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Performance Analysis of Ports Based on the Concepts of Risk, Resilience, Reliability, and Sustainability with a Special Focus on Shahid Rajaee Port

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ABSTRACT

Resilient and sustainable port infrastructures are vital in addressing the growing complexities and uncertainties of modern maritime systems. This study emphasizes the necessity of an integrated understanding of four interrelated concepts (risk, resilience, reliability, and sustainability) in the context of port planning and operations. Despite the abundance of research on each of these dimensions individually, a comprehensive framework that effectively combines them for practical decision-making in port environments remains underdeveloped. Through a conceptual and comparative analysis, this research proposes a cohesive approach to these four dimensions and applies it in a case study of Shahid Rajaee Port, one of the most significant ports in southern Iran. The study identifies key deficiencies in current operational practices and recommends strategic solutions, including the integration of multimodal transport systems, implementation of IoT-based monitoring technologies, and employment of skilled and experienced personnel. A SWOT analysis is employed to assess internal and external factors influencing port performance, and tailored strategies are proposed to enhance long-term resilience and promote sustainable development. This integrated approach offers a comprehensive framework to support decision-making in port management under both environmental and human-induced risks.

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1. Introduction

Over 90% of global trade is conducted through ports. Ports have always played a vital and strategic role in a nation's economy. However, their unique geographic positioning and critical function in supporting economic activities go beyond their essential role as a nexus between the maritime and intermodal supply chains [1]. Research by the Organisation for Economic Co-operation and Development (OECD) highlights that ports and their surrounding regions must be prepared for emerging challenges, including climate change and digitalization. Sole reliance on traditional economic indicators and port competitiveness is no longer sufficient or desirable [2]. Ports are susceptible to a wide range of hazards and disruptions, which may be internal, external, or environmental in nature. This highlights the critical importance of developing efficient and resilient port systems. In addition to external threats such as terrorist and cyber-attacks, ports also face internal challenges, including temporary closures of maritime, road, or rail access routes, oil spills, public gatherings, and industrial accidents that can compromise operational safety across large areas of the port. Beyond these short-term events, there are also slow-moving, long-term societal changes that uniquely impact port operations. These include social tensions, shifts in public perception regarding climate change and the environmental impacts of port activities, as well as challenges in attracting new talent or securing access to a skilled and well-trained workforce [1]. Ports must be able to respond effectively to both short-term and long-term changes, as well as to a variety of internal and external threats. Accordingly, it is essential for port managers to be familiar with the different types of risks and disruptive threats, and to plan appropriate measures to mitigate and adapt to such challenges. This paper aims to provide clear and precise definitions of the four key concepts: risk, resilience, reliability, and sustainability. While numerous studies have addressed each of these concepts individually, this work seeks to present simplified yet accurate interpretations of them, while also exploring the interrelationships among these concepts. A case study of Shahid Rajaee Port is then presented, in which several recommendations for enhancing the port's resilience are proposed. Using a SWOT analysis, a set of strategic approaches is outlined to support the long-term sustainability of the port. Table 1 summarizes the key concepts and various tools and metrics used to assess them, followed by a detailed explanation in the subsequent sections. Furthermore, Figure 1 illustrates the conceptual diagram showing the interconnections among these four dimensions.

TABLE 1. Simple definition and measurement tool for each of the concepts: risk, resilience, reliability, and sustainability

Concept	Simple Definition	Criteria
Risk	Uncertainty and Threat	Risk Assessment Risk Priority Number (RPN)
Resiliency	Ability to Recover from Disruption	Absorptive/Restorative/ Adaptive Capacity Time to Recovery (TTR)
Reliability	Stability in Performance	Reliability-Based Design (RBD) Mean Time Between Failures (MTBF)
Sustainabil ity	Continuity Over Time	Sustainable Development Goals (SDGs) Environmental, social and governance (ESG)

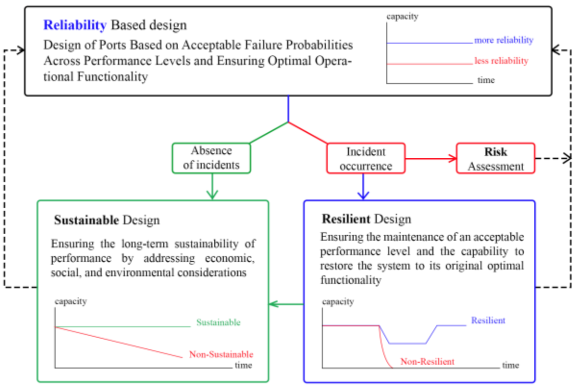

Figure 1. Conceptual Diagram Showing the Relationships Among Risk, Resilience, Reliability, and Sustainability

