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BUILDING RESILIENCE: A HOLISTIC APPROACH MAPPRING RISKS IN PORT TERMINALS

Abstract: *The primary goal of the contemporary port industry is to mitigate risks arising from the dynamic competitive landscape. To achieve this, a range of decision-analysis tools, encompassing qualitative and quantitative methods, have been devised based on a comprehensive hazard classification system for global applicability. While numerous strategic, tactical, and operational approaches have been suggested for diverse port infrastructures, only a limited number of studies have presented a strategic framework for an integrated risk assessment plan. This research study aims to develop a holistic framework for assessing risks in port terminals from a strategic standpoint. The proposed framework explores the interconnection between risk categories and existing risk management methodologies, serving as a comparative tool for strategic decision-making processes.*

Keywords: *Risk Mapping, Port Terminal, Resilience, Strategic Analysis*

1. Introduction

Ports are crucial systems for coastal cities and critical facilities for the economy of a country as over 80% of global trade volumes are carried out by sea (Branch, 2012; Hall, 2007). Port terminals present a high level of complexity where different activities are performed such as cargo transport, oil and chemicals storage, vessel traffic, train and truck movement activity, etc. The required labour in port terminals is high due to the widespread use of personnel and technological equipment as stated by Nevins et al. (1998). This high level of complexity increases the diversity of potential accidents with negative impacts to workforce, environment and property. Moreover, as mentioned by Debelić et al. (2018), in ports cargo flows are changing due to new transport corridors and different conditions exist in different regions and as such, it is difficult to implement a common methodology of risk assessment.

In a global perspective, there are different viewpoints for risk preparedness and as such, risk prevention measures became a research objective for maritime transportation. Managers developed various risk assessment methods in order to incorporate risk analysis in their decision-making process (Chlomoudis et al., 2013, 2016). Even though many diverse approaches of risk assessment have been published according to Parra et al. (2018) study, only few studies demonstrate a strategic framework for integrated risk assessment.

Considering the increased interest for implementation of modern risk planning tools capable to deal with different cargo flows as well as with big ships and their quantities, this paper proposes a holistic framework for risk assessment in ports.

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Previously developed schemes and workflows combine existing methodologies and decision-making tools in a comprehensive form, in order to support port authorities to identify possible poor risk prevention measures and guide them to tackle risks separately with a strategic point of view. The proposed framework studies the linkage between risk type classifications and existing risk management methodologies with the aim to be used as a comparative tool for strategic decision-making processes. This holistic approach is applied in a medium-sized port that provides passenger traffic and cargo transports simultaneously in the Greek territory.

The remainder of this paper is structured as follows. Section 2 introduces an overview of risk categories and factors appearing in ports, and risk stages in a risk prevention plan. Section 3 shows the steps of the proposed risk assessment framework for the main port infrastructure. Section 4 presents the results of the aforementioned holistic approach from a case study application in a medium-sized transit port in the Greek territory. Section 5 discusses the findings of this study and highlights several remarks on the proposed framework. Lastly, Section 6 presents the outcomes and the conclusions of this study.

2. Overview of risks in port terminals

A port terminal constitutes a complex environment surrounded by uncertainty which is defined in modern world as risks. Due to dynamic changes of cargo flows and new tendencies of transport corridors, ports requirements in risk assessment vary and affect both port operations and traffic in the area nearby (Peng et al., 2018). Hence, a risk prevention plan has to be established for complex systems in order to deal with uncertainty.

2.1. Stages in a Risk Prevention Plan

Research community investigating risk management processes have identified many alternative forms of theory, methodology and practical tools for port industry as stated by Chlomoudis et al. (2012). The most general form of a risk management cycle and therefore the main stages in a risk prevention plan are:

1. Risk identification
2. Risk assessment
3. Risk mitigation
4. Risk monitoring

Risk identification, risk assessment and risk mitigation are classified as proactive measures to anticipate risk level in the examined environment and on the other hand, risk monitoring is classified as reactive. The existing literature shows that there has been an extensive interest in hazard identification and risk assessment processes.

