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Conception of decision support system for resilience management of seaport supply chains

Keywords

resilience, decision support system, supply chain, seaport operations

Abstract

The target of this paper is to present the preliminary concept of decision support system for seaports supply chain risk management in the aspect of vulnerability and resilience engineering. As a result, there is discussed a literature review connected with resilience engineering of seaport infrastructure systems and their supply chains. Later, the decision support system conception is investigated. The developed solution is to be based on the *What if?* approach and Bow-Tie method. The work ends up with summary and directions for further research.

1. Introduction

The seaport infrastructure systems and port logistic chains performance issues have been emerging research areas for the last decade [35]. On the one hand, there is a need for proper maritime transport processes and seaport operations management performance in rapidly changing environment due to the defined service delivery or operational effectiveness achieving. As a result of this, seaports have been forced to make complex decisions in ways that will allow them to effectively respond to these dynamic environmental challenges, connected with e.g. intensive competition, port privatization, intermodal transport performance, or piracy threats. Such problems are the area of interest e.g. in works [25], [75], where problems of container terminals performance are analysed, in [47], where maritime terrorism and piracy issues are investigated, or in [10], where climate changes influence on seaports performance is analysed.

On the other hand, ports and their logistic chains may be affected by externally (e.g. country, business related) or internally (e.g. operational, organizational) driven sources of risk and uncertainties at any time. This problem is especially important nowadays, when a large portion of the worlds trade is transported by the sea. Following this, the occurred disruption at any point within the seaport operation or its logistic chain could potentially results in catastrophic and disastrous consequences [35]. There is therefore, the necessity to develop the decision support systems aimed at improvement of safety level of logistic support processes carried out in the corridor to the seaport and in the seaport in the context of proper performance of supply chain.

As a result, the article is aimed at introduction of the preliminary conception of decision-making tool that supports decision processes of chosen stakeholder groups in the area of risk management and that is based on the defined assessment algorithm for vulnerability and resilience of seaport supply chain performance. The developed IT application will be focused on the main informational needs of defined group of stakeholders and may be aimed at e.g. possible hazard scenario definition.

The proposed solution is developed within the framework of HAZARD project, a three year long the Interreg Baltic Sea Region project that started in 2016 within Swedish, Finnish, Estonian, Lithuanian, Polish, and German partners [72]. Its objective is to mitigate major accidents and emergencies in major seaports in the Baltic Sea Region (BSR), all handling large volumes of cargo and passengers.

Following this, the remainder of this paper is organized as follows: Section 2 introduces the short literature review connected with resilience engineering of seaport infrastructure systems and their supply chains. Later, the decision support system conception is investigated. The developed solution is to be based on the What if? approach and Bow-Tie method. The work ends up with summary and directions for further research.

2. Seaports supply chain vulnerability and resilience – literature review

The problems of vulnerability and resilience of maritime infrastructure systems and maritime transportation systems have received a growing interest in recent years [28], [62]. The existing literature may be divided into three main groups taking into account the investigated research areas:

1. seaport as an element of supply chain performance,
2. maritime transport systems problems,
3. seaport operations performance issues.

In the first group of research papers, the seaports performance is investigated as an important element of the global supply chains operation. In this sense, the research focuses mostly on the analyses how a port-related disruption can influence the whole network of supply chains resilience (see e.g. [9], [11], [39]). In this area most of the published works investigate the multimodal container transportation (see e.g. [15], [71], [73]). Some summary of recent developments is given e.g. in [1], [38]).

The second group of models and applications regard to the issues connected with maritime transportation in a sea area risk analysis performance. The known literature mostly addresses the issues connected with accidents at sea investigation (see e.g. [28], [57], [70]), or sustainability in maritime shipping improvement (see e.g. [42]). In this research area recent literature review is provided e.g. by Goerland and Montewka in [29].

The last group regards to critical maritime infrastructure systems performance analyses. In this area the investigated problems mostly refer to policy making issues (see e.g. [6], [34], [43], [45]), optimization of seaport operations performance effectiveness (see e.g. [35]), or risk assessment models development (see e.g. [35]). For literature review, we refer reading e.g. [41].

However, the structure of the seaport operating system is marked by the existence of many critical processes and bottlenecks [12]. Thus, building resilience in maritime systems should base not only on the seaport infrastructure performance analysis. There should be also investigated the logistic support system performance as well as operating procedures, management practices and interactions with the environment. Following this, authors base on the third approach supplementing it with the focus on resilience management of logistics processes performed in the corridor to the seaport and in the seaport.