2. Introduction to Risk

According to ISO 31000, risk is defined as the effect of uncertainty on the achievement of objectives and is quantified as the product of the likelihood of an event occurring and the magnitude of its consequences [3]. This concept may initially appear simple and straightforward; however, the main challenge lies in accurately estimating the likelihood of these events and occurrences. In many cases, probability estimation can be highly misleading, and risks are often assessed with undue optimism. Particularly for low-probability, high-impact events, the ability to make accurate estimations diminishes, leading to a tendency to overlook or underestimate such risks [1]. For example, when dealing with waves 'a highly probable phenomenon' the estimation of occurrence probability can be relatively straightforward, allowing for preventive measures to mitigate wave impacts and appropriate response plans to be implemented. In contrast, the consequences of a maritime accident are far-reaching, while the probability of such an event is often perceived as low. However, it is evident that if such an incident occurs, it would pose significant threats to the port and its facilities. Therefore, to effectively manage various risks, it is essential to first identify and categorize the different types of risks involved.

2. 1. Recognition of Disruptive Threats

Risks and harmful threats to a port can generally be categorized into two groups: internal and external. External threats include terrorist and cyber attacks, natural disasters such as waves, storms, floods, and earthquakes, epidemics, economic recessions, and more. The PESTEL model effectively considers six key dimensions of external vulnerabilities, encompassing political, economic, social, technological, environmental, and legal factors. Internal threats, on the other hand, may involve the port’s organizational vision and values, governance system and management structure, degree of digitalization and reliance on technology, organizational culture, stakeholder relationships, and available resources (financial, human, and technical). The International Association of Ports and Hurbors (iaph) further categorizes various threats into seven groups: economic, environmental, human, access-related, network, technological, and organizational factors. Economic factors include competition with other ports, adverse economic conditions, bankruptcy of a key port user, and seasonal fluctuations in activities. Environmental factors encompass pollution, earthquakes, adverse weather conditions (such as wind, storms, waves, and freezing), hydrological hazards (including floods, droughts, and tsunamis), and the presence of unexploded ordnance (such as shells or mines remaining from past conflicts). Human factors involve terrorism and crime, various sporting, social, and military exercises, labor actions (strikes and protests), human errors in decision-making or operations, and pandemics (such as influenza or COVID-19). Access-related factors include maritime access (such as vessel traffic control, towing, and dredging), land access (roads, traffic congestion, and infrastructure maintenance), and official inspections (customs, safety, and health). Network factors refer to disruptions in upstream or downstream supply chains and disruptive events at other major ports or in hinterland areas. Technological factors cover system and equipment failures, loss of critical infrastructure services (power, water, internet), and accidents related to technology or equipment. Lastly, organizational factors relate to shortages of resources (financial, technical, and human), general confusion or lack of planning, ineffective communications, poor planning, conflicts with contractual obligations or legal requirements, and conflicting priorities among various stakeholders [1].

2. 2. Port Performance Levels

After identifying and understanding various risks, it is essential to clearly define the level at which the risk analysis is conducted. In general, port performance can be examined across three primary levels: operational, economic, and policy domain. The operational domain represents the lowest layer, concerned with the day-to-day functioning of the port. It includes frontline actors such as maritime service providers, port users and vessels, terminal operators, industrial facilities, port workers, customs, firefighting units, and port security forces. Disruptions at this level typically involve operational hazards such as natural disasters, maritime accidents, and public gatherings. The economic level, situated in the middle, reflects the port’s economic ecosystem. It includes stakeholders such as shipping agencies and logistics companies, port owners and cargo owners, other interconnected ports, and port service providers in essence, the port authority itself. This layer is directly affected by market fluctuations, economic shocks, and supply chain disruptions. The highest layer is the policy or governance level, which encompasses the port’s interactions with regulatory bodies and society at large. This includes organizations such as the International Maritime Organization (IMO), national and local governments, legislative authorities, municipalities, non-governmental organizations (NGOs), the media, and the local community. It is important to note that all three levels are interrelated. A disruption at any one level can cascade into the others. The port authority lies at the center of these interconnected layers, playing a pivotal coordinating role [1].