Risk identification is considered the most important step in risk management and aims to create a comprehensive list of all risks (Trbojevic & Carr, 2000). This study utilizes existing risk identification techniques examined and performed by port industry stakeholders for the specified systems of ports according to Berle et al. (2011) and a taxonomy of risks in cargo port terminals is illustrated in Table 1, presenting the six main risk categories identified and their subdivisions. uncertainty.

2.2. Risks in port terminals

According to pertinent literature, different ports are affected by distinct risk categories due to the location of port operations. Chlomoudis et al. (2012) study highlights that even though risk categories and factors are globally applicable; they differ in importance for individual ports. In particular Song et al. (2015) study adds that ports should also consider geographical, technical, economic and organizational factors that subject to continuous changes. Risk factors include different types of risks directly correlated with a risk category and multiple risk examples could be also clustered into a specific risk factor. Following this principle, the taxonomy of risks in port terminals is shown in Table 1.

2.3. Risk Assessment principles

The risk assessment process can be carried out using different qualitative, quantitative or semi-quantitative techniques. As referred by Pasman et al. (2017), the selected approach depends on the available information, the degree of desired quantifications and the complexity of each situation. Qualitative methods primarily define the scale of any risk with the use of consistent evaluation terms. Most frequently, these terms are classified from a scale of “low” to “high” in order to evaluate the probability of an accident (frequency index) and the severity of consequences or damages that can be occurred by a specific accident (impact index). In the same context, a quantitative approach relies on numerical values assigned to the frequency and impact indices of examined risks. This quantitative analysis is based on objective, high-quality data and well-developed project or simulation models. The main difference between a qualitative and quantitative approach relies on the fact that in a quantitative risk assessment, mathematical and simulation tools are used to assess possible outcomes and calculate their probability (Parra et al., 2018).

Although technology development progressed over time in many cases the outcomes of natural disasters have limited data records. Due to these quantitative limitations, a middle ground solution named as “semi-quantitative” method has been proposed by Parra et al. (2018) to provide an intermediary technique between the “word-based” evaluation of qualitative risk assessment and the “numerical” evaluation of quantitative risk assessment. This can combine a quantitative evaluation of the risk frequency and a qualitative assessment of the impact or vice versa. The risk score will be derived as a product of risk frequency and the severity of the consequences (Moonis et al., 2010). This paper proposes a semi-quantitative risk assessment framework to frame, evaluate and potentially solve complex issues.

3. Framework methodology

The proposed risk assessment framework addresses the process of hazard identification in port terminals infrastructure and the evaluation of possibility as well as the impact of identified risk factors. The framework builds on insights gained from a variety of pertinent research studies and empirical input from relevant stakeholders. In detail, a five-stage methodology has been developed:

1. **Investigation of pertinent literature** and development of a taxonomy table for risks in port terminals.
2. A **cause-effect diagram** for the depiction of risk categories is developed according to Stage 1 taxonomy, and categories are divided according to cause-effect diagram guidelines.
3. A **bow-tie diagram** is made for the identification and illustration of threats and consequences that could occur from a specific risk factor.
4. **Development of a risk table** for the quantification of frequency and impact indices. This table aims to provide input on risk indices and rank each risk factor accordingly. A ranking process takes into account the (a) empirical knowledge of port management directors and (b) the available data from port accidents and evaluation reports. In the specific study, only empirical knowledge has been taken into consideration.

5. **Creation of a scenario analysis interface using a risk matrix**, to classify risks according to their likelihood to occur and severity. The classification process follows the empirical assessment made in previous stage (Stage 4) and imports the product of frequency index rank multiplied with impact index.

