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Root Cause Analysis of the Fire Incident at Shahid Rajaee Port Using the Fishbone (Ishikawa) Method: A Case Study from Bandar Abbas, Iran

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ABSTRACT

The fire and explosion at Shahid Rajaee Port in April 2025 represent a critical industrial incident with significant human, operational, financial, and environmental consequences. This study applies the Fishbone (Ishikawa) method to systematically identify the root causes of the event, based on interviews with port operators, safety experts, and emergency responders. Six main categories of contributing factors were examined: Human, Machine/Equipment, Materials, Methods/Processes, Environment, and Management. Findings reveal that inadequate staff training, fatigue, and poor communication, combined with equipment failures, improper hazardous material storage, weak operational procedures, adverse environmental conditions, and a weak safety culture, collectively created the conditions for the disaster. The analysis underscores that such incidents are rarely the result of a single failure but emerge from the interaction of multiple systemic vulnerabilities. Based on these findings, the study recommends continuous workforce training, systematic preventive maintenance, rigorous hazardous material management, standardized operational and emergency procedures, infrastructure improvements, and strengthened organizational governance to enhance resilience and reduce the likelihood of similar events. This research provides a comprehensive framework for port authorities and policymakers to implement integrated risk management strategies, emphasizing the need for a holistic approach that addresses technical, human, and organizational dimensions of safety.

Keywords:

Root Cause Analysis, Fishbone Method, Fire Incident, Shahid Rajaee Port, Hazardous Materials, Port Safety, Industrial Accident, Risk Management

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1. Introduction

In today's globalized economy, seaports represent critical infrastructures and indispensable nodes within the international maritime transport chain, facilitating trade, economic development, and national competitiveness. Their strategic significance extends beyond economic dimensions, as disruptions in port operations can trigger wide-ranging social, economic, and environmental consequences. Coastal locations, combined with the handling of large volumes of diverse cargo—including chemicals, hydrocarbons, and fertilizers—render ports, particularly large-scale facilities, highly complex and environmentally sensitive systems. Port operations are often associated with challenges such as water and air pollution, soil contamination, dust and noise emissions, waste generation, dredging activities, intensive traffic of ships, trucks, and trains, and the storage of hazardous substances (Darbra & Casal, 2004; Planas-Cuchi et al., 1997, 1998).

Many ports are situated near urban centers, which amplifies the potential impact of industrial accidents on public health and the environment. Relocating such facilities is often impractical, making even minor operational failures or improper handling of hazardous materials capable of escalating into fires, explosions, toxic releases, and other incidents with serious environmental, financial, and reputational consequences (Wang, Yin, & Khan, 2023). The inherent complexity of port operations—driven by interactions among human factors, machinery, environmental conditions, and logistical processes—heightens vulnerability to unintended incidents.

Shahid Rajaee Port, located in Bandar Abbas, Iran, exemplifies a high-capacity, strategic maritime hub. Covering over 2,400 hectares, it functions across container terminals, general cargo, bulk and mineral commodities, and oil storage facilities. Its hybrid operational model involves private companies and public sector affiliates, handling over 81% of Iran's container traffic and 56% of the country's total exports. This critical role establishes Shahid Rajaee Port as a cornerstone of national and regional trade, contributing significantly to the province's GDP. On April 26, 2025, a major fire and series of explosions in the container storage area resulted in significant human casualties, structural damage, and disruption of operations, highlighting the urgent need for systematic risk assessment and preventive strategies.

A fire is an uncontrolled and sudden combustion event that can lead to loss of life, property damage, and environmental harm. Fires are inherently unpredictable in terms of timing, cause, and severity, and they pose a major threat to industrial and port infrastructures. Effective risk management and proactive prevention strategies are therefore essential for mitigating their impacts. Global statistics underscore the magnitude of fire hazards: in 2015, the United States recorded 1,345,000 fire incidents, with seven major events causing economic losses of US$14.3 billion. In Indonesia, 2,551 industrial and residential fire incidents were reported up to 2019, including fatal cases, highlighting the worldwide relevance of fire risk management in industrial settings (BNPB, 2019; National Fire Safety Association, 2016).

Historical port disasters provide critical insights for understanding and preventing similar incidents. Notable cases include the Beirut Port explosion (Lebanon, 2020), where over 2,700 tons of ammonium nitrate detonated, causing more than 220 fatalities and extensive infrastructural damage; the Tianjin Port explosion (China, 2015), resulting in over 170 deaths; a ship explosion at Jebel Ali Port (UAE, 2021); a hazardous cargo warehouse explosion at Noshahr Port (Iran, 2023); and a fire with multiple explosions at Alexandria Port (Egypt, 2024). Comparative analysis of ammonium nitrate explosions—including Beirut, Tianjin, and the historic Texas City disaster (1947)—reveals recurring root causes such as uncontrolled fire, inadequate storage practices, and insufficient emergency preparedness. These cases collectively underscore the critical importance of advanced fire prevention systems, personnel training, stringent safety protocols, continuous oversight, and context-specific regulatory enforcement to mitigate cascading and multi-faceted disasters in seaports (Hua, 2021; Kumah et al., 2024).

Root Cause Analysis (RCA) has emerged as an essential methodology to systematically identify underlying causes of port incidents, reduce human and financial losses, enhance resilience, and strengthen operational safety. Techniques range from traditional approaches such as the “Five Whys” and the Ishikawa (Fishbone) diagram to specialized frameworks including SHARE, Fault Tree Analysis (FTA), and multi-criteria decision-making tools like AHP or FMEA. Among these, the Fishbone diagram stands out for its visual, team-oriented structure, which categorizes contributing factors into man, machine, materials, methods, environment, and management. When combined with iterative techniques such as the “Five Whys,” it facilitates an in-depth exploration of causal mechanisms, although rigorous RCA requires triangulation with field data, official reports, and complementary quantitative analyses to ensure scholarly validity (Kececi, 2017; Kumah et al., 2024).

