29th International Congress on Project Management and Engineering
Ferrol, 16th-17th July 2025

01-052 – Risk taxonomy for ports: a case study of the Port of Valencia – Taxonomía de riesgos para puertos: caso de estudio del Puerto de Valencia

Cloquell-Santamarina, Paula-Cristina[1]; *Cloquell-Ballester, Vicente-Agustín*[2]
(1) Autoridad Portuaria de Valencia, (2) Universitat Politècnica de Valencia

English English

Over last years, there has been a clear trend in the port sector towards risk management to ensure the continuity of key activities and achieve resilience. This emphasis is driven by global incidents and the recognition of ports as critical infrastructures. Effective risk management is essential for maintaining the operational integrity and security of these vital nodes in the global supply chains. Defining risks accurately is crucial, as overly generalized risk identification can undermine the effectiveness of risk analysis. This study proposes a comprehensive risk taxonomy for ports, designed to systematically identify and categorize a wide range of potential risks. The methodology involves comparing different literature sources and conducting focus groups with industry experts. This approach ensures a thorough examination of existing knowledge and practical insights. The results include a hierarchical classification of interrelated risk categories, obtaining a detailed risk catalogue. This structured approach enhances the precision of risk identification, enabling ports to better anticipate and mitigate potential threats. A case study of the Port of Valencia is provided to prove the validity of the proposed taxonomy. It demonstrates how taxonomy can be applied in real-world setting, highlighting its practical benefits and effectiveness in improving risk management practices in port operations.

Keywords: *Risk; Taxonomy; Resilience; Business continuity; Ports*

En los últimos años los puertos han centrado su atención en la gestión de riesgos para aumentar su resiliencia, tras su reconocimiento como infraestructuras críticas. La gestión eficaz de riesgos es esencial para mantener la integridad operativa y la seguridad de estos nodos clave en las cadenas de suministro globales. Definir los riesgos con precisión es crucial, ya que una identificación excesivamente generalizada puede mermar la efectividad de su análisis. Este estudio propone una taxonomía de riesgos integral para puertos, diseñada para identificar y categorizar sus riesgos potenciales. La metodología implica la comparación de diferentes fuentes bibliográficas y la realización de comités de expertos. Este enfoque asegura un examen exhaustivo del conocimiento existente y de las percepciones prácticas. Los resultados incluyen una clasificación jerárquica de categorías de riesgos, que conduce a la obtención de un catálogo de riesgos. Este enfoque estructurado mejora la identificación de riesgos, permitiendo a los puertos anticipar y mitigar mejor las amenazas potenciales. Se proporciona un estudio de caso del Puerto de Valencia para mostrar la validez de la taxonomía propuesta. en un entorno real, destacando sus beneficios prácticos y su efectividad en la mejora de la gestión de riesgos en las operaciones portuarias.

Palabras claves: *Riesgo; Taxonomía; Resiliencia; Continuidad de negocio; Puertos*

1. Introduction

Building effective resilience schemes is essential for minimizing the impacts of disruptions in critical sectors. At the core of resilience development lies the process of risk analysis, which provides the foundation for understanding vulnerabilities and implementing measures to mitigate potential risks. Risk analysis consists of multiple phases, with risk identification being one of the most crucial steps. Accurate identification enables targeted planning and prevention strategies, making detailed taxonomies indispensable for facilitating a precise and comprehensive identification process.

A notable contribution to this domain is the work of Ouedraogo et al. (2020), which presents a taxonomy based on a review of literature prior to 2020. This taxonomy served as a valuable framework for categorizing risks at the time. However, the global landscape has undergone significant transformations in the past five years, marked by high-impact events such as the COVID-19 pandemic, geopolitical conflicts, warfare, natural disasters—including floods in Valencia and earthquakes in Asia—trade disruptions, port congestion, and maritime accidents. These occurrences have reshaped the dynamics of risks in the port and maritime sectors, underscoring the need to revisit and update existing taxonomies.

Major global disruptions in the last five years—such as the COVID-19 pandemic, the Russia-Ukraine war, maritime attacks originating from Yemen, and the imposition of trade tariffs by the Trump administration—have introduced a new set of complex risks. These include geopolitical instability, supply chain volatility, and elevated security threats. Such developments necessitate a significant update to pre-2020 risk frameworks to accurately reflect the modern risk environment faced by ports.

This paper addresses the necessity of revising port and maritime risk taxonomies to reflect the evolving risk landscape influenced by recent global events. By incorporating updated insights, it aims to enhance the accuracy and utility of risk identification frameworks, thereby supporting more effective resilience planning.

2. Objectives

The study aims to develop a comprehensive and hierarchical taxonomy for port risks, building on recent advancements and challenges highlighted in the literature from 2021 to 2025. By conducting an extensive review, the proposed taxonomy seeks to reflect the evolving landscape of port risks, incorporating insights from contemporary global events and sector-specific transformations. This effort is designed to provide a robust framework that addresses the need for updated methodologies in risk categorization.

Additionally, the study endeavors to compare this newly developed taxonomy with the framework proposed by Ouedraogo, identifying key differences in scope, focus, and applicability. The comparison will highlight newly emerging risks and those that have gained or lost prominence over time, reflecting changes in priorities driven by recent developments. By contrasting these frameworks, the study aims to underline the advancements and adjustments necessary to address current and future challenges.

Emerging risk trends also form a critical component of the study's objectives. It will delve into the analysis of recently defined risks and evaluate their significance within the port and maritime sectors. This exploration aims to comment on how these risks have evolved, identifying those that have garnered greater attention and those that have diminished in importance due to shifts in the global and industry-specific context.

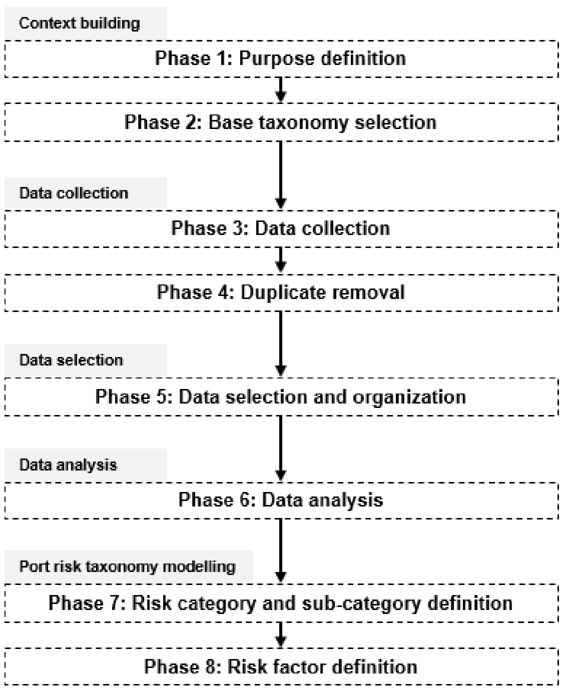
The study further presents a practical application through a case study of the Port of Valencia. Using the proposed taxonomy, the study seeks to illustrate how the port can develop a localized framework to identify and categorize specific risks pertinent to its operations. This customized taxonomy will serve as the foundation for risk measurement and resilience planning, demonstrating the utility of the new framework in real-world scenarios.