2. 3. Quantitative Measure of Risk

In addition to scenario planning and real-time condition monitoring to prevent potential hazards, the Risk Priority Number (RPN) is commonly used in Failure Mode and Effects Analysis (FMEA) to prioritize risks. The RPN is calculated as the product of the severity of the failure consequence, the probability of occurrence, and the probability of detection prior to failure, as shown below [4].

$$\mathrm{RPN} = \mathrm{Severity} * \mathrm{Occurrence} * \mathrm{Detection} \qquad (1)$$

All of these indices are typically evaluated on a 1–10 scale, resulting in an RPN value ranging from 1 to 1000. In the traditional RPN approach, it is assumed that all three factors ‘Severity, Occurrence, and Detection’ are equally important. However, this assumption often does not reflect real-world conditions. To address this limitation, advanced methods such as Analytic Hierarchy Process (AHP), Data Envelopment Analysis (DEA), and fuzzy logic-based approaches can be employed to more accurately estimate the relative importance (weights) of each factor, leading to risk assessments that better align with actual conditions [5].

3. Resiliency

After defining the port's scope of authority, identifying threats, and understanding which level of port functionality each threat or hazard affects, it is essential to implement preventive measures to mitigate risk. It is important to note that risks and threats are constantly evolving; therefore, the risk assessment process must be periodically reviewed and updated. This involves conducting risk analyses, exploring different disruption scenarios, and proposing specific solutions for each case [1]. Nevertheless, resilience planning is often challenging, as hazards are highly unpredictable and the spatial consequences of disasters remain uncertain. Moreover, responses to and impacts of such events vary significantly across different times and locations [2]. It is under such circumstances that the importance of resilience becomes evident. According to the findings of Marashian et al. (2025), resilience is recognized as a single concept with diverse interpretations; even after more than half a century since its emergence, no universally accepted definition has yet been established [6]. In general, resilience is defined as the ability to return to a normal state following an event or disruption [1]. The concept of resilience was first introduced by Holling in the field of social-ecological research. In this definition, resilience is considered a process through which an entity (an individual, organization, or even a community) develops its capacities to interact effectively with its environment, enabling it to maintain its performance before, during, and after a crisis, and to adapt itself to new conditions [7]. Masselink and Lazarus (2019) define coastal resilience as the ability of social, economic, and natural systems to cope with disturbances such as sea-level rise, extreme events, and human impacts through adaptation while maintaining the essential functions of the system. A key point highlighted in their study is that resilience does not imply complete sustainability, but rather effective adaptability to changes. In this research, resilience is categorized into two types: engineering resilience and ecological resilience. Engineering resilience emphasizes a rapid return to the original state, whereas ecological resilience focuses on the capacity to adapt or transform to a new state without system collapse. The authors consider these two types of resilience as complementary, citing coastal dunes and island shores as natural examples of ecological resilience [8].

3. 1. Main dimensions of resilience

The International Association of Ports and Harbors (IAPH) categorizes resilience into three key phases: before, during, and after a disruptive event. Before the event, the focus is on anticipation and preparedness. In this phase, risk analysis and scenario planning are essential to forecast potential disruptions. Both real-world and virtual drills should be conducted to ensure that port personnel are adequately prepared to respond effectively. During the event, emphasis shifts to crisis response. The ability to maintain essential operations and manage the situation efficiently is critical in minimizing the impact of the disruption. After the event, the learning phase begins. This stage determines whether the port returns to its original functional state, operates at a reduced capacity, or ideally uses the lessons learned to adapt and implement positive changes that enhance overall capacity and performance beyond the pre-disruption level [1]. The United Nations Conference on Trade and Development (UNCTAD) defines port resilience as the ability of a port to maintain an acceptable level of service during disruptions such as natural disasters, pandemics, cyberattacks, and terrorist incidents. According to UNCTAD, the degree of a port’s resilience depends on factors such as its size, geographical location, and the nature of its operations [9]. The three main dimensions of port resilience are summarized as: Absorptive Capacity: the ability to withstand and minimize the impact of disruptions; Recovery Capacity: the ability to restore operations quickly and efficiently after a disruption; Adaptive Capacity: the ability to adjust to new conditions and improve performance in response to future risks [10]. Figure 2 illustrates the three core dimensions of resilience.