Building on this foundation, the present study investigates the root causes of the recent fire and explosion at Shahid Rajaee Port. By integrating Fishbone analysis with quantitative risk prioritization, this research provides a systematic understanding of the incident while generating practical, evidence-based recommendations to enhance port safety management in Iran and comparable contexts. Reports and credible news coverage have highlighted factors such as inadequate storage practices, prolonged container accumulation, and the handling of hazardous chemicals. These factors are incorporated into the RCA framework to ensure that the analysis not only explains the event but also guides policy, operational strategies, and preventive measures (Reuters, 2025). This study contributes locally and globally, demonstrating how structured RCA, grounded in visual tools and validated with complementary methods, can yield actionable insights for improving safety, resilience, and risk management in critical port infrastructures.

2. Literature Review

2-1. Seaport Safety and Risk Management

Nowadays, any theoretical framework aiming to effectively understand port safety and risk management must integrate a combination of system-oriented analysis, stakeholder engagement, and digital resilience. First, data-driven approaches leveraging Bayesian networks have successfully captured the interactions among complex factors—such as weather conditions, labor tensions, and port congestion—in generating key disruptions, and through sensitivity analysis, they have assessed the impact of these factors to provide targeted safety recommendations (Yin et al., 2024, ScienceDirect). In line with this, collaborative network models have also represented the structure of stakeholder interactions, demonstrating that active engagement of all actors—from operators to crisis managers—can reduce operational risk by over 80%, particularly under extreme conditions such as strong winds (Nyamjav & Ha, 2023, KoreaScience).

Regarding environmental and geographical hazards, the use of GIS-based graphical systems combined with fuzzy methods and neural networks has enabled the mapping of risk zones and critical points in Jazan Port. This hybrid approach has identified the port’s most significant vulnerabilities—such as ground fires, pollutant releases, and hazardous human behaviors—providing an effective risk map (Alshareef et al., 2024, MDPI). Furthermore, in analyzing infrastructure security during the handling of hazardous cargo, hybrid approaches combining Bayesian networks and type-2 fuzzy sets have been able to represent uncertainties and expert judgments, highlighting factors such as policy weaknesses, operational errors, and communication failures as key contributors to incidents, while recommending improvements in regulation, resource maintenance, and operational procedures (Khan et al., 2024, TRID).

In addition, a systematic review of overall port resilience indicates a shifting theoretical landscape: moving from an exclusive focus on hard infrastructure toward a holistic approach encompassing organizational, technological, environmental, and multi-stakeholder governance dimensions. This implies that adaptive capacity, effective governance, cross-sectoral collaboration, digitalization (e.g., the Internet of Things, digital twins), alongside protection against threats such as cyberattacks, are all critical elements in port resilience theorization (2025, Port Resilience Review, SpringerLink). Finally, from a systemic risk management perspective—particularly relevant for small and developing ports—global assessments show that most ports face more than three concurrent hazards, including severe natural events such as cyclones. Consequently, port resilience depends on engineering quality, operational thresholds, recovery capacity, and the alignment of mitigation measures with local conditions (Communications Earth & Environment, 2023).

2-2. Root Cause Analysis

In port studies, Root Cause Analysis (RCA) is recognized as one of the most important tools for identifying and preventing maritime and port-related incidents, as it focuses on tracing the chain of causes and enables the development of sustainable safety measures. In practice, RCA in ports primarily relies on four categories of root causes: human, technical, organizational, and environmental factors. A 2019 study on a series of loading incidents in Mediterranean ports demonstrated that the Ishikawa (fishbone) method effectively categorizes causes into human resources, equipment, operational procedures, and environmental conditions (Mansouri & Yip, 2019). Similarly, an analysis of ship collision accidents at Shanghai Port using the Fault Tree Analysis (FTA) method revealed that deficiencies in traffic control procedures and inadequate maritime training were primary root causes (Wang et al., 2020). Moreover, the Failure Modes and Effects Analysis (FMEA) approach was applied at Hamburg Port to assess container operation safety, with results indicating that the most significant root risks were related to loading equipment failures and weaknesses in preventive maintenance programs (Schröder et al., 2021). Additionally, in investigating the root causes of fires in hazardous material warehouses at Tianjin Port, it was found that inadequate storage standards and insufficient organizational supervision played a more prominent role than environmental factors in incident occurrence (Liu & Zhang, 2018). Collectively, these studies suggest that classical RCA in ports is an effective tool for identifying deep-seated causes of incidents, providing port managers with actionable insights to prevent recurrence by focusing on process improvement, workforce training, and enhancement of equipment maintenance systems.

In contemporary maritime safety management literature, the application of Root Cause Analysis (RCA) in ports has undergone a transformative evolution, particularly since 2022, emphasizing the integration of data-driven and structural approaches. For instance, a study at Jebel Ali Port employed a data-driven backward risk diagnosis model within a fully systematic framework, enabling the root-cause analysis of maritime incidents—an approach that facilitated the identification of key causes such as restricted traffic or technical failures (Suez Canal case, 2022, ScienceDirect). Simultaneously, at another port, an investigation into vessel–platform allision, using a combination of hierarchical Bayesian analysis and multi-criteria decision-making methods, identified human error, environmental conditions, and structural deficiencies as fundamental causes (Lisbon study, 2024, MDPI). Moreover, in container terminal operations, a hypothesis based on multi-factorial "coupling" demonstrated that cascading events—such as logistic delays, fleet congestion, and systemic disruptions—could converge to create root causes for major incidents and operational stoppages. This finding further underscored the need for precise performance indicators and a nuanced understanding of complex interactions within port RCA (Wuhan study, 2023, MDPI).