3. Methodology

This section aims to detail the methodology followed to define a novel port risk taxonomy by means of a systematic literature review and the analysis of an expert focus group. This group was assembled, consisting of two industrial engineers with expertise in port organization management, two academics specialized in project management, and two professionals from port-related organizations. The methodology is divided in five sections and eight phases (*Figure 1*).

- **Context building.** It involves establishing the foundation of the study, clearly defining the objectives to streamline the bibliographic search and enhance the effectiveness of the subsequent analysis.
- **Data collection.** Its aim is to identify the appropriate data sources and formulate a precise search strategy to collect the information that most effectively aligns with the intended objective.
- **Data selection.** This section aims at gathering the most relevant articles and classifying them in specific categories to optimize the subsequent analysis.
- **Data analysis.** This process involves a detailed examination of pertinent information to identify patterns, uncover insights, and extract meaningful trends.
- **Port risk taxonomy modelling.** The focus group works on establishing the novel taxonomy considering the trends and patterns observed.

Figure 1: Methodology phases.



3.1 Purpose definition (phase 1)

The main purpose of this study is to develop a comprehensive hierarchical taxonomy of port risks, drawing insights from the analysis and review of literature published between 2021 and 2025.

Risk taxonomies seen in literature are usually structured into two levels: risk typology and the risk itself. This can result in a non-uniform definition of risks due to the absence of a higher level of granularity. When applying two-leveled taxonomies to specific scenarios, such as a port case study, this limitation manifests in lists of risks where some are overly generic while others are excessively specific.

To address this issue, it is crucial to expand the taxonomy structure by incorporating more levels. This adjustment allows for a clear distinction between risk categories, risk factors, and the risks themselves, ensuring a more precise and consistent classification.

Risk categories serve as classifications that group together various risk factors, each representing a specific level of division. These risk factors are distinct types of risks that are directly associated with a particular category or subcategory, which, in turn, may encompass numerous examples of risks (Akac & Anagnostopoulou, 2025).

3.2 Base taxonomy selection (phase 2)

Since the purpose is to research port risk taxonomies that have been studied in the past five years, there should be a reference taxonomy to part from relative to the years before. In this study, the taxonomy from Ouedraogo et al. (2020) was selected as it does an extensive literature review on port risk catalogues from before 2020.

Ouedraogo et al. (2020) specifically identify several risk class associated to seven risk typologies: supply risk, demand risk, business risk, operational risk, environmental risk, organizational risk and infrastructural risk. A risk class refers to the regrouping of risks into distinct categories. The outcome of their analysis revealed the risk class shown in *Table 1*.

Supply risks, for example, also known as logistical risks, disrupt the flow of products through bottlenecks, labor strikes, or equipment shortages, highlighting the need for a resilient port system. These foundational risks directly impact the smooth circulation of goods, making them critical considerations in risk management strategies. Complementing these are *demand risks*, which emerge from unpredictable variations in customer requirements, such as unexpected fluctuations in long-term contracts or spot market needs. These uncertainties compel maritime companies to adapt their pricing strategies and operational capacities swiftly.

Financial stability is heavily influenced by *business risks*, which encompass economic challenges like supplier management, fluctuations in stock market returns, and macroeconomic factors. These risks are connected to *operational risks*, or technical risks, which arise during the transportation process. Whether it is congestion, fire, terrorism, piracy, or even mismanagement in handling and stowage, operational risks have been at the forefront of maritime literature due to their direct and immediate impact on port activities (C. A. Ouedraogo et al., 2020).

However, risks in maritime transport are not limited to human or logistical factors. The sector also contends with *environmental risks*, spanning from natural disasters like earthquakes and cyclones to man-made crises such as political conflicts or civil unrest. These hazards are disruptive, often resulting in delays, financial losses, and impediments to cargo flow. While natural elements challenge operations, internal management inefficiencies, contained within *organizational risks*, further aggravate potential situations. Such risks stem from inadequate planning, poor estimation, or mismanagement, all of which can compromise safety and operational effectiveness.

Lastly, ports are susceptible to *infrastructural risks*, which highlight vulnerabilities within the very structures supporting maritime transport. Failures in infrastructure, delays in information flow, insufficient transportation options, or inadequate port capacity can severely disrupt the maritime supply chain. These risks, coupled with technological considerations, underscore the necessity for robust infrastructure development to sustain efficient operations.

Table 1: Risk class (C. A. Ouedraogo et al., 2020).

Risk class	Risk
SUPPLY RISK	Lack of equipment Bottlenecks Labor strike Bad handling Lack of human resource Unstable maintenance Carelessness Lack of motivation among workforce Lack of skilled workers
DEMAND RISK	Unexpected customer demand
BUSINESS RISK	Purchase and sale of supplier companies Production cost Fuel cost Storage cost Funding Tax changes Debt ratio changes Return on investment changes
OPERATIONAL RISK	Route deviation Congestion Fire Terrorism Unexpected door opening Unexpected temperature variation Unexpected humidity variation Container/goods damage Container/good theft Container lost Piracy Long waiting time Stowage

Risk class	Risk
	Ship collision Condition of cargo handling Explosion Shocks
ENVIRONMENTAL	Uncertainty weather Natural disasters Political conflicts Man made crises
ORGANIZATIONAL	Problems with document interpretation Inappropriate estimation of planning
INFRASTRUCTURAL	Lack of visibility Delay in transmission Lack of transportation mode Port capacity Lack of relevant information Cyber-attack

3.3 Data collection (phase 3)

The study's articles were gathered from four primary bibliographic databases: Google Scholar (91 articles), ScienceDirect (49 articles), Scopus (33 articles), and WoS (52 articles). Additionally, 15 articles were sourced from other relevant platforms, including the websites of key organizations and institutions within the sector, such as ESPO (European Sea Ports Organization), UNCTAD (United Nations Conference on Trade and Development), and IAPH (International Association of Ports and Harbors).

