evaluation platform, the overall pre-incident safety score was calculated as 52.51 out of 100. This score is significantly below the standard safety threshold, confirming that the evaluation system effectively identified critical safety risks prior to the explosion.

4. Application of the Safety Evaluation System

To further validate the applicability and reliability of the proposed safety evaluation system for customs supervision sites, two representative sites under the jurisdiction of Shanghai Customs were selected for testing. These sites include a waterway transportation facility specializing in hazardous goods logistics and an air cargo facility responsible for handling international shipments at Pudong Airport

4.1 Safety Evaluation of a Waterway Transportation Facility

Company A is a customs supervision site specializing in the storage and transportation of hazardous materials, including chemicals, gases, and high-risk cargo. It provides tailored logistics solutions for the import and export of hazardous goods, covering storage, transportation, customs declaration, and safety inspection. The company is officially registered as a customs supervision site, with customs officers stationed on-site for regulatory oversight.

Using the previously established evaluation model, on-site customs officers conducted a comprehensive inspection of the facility, reviewing operational records, management protocols, and surveillance footage. The Customs Supervision Site Safety Risk Assessment Platform was utilized to score physical infrastructure, digital management systems, personnel safety, regulatory compliance, and daily operations. The platform automatically aggregated the evaluation data and generated a final safety score of 82.5.

The analysis of the test results is as follows:In terms of physical safety, the facility adheres to high standards for fire prevention, explosion mitigation, and leakage control. It is equipped with specialized explosion-proof storage areas and advanced ventilation systems, ensuring safe storage conditions under varying environmental factors. Hazardous goods are

segregated based on chemical compatibility, preventing unintended reactions. The warehouse design complies with industry standards, maintaining dedicated safety corridors between storage and operational zones to minimize worker exposure. Automated handling equipment further enhances safety, while temperature-controlled storage supports cargo requiring specific environmental conditions. Additionally, real-time monitoring systems, gas detectors, and temperature/humidity sensors are deployed to ensure cargo integrity.

Table 4. Pre-Incident Safety Evaluation Scores for Beirut Port Warehouse

Evaluation Criteria	Score (Scale: 1-5)
Distance to residential/chemical zones	5
Frequency of extreme weather and geological hazards	1
Traffic capacity of internal and surrounding roads	5
Fire safety and evacuation route planning	5
Complexity and number of functional zones	1
Presence of designated hazardous goods storage areas	1
Availability of personal protective equipment	5
Structural safety and routine maintenance	5
Firefighting and emergency evacuation facilities	5
Placement of safety warning signage	5
Surveillance system coverage	5
Level of digitalization in management	3
Accuracy of cargo inflow, outflow, and storage data	3
Compliance with customs data transmission requirements	3
Accessibility of operational data to customs	3
Wireless network coverage and stability	3
Network security management	3
Registration and management of personnel access	1
Human intervention required in operations	1
Implementation of worker safety training	3
Average education level of management staff	3
Average education level of operational staff	3
Appointment of safety supervisors	1
Customs law enforcement supervision	1
Land-use planning compliance	5
Environmental assessment compliance	5
Qualification for hazardous material storage	1
Functional zoning compliance with operational needs	3
Compliance with customs administrative approval processes	3
Routine customs safety inspection evaluation	1
Safety evaluation by other regulatory agencies	1
Completeness of safety management regulations	3
Adequacy of emergency response mechanisms	3
Effectiveness of emergency response plans	3
Implementation of emergency drills	3
Routine safety inspections by operating entity	1
Routine safety inspections by external regulatory agencies	1
Routine safety inspections by customs authority	1

Regarding personnel safety, all operational staff undergo rigorous hazardous material handling training to ensure proficiency in chemical safety and emergency response. Strict operational procedures govern loading, unloading, and transportation to prevent accidents. Given the variety of hazardous materials managed, the facility provides comprehensive personal protective equipment (PPE), including protective suits and

respirators. Regular health assessments are conducted to monitor long-term exposure effects on workers.