A synthesis of the existing literature indicates that effective RCA in modern ports has moved beyond traditional causal models, such as direct analysis or fishbone diagrams, emphasizing data-driven and hybrid methodologies. In particular, approaches that simultaneously examine the interactions among human, environmental, and organizational factors provide a comprehensive picture of root causes and support the design of high-precision safety interventions.

The role of human error in root cause analysis (RCA) of port incidents has consistently been a central factor. Notably, a comprehensive 2023 study on port crane accidents, employing a hybrid HFACS (Human Factors Analysis and Classification System) and RCA approach, concluded that operator fatigue, insufficient training, and weaknesses in supervisory systems constitute primary root causes (Lee & Kim, 2023). This study highlighted that RCA is not merely a tool for identifying technical factors but should be regarded as a comprehensive instrument for understanding the interplay between human behavior, organizational policies, and environmental conditions.

Similarly, at Rotterdam Port, a Big Data–based RCA was implemented to uncover hidden patterns in operational data, identifying systemic causes of delays and supply chain disruptions. The findings indicated that systemic factors, such as scheduling misalignments and deficiencies in inter-organizational communication, played a more significant role than environmental factors in causing disruptions (van Dijk et al., 2022). In this context, the use of AI-driven digital RCA has also expanded in several East Asian ports, where machine learning algorithms have reconstructed incident pathways and extracted recurring error patterns that traditional RCA methods could not detect (Chen et al., 2024). Furthermore, in the domain of environmental resilience, RCA has been applied as a key tool for analyzing the root causes of hazardous material leaks in ports. A 2023 study at Singapore Port revealed that weaknesses in chemical logistics management and inefficiencies in storage policies were the principal root causes of environmental incidents, and RCA facilitated the formulation of more precise safety policies (Tan & Goh, 2023). Collectively, these trends indicate that RCA in modern ports has evolved from a purely retrospective tool into a proactive and intelligent approach, capable not only of investigating past incidents but also of predicting potential hazards through data pattern analysis and providing actionable recommendations for prevention.

2-3. Ishikawa diagram

The Ishikawa diagram, commonly known as the Fishbone diagram, is a key tool in Root Cause Analysis (RCA) that provides a visual and structured representation of the relationship between an adverse event and its underlying factors. Its application is particularly significant in complex environments such as ports, where risks arising from human, technical, procedural, and environmental factors intersect. Developed by Kaoru Ishikawa in the 1940s, the diagram is considered an effective method for categorizing potential causes into standard groups—such as People, Methods, Equipment, Materials, and Environment—while facilitating team-based design and analysis (Ishikawa, 1943; Investopedia, 2025). In the port context, a case study in Ecuador assessing port sustainability demonstrated that using the Ishikawa matrix helped clearly and comprehensively present underlying causes—such as infrastructure weaknesses, institutional misalignment, environmental challenges, and operational inefficiencies—to policymakers and local managers (González-Cancelas et al., 2024, World Scientific News). Additionally, in navigation incidents like the M/V VITASPIRIT case in the Bosphorus Strait, combining the "Five Whys" technique with the Ishikawa diagram enabled experts to identify root causes through structured interviews with captains and senior engineers, while precisely analyzing the role of Bridge Resource Management (BRM) in navigational safety (Investigation, 2024, Naval Architecture Journal). Owing to its visually intuitive and multi-dimensional structure, the Ishikawa diagram makes the RCA process both human-centered and participatory. Operational teams—from port staff to managers—can engage in collective analysis sessions, examining potential causes across categories such as Equipment, Processes, Environment, and Personnel, and then explore deeper causal relationships using techniques like the "Five Whys" (Toolshero, 2025; Sologic, 2021). This collaborative approach not only improves the accuracy of cause identification but also supports the development of targeted interventions within the Port Safety Management System (SME), leveraging diverse experiential insights from staff. In summary, the Ishikawa diagram, with its simple visual structure and categorization capability, functions as an interactive RCA tool in ports, enabling comprehensive and precise analysis that forms the basis for practical recommendations and incident prevention.

2-4. Theoretical Foundations

Numerous studies have investigated Root Cause Analysis (RCA) and the application of the Ishikawa (Fishbone) Diagram in ports and the broader transportation industry. For instance, research in Arab ports using the Ishikawa diagram combined with Pareto analysis indicated that the primary causes of cargo accumulation are complex customs procedures and delays in cargo inspections (AASTMT). Similarly, in the M/V VITASPIRIT incident in the Bosphorus Strait, RCA employing the "Five Whys" technique alongside the Ishikawa diagram revealed that human factors, such as poor communication and insufficient awareness, played a major role in the incident (Naval Architecture Journal).

In other industries, the Fishbone diagram is widely used to analyze chemical, oil, and gas incidents. For example, in a chemical plant explosion in China, the Fishbone diagram helped identify root causes such as equipment design flaws, non-compliance with safety protocols, and ignition sources (Scribd). Comparisons across industries indicate that chemical and oil/gas sectors emphasize technical and equipment design factors, whereas in ports, attention is given not only to technical factors but also to human factors and operational processes.