The search period was restricted to publications from 2021 to 2025. The search employed keywords such as "port risks," "maritime risks," "risk identification," "risk analysis," "maritime resilience," "port risk taxonomy," and "maritime risk categories." This process resulted in the collection of a total of 240 articles during this stage.

3.4 Duplicate removal (phase 4)

The fourth phase involved identifying duplicate articles and excluding them from the analysis. As a result, 26 articles were eliminated, leaving a total of 214 articles for the subsequent phase.

3.5 Data selection and organization (phase 5)

Selecting the most relevant articles for the analysis constitutes a crucial phase of the methodology, as it sharpens the focus and refines the scope of the study. The process began with an initial screening of titles, abstracts, and conclusions, which led to the exclusion of 11 articles whose objectives were not directly related to or aligned with the final goal of the study. Subsequently, a deeper review and analysis of the remaining articles were conducted, concentrating on the risk identification phase within risk assessment frameworks to extract lists and catalogs of risks.

As a result of this in-depth process, the articles were categorized into 11 main thematic groups:

1. Environmental, climate change, and biosecurity risks (19 articles)
2. Cybersecurity risks (36 articles)
3. Events and disasters (3 articles)
4. Natural hazards (8 articles)
5. Maritime accident risks (46 articles)
6. Operational risks (29 articles)
7. Safety and security risks (21 articles)
8. Risk propagation (5 articles)
9. Risk taxonomy methodologies (18 articles)
10. Resilience frameworks (11 articles)
11. Port risk categorization (48 articles).

It is worth noting that some articles were classified into more than one group, given their relevance across multiple categories.

3.6 Data analysis (phase 6)

Most of the literature reviewed make a first classification of risks into internal and external. Factors within the control of ports and the shipping industry are considered internal. These include the organization of shipping networks and the capacity of ports to handle demands efficiently, which are vital to supporting global supply chains. The expansion and enhancement of container terminals by port authorities and terminal operators often align with evolving global supply chains and associated shipping frameworks (United Nations Conference on Trade and Development, 2022). In recent years, internal risks have notably influenced the safety and efficiency of maritime container supply chains. Issues within organizational processes can severely disrupt logistics and operational performance (Ilyas et al., 2023).

Conversely, external factors arise from outside the maritime supply chain and encompass external forces that typically influence the demand for maritime transport. These, in turn, affect the volume of cargo processed by ports and shipping services. Generally, the shipping industry and ports have limited or no influence over such factors, such as economic trends that impact trade volumes (United Nations Conference on Trade and Development, 2022).

According to Kuang et al. (2021) external influences are more significant than internal ones as they are often unforeseen and beyond control. Natural occurrences play a prominent role among external factors, often causing interruptions and delays. However, internal challenges also contribute to these delays and are shaped by factors such as human involvement, infrastructure, management processes, and information flow.

Risks can also be categorized broadly as either natural or human-induced. Natural risks are abrupt, uncontrollable changes in the environment, whereas human-made risks stem from either deliberate or accidental actions within society that may harm or disrupt organizations and individuals (Nagi & Kersten, 2022).

When comparing recent literature to the base taxonomy established by Ouedraogo et al. (2020), it is evident that all originally defined categories remain consistent across subsequent publications. Classifications such as supply, business, operational, environmental, organizational, and infrastructural factors continue to hold relevance. Furthermore, Ouedraogo et al. (2022) builds upon its earlier analysis by examining these categories in the context of varying actors and decision-making levels throughout the supply chain.

In addition to the foundational categories, new risk classifications have emerged, expanding the base taxonomy to include aspects such as management, technology, social dynamics, market trends, political influences, and network-related factors. These additional categories have been acknowledged and studied extensively in recent Works (Akac & Anagnostopoulou, 2025; IAPH, 2023; Ilyas et al., 2023; Jia & Zhang, 2021; Kuang et al., 2021; Lamii et al., 2022; Nagi & Kersten, 2022; Ouedraogo et al., 2022; Sajith et al., 2024; Wang et al., 2024; Zhou, 2022).

Emerging trends in risk analysis increasingly focus on failures related to artificial intelligence, which pose threats to cybersecurity and encompass issues such as data inaccuracies, software defects, system integration challenges, algorithmic errors, and human mistakes (Durlik et al., 2024). Another innovative aspect gaining prominence in recent literature is the concept of resilience enablers, which highlight critical inflection points where errors might occur. Examples of resilience enablers include flexibility, market regulation, operational efficiency, agility, schedule reliability, port governance, and collaborative partnerships, among others (Deng et al., 2025; Jiang et al., 2021; Liu et al., 2023; Tian et al., 2025; Wendler-Bosco & Nicholson, 2020).

3.7 Risk category and sub-category definition (phase 7)

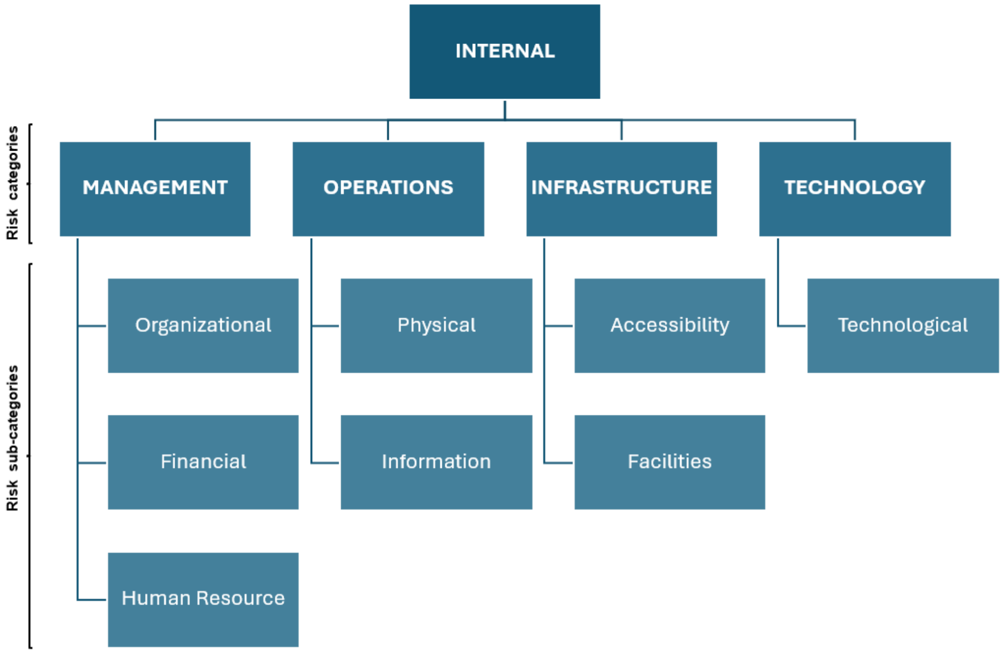
After analyzing the selected data, a focus group of maritime sector experts convened to define the first two levels of the proposed port risk taxonomy: risk categories (first order) and subcategories (second order). The group initially sought to distinguish between internal and external factors. While man-made factors could be classified as either internal or external, natural factors were consistently external. Consequently, experts deemed this distinction redundant. Given that the taxonomy focuses on ports, internal factors were defined as those within the port’s control, while external factors referred to elements beyond their influence.

