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An approach to improve selected risk assessment methods in seaports

Keywords

Risk assessment, AHP, scenario-based method, improving.

Abstract

The scope of the paper is to introduce the solution for improving the risk management methods for seaports. First, the paper presents general information about ports and their main business scope. Next, we introduce the definition of critical infrastructure (CI) according to the EU directive, and we apply it to seaports. The paper also presents the basic concepts of dependencies and interdependencies and introduces a general classification of natural hazards and threats of influencing ports. Moreover, the multiple criteria decision analysis, particularly the application of the AHP method, is presented as the solution for improving seaports risk assessment based on scenarios. Finally, some examples of different approaches for risk assessment improving are presented.

1. Introduction

It is estimated that currently, sea transport accounts for 80% of world cargo transport. Thus, the sea-land supply chains are gaining importance, especially between major global economic centers located in Asia, Europe and in the United States. Seaports act as a node in the logistics network and from this point of view are subjected to logistic management in sea-land supply chains. The main business scope of the seaports with their industrial facilities is:

- activities of transshipment, storage, and warehousing, mainly in the field of foreign trade cargo handling and transport vessels;
- support for tourism and passenger traffic, including marine shipping and ferry travel;
- support for seawater sports and leisure (e.g., Marinas);
- industrial activities, especially the shipbuilding industry (including construction and repair of ships and cooperation), marine fisheries and the processing industry, including the refining and chemical industries;
- distribution and logistics services, including services provided by the port logistics centers, especially cooperating with the container terminals;
- commercial and technical related, among others the services provided to ships (e.g., towage and port, technical workshops) and trade in goods and services of inland transport (rail and road);
- security services for port facilities and industrial and rescue at sea;
- activity port administration institutions, providing services for the trading port and maritime and shipping and passenger traffic.

It has a significant impact on the complexity of the safety problems in ports. They consist of land facilities constructed to transfer goods between water and land. The major port features are as follows:

- docks, quays or berths where vessels moor;
- port approach channels and roadsteads;
- equipment and personnel necessary to do loading and unloading vessels, i.e., cranes (gantry, self-propelled, stacking), conveyors, forklifts, Roll-on-Roll-off (RoRo) tractors and trailers, transport vehicles, equipment for monitoring port inland waters, equipment for ship's bunkering (fuel and water), etc.;
- connections to infrastructure of other transport modes (such as highways, railways, and pipelines);
- telecommunications and management (internal and external);
- cargo storage areas, i.e., hangars, warehouses, storage yards and large reservoirs, such as silos.

The above features indicate the possibility to consider the two port's areas: water and land. The first part includes the following items: approach channels, roadsteads, and inner pools. In the land side, we take into account the elements as follows: equipment for load and unload vessels, cargo storage areas, car

maneuvering areas, access roads, and railways. Additionally, we consider the hydro-technical structures and equipment such as breakwaters, piers, quays, berths, and docks. According to maritime law, the water side of the port is part of the internal waters. Furthermore, the fact is that ports are intermodal facilities, a place where rail, truck, barge, ship, and other transport methods converge. In this way, ports play a critical role in moving products both to other countries and to the interior of the country. The port's terminals handle makes possible the docking and the handling, storage, and transfer of a wide variety of types of cargo: bulk or loose, breakbulk in packages (bundles, crates, barrels, pallets) [13].
The main aim this paper is proposed the concept of improving seaport risk assessment methods. It can be done by selection of the optimal scenario of risk or vulnerability approach.

2. Critical infrastructures

The seaports because of their importance for country economics and people are Critical Infrastructures (CI) and consist of the different types of assets [3]. The a ssets can be categorized in many ways, including peo ple, information, equipment, facilities and activities o r operations. For the ports, we can distinguish the ass ets like

a) direct:
  - passengers and goods,
  - docks or berths,
  - approach channels,
  - roadsteads and inner pools,
  - equipment for load and unload vessels,
  - breakwaters,
  - piers,
  - quays,
  - roads and railways (internal and external),
  - pipelines,
  - navigational signs,
  - means of transport.

b) auxiliary:
  - cargo storage areas,
  - warehouses.

The EU sets the goal to improve the critical infrastruc ture protection capabilities across all EU Member Sta tes against natural hazards and other threats. Thus, th e European Programme for Critical Infrastructure Pro tection (EPCIP) has proposed a list of European critic al infrastructures based upon inputs by its Member St ates. The European Commission's "Green Paper" on EPCIP specifies 11 infrastructures as being critical [3]:

1. Energy
2. Information and communication technology (I CT)
3. Water
4. Food
5. Health
6. Financial
7. Public and legal order and safety
8. Civil administration
9. Transportation
10. The chemical and nuclear industry
11. Space and research.