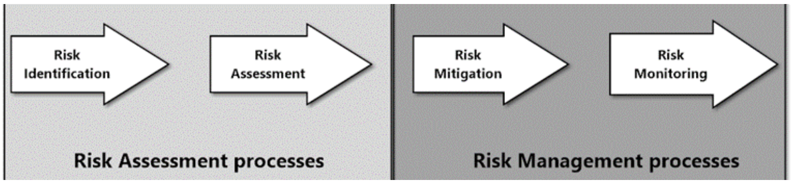

Figure 1. Risk assessment framework stages

3.1. Stages in a Risk Prevention Plan

Following the results derived by the reviews and the comprehensive combination of taxonomy methods used in pertinent literature, risks have been classified into six main categories:

- **socio-economic and political** (i.e. economic instability, cultural obstacles, etc.),
- **environmental and natural disasters** (i.e. water pollution, ship emissions and toxics, etc.),
- **organizational** (design efficiency, permit approvals, etc.),
- **human** (i.e. errors in cargo handling, pilotage errors, etc.),
- **market** (i.e. suppliers risk, legislation changes, etc.),
- **technological** (i.e. machinery failure, high maintenance costs, etc.).

The risk categories include risk factors, which constitute the first sub-division level. Risk factors are different types of risks directly correlated with a risk category which may contain multiple risk examples. Following this principle, the taxonomy of risks in port terminals are shown in Table 1 (see Appendix).

Table 1 may represent factors in any typical port, while each port authority may select and rank the risks according to their operations, products, and individual hazard identification processes, creating a tailored taxonomy for a specific port infrastructure. In the applied case study, the list of risks is presented and ranked (Table 3) according the following steps of the proposed methodology.

3.2. Cause-effect diagram

On the 2nd stage of the proposed risk assessment framework, stakeholders could understand the factors which may harm port’s operability standards and as such, this framework could help them visualize a holistic port risk environment. This is achieved via a “cause-effect” diagram method, which is an empirical and visual approach to depict all possible risk factors. It uses an approved taxonomy (Stage 1) and each risk category is placed as a major tree root on the diagram. Risk factors of a specific category are illustrated as a sub-branch of a root. Every risk factor sub-division can be shown as a sub-branch, moving several layers deeper as the analysis progresses. The result will expand extensions of branches according to established levels of layers. A sample of the cause-effect diagram used in our case study is illustrated in the Figure 2.