For internal risk categories, the most relevant classifications identified were management, operations, infrastructure, and technology (see *Figure 2*). The management category encompasses organizational, financial, and human resource subcategories, addressing risks such as inadequate resource planning, ineffective decision-making, limited access to financial resources for operational costs, and challenges in maintaining optimal human resource conditions.

Although the literature typically divides operational categories into three subcategories—physical, information, and financial flows—the experts opted to align financial flows under management due to its growing strategic importance (Ilyas et al., 2023). The physical subcategory pertains to operational risks with tangible impacts, such as capacity shortages, congestion, or accidents. The information subcategory focuses on delays, inaccuracies, and security issues related to the exchange of information among supply chain actors.

Infrastructure risks, another internal category, reflect a port's responsibility to maintain accessibility from various modes of transport, including land, marine, rail, and highways. As a result, the subcategories identified were accessibility risks and facilities risks. Similarly, technological risks were classified as those arising from system failures, vulnerabilities in communication systems, and issues related to information and automation technologies.

Figure 2: Internal risk categories and sub-categories (own elaboration).

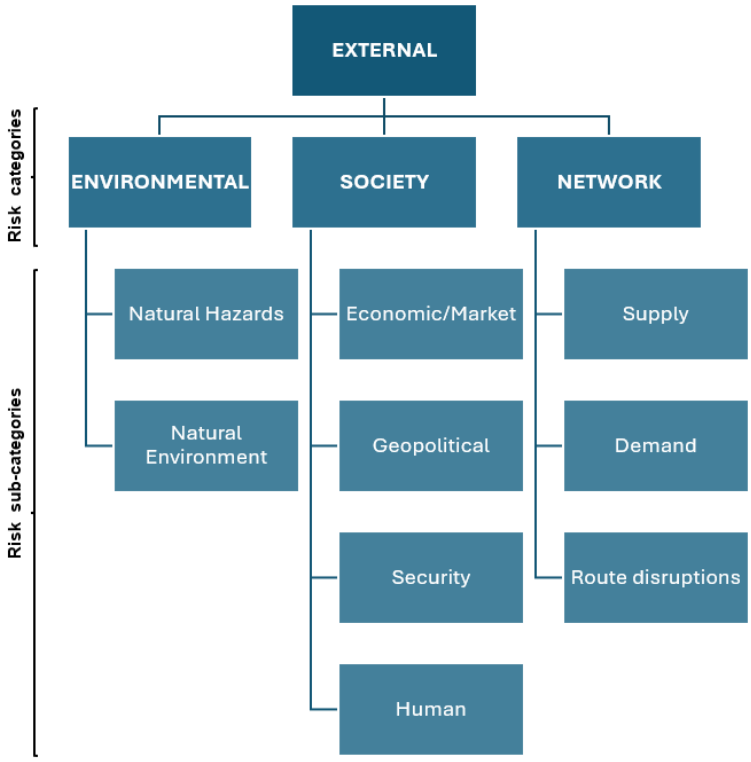


On the other hand, external risk categories were classified as environmental, societal, and network-related (see *Figure 3)*. The environmental category was further divided into two subcategories: natural hazards, which depend on geography and include uncontrollable disasters that can harm infrastructure and people, and natural environment risks, such as adverse weather, pollution, or impacts on marine habitats.

Society, a complex category over which ports have minimal or no control, was broken into four subcategories. Economic or market risks include economic crises, seasonality, and changes in trade policies. Geopolitical risks, which have gained prominence recently, include political instability, wars, conflicts, and migration. Security risks have also become more significant, encompassing cyberattacks, terrorism, smuggling, and security failures. In addition, human factors were identified, such as strikes, public opposition, or epidemics.

Finally, a first-order category for network risks was established, based on the International Association of Ports and Harbors recommendations (IAPH, 2023). This category was deemed crucial due to ports' dependence on supply chain actors upstream and downstream. The subcategories defined for this group were supply risks, demand risks, and route disruption risks. Although these are external factors, their occurrence directly impacts port operations negatively.

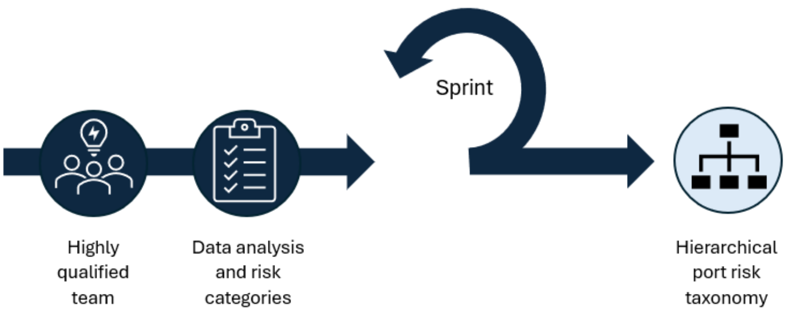
Figure 3: External risk categories and sub-categories (own elaboration).



3.8 Risk factor definition (phase 8) – Case study: Port of Valencia, Spain

The focus group of experts in the port sector – as mentioned before, two industrial engineers with expertise in port organization management, two academics specialized in project management, and two professionals from port-related organizations – defined the third level of the taxonomy for the case study of the Port of Valencia, Spain. It consisted of identifying the through Scrum methodology (*Figure 4*).

Figure 4: Scrum methodology phases.



Scrum is applied to collaborative teamwork and is considered to have a great potential in complex environments where innovation and flexibility are essential. In this way, sprints were organized by a Scrum Master who was responsible for convening and leading 45 minutes work sessions that allowed for an optimized disaggregation of risk sub-categories in specific risk factors.