According to EU regulation, the seaports are element s of the transportation critical infrastructure.

3. Approach to dependencies and interdependencies in seaports

These eleven CIs can be dependent on each other. Similarly, there are some interdependencies in these CIs between the assets that compose them.
There are different types of interdependencies and different ways of characterizing them. The categorization proposed by Rinaldi, Peerenboom, and Kelly [9], [10], is often used and distinguish four primary classes of interdependencies:

- Physical interdependency (PhyI) – two infrastructures are physically interdependent if the state of each depends upon the material output(s) of the other. Physical interdependencies arise from physical linkages or connections among elements of the infrastructures;
- Cyber interdependency (CybI)– an infrastructure has a cyber interdependency if its state depends on information transmitted through the information infrastructure. The computerization and automation of modern infrastructures and widespread use of supervisory control and data acquisition (SCADA) systems have led to pervasive cyber interdependencies;
- Geographic interdependency (GeoI) – infrastructures are geographically interdependent if a local environmental event can create state changes in all of them. This implies close spatial proximity of elements of different infrastructures, such as collocated elements of different infrastructures in a common right-of-way;
- Logical interdependency (LogI) – two infrastructures are logically interdependent if the state of each depends upon the state of the other via some mechanism that is not a physical, cyber, or geographic connection. For example, various policy, legal, or regulatory regimes can give rise to a logical linkage between two or more infrastructures.

According to the above classification, the dependency and interdependency for seaports are introduced in *Table 1* below.

Table 1. Sub-sectors that the asset is connected and dependent on for its operation

SEAPORTS								
CI	Dependency				Interdependency			
	PhyI	CybI	GeoI	LogI	PhyI	CybI	GeoI	LogI
Electricity	☒	☐	☒	☐	☒	☐	☒	☐
Road	☒	☐	☒	☐	☐	☐	☒	☐
Rail	☒	☐	☒	☐	☐	☐	☒	☐
Sea and inland waterways	☒	☒	☒	☐	☒	☒	☒	☐
Telecommunication	☒	☐	☐	☐	☒	☐	☐	☐
Information Systems	☒	☒	☐	☐	☒	☒	☐	☐

4. Risk in seaports

We use notation hazard in term of natural hazards classified as severe and extreme weather and climate events, while threats refer to events coming from human activity and other systems or infrastructures [1].

We can give the following five risk categories in ports [2]:

A. Human, where we distinguish the following selected sub-categories (threats):
  - ship collisions,
  - grounding,
  - sinking,
  - navigation error,
  - pilotage error,
  - poor maintenance,
  - falling of a cargo handling facilities (e.g., crane, conveyors, etc.),
  - falling of a container,
  - error in cargo handling and storage.

B. Machinery, where we distinguish the following selected sub-categories (threats):
  - damage to equipment,
  - fire/explosion,
  - machinery failure,
  - system failure.

C. Environment, where we distinguish the following selected sub-categories (threats):
  - ships emissions,
  - dredging,
  - oil spills,
  - chemical contaminants,
  - ballast waters,
  - ship breaking /salvage activities,
  - air toxics,
  - noise pollution,
  - alien species.

D. Security, where we distinguish the following selected sub-categories (threats):
  - security,
  - war / political instability,
  - terrorist,
  - theft,
  - smuggling,
  - illegal trade,
  - vandalism,
  - illegal immigration,
  - blockade.

E. Natural, where we distinguish the following selected sub-categories (hazards):
  - earthquakes,
  - volcanic eruptions,
  - hurricane,
  - strong winds,
  - heavy swell and sea,
  - floods,
  - high temperature during working hours,
  - heavy rain,
  - heat waves, cold snaps,
  - sea level rise,
  - ice, frost, permafrost,
  - storm surges, waves,
  - lightning/thunderstorm,
  - earth movement caused by climate drivers such as rain (landslide, erosion, avalanches, rock fall, soil subsidence, liquefaction, etc.).

Taking into account the changing of world climate, we can propose the following hazards impacted the seaports and their assets. The particular information for general seaports is giving in *Table 2*.