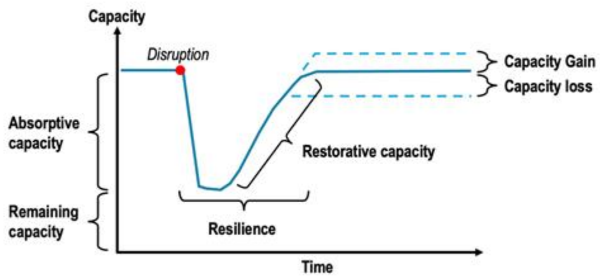

Figure 2. Conceptual Diagram of System Resilience to Disruption: From Absorptive Capacity to Recovery [11]

As illustrated in Figure 2, before the occurrence of a disruption, the port operates at its full capacity. However, once a disruption occurs, absorptive capacity determines the extent to which the port can continue operating. This capacity includes features such as robustness, redundancy, and Visibility. Robustness refers to the system’s ability to resist disturbances, meaning it can maintain operations without significant damage. For example, the use of durable construction materials in quay walls can help absorb wave and storm impacts without structural failure. Therefore, ports and marine infrastructures must be technically designed to withstand natural events and disruptions. Redundancy indicates the extent to which the port can increase its operational performance during disruptions or maintain extra storage of cargo. This serves as a buffer to absorb the shock of the disturbance. Transparency enables users to access real-time information necessary for decision-making. During disruptions, visibility and timely communication help mitigate the impacts across the supply chain. After absorptive capacity, the system's recovery capacity comes into play, which is the ability to return to its pre-disruption operational state. This dimension involves two key components: response and recovery. A port must first respond effectively to the disruption, which requires a high level of preparedness, and then focus on regaining operational functionality. Post-recovery, the port may experience reduced capacity and lower productivity. However, in some cases, a disruption can serve as a learning opportunity, leading to improved efficiency. These outcomes are shaped by the port's adaptive capacity, or its ability to modify its operations and management in response to the event. Key factors influencing adaptive capacity include: Flexibility in workflows and scheduling to mitigate the effects of disruptions, A multi-skilled workforce, Agility in responding to disturbances, Cooperation and coordination with other ports, Utilizing alternative routes for cargo transportation, and Effective communication with stakeholders to both disseminate and gather information, especially from shipping companies [9-11]. Figure 3 illustrates the normal distribution of cargo handled over time. It is evident that under normal, disruption-free conditions, the maximum volume of cargo is handled in the shortest possible time. However, when a disruption occurs, not only does the volume of cargo handled decrease, but the time required for handling also increases [11].

Figure 3. The ratio of cargo handled over time under both normal and disrupted conditions. Ask ChatGPT (11)

3. 2. Numerical metrics for measuring resilience

In addition to the above explanations, there is another measurable and quantifiable resilience indicator called TTR, or MTTR (Mean Time to Recovery). It represents the average time a system takes to recover after a disruption or failure, including the duration from the moment the issue occurs until the service fully returns to normal operation. It is calculated as follows [12].

$$\text{MTTR} = \frac{\sum \text{Downtime for all incidents}}{\text{Number of incidents}} \qquad (2)$$

4. Reliability

Asadabadi and Miller-Hooks (2020) define reliability as the stability of a port or maritime transportation route's performance under normal and predictable conditions; however, resilience is defined as the ability of the port system to respond to disruptions and recover to an acceptable or improved level of performance [13]. Bali et al. (2017) also define the reliability of a system as the probability of satisfactory performance of the system under specified environmental conditions and for a given period of time [14]. Therefore, the main difference between reliability and resilience lies in a system's performance under normal and critical conditions. Reliability emphasizes performance during normal, planned conditions, whereas resilience becomes relevant only during crises, whether short-term or long-term. Although these two concepts are distinct, they are interconnected and complementary. In fact, a port must perform adequately under predictable conditions to be able to maintain some level of functionality during crises and subsequently recover to its previous state. Hence, reliability serves as a prerequisite for resilience, and resilience without reliability is meaningless. Shafieezadeh and Burden (2014), by developing a scenario-based framework to assess infrastructure resilience against natural disasters, not only facilitate the identification of key vulnerabilities in port operations but also demonstrate the close relationship between resilience and reliability [15].