In terms of safety management, Company A has established comprehensive emergency response protocols covering chemical spills, fires, and explosions. Adequate emergency resources, including response equipment and chemical containment tools, are readily available. A dedicated firefighting team is stationed at the site, conducting regular emergency drills in coordination with customs, fire departments, and other regulatory bodies to ensure efficient crisis management.

Based on the evaluation results, Company A demonstrated strong performance in physical safety, personnel management, and regulatory compliance, particularly in hazardous material handling. However, improvements in digital safety monitoring are recommended. Given the complexity of hazardous materials logistics, enhancing automated monitoring systems and integrating digital customs supervision platforms could further strengthen risk prevention measures.

4.2 Safety Evaluation of an Air Cargo Facility

Company B is an air cargo terminal responsible for breakdown, tallying, sorting, and temporary storage of international airfreight under customs supervision at Shanghai Pudong Airport. It handles a diverse range of cargo, including general goods and hazardous materials, requiring stringent operational controls.

Using the evaluation framework, customs officers conducted an on-site inspection, reviewing management policies, operational records, and surveillance data. The evaluation platform generated a final safety score of 81.2.

The analysis of the test results is as follows:In terms of physical safety, Company B’s high cargo turnover rate necessitates precise cargo classification and storage protocols. High-risk goods, such as flammable and explosive materials, are stored separately from general cargo. The facility includes temperature-controlled storage zones to preserve cargo integrity and prevent environmental-induced risks. Given the dense storage and sorting processes, the site is equipped with fire suppression systems, automatic extinguishers, and regularly maintained fire alarms. A comprehensive surveillance system monitors key operational areas in real-time, reducing human error and enhancing safety oversight.

Regarding personnel safety, Company B employs highly trained staff to manage air cargo handling efficiently. Routine safety training and competency assessments ensure compliance with the latest handling and emergency response protocols, particularly for hazardous materials. The facility optimizes work schedules to prevent operator fatigue, and protective gear is mandated for high-risk tasks.

In terms of safety management, given the fast-paced nature of air cargo logistics, the facility's emergency response system is designed for rapid reaction to fires, explosions, and hazardous spills. Frequent multi-agency emergency drills involving aviation authorities, fire departments, and customs ensure effective crisis response coordination.

Company B demonstrated strong performance in personnel management and emergency preparedness, adhering to high safety standards. However, aging infrastructure and operational bottlenecks pose challenges. The facility operates near full capacity, requiring offsite sorting and distribution, which complicates customs supervision and cargo security. Future improvements should explore the feasibility of constructing an advanced, fully automated cargo terminal to enhance efficiency and security.

5. Conclusion and Future Outlook

This study developed a multidimensional safety evaluation framework for customs supervision sites, validated through real-world case studies. The framework integrates physical safety, information security, personnel safety, management efficiency, and regulatory compliance, with weight assignments determined using Analytic Hierarchy Process (AHP) and expert evaluation.

A custom-built Customs Supervision Site Safety Risk Assessment Platform was developed to facilitate real-time risk monitoring and comprehensive safety assessments. The framework was tested using historical case studies of major port disasters (Tianjin Port 8.12 and Beirut Port 8.4), demonstrating its ability to identify critical

pre-incident safety vulnerabilities. Additional validation using two active customs supervision sites in Shanghai confirmed the model's practical applicability and accuracy in risk assessment.

Despite its effectiveness, the study has certain limitations. First, data availability was constrained, as the evaluation relied on a limited sample size and expert input. Second, the framework primarily assesses static safety conditions, without fully accounting for dynamic operational changes over time. Lastly, the evaluation platform requires further refinement in interactive functionalities.

Future research should focus on expanding the dataset by incorporating a larger pool of customs supervision sites. Additionally, integrating AI-driven predictive analytics and machine learning-based risk detection could enhance the platform's ability to identify emerging safety threats. Furthermore, strengthening the link between safety assessments and risk mitigation strategies will allow for more proactive regulatory decision-making, ensuring safer and more efficient customs supervision operations.

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