Table 2. Hazards that can impact the seaport CI

Hazards that can impact the seaport CI	
Heat waves, cold snaps	☒
Floods / costal floods	☒
Forest Fires	☐
Droughts	☐
Sea level rise	☒
Ice, frost, permafrost	☒
Storm surges, waves	☒
Lightning/thunderstorm	☒
Earth movement caused by climate drivers such as rain (landslide, erosion, avalanches, rock fall, soil subsidence, liquefaction, etc.)	☒

By international regulations such as the International Convention on the Safety of Life at Sea and the International Ship and Port Facility Security Code, each seaport is obliged to have rules by the ISM Code

[7], [8].
Application of this approach can be used to neutralize the threats, which can occur due to port operation. The main threats are presented above in risk categories from A to D.

5. Improving risk methods for seaports

5.1. Theoretical background

A port is a significant asset in the global supply chain. The decision-making about the port is essential not only for his operations but also for the national economies. Thus, the potential tradeoffs among cost, risk, and opportunity must be taken into account in order to make strategic and protective decisions. The risk assessment and risk management play both crucial roles in mitigating the effects of different disruptive events or activities. There are several risk assessment methods comprehensive for seaports. Usually, it is very complex and multiple criteria problem. In this case, the useful tool is multiple criteria decision analysis (MCDA), which helps in the evaluation of policy decision considering possibly not commensurate criteria. In Hazard report [5] one of the proposed risk assessment methods for port risk assessment is scenario analysis. Many insurance companies use scenarios to assess and identify threats and hazards in seaports. Furthermore, the cost analysis is possible to do with accordance to this method. The scenario method also allows both qualitative and quantitative assessment of risk or vulnerabilities. These possibilities are extended when the combination of MCDA and scenario analysis is used. It can be applied to solve the risk optimization problem for seaports. In this case, the Analytical Hierarchy Process method (AHP method) is one of the more appropriate ones. Thomas Saaty introduces this multi-criteria optimization method in the 70s. The general structure of the AHP method is presented in *Figure 1*.

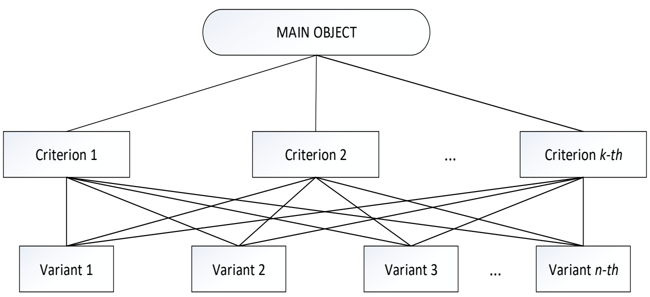

Figure 1. General diagram of the AHP method ([5], [11]).

This method requires, in general, the assumption that there is a set of the n-variants (options) to consider and every one of these components takes the value for k-criteria. In this way, the decision matrix $[DM]_{n\times k}$ is given. According to [4]-[5], [11] the steps of the AHP algorithm are as follows:

Step 1. Hierarchization of the problem.

Step 2. Paired comparison of the objectives being on the same level – matrixes of the paired comparisons.

Step 3. Definition of the mutual weight of the criteria and decision variants.

Step 4. Choosing the best options.

Step 1 is followed by a detailed description of a problem and definition of the primary goal and expectations of them. The decomposition of the problem in the form of the principal criteria and the main options considered, which generate a certain degree of fulfillment of objectives of the function at different levels of the hierarchical model is defined (see *Figure 1*).

In s*tep 2*, the decision maker compares together in pairs criteria about the primary goal and the options to the specific guidelines. A subjective determination does this that the criteria and options, and to what extent are more important than the other.
Relations between the elements can be determined based on a 9-point scale [4]-[5], [11]:

1 – the same significance;
3 - a small advantage;
5 - a strong advantage;
7 – a very strong advantage;
9 – an absolute advantage;
2, 4, 6, 8 – an intermediate value.

Evaluation of the inverse relations is determined as a reciprocal of integers.
Furthermore, this step completes the formation of a matrix $\mathbf{B}^{level}$, $level = 2,3$, size $k\times k$ and $n\times n$ in case of the second and third levels, respectively, which is made of $k(k-1)/2$ and $n(n-1)/2$ of these comparisons. The general structure of this matrix is given as ([5], [11])

$$\mathbf{B}^{level} = \begin{bmatrix} 1 & b_{12} & \cdots & b_{1n} \\ b_{21} & 1 & \cdots & b_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ b_{n1} & b_{n2} & \cdots & 1 \end{bmatrix}. \quad (1)$$

As we see, the characteristic feature of this matrix is diagonal equal to 1, which consists of the following property

$$b_{ij} = \frac{1}{b_{ji}}. \quad (2)$$

where b_{ij} are an element in an *i*-th row and *j*-th column and b_{ji} are an element in a *j*-th row and *i*-th column.