4. 1. Differences between Reliability-Based Design and Traditional Design Methods

Paliou et al. (1987) discuss the differences between traditional design methods and reliability-based design, emphasizing the importance of using the latter in environments characterized by randomness. Given that marine environments are constantly subjected to variable wind and wave loads, there exists significant uncertainty affecting these conditions. Therefore, traditional design methods, which consider only fixed loads using predetermined and constant safety factors, may not be entirely suitable. In reliability-based design, the process is probabilistic, involving numerical and probabilistic modeling. For example, probabilistic methods such as Monte Carlo simulation, FORM (First Order Reliability Method), and SORM (Second Order Reliability Method) can be employed. These methods account for the stochastic nature of the environment by considering uncertainties and different probabilities, and by analyzing various scenarios, they identify different failure modes along with the corresponding probability of failure under general conditions [16].

While reliability may seem to be merely a technical design approach, Rosca et al. (2014) argue that reliability extends beyond a purely technical or engineering method; it represents a comprehensive risk management approach encompassing various organizational, operational, and even social aspects. Furthermore, simulation modeling demonstrates that reliability is not limited to the quality of structures or equipment but also includes the actual performance of the system, such as ship waiting times, storage capacity, and service flow. Reliability assessment should involve the simulation of real scenarios to evaluate the system's capacity to maintain operations during crises and unexpected events [17].

4. 2. Numerical Metric for Measuring Reliability

To ensure system performance under various conditions and quantitatively calculate the failure probability, reliability-based design (RBD) is employed. The objective of RBD is to design a system with a failure probability below a specified threshold, ensuring stable and reliable operation under operational conditions. The RBD process includes the following steps: Identification of reliability criteria, Modeling uncertainties and variations in materials, loads, and environmental conditions, Probabilistic analysis of failures and breakdowns, and Optimization of the design to meet reliability targets with minimal cost or weight [18].

The MTBF (Mean Time Between Failures) index refers to the average operating time of a system or component without failure between two consecutive breakdowns. This metric is one of the key indicators for measuring reliability. It is calculated using the following formula, and the higher its value, the greater the reliability of the system [19].

$$\mathrm{MTBF} = \frac{\text{Total operating time of the system}}{\text{Number of failures}} \tag{3}$$

5. Sustainability

While ports play a significant role in economic development and crisis response, maritime traffic, cargo handling, and road and rail transportation around them harm the environment through air and water pollution. These pollutions originate from port equipment, ships, trucks, trains, and power plants that provide the energy needed for port operations. These emissions include greenhouse gases such as carbon dioxide and particulate matter, which cause respiratory diseases and chronic cardiovascular and pulmonary illnesses. Reducing pollutant emissions from ports decreases air and water pollution, improves the health of more than 3.5 billion people, and helps mitigate climate change [9].

5. 1. Environmental Sustainability

Redesigning infrastructures using nature-based solutions and working with natural processes can help improve the biological performance and durability of concrete structures in marine environments, thereby enhancing the environmental sustainability of ports [20]. Lin and Singh (2024) emphasized the role of natural coastal ecosystems in enhancing coastal resilience. By simulating the removal of natural ecosystems, they examined their impact on the vulnerability of ports. The results showed that large green spaces had a significant effect in reducing coastal vulnerability. Therefore, strengthening and preserving key natural ecosystems is recommended to enhance resilience against flooding and erosion, which also contributes to environmental sustainability [21]. Santos (2025) conducted a comprehensive study on pollution reduction and prevention strategies in ports, emphasizing port waste management, air and water pollution control, energy efficiency, and the use of renewable resources. According to Santos, using solar and wind energy to power port equipment, replacing diesel-powered cranes, trucks, and vehicles with electric versions—thereby reducing greenhouse gas emissions and noise pollution—along with adopting alternative fuels for ships such as LNG, methanol, ammonia, and biofuels as low- or zero-carbon options, are crucial. Additionally, collecting, sorting, and recycling waste from ships and port equipment, treating runoff to prevent pollutants from entering the marine environment, utilizing the Internet of Things to monitor energy consumption, and implementing intelligent maritime traffic management systems to reduce congestion and increase efficiency are all effective strategies for achieving environmental sustainability in ports [22]. However, it is important to note that sustainability encompasses dimensions beyond just environmental sustainability.