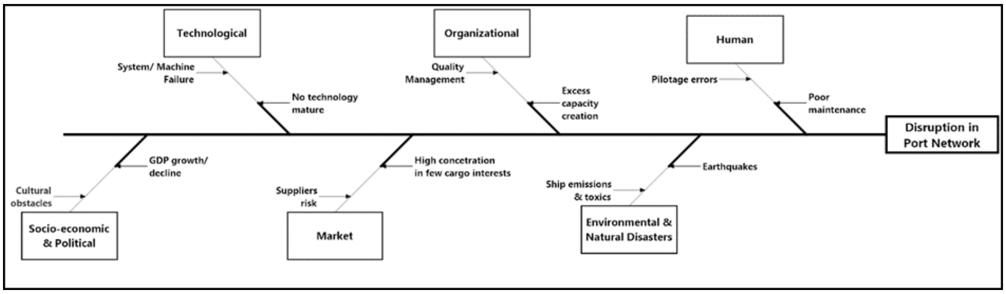

Figure 2. Indicative cause-effect diagram

3.3. Bow-tie diagram

After the identification of potential risks that may harm a port infrastructure, port authorities need to map their established security controls and existing risk mitigation strategies. Security controls and actions to mitigate threats and limit consequences (called "escalation control") are presented in every port environment and needed to be pointed out. According to Trbojevic & Carr (2000), a suitable methodology for safety management mapping process is the "bow-tie" diagram. In this approach it is assumed that each specific risk factor can be represented by one or several threats that have a potential to lead to an incident. A threat can be a specific accident or a group of hazards. In the example shown in Figure 3, top event (risk factor) in the middle is "pilotage error", which can be initiated from a possible threat (i.e. pilot inappropriate command), represented at the end of the left side of the diagram. Respectively, at the end of the right side of the diagram, consequences (i.e. spillage) that may occur from the presence of the top event are illustrated. Between threats and consequences, one or several "barriers" are defined (i.e. navigational aids, effective tug support), which prevent or minimize the likelihood of risk release. For any barrier there may be internal or external factors which affect its effectiveness, such as workforce inexperience or over-worked. These barriers are called "escalation controls" and are considered vital for every port security management system. "Bow-tie" diagram is used in this framework as a "signal indicator" to alert port authorities about strong and weak points on their existing risk mitigation strategy.

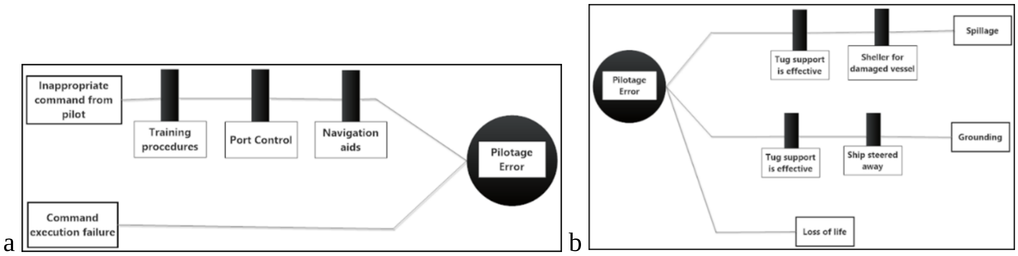

Figure 3. (a) Bow-tie diagram example (left-side); (b) Bow-tie diagram example (right-side)

3.4. Risk factor (R) assessment table

As we concluded with the previous three stages, which were focusing on risk identification methodologies, we proceed to the fourth stage of the proposed risk assessment framework. In this section, as part of risk assessment stage, a summary of risk factors importance is created. This summary is presented in the form of a table, in which each column shows the risk types and values of examined indices, and each row presents a different type of risk factor. More specifically in this paper we used two indices, Frequency index (F) to determine the likelihood of a risk factor appearance and Impact index (I) to enumerate the severity of damage occurred during port operations and effect on any port system. The product of these two indices would give the value of Risk factor (R) index (R = F x I).

Chlomoudis et al. (2012) applied this simple method to add value to these two indices by using the empirical and available quantitative data from experts. The value of indices is provided from academia experts, port authority management and key stakeholders actively operating on the port terminal area. As we described previously in Chapter 2.3, port experts validate the proposed taxonomy of port risks and grade each risk factor separately. Both indices use a qualitative scale from "low" to "very high" and they are translated to numerical values of 1 to 4 accordingly (i.e. 1 for lowest possibility/impact and 4 for highest). This step is highly important to assess and initially categorize the risks identified. In Chapter 4 where the results of this study are presented, a detailed table for the applied case study is illustrated (Table 3).

3.5. Scenario analysis interface

Final stage of the proposed framework focuses on the illustration of a port terminal scenario analysis. Fig. 4 shows the summary of strategic risks presented in the previous assessment stages. Each risk uses the values of Risk factor (R) according to Stage 4 and is placed on the equivalent quadrant of the strategic risk grid. Risk exposures are classified as unacceptable with urgent action required (black area), acceptable but required further action (grey area) and acceptable with periodic monitoring required (white/blank area). This colour code process can be described with the clarification of impact provided in Table 2.