The risk factors included in the Port of Valencia case study were determined through an expert-driven approach using Scrum methodology. This process incorporated both recent literature findings and professional judgment from a focus group composed of maritime sector experts. This ensures that the risks identified are both empirically grounded and practically relevant to the port context.

4. Results

As a result, this study presents an innovative hierarchical taxonomy of port risks for the case of the Port of Valencia (Spain), structured across three distinct levels: Level 1 comprises the overarching risk categories, Level 2 encompasses the specific risk sub-categories, and Level 3 details the individual risk factors (*Table 2*).

Table 2: Port risk taxonomy (own elaboration).

Risk category	Risk sub-category	Risk factor	References
ENVIRONMENTAL	NATURAL HAZARDS	Hydrological Geophysical Gravitational Atmospheric	(Verschuur et al., 2022); (Balakrishnan et al., 2022); (Verschuur et al., 2023); (Wang T., Ding, et al., 2024); (Wang T., Ng, et al., 2024)
	NATURAL ENVIRONMENT	Adverse/ severe weather conditions Geotechnical conditions Marine habitat Maritime pollution Noise pollution Archeological risk Unexploded ordnance Chemical contaminants	(Azevêdo et al., 2021); (Dang et al., 2025); (Tzeng et al., 2021); (Wang P. et al., 2023); (Karaca et al., 2022); (IAPH, 2023); (Itoh & Zhang, 2023); (Fernandez-Perez et al., 2024)
SOCIETY	ECONOMIC / MARKET FACTORS	Market changes Trade policy instability Economic instability GDP growth or decline Change in customs rules Supplier risk High concentration in few cargo interests	(Nagi & Kersten, 2022); (Wu & Liu, 2025); (Kuang et al., 2021); (Verschuur et al., 2023); (IAPH, 2023); (Wang N. et al., 2024);

Risk category	Risk sub-category	Risk factor	References
SOCIETY	ECONOMIC / MARKET FACTORS	Major variabilities in demand Competition from another port Adverse economic climate Seasonality Changes in customer preferences Bankruptcy of a major port user Change of interest rates Fluctuation of fuel and electricity price Unattractive markets Taxes changes	(Sajith et al., 2024); (Rodrigues et al., 2024); (Akac & Anagnostopoulou , 2025); (Jia & Zhang, 2021); (Zhou, 2022)
	GEOPOLITICAL	Government decision changes Contract changes Irregular migration War and conflict Policy risks Bribery and corruption Cultural obstacles Political instability Expropriation or nationalization of assets	(IAPH, 2023); (Rodriguez-Diaz et al., 2024); (Wang N. et al., 2024); (Sajith et al., 2024); (Rodrigues et al., 2024)
	SECURITY	Cyber attack Fire and explosion Piracy Terrorism Crime Smuggling Cargo theft Trafficking Security failures Spying	(Chlomoudis et al., 2024); (Grigoriadis et al., 2022); (Hu et al., 2023); (Rodriguez-Diaz et al., 2024); (Perkovič et al., 2024); (Tahesh et al., 2023)
	HUMAN	Strikes or blockages Public opposition Epidemics Industrial action Human errors	(Ilyas et al., 2023); (IAPH, 2023); (Gonçalves et al., 2025); (Wang N. et al., 2024)

Risk category	Risk sub-category	Risk factor	References
NETWORK	SUPPLY	High dependency on key suppliers Disruption / events further up the supply chain	(IAPH, 2023); (Zhou, 2022); (Akac & Anagnostopoulou, 2025)
	DEMAND	Changing vessel size High dependency on key clients Disruption / events further down the supply chain	(IAPH, 2023); (Zhou, 2022); (United Nations Conference on Trade and Development, 2022)
	ROUTE DISRUPTIONS	Changing routes Maritime accidents Bottlenecks/ restriction transportation routes	(United Nations Conference on Trade and Development, 2022)
MANAGEMENT	ORGANIZATIONAL	Ineffective governance Lack of oversight Insufficient resources Poor planning Intervention by authorities Conflicting priorities among port stakeholders Ineffective communication Poor quality management Complex and lengthy approval procedure Innovation risks Bureaucracy Conflicts with contractual and statutory obligations Lack of cooperation Poor safety culture	(Nagi & Kersten, 2022); (Akac & Anagnostopoulou, 2025); (Kuang et al., 2021)
	FINANCIAL	Absence of risk transfer (Insurance and diversification) Insufficient access to credit Uncertainty of revenue due to price volatility Access to finance Payment delay from partners Break of contracts Partners with bad credit Cash flow problem	(Sajith et al., 2024); (Ilyas et al., 2023); (Jia & Zhang, 2021); (Lamii et al., 2022)

Risk category	Risk sub-category	Risk factor	References
OPERATIONS	HUMAN RESOURCE	Worker health Lack of training Accuracy of work Performance rates Lack of skilled workers Lack of motivation Mental health risks Human errors Inadequate compliance of standards	(Akac & Anagnostopoulou, 2025); (S. Wang et al., 2024); (Ilyas et al., 2023); (Kuang et al., 2021); (Lamii et al., 2022)
	PHYSICAL	Container handling capacity Operational services risks Navigation channels Inaccurate demand forecast Dangerous goods risks Congestions Lack of flexibility Accidents Cargo waste risks	(Rodrigues et al., 2024); (Ilyas et al., 2023); (Jia & Zhang, 2021); (Ouedraogo et al., 2022); (Gui et al., 2022)
	INFORMATION	Information delay Information inaccuracy Internet security Poor information sharing Lack of information Standardization and compatibility	(Ilyas et al., 2023); (Jia & Zhang, 2021); (Zhou, 2022)
INFRASTRUCTURE	ACCESSIBILITY	Marine access Official inspections Land access Accessibility to railways Accessibility to highways Accessibility to other facilities Accessibility to customers Hinterland connectivity Insufficient berthing capability	(IAPH, 2023); (Rodrigues et al., 2024)

Risk category	Risk sub-category	Risk factor	References
	FACILITIES	Damage to facilities Maintenance risks Infrastructure maintenance costs Construction delays Multimodal infrastructure development Port capacity and space Electricity failures Asset damage or loss	(Wang S. et al., 2024); (Ouedraogo et al., 2022); (Jia & Zhang, 2021); (Kuang et al., 2021)
TECHNOLOGY	TECHNOLOGICAL	System / machine failure Communications disruptions Automation disruptions Information systems disruptions No technology mature Old technological means and methods Technological maintenance costs Fire/explosion in machinery Loss of key utilities IT vulnerability	(Nagi & Kersten, 2022); (Akac & Anagnostopoulou, 2025); (Lamii et al., 2022)

5. Comparative analysis of risk taxonomies

A thorough comparison between the baseline taxonomy from Ouedraogo et al. (2020) (Table 1) and the updated, hierarchical taxonomy proposed by the authors of this study for the Port of Valencia (Table 2) reveals several significant advancements in both structure and content. These changes substantiate the validity and practical relevance of the new taxonomy.