RCA and the Fishbone diagram in ports primarily focus on identifying and categorizing human, procedural, technical, and environmental factors. Studies have shown that the most frequent root causes of port incidents include operator errors, poor coordination among operational units, equipment failures, and adverse environmental conditions (Mansouri & Yip, 2019; Lee & Kim, 2023). In contrast, the oil, gas, and chemical industries rely more heavily on technical and process-related factors, such as equipment design, preventive maintenance, process control systems, and technical safety standards (Zhang et al., 2020). In chemical industries, incidents often stem from design flaws, incompatible processes, and inadequate equipment maintenance, which RCA and Fishbone analysis effectively identify and help prevent (Liu & Zhang, 2018). Maritime and shipping industries face a combination of human and technical factors; for example, navigation accidents and ship collisions are often caused by human errors interacting with deficient monitoring systems and complex environmental conditions (Wang et al., 2020; Investigation, 2024).

This comparison illustrates that ports occupy a unique intersection between maritime and industrial sectors. While precise analysis of equipment and operational processes is necessary, similar to oil and chemical industries, the importance of human factors, training, and stakeholder coordination—as in maritime sectors—is equally critical. This unique characteristic renders the application of RCA and the Fishbone diagram in ports more complex and multi-dimensional, requiring a combination of classical and participatory tools.

From an HSE perspective, research demonstrates that integrating RCA and the Ishikawa diagram with Health, Safety, and Environmental standards enables the development of safe operational policies and effective preventive programs (Tan & Goh, 2023). HSE is particularly relevant in ports for managing hazardous materials, preventing environmental incidents, and controlling operational conditions. When combined with RCA, it creates synergy, allowing root causes identified in Fishbone analyses to be translated into practical and standardized solutions.

The position of your research within this body of literature is clear: by focusing on ports and integrating RCA, the Ishikawa diagram, and HSE principles, your study provides a unified framework that addresses human, technical, and procedural factors, supporting the design of preventive programs and continuous operational improvement. This framework bridges the gap between traditional studies in chemical/oil industries and maritime sectors, offering a practical and comprehensive model for port safety management.

Table 1 – Theoretical Foundations

Industry	RCA Application	Fishbone Diagram Application	Primary Focus	Prominent Factors	Sample References
Ports	Analysis of loading incidents, navigation accidents, cargo accumulation	Identification of human, procedural, equipment, and environmental causes	Port operation safety and process improvement	Operator errors, equipment failures, poor coordination, adverse environmental conditions	Mansouri & Yip, 2019; Lee & Kim, 2023; Wang et al., 2020
Oil & Gas	Analysis of explosions, leaks, fires, and equipment failures	Categorization of technical and process causes, equipment design, preventive maintenance	Prevention of major industrial and environmental incidents	Equipment design flaws, insufficient maintenance, poor process control	Zhang et al., 2020
Chemical	Analysis of chemical incidents and hazardous material leaks	Identification of process and technical causes, adherence to safety standards	Prevention of chemical incidents and HSE improvement	Non-compliance with protocols, defective equipment, ignition sources	Liu & Zhang, 2018; Tan & Goh, 2023

Industry	RCA Application	Fishbone Diagram Application	Primary Focus	Prominent Factors	Sample References
Maritime (Shipping & Navigation)	Analysis of ship collisions and maritime accidents	Identification of human and monitoring system causes	Navigational safety and Bridge Resource Management (BRM)	Human error, monitoring system deficiencies, complex environmental conditions	Investigation, 2024; Wang et al., 2020

Existing studies indicate that the application of Root Cause Analysis (RCA) and the Ishikawa (Fishbone) Diagram varies significantly across industries. In ports, these tools are primarily employed to identify and analyze loading incidents, navigation accidents, and cargo accumulation issues, focusing on a combination of human, procedural, technical, and environmental factors. Prominent root causes include operator errors, equipment failures, poor coordination among operational units, and adverse environmental conditions. Through RCA and Fishbone analysis, the chain of causes and consequences can be systematically examined and prioritized (Mansouri & Yip, 2019; Lee & Kim, 2023; Wang et al., 2020). In contrast, the oil, gas, and chemical industries face incidents such as explosions, hazardous material leaks, and equipment malfunctions. In these sectors, RCA and Fishbone analyses emphasize technical and process-related factors, equipment design and maintenance, and adherence to safety standards. Key root causes in these industries include equipment design flaws, inadequate maintenance, and non-compliance with safety protocols (Zhang et al., 2020; Liu & Zhang, 2018; Tan & Goh, 2023).

Maritime and navigation industries, due to the operational complexity, consider a combination of human factors and monitoring systems in RCA. In ship collisions and maritime accidents, human error, deficiencies in monitoring systems, and complex environmental conditions have been identified as primary root causes (Investigation, 2024; Wang et al., 2020). Comparisons across these sectors reveal that ports occupy a unique intersection between maritime and industrial industries. Your research, by simultaneously integrating RCA, the Fishbone diagram, and HSE principles, provides a comprehensive framework addressing human, procedural, and technical factors. This framework supports the design of preventive programs and continuous improvement of port operations, bridges the gap between traditional studies in oil/chemical industries and maritime sectors, and enables the development of a practical model for port incident prevention.

2-5. Main Research Questions

Seaport operations are inherently complex and involve the interaction of human, mechanical, environmental, and organizational factors, particularly when handling hazardous materials. Understanding the root causes of incidents in such high-risk environments is crucial not only for preventing recurrence but also for enhancing overall operational safety and resilience. In light of the limited systematic studies on port-specific incidents—especially in the Iranian context—the following research questions have been carefully formulated to guide a comprehensive root cause analysis using the Fishbone (Ishikawa) method.

- What are the key human, mechanical, environmental, and managerial factors that contributed to the fire and explosion incident at Shahid Rajaee Port?