Table 2. Risk matrix impact axis definitions

Impact			
People	**Assets**	**Environment**	**Reputation**
Minor injury or none	Minor damage or none	Minor damage or none	Slight impact
Major injury	Local damage	Localized effect	Limited impact
Single fatality	Major damage	Major effect	National impact
Multiple fatalities	Total loss	Massive effect	International impact

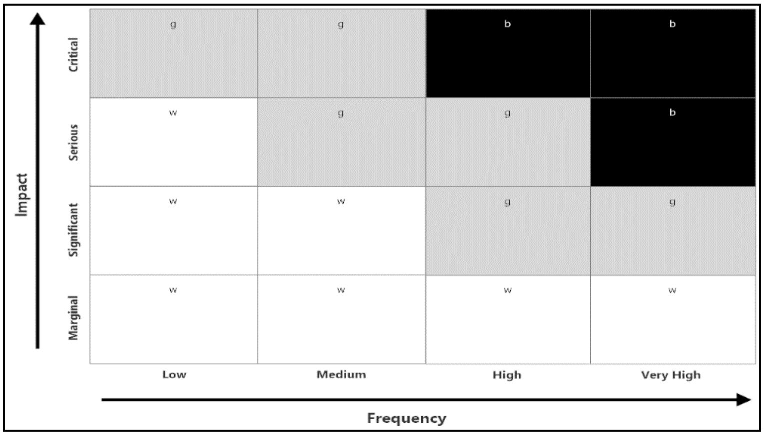

Figure 4. Risk assessment scenario analysis indicative ranking matrix

In more detail, risk factors with R value lower than 4 (R: 1-4), are considered acceptable and “to be monitored” (white/blank area). In this context, risk types with R value between 5 and 9 (R: 5-9) and R value higher than 10 (R: 10-12) are considered as acceptable but dangerous and unacceptable accordingly. After completing all the steps of the risk assessment framework, a Port Authority could exploit the outcomes of this risk analysis and proceed with further strategic decisions. These decisions will impact the future risk management system in a tactical and operational level, converting strategic risks into opportunities. In case that existing safeguards are inadequate and make a risk unacceptable, additional measures will be proposed and be made acceptable within a specified time frame from port management.

4. Experimental Results

The proposed framework analysed in the previous chapter has been applied in a real port of the Mediterranean Sea. More specifically, a medium-sized port located in Northern Greece was chosen as a case study in this paper. This case study is used to apply the holistic framework for assessing risks from a strategic view. Details about the specific port terminal and its characteristics are provided below together with the respective risk assessment results.

4.1. Case study location characteristics: Medium-sized port in northern Greece

The applied case study utilizes a port in the northern Greek territory, which is referred as “NG Med”. Due to legal restictions, GDPR issues and other relevant data that are sensitive, its identity should be remain anonymous. The “NG Med” is a medium size port located in northern Greece, and particularly covers significant part of the exports of the country through northern Greece. At the same time, it is a transit port for southeastern Europe and Balkan countries, which gives it a unique identity and complex working environment. It is located on the northern section of the Eastern Mediterranean Sea and provides bulk cargo transport services, handling containers and conventional cargo, plus handling tourist transport services to cruise Ro-Ro passenger ships and yachts. The port contains three terminals which are in close proximity to the national road network to bypass the city centre and provide quicker transportation of cargoes. However, the urban area next to the port terminal (about only 4 km away) suffers from air, water and land pollution. Citizens in the nearby region have demanded solutions to the air pollution problem such as install renewable energy infrastructure or air filters in nearby factories.

4.2. Risk factors identification and assessment

For identifying and assessing the potential risks of this port, several semi-structured interview sessions were conducted with the Port Authority stakeholders of the “NG Med” Port. In addition, extra interviews were occurred with cooperating academia / research experts with prior involvement in port and asset infrastructure management as well as expertise in relevant research projects. These insights together summarised the risk assessment factors of the “NG Med” Port and are presented in Table 3.