Moreover, today's ports are more than simply a system of channels, wharves, and multi-modal connections. They serve as profit centres for a variety of business, including shippers, shipping agents, energy companies, importers and exporters, and port authorities [10]. Thus, stakeholders in port logistics chain include all the entities involved in the international trade processes, such as the importers and exporters, the Port Authority, the terminal operators, customs and customs agents, transport companies, freight forwarders, etc. [6]. In work [12], author classified the main seaport stakeholders according to their operation in one of the three types main channels:

- trade channel (customs, transport regulators, port authorities, etc.),
- supply channel (suppliers, shippers/receivers, subcontracting),
- logistics channel (ocean carriers, ports/terminal operators, logistics providers, shipping agents, etc.).

Following this, according to [10] there can be defined two main group of seaport stakeholders: internal and external stakeholders:

- internal port – port authority organization (e.g. port operator, shareholders, managers, employees),
- external economic/contractual stakeholders – being involved in certain port operations (shippers, tenants, insurers, trucking companies, etc.),
- external community/environmental groups – who typically advocate on behalf of a particular cause or population (neighbourhood associations, non-profit organizations, etc.),
- external academia/research stakeholders – typically conduct individual (research) work or are contracted by another stakeholders (universities, consultants, boundary organizations, etc.),
- public policy stakeholders – include government agencies responsible for transport and economic affairs, environmental agencies, planning departments, and emergency management agencies.

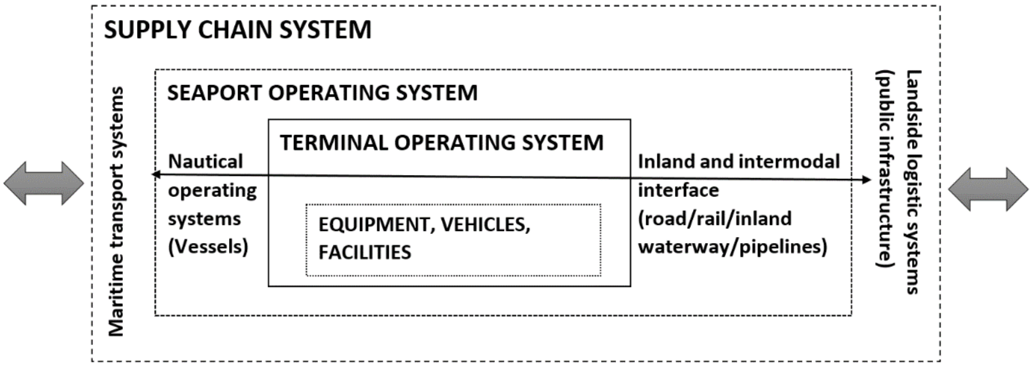

Figure 1. Seaport supply chain scheme
Source: Own contribution based on [12]

In this context, the seaport supply chain may be defined *as the process-oriented seaport subsystem that supports:*

- *its operational processes through the integration of all activities, being necessary to assure the effective and economical flow of needed materials and related information,*
- *its maintenance processes in the aspect of providing the necessary maintenance and support infrastructure,*

taking into account the multi-institutional and cross-functional dimensions of ports (*Figure 1*).

Following this, the key mission of seaport supply chain is to serve as *a throughput mechanism of goods, and in hardship, protect the dependents from the consequences of disruptive events* [11]. Thus, the resilience issues are gaining in importance.

Resilience is one of the strategies (as e.g. robustness, flexibility, adaptability, agility) that might be adopted an utilized by systems in response to occurred disruptions. Currently, there are varieties of definitions available in the literature that explain the term in the context of ecosystems, manufacturing, enterprise, network, infrastructure systems, etc. To make a distinction between resilience and other strategies applied by systems the main definitions of risk and vulnerability are given below.

Following authors [16] the existing definitions of ***risk*** express basically the same idea, adding the uncertainty dimension to events and consequences. The main risk analysis and risk-assessment methods and techniques are reviewed e.g. in [44]. The literature review on types of disasters is given in [63]. Author in his work provide the detailed review of three groups of disasters: natural, man-made and hybrid disasters.