Step 3, is the stage of the AHP algorithm in which the mutual weights for criteria and variants (options) are calculated. The normalized rows of the matrix $\mathbf{B}^{level}$, $level = 2,3$, are summed, and the eigenvector of it is found. Furthermore, the matrix $\mathbf{B}^{level}$, $level = 2,3$, satisfies [4]-[5], [11]:

$$\mathbf{B}^{level} \cdot \mathbf{w} = \lambda \cdot \mathbf{w}, \quad (3)$$

where
$\mathbf{w}$ - the eigenvector of a matrix $\mathbf{B}^{level}$,
λ - the eigenvalue of a matrix $\mathbf{B}^{level}$,
$level = 2,3$.

The experts' assessments are not always completely neutral, so it is necessary to introduce the inconsistency coefficient IF defined as follows [4]-[5], [11]:

$$IF = \frac{CR}{RI}, \quad (4)$$

where
CR - consequence ratio,
RI - random index.

This number should be less than or equal to 0.2. In the case when $CI = 0$ then the value of the coefficient IF is calculated respect to the random index *RI*. It is the average CI for a large number of a randomly generated matrix of comparisons. Moreover, the consequence ratio CI for matrix size n is given by [5], [11]:

$$CI = \frac{\lambda_{\max} - n}{n - 1}, \quad (5)$$

where $\lambda_{\max}$ is a maximal eigenvalue of a matrix $\mathbf{B}^{level}$, $level = 2,3$, calculated with equation (3).

According to [11], it is believed that the data are consistent that the value of the ratio CI, given in (5), is less than 0.1.

The values of the random index RI are given in *Table 3*.

Table 3. Values of RI according to number n [4]

n	RI	n	RI
2	0.00	8	1.40
3	0.52	9	1.45
4	0.89	10	1.49
5	1.11	11	1.52
6	1.25	12	1.54
7	1.35		

Finally, in Step 4, the decision-maker chooses the optimal option for established criteria based on the ranking vector for the choosing option/scenario.

It should be noted that this is a helpful method when the expert opinions are collected during the research, i.e., build the scenarios.

5.2. Application of AHP method for scenario-based risk and vulnerability assessment for ports

Risk management does not have to relate to risk assessment directly. It may also rely on finding vulnerabilities in the port organization and operation. The proposed method can be used to find measure port components vulnerability to a variety of disruption scenarios or risk measure.

We take into account the following transportation sectors operating in the port area, which are impacted by initial disruption:

- rail transportation,
- water transportation (sea and inland),
- truck transportation,
- transit and ground passenger transportation,
- pipeline transportation,
- other transportation and support activities,
- warehousing and storage.

Furthermore, according to research results given in [12], the following scenarios for port disruptions can be considered [12]:

Scenario 1: Port/terminal worker strike at the port facility resulting in a work stoppage,
Scenario 2: Strong wind/hurricane,
Scenario 3: Terrorist attack on the port facility,
Scenario 4: Baseline scenario.

In Scenario 1 we assume, that the direct impact comes from labour shortages or its slowdowns, what is harmful to the port operations. This scenario should base on historical data about the operations done by dockworkers within the port industry. The largest inoperability is related to cargo handling

responsibilities of dockworkers and slowing of shipping activities (water transportation). Port operations also include rail transportation, truck transportation, and storage to handle intermodal transportation services. Thus, for these sectors, we assume a lower inoperability within this scenario. Furthermore, we can assume, that port disruptions traditionally extend from 5 to10 days, followed by an operational recovery period extending another 5 to 10 days. Finally, we can assume that the mean time to restore full port operability is 20 days in this scenario.
The direct impact of a natural disaster such as a strong wind or hurricane, consider as Scenario 2, leads to conditions unsuitable for shipping activities. The largest inoperability is again related to shipping activities. The direct impact on non-water transportation sectors is contingent upon the severity of the strong wind or hurricane. In severe cases, there may be a potential reduction in available resources (workers and technology) and potential damage to transportation infrastructure. Therefore, this scenario assumes that inoperability directly impacts all transportation sectors. For fixing the time needed to recover transportation operations after hurricane events, the risk manager should study the historical data about time of restoration all damages after a strong wind/hurricane. We can assume, exemplary, the time needed to resume status quo operations as 30 days.
The implications of Scenario 3 across sectors can vary widely depending on the specific event. In order to maintain generality, this scenario assumes inoperability directly impacts all studied transportation sectors equally. Consistent with related work that assumes a one-month port closure, this scenario assumes the restoration time equal to 30 days.
Baseline Scenario 4 assumes that inoperability directly impacts all transportation sectors. As this scenario models minor disruptions requiring minimal recovery time, this scenario assumes the time of full restoration is seven days.