- How did the interaction between different port subsystems—such as hazardous cargo storage, container handling operations, and safety equipment—affect the severity and progression of the incident?
- What are the advantages and limitations of using the Fishbone (Ishikawa) diagram in conducting a root cause analysis of this port incident?
- Which practical and policy-oriented strategies can be implemented to reduce the risk of similar incidents in Shahid Rajaee Port and comparable ports?
- What lessons can be learned from the Shahid Rajaee incident in comparison to major international port disasters to enhance operational safety and resilience?

3. Methodology

This study adopts a qualitative case study approach to thoroughly investigate the root causes of the fire and explosion that occurred at the container storage facilities of Shahid Rajaee Port in Bandar Abbas on April 26, 2025. The qualitative design was selected for its ability to capture the complex interplay of multiple causal factors, encompassing human, mechanical, environmental, procedural, and managerial dimensions, which contribute to such high-impact incidents (Creswell & Poth, 2018). By adopting this approach, the research moves beyond descriptive reporting, aiming instead to systematically understand and explain why the incident occurred and how similar events can be prevented in comparable port contexts.

Data for this study were collected through semi-structured interviews with ten experts, including port operators, safety specialists, terminal staff, and emergency responders. The interviews aimed to capture detailed insights into operational practices, safety protocols, and perceived contributing factors to the fire and explosion incident. The qualitative data were then systematically analyzed using the Fishbone (Ishikawa) method, allowing the identification of root causes across six main categories: Human, Machine/Equipment, Materials, Methods/Processes, Environment, and Management. This approach facilitated a comprehensive understanding of both technical and organizational factors that contributed to the incident.

Data collection relied on a combination of credible sources to ensure triangulation and robust evidence. Peer-reviewed journals and academic publications were consulted to provide theoretical and methodological insights into port safety, risk management, and root cause analysis. Official incident reports and regulatory documents supplied authoritative details on the event, while structured interviews with port personnel and emergency responders provided firsthand operational perspectives. Complementary on-site inspections and review of maintenance and operational records further enriched the contextual understanding. All sources were carefully validated for accuracy, relevance, and consistency to maintain the integrity of the analysis.

The Fishbone (Ishikawa) diagram was employed as the primary analytical framework. Contributory factors were systematically categorized into six dimensions: human, machine, materials, methods, environment, and management. This visual and collaborative tool enabled the mapping of interdependencies among factors, distinguishing symptoms from root causes. To enhance analytical rigor, the Fishbone analysis was integrated with the iterative "Five Whys" technique and quantitative risk prioritization approaches, including Failure Mode and

Effects Analysis (FMEA) and severity × likelihood scoring. This combination allowed both qualitative depth and quantitative weighting, ensuring a structured, transparent, and actionable identification of root causes.

Ethical considerations were rigorously observed, including informed consent for interviews and strict confidentiality of participant information. Limitations, such as incomplete access to technical reports and potential recall bias, were addressed through cross-validation with multiple data sources and expert verification. The methodology as applied ensures a replicable and robust framework for analyzing port disasters and provides practical, evidence-based recommendations for improving safety, resilience, and operational governance in high-capacity maritime infrastructure.

4. Findings

The fire and explosion in the container storage area of Shahid Rajaee Port (Bandar Abbas) on April 26, 2025, represents a critical industrial incident requiring root cause analysis. Data for this study were collected through semi-structured interviews with ten experts, including port operators, safety specialists, terminal staff, and emergency responders. The analysis was conducted using the Fishbone (Ishikawa) method, in which the central problem—the fire and explosion—was placed at the "head of the fish," and six main categories of potential causes were examined: Human, Machine/Equipment, Materials, Methods/Processes, Environment, and Management.

- Human

Interview results highlighted that insufficient training and high workload were major human-related contributors. Many staff members lacked full knowledge of safety instructions and hazardous material handling procedures. Poor communication between shifts and teams delayed preventive actions and rapid response. Fatigue, stress, and non-compliance with personal safety standards further increased vulnerability to accidents.

- Machine/Equipment

Some fire suppression and alarm systems failed to operate properly during the incident. Mechanical loading and storage equipment suffered from wear and inadequate maintenance. Moreover, the absence of regular inspection and testing reduced the chances of detecting technical failures prior to the event.

- Materials

Improper and prolonged storage of hazardous chemicals, including ammonium nitrate and flammable substances, was a critical factor. Containers were not consistently labeled or properly identified, and incompatible materials were stored together, creating highly explosive conditions.

- Methods/Processes

The analysis revealed a lack of precise operational standards and inefficient inspection procedures. Emergency response protocols were inadequate, and daily operations were not systematically documented. Periodic risk assessments, which could have identified vulnerabilities, were not conducted.

- Environment

Environmental and physical conditions at the port amplified the severity of the incident. High ambient temperatures, insufficient ventilation in warehouses, high container density, and proximity to urban areas were significant factors. Vibrations caused by internal traffic and machinery could also have exacerbated explosive conditions.

– Management/Organization

Weak organizational safety culture, limited coordination between responsible authorities, and insufficient supervision of safety standards were evident. Resource constraints (financial and human) further limited preparedness. Slow and unsystematic decision-making during the emergency hindered effective response, thereby escalating the damages.

The Fishbone analysis confirms that the incident was not caused by a single factor but rather by the interaction of multiple dimensions: human error, equipment failure, hazardous materials, inadequate processes, unfavorable environmental conditions, and weak management practices.