Table 3. Risk assessment factors matrix for the “NG Med” port

No.	Risks	Frequency (F)	Impact (I)	Risk Index (R)
1	Economic instability	2	3	6
2	Political instability / War	1	4	4
3	Terrorist attack	1	4	4

No.	Risks	Frequency (F)	Impact (I)	Risk Index (R)
4	Theft	2	2	4
5	Illegal trade / Smuggling	2	3	6
6	Poor public decision-making process	1	3	3
7	Sinking	1	4	4
8	Expropriation or nationalization of assets	1	1	1
9	GDP growth/decline	1	2	2
10	Change in tax regulations	2	3	6
11	Cultural obstacles	1	1	1
12	Geotechnical conditions	1	3	3
13	Severe weather conditions (i.e heavy rain, strong winds, etc.)	2	3	6
14	Water pollution	3	4	12
15	Noise pollution	3	4	12
16	Dredging	2	2	4
17	Archeological risk	2	1	2
18	Ships emissions and toxics	3	3	9
19	Earthquakes	2	4	8
20	Floods	2	4	8
21	Extreme high temperature during working hours	3	3	9
22	Excess capacity creation	3	3	9
23	Error in cargo handling and storage	3	2	6
24	Poor maintenance	2	3	6
25	Navigation errors	2	2	4
26	Pilotage errors	2	2	4
27	Lack of training	1	2	2
28	Old technological means and methods	3	1	3
29	High maintenance costs	1	3	3
30	Fire/Explosion in machinery	1	4	4
31	System/Machinery failure	3	3	9
32	Establishment of new competitive infrastructure (port, terminals, hinterland etc.)	1	1	1
33	Grounding	1	3	3
34	Major variabilities in demand	4	1	4
35	Suppliers risk	2	3	6
36	Ship collisions	2	2	4

4.3. Case study risk analysis ranking matrix

Following the aggregated risk factors identified and illustrated in Table 3, this section presents the risk matrix ranking step (5th step of the proposed methodology). In the Fig.5 below all risks are presented according to their impact (severity) and frequency rate. As it can be observed, eight risks were identified as “severe and unacceptable” which means they should be dealt with as soon as possible. These risks focused were related with environmental aspects (air and noise pollution) or technological (frequent equipment failures). In the same context, the majority of identified risks (23 out of 37 risks) were considered as “insignificant”. The rest of the risk factors (7 out of 37) are considered “noteworthy but acceptable”. The results are noted and further discussed in the next chapter (Chapter 5).