5. 2. Economic Sustainability

For a port to remain sustainable in the long term, it must enhance its operational efficiency and productivity in a way that minimizes transportation costs and fuel consumption. By expanding smart infrastructure and utilizing systems such as the Internet of Things (IoT), a port can attract various investments and compete with other ports through diverse innovations.

5. 3. Social Sustainability

Elements of social sustainability include creating job opportunities for local and indigenous populations, ensuring gender equality in employment, enhancing the skills of the port workforce, empowering local communities surrounding the port, and ensuring transparent stakeholder participation in decision-making processes [23,24]. Ports are a significant source of local employment; however, they have traditionally created more jobs for men than for women. According to data from over 50 ports participating in UNCTAD's Train for Trade Port Management Program, only 18% of formal port jobs were held by women in 2021. A closer look reveals that while the global average for women in managerial and administrative roles is around 42%, they account for just 6% of the workforce in operational and cargo-handling positions. To reduce this gap, it is essential not only to provide targeted training and support empowerment programs, but also to challenge traditional mindsets and stereotypes in order to move toward genuine gender balance [25].

5. 4. Sustainability Criteria

The two concepts SDGs and ESG are commonly used to assess the sustainability of ports. The Sustainable Development Goals (SDGs) are a set of 17 global goals adopted by the United Nations in 2015 as part of the 2030 Agenda for Sustainable Development. These goals are comprehensive and interlinked, addressing a wide range of global challenges including poverty, inequality, climate change, environmental degradation, peace, and justice. The SDGs framework includes: 17 Goals 169 Targets Over 200 measurable indicators; These cover all three dimensions of sustainability: Economic (e.g., decent work and economic growth) Social (e.g., quality education, gender equality) Environmental (e.g., climate action, life below water) [26]. ESG is a responsible investment framework that evaluates a company's performance based on three key pillars: Environmental, Social, and Governance. Environmental (E): Assesses the impact of a company's operations on the environment by measuring: Resource consumption, Greenhouse gas emissions, Waste management, Biodiversity conservation; Social (S): Evaluates how the company interacts with stakeholders, focusing on: Employee well-being, Customer rights and privacy, Community engagement, Respect for human rights; Governance (G): Examines the internal structure and decision-making processes of the company, including: Transparency in governance, Board composition, Accountability and ethical management. Together, ESG metrics provide insight into the sustainability and ethical impact of an organization's operations and are increasingly used in investment decisions and performance assessments [27].

6. Case study: Shahid Rajaei Port

Shahid Rajaee Port, with an area of over 2,400 hectares, operates in four main sectors including container terminals, general cargo, bulk and mineral materials, and oil storage tanks. It accounts for more than 81% of the total container unloading and loading operations and over 56% of the country's total exports, making it the most vital port for cargo transportation in the country. On the afternoon of April 25, 2025 (6 Ordibehesht 1404 in the Iranian calendar), a tragic incident occurred involving a fire in one of the containers located in the container yard of Sina Company. The fire escalated, causing a severe explosion, which engulfed a wide area of the dock and surrounding zones in flames. The fire inflicted extensive damage on vehicles and buildings within a 30-kilometer radius. Key causes of this incident include the lack of a standardized structure for separating and storing goods within the port area, absence of a smart system for tracking and monitoring hazardous cargo, abnormal accumulation of goods, containers, and bulk and mineral materials in the port area, non-compliance with passive defense regulations in critical zones, and lack of an organized framework for declaration, identification, and control of hazardous transit cargo. Following this event, over 57 people lost their lives and more than 1,500 were injured. Such an incident also leaves a profound psychological impact on workers and staff of companies and agencies operating in the port. Additionally, it raises concerns among foreign trade partners, causing doubt, reduced trust, and a decreased willingness to cooperate and engage in future trade exchanges with the port. This disruption has severely affected the clearance, unloading, and distribution of essential goods, resulting in a heavy financial and economic burden for the country. Moreover, the fire has caused significant environmental pollution. The preliminary estimated damages from this incident amount to approximately 159,050 billion Iranian rials [28]. With the current exchange rate of about 90,000 IRR per USD, the damage of 159,050 billion rials is approximately 1.77 billion US dollars.