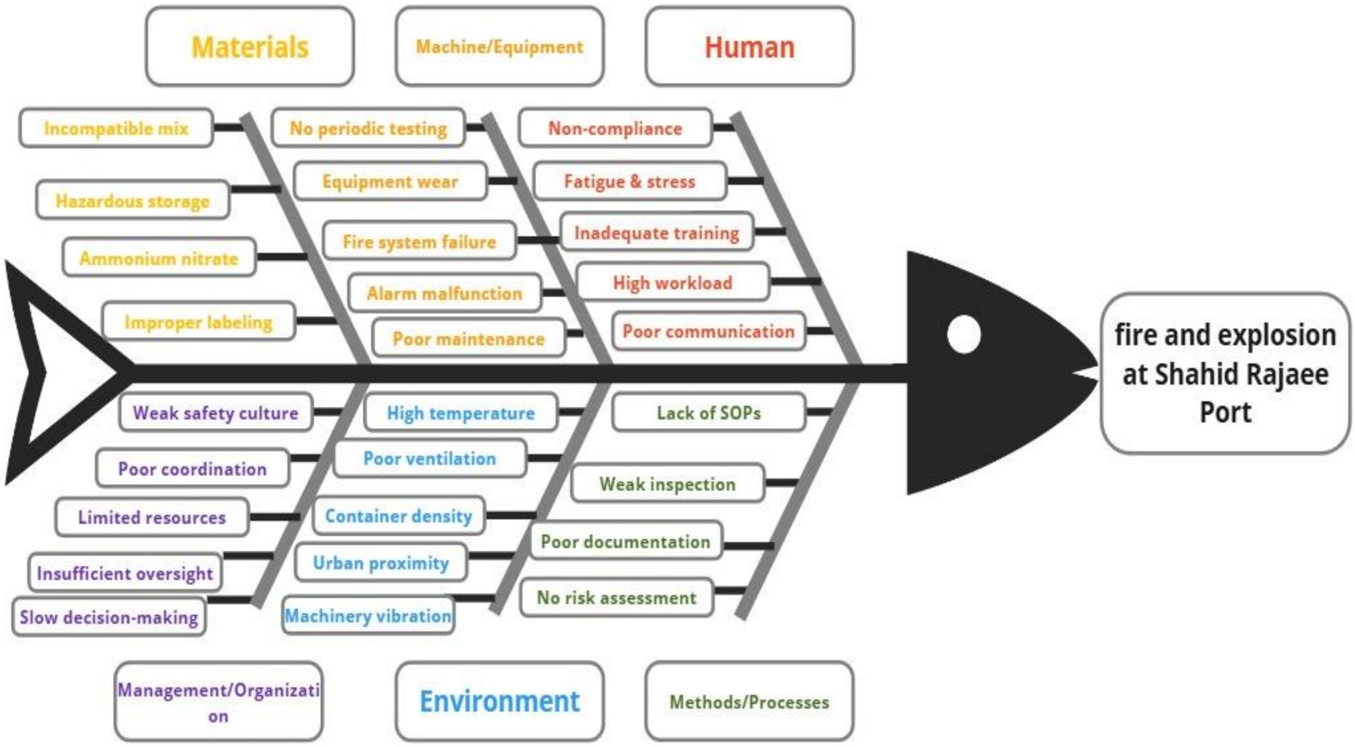

Figure 1. Fishbone Diagram of Root Causes of the Shahid Rajaee Port Fire and Explosion

The Fishbone (Ishikawa) diagram of the Shahid Rajaee Port fire and explosion illustrates the root causes of the incident across six main categories: Human, Machine/Equipment, Materials, Methods/Processes, Environment, and Management. Each branch highlights the key contributing factors identified through expert interviews, such as inadequate training, equipment failures, improper hazardous material storage, weak operational standards, unfavorable environmental conditions, and poor organizational safety culture. By visualizing these interrelated factors, the diagram clarifies how multiple dimensions combined to trigger the incident and emphasizes the need for a comprehensive risk management approach in high-capacity ports.