The valuable overview of supply chain risk literature is given in [59], where authors divide the existing literature into a typology of risk sources, consisting of environmental factors, industry factors, organizational factors, problem-specific factors and decision-maker related factors. This problem is also continued e.g. in work [71], where authors map the processes and the structure of multimodal maritime supply chain and present a framework for categorizing the risks in terms of their driver factors. Moreover, authors analyse the risk impacts in terms of delays in the chain with the use of MC simulation. The risk of seaport system is extensively analysed e.g. in [35]. The risk analyses in published research works base on the information on potential direct and indirect economic losses from potential failure of facilities and operations at ports.

There exist many definitions of ***vulnerability*** term in known scientific works. In work [61] author identified trend in the definitions of the vulnerability, resilience and adaptation concepts, providing a short historical overview of their developments. Later in [69] authors present thirty-seven definitions of vulnerability term depending on the source and scientific area. Moreover in work [49] author tried to specify how to understand and define terms vulnerability, dependability and risk. For more information we refer reading e.g. [16], [50].

The term supply chain vulnerability also has been studied and defined by researchers in various ways. Some of the researchers studied supply chain vulnerability e.g. conceptually (see e.g. [53], [66], or mathematically (see e.g. [2]-[3]. Following authors of work [65] reducing vulnerability means reducing the likelihood of a disruption and increasing resilience – the ability to bounce back from a disruption. Some summary of vulnerability definitions in the context of supply chain performance was presented e.g. in works [14], [40], [48], [51].

Vulnerability within the seaport logistic chains may be defined as *the properties of a supply chain, its premises, facilities, handling and transportation equipment, inter- and intra-organizational construction, including contracts and incentives, human resources, human organization and all its software, hardware, and Netware, that may weaken or limit its ability to endure threats and survive* *accidental events that originate both within and outside the boundaries of the logistics chains* [5]. The similar definition is also presented e.g. in [11].

The presented short overview gives the possibility to define the term of ***resilience***. Resilience may be defined as *a system's ability to adapt and return to a new stable situation after an accidental event* [5]. Following the literature, supply chain resilience may be defined as the ability of the supply chain to handle a disruption without significant impact on the ability to serve the supply chain mission [11]. As reported e.g. in [21], the resilience definitions took into account the following supply chain aspects: its flexibility, agility, velocity, visibility and redundancy. A brief survey of resilience definitions from different disciplinary perspectives is given in e.g. [20], [27], [51]. The comprehensive literature review on supply chain resilience is presented e.g. in [14], [18], [40], [54], [61].

The resilience assessment issues is seaports operations and their logistics support performance are given e.g. in [74], where authors introduce a community resilience cost index aimed at estimation of recovery costs in resilience quantification. Discussion of modelling paradigm for quantifying system resilience, primarily as a function of vulnerability and recoverability is given in work [52]. There are proposed three metrics to quantify the resilience of inland waterway ports and seaports. Another approach is given in [36], where authors develop an original quality function deployment approach to enhance maritime supply chain resilience taking into account the customer requirements and maritime risk. The issues of disaster resilience of transportation infrastructure and seaports are reviewed in [41]. The authors reviewed the papers that have been published within the last 10 years since 2011. In 2014, authors in their work [33] propose a model for disruption risk of a seaport operation to optimize its performance effectiveness in a systematic manner. Later, in work [37], authors analyse and categorise the disruptions that have occurred in Asian ports and estimate the likelihood of their occurrence based on the data since the year 1900.

The seismic resilience of seaports is investigated in Shaf, 2014, where authors propose a scenario-based system resilience assessment for infrastructure systems. The complex approach for seaport resilience on climate change adaptation is given in [10]. Authors focus on the problems of storm impacts on seaports vulnerability and planning and policy making issues. The threats in maritime domain (e.g. piracy) are the field of research in work [7].

3. Conception of decision support system for seaports supply chain resilience management

3.1. Decision support systems for seaport operations and their supply chains - review

According to [30], [60], the decision making process includes three main steps, information gathering and analysis (including problem definition and classification, information model designing), available decisions definition (model solution), and optimal solution choice. Improvement of decision making process can be achieved with the use of decision support systems.

The concept of a decision support system (DSS) is extremely broad and its definitions may vary depending on the author's point of view and the way of its use [23]. Following [55], a DSS is defined as *an interactive computer-based system or subsystem intended to help decision makers use communications technologies, data, documents, knowledge, and/or models to identify and solve the problems, complete decision process tasks, and make decisions*.