5.1 Structural evolution: from flat to hierarchical

The original taxonomy from Ouedraogo et al. consists of a flat two-level structure—risk classes and associated risk items. While foundational for its time, this format lacks granularity and becomes unwieldy when applied to complex, real-world scenarios such as those faced by modern ports. The new taxonomy addresses this limitation by introducing a three-tier structure: categories (Level 1), subcategories (Level 2), and specific risk factors (Level 3). This layered architecture provides a clearer, more actionable framework for decision-makers, supporting better prioritization and risk treatment planning.

5.2 Content expansion and thematic refinement

Whereas Table 1 from Ouedraogo et al. offers a useful baseline through seven broad risk classes, the proposed taxonomy in Table 2 reorganizes and significantly expands the scope and specificity of port-related risks. This shift reflects not only the complexity of the modern maritime environment but also new technological and social dynamics.

Technology Risk. This is a major innovation absent from the original taxonomy. Table 2 includes a dedicated technology category that addresses system failures, automation disruptions, and communication breakdowns. Crucially, it also acknowledges the exponential development of artificial intelligence (AI). While AI offers efficiency gains, it also introduces vulnerabilities such as algorithmic errors, data quality issues, and exposure to sophisticated cyberattacks – which are becoming increasingly prominent in the digitalization of port operations.

Societal Risks. The proposed taxonomy expands societal risks beyond general security issues to include human factors such as public opposition to port expansions or environmental degradation. These concerns reflect a broader generational shift in values, particularly among Generation Z, who are more environmentally conscious and globally aware. Their perception of ports is not just as logistical hubs but as entities with significant environmental and social footprints. Table 2 also introduces a more granular approach to workforce-related risks by recognizing strikes or industrial actions from various collectives—not just port workers, but also freight forwarders, carriers, and customs brokers, among others. The experience of the COVID-19 pandemic has also elevated the relevance of public health-related disruptions, leading to the inclusion of epidemics as a defined risk subcategory.

Organizational Risks. While in Table 1 these are limited to inefficiency and poor planning, the new taxonomy embeds them under a more structured management category. Within this, organizational risks now include failures in governance, oversight, and communication, along with emerging issues like innovation risks—such as failure to adopt new technologies or resistance to change in port governance structures. The taxonomy also separates out human resource-related risks, giving distinct attention to worker health, motivation, training, skill shortages, and even mental health concerns, all of which have gained significant importance in recent literature and port resilience planning.

Network Risks. Table 2 introduces a robust classification of risks stemming from a port's interconnectedness within global logistics networks. In particular, route disruption risks are a critical addition. Events such as the blockage of the Suez Canal in 2021 or rerouting of vessels around the Cape of Good Hope are illustrative of how a single chokepoint can create cascading delays and congestion. These examples underline the necessity of accounting for macro-logistical vulnerabilities in modern port risk assessments.

5.3 Addressing recent global events

The updated taxonomy directly responds to major global disruptions that have reshaped the maritime sector over the past five years—disruptions that were not yet present or fully identified when Ouedraogo et al. developed their framework. Key additions include:

Geopolitical Risks. Table 2 introduces a detailed subcategory capturing risks such as wars, policy shifts, irregular migration, and nationalization of assets. These reflect the heightened volatility in global affairs following the Russia-Ukraine war, Middle Eastern instability (e.g., ship attacks from Yemen), and the imposition of unilateral trade measures such as the Trump-era tariffs.

Public Health and Human Risk. In light of the COVID-19 pandemic, risks such as epidemics, industrial action, and workforce availability have been given their own subcategories, acknowledging their disruptive potential on port operations.

Natural Environment Risks. Unlike the original taxonomy which grouped all environmental hazards into a single broad category, Table 2 distinguishes between natural hazards (e.g., earthquakes, floods) and natural environment risks. The latter subcategory was deliberately created to capture the environmental effects caused by the port's own activities, including marine habitat degradation, maritime pollution, chemical contamination, and noise pollution. These risks reflect increasing environmental scrutiny of port operations and recognize their role as both victims and contributors to environmental stress. Notably, this subcategory also acknowledges the shifting priorities of younger generations—particularly Generation Z—who exhibit heightened environmental consciousness and expect sustainability to be a core consideration in infrastructure planning and governance. Addressing such environmental concerns is essential not only for regulatory compliance but also for maintaining public legitimacy and stakeholder trust.

5.4 Risk factor granularity

Another major advancement in Table 2 is its significantly enhanced level of granularity. Rather than presenting generalized or overlapping risks, the new taxonomy disaggregates complex risks into their component elements. This allows for more precise diagnosis, prioritization, and mitigation strategies within port management and resilience planning.

For instance, in Table 1, the supply risk "lack of equipment" is listed as a standalone item. The new taxonomy dissects this into container handling capacity, congestion, damage to facilities, and technological obsolescence, offering more actionable insight for operational planning.

Similarly, where "fire" and "piracy" are broadly categorized under operational risk in Table 1, Table 2 moves these to a security subcategory under societal risks. This reflects contemporary understandings of threat sources—positioning these as part of intentional, hostile, or criminal actions rather than internal operational failures.

In addition, there is an increase in granularity of information-related risks, Table 1 omits these entirely, whereas the new taxonomy highlights issues such as information delays, inaccuracy, lack of compatibility between systems, and standardization failures, all of which can severely impact real-time port operations and coordination with external actors.

By grounding Table 2 in localized expertise and operational data, the taxonomy moves beyond theoretical generalizations and becomes a practically usable tool for port authorities, terminal operators, and resilience planners. This level of contextualization significantly enhances its value for applied risk management.

6. Conclusions

In conclusion, the proposed taxonomy by the authors of the present contribution a major advancement in the categorization of risks, offering a more structured and detailed approach compared to the base taxonomy. By incorporating categories, subcategories, and individual risk factors, it enhances clarity and precision. Its inclusion of specific elements—such as "Accessibility," "Facilities," and "Technological Maintenance"—and context-specific risks like maritime pollution and hinterland connectivity underscores its relevance to evolving industry demands.