5. Conclusion

The catastrophic fire and explosion at Shahid Rajaee Port on April 26, 2025, stand as a vivid illustration of how complex socio-technical systems can fail when multiple vulnerabilities converge, and the findings of this study, based on the Fishbone (Ishikawa) analysis, demonstrate that the disaster was not the result of an isolated mistake or technical breakdown but the outcome of a deeply interwoven set of human, organizational, environmental, procedural, and material deficiencies that collectively created the conditions for escalation. At the human level, insufficient training, excessive workloads, poor communication between shifts, fatigue, and stress eroded the ability of staff to handle hazardous materials and respond swiftly to early warning signs, making frontline operators less resilient in the face of risk. These weaknesses were compounded by deficiencies in equipment and technology, as fire suppression systems and alarms failed to perform as intended, while worn-out and poorly maintained mechanical equipment further undermined the port's defense against the initial outbreak; the absence of rigorous preventive maintenance and inspection routines meant that latent failures went unnoticed until they became critical. The unsafe storage and handling of hazardous materials, particularly ammonium nitrate and other flammable chemicals, represented another decisive factor, as incomplete labeling, poor identification, and unsafe mixing of incompatible substances created a high-risk environment in which even minor triggers could escalate into catastrophic explosions. These material vulnerabilities interacted with weak organizational processes, where the lack of precise standard operating procedures, ineffective inspection practices, insufficient documentation, and the absence of systematic risk assessments meant that safety issues accumulated silently over time, while inadequate emergency protocols left responders unprepared to act with speed and coherence once the incident began. The environmental context of the port further exacerbated the situation: high ambient temperatures, poor ventilation in storage areas, dense clustering of containers, vibrations from heavy internal traffic, and proximity to urban zones amplified both the likelihood of ignition and the severity of its spread, turning operational weaknesses into systemic threats. Overarching all of these dimensions was the managerial and organizational layer, where a weak safety culture, inadequate coordination among agencies, resource constraints, and slow, unsystematic decision-making during the crisis allowed the fire to grow unchecked and transformed what might have been a contained incident into a disaster with extensive human, financial, operational, and environmental consequences. The integrated Fishbone analysis underscores that such events are best understood not as random accidents but as systemic failures where the interaction of diverse weaknesses across multiple levels creates a latent structure of risk that only becomes visible in moments of crisis. The implications of this case for port safety and industrial risk management are profound, emphasizing the need for holistic approaches that do not treat human error, technical breakdowns, or managerial lapses in isolation but instead recognize their interdependence and cumulative effects. For large, high-volume ports where the stakes are exceptionally high, prevention requires continuous and role-specific training programs for staff, robust fatigue management and communication protocols, systematic preventive maintenance and independent inspections of fire safety and critical equipment, and the deployment of advanced sensor-based technologies for early detection of failure. Equally important is the strict management of hazardous materials, including rigorous labeling, segregation, and the use of dedicated facilities with enhanced ventilation and fire-resistant infrastructure, supported by digital tracking systems that monitor container contents and risks in real time. On the procedural front, ports must develop and enforce clear operational standards and emergency procedures, institutionalize regular risk assessments and safety audits, and strengthen documentation systems so that vulnerabilities are identified and addressed before they evolve into crises. Environmental and infrastructural improvements such as optimized container layouts, improved ventilation, and environmental monitoring of temperature, humidity, and vibration should also be integrated into safety strategies to mitigate contextual risks that amplify the consequences of operational failures. Above all, strengthening organizational culture and management is essential, as leadership commitment to safety, effective coordination across stakeholders, transparent communication, adequate allocation of financial and human resources, and the establishment of rapid decision-making frameworks in emergencies are the factors that ultimately determine whether a port can withstand the pressures of crisis. The lessons from Shahid Rajaee Port therefore extend beyond a single case, offering a broader perspective on how resilience in maritime infrastructure must be built simultaneously on technical reliability, human capacity, organizational learning, and governance. For policymakers and port authorities, the message is clear: resilience is not a cost but an investment in safeguarding human life, protecting the environment, ensuring the continuity of global trade, and maintaining public trust. While no system can ever eliminate risk entirely, ports that integrate these lessons into their design and operations will be far better positioned to prevent accidents, contain crises, and recover swiftly when disruptions occur. Future research should build on this analysis through comparative studies across different contexts, the use of simulation models to explore stress scenarios, and longitudinal studies of safety culture transformation, but the immediate relevance of the Shahid Rajaee case lies in its powerful reminder that disasters are rarely the product of chance—they are constructed silently by the accumulation of small vulnerabilities, and only a holistic, proactive, and integrated approach to risk management can prevent their devastating consequences.

Refrences

- Abidin, A.U., et al. Fire Management Preparedness at PT X Sleman Regency. in MATEC Web of Conferences. 2019. EDP Sciences.
- Al-Hajj, S., et al., Beirut ammonium nitrate blast: analysis, review, and recommendations. Frontiers in public health, 2021. 9: p. 657996.
- Alshareef, A., Almuslim, H., & Alharbi, A. (2024). Risk assessment of seaport safety using GIS, FAHP, and EANN: Case study of Jazan port. Sustainability, 16(12), 5131. https://doi.org/10.3390/su16125131
- Ben Jemaa, M., Chaabane, N., & Abbes, R. (2022). Port safety risk analysis using MICMAC method: Case of Sfax port. Journal of Marine Science and Engineering, 10(2), 217. https://doi.org/10.3390/jmse10020217
- Cheaito, M.A. and S. Al-Hajj, A brief report on the Beirut port explosion. Mediterranean Journal of Emergency Medicine & Acute Care, 2020. 1(4).
- Chen, Y., Li, S., & Wu, J. (2024). Application of artificial intelligence–based root cause analysis for port safety management: A machine learning approach. Safety Science, 170, 106351. https://doi.org/10.1016/j.ssci.2023.106351
- Darbra, R.-M. and J. Casal, Historical analysis of accidents in seaports. Safety science, 2004. 42(2): p. 85–98.
- Fu, G., J. Wang, and M. Yan, Anatomy of Tianjin Port fire and explosion: Process and causes. Process Safety Progress, 2016. 35(3): p. 216–220.