According to the above scenarios, we can consider three different approaches to port risk management. The one way is based on the vulnerability of distinguishing scenarios, i.e., it is searching the weakest link. Another two approaches take into account the risk measures for different criteria.
Taking into account the vulnerability, we assume that the optimization criteria in AHP method are fixed in the following way:

a) C1 – inoperability factor – a number from 0 to 1,
b) C2 – restoration time [days],
c) C3 – total loss [USD].

A suitable example diagram for the AHP method in vulnerability approach is presented in *Figure 2*

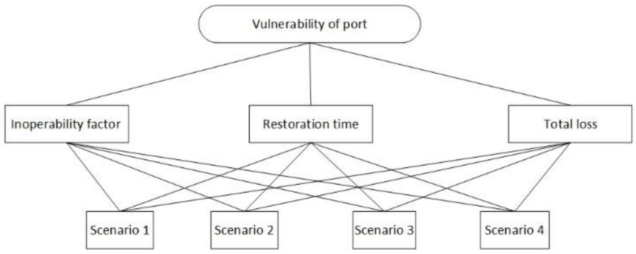

Figure 2. AHP schema for the vulnerability of port.

Next, taking into account the risk measures, we assume that the optimization criteria in AHP method are fixed in the following way:

a) C1 – the probability of hazards occur – a number from 0 to 1,
b) C2 – the probability of hazards occur – a number from 0 to 1,
c) C3 – restoration time [days],
d) C4 – total cost [USD].

A suitable example diagram for the AHP method in risk approach is presented in *Figure 3.*

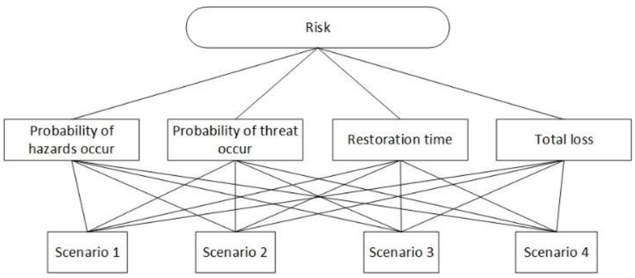

Figure 3. AHP schema for risk assessment of port, case 1

Finally, taking into account the risk measures in the second case, we assume that the optimization criteria in AHP method are fixed in the following way:

a) C1 – the probability of hazards occur – a number from 0 to 1,
b) C2 – the probability of hazards occur – a number from 0 to 1,
c) C3 – total cost [USD].

A suitable example diagram for the AHP method in risk approach is presented in *Figure 4*.

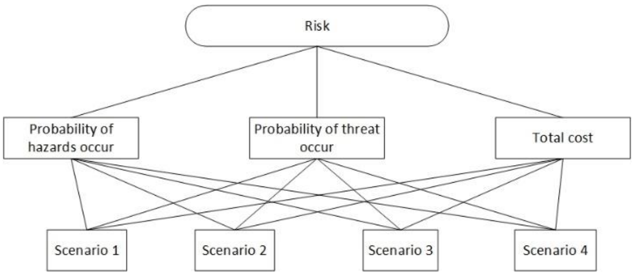

Figure 4. AHP schema for risk assessment of port, case 2.

Under these assumptions, presented in figures occurs 2 – 4, and using formulae (1) – (5) with introduced scenarios 1 – 4, the framework for seaports risk management is proposed and optimal values risk or vulnerability are possible to find.

6. Conclusion

The scope of the paper is reached. A general information about ports and their main business scope has been presented. Following this way of thinking, we introduced the definition of critical infrastructure (CI) according to the EU directive, and we apply it to seaports. Furthermore, the paper also presented the basic concepts of dependencies and interdependencies and introduced a general classification of natural hazards and threats of influencing ports. The proposed method of improving the seaport risk assessment method has been usage of the multiple criteria decision analysis, particularly due to the AHP method, It has been done according to scenario-based method. Finally, some examples of different approaches for risk assessment improving has been presented.

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