Notably, the taxonomy's interdisciplinary scope covers environmental, financial, societal, and technological risks, enabling a comprehensive approach to risk management. Its emphasis on governance, oversight, and communication as part of organizational risks highlights the critical role of efficient management in mitigating disruptions. By addressing both traditional and emerging risks, including automation failures and outdated technologies, the taxonomy demonstrates adaptability and forward-thinking in its design.

This updated framework, grounded in research spanning 2021 to 2025, reflects contemporary trends and offers a more nuanced perspective compared to pre-2020 classifications. The introduction of subcategories within broader risk categories, such as "Natural Hazards" and "Geopolitical," enhances its practical applicability, particularly for industries like maritime and port operations that require detailed risk assessments. Overall, the refined taxonomy provides a robust, systematic tool for risk identification and decision-making, meeting current challenges while remaining flexible for future developments.

Further research should focus on the establishment of a robust methodology to identify and define individual risks stemming from the risk factors outlined in the taxonomy. This methodology should ensure that risks are specific enough to allow for detailed analyses of their impact and probability. Additionally, the prioritization of categories and risk factors should be refined using accurate and systematic criteria to improve decision-making processes and enhane the taxonomy's effectiveness in managing risks across diverse domains

7. References

Akac, A., & Anagnostopoulou, A. (2025). BUILDING RESILIENCE: A HOLISTIC APPROACH MAPPRING RISKS IN PORT TERMINALS. *International Journal for Quality Research*, *19*(1), 235-246. https://doi.org/10.24874/IJQR19.01-16

Azevêdo, L., Duarte, H., Galvão, D., Michima, P., Veleda, D., & Kreuger, A. (2021). Methodology for Maritime Risk Assessment in Ports due to Meteo-oceanographic Factors: The Case of the port of Suape, Brazil. *Risk Analysis*, *41*(10), 1823-1839. https://doi.org/10.1111/risa.13677

Balakrishnan, S., Lim, T., & Zhang, Z. (2022). A methodology for evaluating the economic risks of hurricane-related disruptions to port operations. *Transportation Research Part A: Policy and Practice*, *162*, 58-79. https://doi.org/10.1016/j.tra.2022.05.010

Constantinos Chlomoudis, Petros Pallis, & Theodore Styliadis. (2024). Security Risk Assessment in Container Terminals: Empirical Evidence from Greece. *Journal of Traffic and Transportation Engineering*, *12*(5). https://doi.org/10.17265/2328-2142/2024.05.002

Dang, T. T. M., Li, L.-M., Huang, B.-W., Huang, C.-E., Wu, C.-H., Cheruiyot, N. K., & Chang-Chien, G.-P. (2025). Flame retardant contamination and ecological risk analysis in estuarine and marine sediments around an industrial port. *Marine Pollution Bulletin*, *214*, 117783. https://doi.org/10.1016/j.marpolbul.2025.117783

Deng, W., Ma, X., & Qiao, W. (2025). Resilience-oriented safety barrier performance assessment in maritime operational risk management. *Transportation Research Part D: Transport and Environment*, *139*, 104581. https://doi.org/10.1016/j.trd.2024.104581

Durlik, I., Miller, T., Kostecka, E., & Tuński, T. (2024). Artificial Intelligence in Maritime Transportation: A Comprehensive Review of Safety and Risk Management Applications. *Applied Sciences*, *14*(18), Article 18. https://doi.org/10.3390/app14188420

Fernandez-Perez, A., Lara, J. L., Lucio, D., & Losada, I. J. (2024). Compound climate change risk analysis for port infrastructures. *Coastal Engineering*, *193*, 104560. https://doi.org/10.1016/j.coastaleng.2024.104560

Gonçalves, A., Dutra, A., & Mussi, C. C. (2025). Occupational risks and health and safety management strategies in the port sector: A systematic literature review. *Safety Science*, *184*, 106767. https://doi.org/10.1016/j.ssci.2024.106767

Grigoriadis, C., Laborde, R., Verdier, A., & Kotzanikolaou, P. (2022). An Adaptive, Situation-Based Risk Assessment and Security Enforcement Framework for the Maritime Sector. *Sensors*, *22*(1), Article 1. https://doi.org/10.3390/s22010238

Gui, D., Wang, H., & Yu, M. (2022). Risk Assessment of Port Congestion Risk during the COVID-19 Pandemic. *Journal of Marine Science and Engineering*, *10*(2), Article 2. https://doi.org/10.3390/jmse10020150

Hu, X., Xia, H., Xuan, S., & Hu, S. (2023). Exploring the Pirate Attack Process Risk along the Maritime Silk Road via Dynamic Bayesian Network Analysis. *Journal of Marine Science and Engineering*, *11*(7), Article 7. https://doi.org/10.3390/jmse11071430

IAPH. (2023, enero 11). *IAPH Risk and Resilience Guidelines for Ports by Ports & Harbors—Issuu*. https://issuu.com/portsandharbors/docs/iaph_risk_and_resilience_guidelines_for_ports_sp

Ilyas, M., Jin, Z., Ullah, I., & Jafri, A. A. (2023). Investigation of Risk Factors Influencing the Safety of Maritime Containers Supply Chain: In the Period of the Pandemic. *Sustainability*, *15*(11), Article 11. https://doi.org/10.3390/su15118803

Itoh, R., & Zhang, A. (2023). How should ports share risk of natural and climate change disasters? Analytical modelling and implications for adaptation investments. *Economics of Transportation*, *33*, 100301. https://doi.org/10.1016/j.ecotra.2023.100301

Jia, X., & Zhang, D. (2021). Prediction of maritime logistics service risks applying soft set based association rule: An early warning model. *Reliability Engineering & System Safety*, *207*, 107339. https://doi.org/10.1016/j.ress.2020.107339

Jiang, M., Lu, J., Qu, Z., & Yang, Z. (2021). Port vulnerability assessment from a supply Chain perspective. *Ocean & Coastal Management*, *213*, 105851. https://doi.org/10.1016/j.ocecoaman.2021.105851

Karaca, İ., Soner, Ö., & Saraçoğlu, R. (2022). Meteorological Risk Assessment Based on Fuzzy Logic Systems for Maritime. *Journal of ETA Maritime Science*, *10*(2), 97-107. https://doi.org/10.4274/jems.2022.65668

Kuang, H., Zhang, P., Han, B., & Ouyang, P. (2021). Stability Analysis and Control Strategy for the Chained Propagation of Delay or Disruption Risk in a Port-Hinterland Service Network. *Mathematical Problems in Engineering*, *2021*(1), 8859298. https://doi.org/10.1155/2021/8859298