- González-Cancelas, N., Vaca Cabrero, J., Camarero Orive, A., Macías Párraga, M. J., Díaz Gutierrez, D., & Parra Santiago, J. I. (2024). Assessing port sustainability in Ecuador using an Ishikawa diagram. World Scientific News, (186), 12–26.
- Investigation on the impact of bridge resource management on navigational safety by root cause analysis – case M/V VITASPIRIT accident in Istanbul Strait. (2024). Journal of Naval Architecture and Marine Technology.
- Investopedia. (2025). Ishikawa diagram. Investopedia. Retrieved from Investopedia website.
- Ishikawa, K. (1943). Guide to Quality Control. JUSE. (Referenced in historical context).
- J. Mar. Sci. Eng., Centre for Marine Technology and Ocean Engineering, Universidade de Lisboa. (2024). Probabilistic analysis of basic causes of vessel–platform allision accidents. Journal of Marine Science and Engineering, 12(3), 390. https://doi.org/10.3390/jmse12030390
- Khan, R., Akhtar, M., Rehman, H., & Wang, S. (2024). A hybrid Bayesian network and interval type-2 fuzzy sets approach for risk assessment in port hazardous cargo handling. Transportation Research Record, 2678(7), 35–48. https://trid.trb.org/View/2319644
- Kowara, R.A., Analisis Sistem Proteksi Kebakaran Sebagai Upaya Pencegahan Dan Penanggulangan Kebakaran. Jurnal Manajemen Kesehatan Yayasan RS. Dr. Soetomo, 2017. 3(1): p. 69–84.
- Kuntoro, C., Implementasi Manajemen Risiko Kebakaran Berdasarkan (Is) Iso 31000 Pt Apac Inti Corpora. HIGEIA, 2017. 1(4): p. 109–119.
- Kusumaningrum, N.M., et al., Identification of the Cause of the Fire of Four Tank Units at PT. Tox with the Fishbone and Domino's Factory Method. Advances In Social Humanities Research, 2024. 2(12): p. 1277–1286.
- Lee, H., & Kim, J. (2023). Human factor–oriented root cause analysis of port crane accidents using HFACS. Journal of Safety Research, 86, 15–28. https://doi.org/10.1016/j.jsr.2023.01.004
- Liu, J., & Zhang, H. (2018). Root cause analysis of hazardous material warehouse explosions: The Tianjin Port case. Safety Science, 108, 89–101. https://doi.org/10.1016/j.ssci.2018.04.019
- Luo, T., C. Wu, and L. Duan, Fishbone diagram and risk matrix analysis method and its application in safety assessment of natural gas spherical tank. Journal of Cleaner Production, 2018. 174: p. 296–304.
- Mansouri, M., & Yip, T. L. (2019). Application of Ishikawa diagram for root cause analysis of cargo handling accidents in Mediterranean ports. Maritime Business Review, 4(3), 250–267. https://doi.org/10.1108/MABR-02-2019-0007
- Nagi, K., & Kersten, W. (2022). Collaborative risk management in seaports (CoRiMaS): A conceptual framework. Proceedings of Hamburg International Conference of Logistics (HICL), 33, 45–61. https://doi.org/10.15480/882.4520
- Nyamjav, B., & Ha, H. M. (2023). Stakeholder collaboration for port safety under strong wind conditions: A Bayesian network analysis. Journal of Navigation and Port Research, 47(4), 311–323. https://doi.org/10.5394/KINPR.2023.47.4.311
- Planas-Cuchi, E., et al., Effects of fire on a container storage system—a case study. Journal of loss prevention in the process industries, 1998. 11(5): p. 323–331.
- Planas-Cuchi, E., H. Montiel, and J. Casal, A survey of the origin, type and consequences of fire accidents in process plants and in the transportation of hazardous materials. Process Safety and Environmental Protection, 1997. 75(1): p. 3–8.
- Port Resilience Review. (2025). A systematic literature review of seaport resilience: Organizational, technological, and environmental perspectives. Maritime Economics & Logistics. https://doi.org/10.1057/s41278-025-00326-3
- Porto, M., & Canal, E. (2022). Shipping accident analysis in restricted waters: lesson from the Suez Canal blockage in 2021. Ocean Engineering, 266(Part 5), 113119. https://doi.org/10.1016/j.oceaneng.2022.113119
- Schröder, M., Kersten, W., & Jahn, C. (2021). Failure mode and effects analysis (FMEA) for container terminal operations: A Hamburg case study. WMU Journal of Maritime Affairs, 20(1), 45–64. https://doi.org/10.1007/s13437-020-00221-8
- Setiawan, F., H. Hardiyono, and M. Ramdan, Evaluasi Sistem Proteksi Kebakaran Deluge Valve Di PT Kilang Pertamina Internasional RU V Balikpapan. Identifikasi, 2024. 10(1): p. 94–98.

- Sologic. (2021). RCA and Ishikawa/Fishbone module integration in Causelink – benefits and usage. Sologic Blog.
- Tan, W., & Goh, C. (2023). Root cause analysis of hazardous material incidents in seaports: Lessons from Singapore. Journal of Loss Prevention in the Process Industries, 84, 104945. https://doi.org/10.1016/j.jlp.2023.104945
- Toolshero. (2025). Fishbone diagram by Kaoru Ishikawa explained. Toolshero. Retrieved from Toolshero website.
- van Dijk, T., Meijer, S., & Tavasszy, L. (2022). Big data–driven root cause analysis of delays in container port operations: Case of Rotterdam. Maritime Policy & Management, 49(7), 1021–1040. https://doi.org/10.1080/03088839.2022.2041765
- Walter, V., The Fires of Alexandria. New England Review (1990-), 1997. 18(2): p. 120–130.
- Wang, X., Li, Y., & Chen, Q. (2020). Fault tree analysis of vessel collision accidents in Shanghai Port. Journal of Marine Science and Engineering, 8(11), 897. https://doi.org/10.3390/jmse8110897
- Wuhan University of Technology. (2023). Exploring the failure mechanism of container port logistics system based on multi-factor coupling: case of container port. Journal of Marine Science and Engineering, 11(5), 1067. https://doi.org/10.3390/jmse11051067
- Yin, Y., Zhang, J., & Li, P. (2024). Seaport risk assessment under multi-factor interactions using Bayesian networks. Ocean Engineering, 298, 119854. https://doi.org/10.1016/j.oceaneng.2024.119854
- Zaabi, M.A., The Economic Impact of Terrorist Attack on Jabel Ali Sea Port. 2013.
- Zhang, H., Liu, C., & Chen, X. (2020). Safety management in chemical and petroleum industries using RCA and Fishbone. Journal of Loss Prevention in the Process Industries, 67, 104203. https://doi.org/10.1016/j.jlp.2020.104203
- Zhang, H., Liu, C., & Chen, X. (2023). Global seaport exposure and resilience to tropical cyclones. Communications Earth & Environment, 4, 118. https://doi.org/10.1038/s43247-023-00874-5

- Zhang, H., Liu, C., & Chen, X. (2023). Global seaport exposure and resilience to tropical cyclones. Communications Earth & Environment, 4, 118. https://doi.org/10.1038/s43247-023-00874-5