6. 1. Measures to Prevent Recurrence of the Incident

Studies show that to prevent similar incidents in the future, certain actions and programs must be prioritized; these include: 1- Full implementation of passive defense plans: It is necessary to develop and enforce precise national guidelines for the safe storage of chemicals and hazardous materials in compliance with international standards. Continuous and consistent monitoring of companies' adherence to safety and passive defense protocols, as well as the installation and operation of advanced automatic fire extinguishing systems, can also be effective; 2- Establishment of a national system for identifying and tracking hazardous shipments: By assigning a unique identification code to each shipment, continuous monitoring and tracking of shipments becomes possible. Shipment information will be accessible along with the ability for systematic and random verification through intelligent and supervisory systems; 3- Strengthening inspection and monitoring equipment: Installing and deploying advanced scanners helps accurately identify the actual contents of containers and reduces the entry of hazardous materials into transportation processes. Continuous improvement of early warning and alert systems is also effective in crisis management and forecasting; 4- Establishing a coordinated management structure among port authorities: By clearly defining roles and authorities in various areas, conflicts of responsibility between different operating and supervisory entities can be avoided, and transparency can be enhanced; 5- Comprehensive revision of customs, port, and transportation processes to reduce cargo dwell time and increase transit efficiency: Creating a unified, integrated, and systematic structure to eliminate unnecessary procedures will reduce the total cost of goods and services and decrease cargo dwell time. Additionally, implementing a system based on penalties and incentives will accelerate the enforcement of policies aimed at preventing cargo storage [28]; 6- Using the Internet of Things (IoT): By installing IoT sensors on containers, cranes, and other equipment, continuous monitoring of operational status and rapid detection of anomalies become possible. For example, temperature and gas sensors can quickly detect abnormal temperature rises inside a container carrying chemicals and issue warnings before a fire occurs; 7- Big Data Analysis and Artificial Intelligence: Utilizing machine learning algorithms and data analytics platforms helps identify hidden patterns in port operations and predict future events. Predictive systems can analyze trends in temperature, pressure, vibration, etc., to foresee failures or accidents. Studies show that sensor-based predictive analytics can prevent up to 85% of incidents related to hazardous cargo. This approach has even been piloted at ports like Bandar Anzali, successfully monitoring temperature and humidity in chemical containers with 95% accuracy, though full implementation has been delayed due to financial constraints; 8- Digital Twin: This technology creates a digital replica of facilities or equipment (e.g., a fuel tank, quay crane, or container warehouse) updated through IoT sensor data, reflecting the real system's behavior in a virtual environment. Digital twins allow risk-free testing of critical scenarios—for instance, simulating temperature increases inside a hazardous container and predicting explosion probabilities. These models provide powerful decision-making tools in real conditions and, combined with AI, enable proactive accident prevention for managers; 9- Robotics and Equipment Automation: In 4th generation ports prioritizing automation of repetitive and hazardous operations, autonomous robots and intelligent transport systems are employed to handle cargo continuously with minimal error. For example, Jebel Ali Port in the UAE has automated over 92% of container unloading operations, reducing average ship waiting times from 12 hours to 3 hours; 10- Blockchain: In the port sector, blockchain can be used to track the origin and status of shipments, providing all stakeholders (customs, port authorities, transport companies, and cargo owners) access to a shared, reliable data source; 11- Hybrid Training and Empowerment of Human Resources: 5th generation ports emphasize not only operation automation but also staff knowledge enhancement programs. These should be multi-level: senior managers receive courses on digital transformation, data analytics, and smart governance to gain support and understanding; operational staff attend workshops on new sensor equipment, RFID devices, industrial tablets, and advanced safety training in automated environments. Additionally, selected operators trained in data mining and analytical software strengthen internal data analysis capabilities. This improves internal capacity and reduces workers' fear of new technologies, boosting job security and motivation when employees see they are trained to work alongside technology; 12- Governance Reform and Strengthening Stakeholder Participation: Leveraging the experiences and opinions of all stakeholders (private sector, port businesses, workers, academics, and local communities) in drafting smart port roadmaps and standards can be effective. Furthermore, policies based on transparency are needed to prevent corruption. This approach also encourages private sector investment and development in ports [29].

6. 2. SWOT Analysis for Shahid Rajaee Port

In SWOT analysis, strengths and weaknesses of the system are considered internal factors, while opportunities and threats are regarded as external factors. Table 2 shows the SWOT analysis of Shahid Rajaee Port.