Lamii, N., Bentaleb, F., Fri, M., Mabrouki, C., & Semma, E. A. (2022). Use of DELPHI-AHP Method to Identify annd Analyze Risks in Seaport Dry Port System. *Transactions on Maritime Science*, *11*(01), 185-206. https://doi.org/10.7225/toms.v11.n01.w12

Liu, J., Gu, B., & Chen, J. (2023). Enablers for maritime supply chain resilience during pandemic: An integrated MCDM approach. *Transportation Research Part A: Policy and Practice*, *175*, 103777. https://doi.org/10.1016/j.tra.2023.103777

Nagi, A., & Kersten, W. (2022). A Process Model for Cooperative Risk Management in Seaports. *Sustainability*, *14*(3), Article 3. https://doi.org/10.3390/su14031662

Ouedraogo, C. A., Rosemont, C., Namakiaraghi, S., Montarnal, A., & Gourc, D. (2020). Maritime risks taxonomy: A structured literature review of maritime risks classification. *Extrait de : MOSIM 2020 - Nouvelles avancees et defis pour des industries durables et avisees*, 17 p. https://hal.science/hal-03048795

Ouedraogo, C., Montarnal, A., & Gourc, D. (2022). Multimodal Container Ttransportation Ttraceability and Supply Chain Risk Management: A Review of Methods and Solutions. *International Journal of Supply and Operations Management*, *9*(2), 212-234. https://doi.org/10.22034/ijsom.2022.109139.2201

Perkovič, M., Gucma, L., & Feuerstack, S. (2024). Maritime Security and Risk Assessments. *Journal of Marine Science and Engineering*, *12*(6), Article 6. https://doi.org/10.3390/jmse12060988

Rodrigues, T. de A., Ojiako, U., Mota, C. M. de M., Marshall, A., Chipulu, M., & Dweiri, F. (2024). Assessing risk dimensions in dry port projects: Prioritization, interdependence and heterogeneity. *Maritime Business Review*, *9*(4), 311-330. https://doi.org/10.1108/MABR-09-2023-0064

Rodriguez-Diaz, E., Alcaide, J. I., & Garcia-Llave, R. (2024). Challenges and Security Risks in the Red Sea: Impact of Houthi Attacks on Maritime Traffic. *Journal of Marine Science and Engineering*, *12*(11), Article 11. https://doi.org/10.3390/jmse12111900

Sajith, S., Raju, T. B., & Aswani, R. (2024). Are Indian ports safe? Identifying, analysing and prioritizing the risks affecting India's major ports. *Maritime Transport Research*, *6*, 100108. https://doi.org/10.1016/j.martra.2024.100108

Tahesh, G., Abdulsattar, H., Abou Zeid, M., & Chen, C. (2023). Risk perception and travel behavior under short-lead evacuation: Post disaster analysis of 2020 Beirut Port Explosion. *International Journal of Disaster Risk Reduction*, *89*, 103603. https://doi.org/10.1016/j.ijdrr.2023.103603

Tian, C., Liang, Y., Jin, X., You, D., & Lin, Q. (2025). Evaluating resilience and risk mitigation strategies in Chinese petrochemical port cities. *International Journal of Disaster Risk Reduction*, *116*, 105076. https://doi.org/10.1016/j.ijdrr.2024.105076

Tzeng, M. W., Floerl, O., & Zaiko, A. (2021). A Framework for Compiling Quantifications of Marine Biosecurity Risk Factors Associated With Common Vessel Types. *Frontiers in Marine Science*, *8*. https://doi.org/10.3389/fmars.2021.723782

United Nations Conference on Trade and Development. (2022). *Building Capacity to Manage Risks and Enhance Resilience: A Guidebook for Ports*. https://unctad.org/system/files/official-document/tcsdtlinf2022d3_en.pdf

Verschuur, J., Koks, E. E., Li, S., & Hall, J. W. (2023). Multi-hazard risk to global port infrastructure and resulting trade and logistics losses. *Communications Earth & Environment*, *4*(1), 1-12. https://doi.org/10.1038/s43247-022-00656-7

Verschuur, J., Pant, R., Koks, E., & Hall, J. (2022). A systemic risk framework to improve the resilience of port and supply-chain networks to natural hazards. *Maritime Economics & Logistics*, *24*(3), 489-506. https://doi.org/10.1057/s41278-021-00204-8

Wang, N., Mu, W., & Ma, R. (2024). A Systematic understanding of the risk development process for port authority. *Marine Policy*, *167*, 106243. https://doi.org/10.1016/j.marpol.2024.106243

Wang, P., Wang, M., Zuo, L., Xi, M., Li, S., & Wang, Z. (2023). Risk assessment of marine disasters in fishing ports of Qinhuangdao, China. *Regional Studies in Marine Science*, *60*, 102832. https://doi.org/10.1016/j.rsma.2023.102832

Wang, S., Wang, H., Xue, G., Han, Y., Qin, Q., Zhang, L., & Ma, X. (2024). Correlation analysis of failure risk factors in automated container port logistics systems from a resilience perspective. *Journal of Sea Research*, *202*, 102552. https://doi.org/10.1016/j.seares.2024.102552

Wang, T., Ding, Z., Poo, M. C.-P., & Lau, Y.-Y. (2024). Research on Port Risk Assessment Based on Various Meteorological Disasters. *Urban Science*, *8*(2), Article 2. https://doi.org/10.3390/urbansci8020051

Wang, T., Ng, A. K. Y., Wang, J., Chen, Q., Pang, J., & Tang, J. (2024). Adaptation planning of container ports in the context of typhoon risks: The case of Ningbo-Zhoushan port in China. *Ocean & Coastal Management*, *257*, 107303. https://doi.org/10.1016/j.ocecoaman.2024.107303

Wendler-Bosco, V., & and Nicholson, C. (2020). Port disruption impact on the maritime supply chain: A literature review. *Sustainable and Resilient Infrastructure*, *5*(6), 378-394. https://doi.org/10.1080/23789689.2019.1600961

Wu, J., & Liu, J. (2025). Cooperation strategies for competing ports considering risk Linkages. *Computers & Industrial Engineering*, *200*, 110796. https://doi.org/10.1016/j.cie.2024.110796

Zhou, J. (2022). *Risk management in the cruise supply chain: An empirical study in China* [University of Tasmania]. https://figshare.utas.edu.au/articles/thesis/Risk_management_in_the_cruise_supply_chain_an_empirical_study_in_China/23246459?file=45722757

Use of Generative Artificial Intelligence

No generative artificial intelligence was used in preparing this communication.

Communication aligned with the Sustainable Development Goals