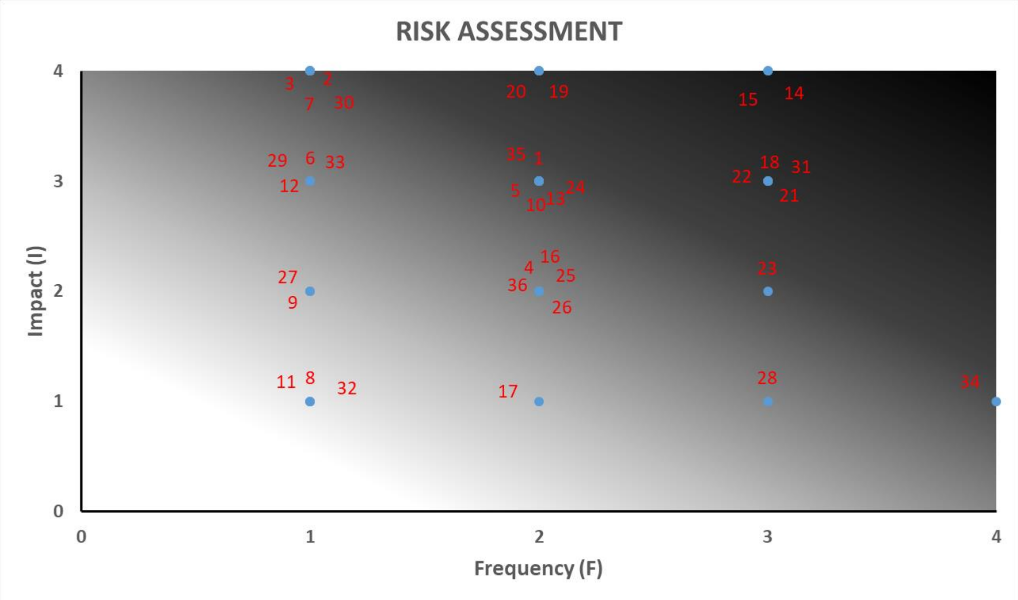

Figure 5. Case study Final Risk assessment ranking matrix

5. Discussion

By addressing the limitations of existing approaches, the proposed holistic framework could assess risks in port terminals considering the interconnections between different risk categories such as operational, financial, environmental, and security. This provides a more accurate and realistic understanding of the overall risk landscape that support decision makers in identifying potential vulnerabilities and developing effective risk management strategies. The interconnections between risk categories are highlighted using the proposed framework and as such the potential cascading effects of risks are identified and proactive measures could be developed to mitigate them. In addition, it could serve as a comparative tool at a strategic level since insights into the strengths, limitations, and applicability of different approaches are provided to port stakeholders. This information can support informed decision-making, resource allocation, and prioritization of risk mitigation efforts.

The findings of the case study indicate that the methodology of the proposed framework also contributes to the development of industry best practices for risk assessment and management in port terminals. The proposed framework enables collaboration among different stakeholders involved in port terminal operations as it could set the basis for understanding risks that often transcend organizational boundaries. Hence, effective communication and cooperation among port authorities, terminal operators, shipping companies, regulatory bodies, and other relevant stakeholders could be enabled for addressing complex risks and developing coordinated risk management strategies. Finally, it is worth to mention that the proposed holistic framework could identify gaps and propose improvements to current practices. This can lead to the establishment of standardized guidelines and plans that promote consistent and effective risk management across different port terminals globally.

6. Conclusion

The developed risk assessment framework addresses the process of hazard identification in port terminal infrastructure and the evaluation of possibility as well as the impact of identified risk factors. It is the first time to the best of our knowledge that a framework proposes to analyze the linkage between risk categories and existing risk management methodologies so as to be used as a comparative tool for strategic decision-making processes. The framework builds on insights gained from a variety of pertinent research studies and empirical input from relevant stakeholders.

The above-mentioned risk assessment framework could be employed as a tool for ports to assess risks at a generic level. This study could be extended with more through case studies, especially at the geographical region of the South-eastern Europe due to the similar characteristics and culture of the region. Through the evaluation of future case studies' outcomes, the proposed risk assessment framework can be evaluated and adjusted accordingly. The proposed approach is suitable for further extensions on the side of economic and societal impact, as well as for cost benefit approaches in order to help relevant authorities to achieve the most profitable improvements and implications.

Acknowledgment: The results in this paper reflect only the authors' view.

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Appendix

Table 1. Taxonomy of risk factors in port terminals

Risk Category	Risk factors	Risk Category	Risk factors
Socio-economic & Political	• Economic instability (i.e GDP, tax regulations) • Political instability / War • Terrorist attack • Theft • Illegal trade / Smuggling • Expropriation or nationalization of assets • Cultural obstacles • Railway/Highway transportation blockage	Human	• Poor quality workmanship • Ship/Truck collisions • Sinking • Grounding • Navigation errors in vessels and trucks • Pilotage errors in vessels and trucks • Poor maintenance • Falling of a crane or container • Error in cargo handling, storage and transshipment
Environmental & Natural disasters	• Severe weather conditions (i.e. strong winds, etc.) • Water pollution (i.e. oil spills) • Noise pollution • Dredging • Ship breaking/salvage activities • Ships/Trucks emissions and toxics • Earthquakes • Floods • Extreme high temperature during working hours	Market	• Establishment of new competitive infrastructure (port, terminals, hinterland etc.) • Expansion of existing nearby ports and warehouses • Major variabilities in demand • Suppliers risk Legislation or customs changes
Organizational	• Delay in approvals and permits • High operational or low expected revenues/productivity • Lack of training	Technological	• Old technological means and methods • High maintenance costs • Fire/Explosion in machinery • System/Machinery failure