TABLE 2. Strouhal number for different geometric cases

Strengths	Opportunities
Strategic geographical location in the Persian Gulf Access to rail, road, and maritime transportation networks High cargo handling capacity Strong container infrastructure Proximity to Central Asian markets Direct rail access to the borders of Turkmenistan, Pakistan, Afghanistan, Armenia, and Turkey	Growth of regional trade through Shanghai and Eurasian unions Potential to become an international transit hub (within the North-South Corridor framework) Attraction of foreign investment from neighboring countries or China
Weaknesses	**Threats**
Limited development space in the hinterland Lack of sufficient foreign investment Incomplete modernization of domestic logistics fleet Customs challenges and administrative bureaucracy	International sanctions and political pressures Competition with neighboring ports like Jebel Ali (UAE) and Sohar (Oman) Currency exchange rate fluctuations affecting transportation costs Maritime security threats in the Strait of Hormuz Risk of regional military conflict or war with Israel or its allies

Based on Table 2, various strategies can be considered. These strategies fall into four categories as shown in Table 3, which are explained in detail below.

TABLE 3. Different Strategies in SWOT Analysis

	S	W
O	SO	WO
T	ST	WT

According to Table 3, four different strategies can be considered, which are as follows: SO Strategy (Strengths–Opportunities): Leveraging strengths to take advantage of opportunities. In this strategy, the strong infrastructure and strategic location of Shahid Rajaee Port can be used to attract new shipping lines, while marketing efforts and favorable conditions help expand relationships with foreign investors. WO Strategy (Weaknesses–Opportunities): Overcoming weaknesses by utilizing opportunities. This includes improving customs processes through domestic and foreign investment, engaging the private sector, adopting modern technologies, and developing the port's hinterland through public participation in national development projects. ST Strategy (Strengths–Threats): Using strengths to counter threats. Through international marketing and improved performance, Shahid Rajaee Port’s position in competition with Jebel Ali Port can be enhanced. Moreover, safety and preparedness can be reinforced through training and crisis readiness programs. WT Strategy (Weaknesses–Threats): Reducing weaknesses and addressing threats. This involves a comprehensive review of customs and administrative procedures to reduce the impact of sanctions, and focusing on port digitalization, smart technologies, and workforce training to minimize incidents and enhance safety.

7. Conclusion

In this study, four key concepts related to port design, planning, and management and their interrelationships were presented. The concept of reliability reflects how a system performs over time under defined and predictable conditions. However, when a disruption occurs in the system, the concept of resilience determines the extent to which a port can maintain its critical operations. Therefore, reliability is a prerequisite for resilience, and resilience has no meaning without reliability. Ultimately, sustainability is achieved when a port is resilient to disruptions and can adapt to various conditions in the long term. Port sustainability is not limited to environmental aspects; it also includes economic and social sustainability. One important component of social sustainability and justice in ports is women’s participation, which has often been overlooked. Improving this situation requires offering dedicated training programs for women and implementing incentive-based hiring policies.

In the next step, to better understand the application of these concepts in port planning, the Shahid Rajaee Port incident was reviewed, and recommendations were proposed to prevent such incidents from recurring. The most important of these included implementing an integrated system for monitoring and managing cargo, using the Internet of Things (IoT) and early warning systems to predict and prepare for crises, and providing training and empowerment of human resources. Additionally, through the SWOT analysis, various strategic approaches were introduced to ensure the port’s long-term sustainability. Key findings included attracting domestic and foreign investment, digitalization and smart technologies, training for improved safety, public participation in port development, and strengthening the regional position of Iranian ports.

8. List of Symbols

OECD	Organisation for Economic Co-operation and Development
RPN	Risk Priority Number
TTR	Time to Recovery
UNCTAD	United Nations Conference on Trade and Development
RBD	Reliability based design
NBS	Nature based solutions
RBD	Reliability-Based Design
MTBF	Mean Time Between Failures
FORM	First Order Reliability Method
ESG	Environmental, social and governance
IMO	International Maritime Organization
NGO	Non-governmental organization
MTTR	Mean Time To Recovery
MCM	Monte Carlo method
WWN	Working with nature
IOT	Internet of Things
SDGs	Sustainable Development Goals
SORM	Second Order Reliability Method

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