There can be found many classifications of support systems in the literature. According to the authors [46], there is proposed the following classification:

- Transaction Processing System (TPS) – programs for gathering, updating and posting information according to pre-defined procedures,
- Management Information System (MIS) – a system with pre-defined aggregation and reporting capabilities,
- Decision Support System (DSS) – an extensible system with intrinsic capability to support ad hoc data analysis and reduction, as well as decision modelling activities.

Taking into account another approaches, there can be distinguished [56], [23]:

- at a conceptual level: Communication-Driven DSS, Data-Driven DSS, Document-Driven DSS, Knowledge-Driven DSS, and Model-Driven DSS,
- at a technical level: enterprise-wide DSS and desktop DSS.

In the article [30] authors define the main types of DSS being used in practical applications and investigate the problem of their reliability. The authors focus on two types of DSS: Executive Information Systems (EIS) and Expert Systems (EX). Moreover, they analyse the DSS being offered by different producers according to their possibility of implementations and main functions (e.g. systems INSERT Analityk or Matrix).

For more information, we recommend reading e.g. [4], [24], [26], [32], [42], [55], [64], [76], where literature review in the area of decision support systems designing and applications issues is provided.

The target of this study needs the investigation of DSS which were developed in the area of seaport supply chains performance. There are a lot of system solutions which support the decision process performance in the supply and distribution areas. The solutions are developed to support strategic decisions process performance in the area of enterprise management (see e.g. [22]), warehouse management (see e.g. [17]), transportation performance (see e.g. [31], [68]), or supply chain management (see e.g. [13]). For more information we recommend reading e.g. [67].

The seaports operation risk management issues are analysed e.g. in works [33], [45]. In work [45] authors develop a generic risk evaluation model in order to apply it to real port to port risk-based comparisons. The proposed solution bases on fuzzy set theory and evidential reasoning approach implementation. In work [32] authors focus on fuzzy risk analysis model for assessment of seaport operations. This problem is later investigated by the authors in work [35], where the risk assessment approach is developed with using Bayesian networks.

The fuzzy set theory is also used to develop a decision-making system to maritime risk assessment at open sea given in [8]. The work is aimed at evaluation of an individual maritime risk factor in the oil pollution prevention context.

Another interesting approach for resilient port infrastructure systems investigation is given in [43]. In this work, authors develop a risk-management-based decision analysis framework for management of risk involved in port infrastructure systems operation. Later, resilience of seaport operations performance is investigated in [34]. Authors in their work develop a fuzzy multi-attribute decision making methodology for the selection of an appropriate resilience investment strategy. The solution is based on fuzzy AHP analysis implementation. The seismic resilience of seaports is under study by the authors of work [62], while the issues of seaport resilience for climate change adaptation are investigated in [10]. The maritime port logistics chain management system is also given in [6], where authors propose a logistics management platform system and validate it with respect to a real port logistics chain in Chile.

To sum up, large numbers of operational maritime safety and security control measures and models have been developed during the last decade. Most of them base on the implementation of conventional techniques such as Fault Tree Analysis (FTA) and Event Tree Analysis (ETA), or assessment methods such as fuzzy set theory and AHP. However, the occurrence of natural disasters and man-made disruptions on seaport infrastructure and their logistic chains still demands further development. Following this, there are presented below the main assumptions for the development of DSS aimed at improvement of safety level of logistic support processes carried out in the corridor to the seaport and in the seaport in the context of proper performance of supply chain.

3.2. Preliminary conception of DSS for seaport supply chain vulnerability and resilience assessment

The proposed framework is going to be based on simple IT application that supports decision processes of chosen stakeholder groups in the area of risk management and that is based on the defined assessment algorithm for vulnerability and resilience of seaport supply chain performance. The developed IT application will be focused on the main informational needs of defined group of stakeholders and may be aimed at e.g. possible hazard scenario definition. The final structure of the IT application and its main operational tasks will be defined after the comprehensive performance of the following research tasks:

1. *Development of system for operational and maintenance data collection and processing in order to identify hazard events.*

The first research task is aimed at the development of database for resilience management of logistics processes performed in the corridor to the seaport and in the seaport. This project phase is also crucial for definition of guidelines for vulnerability and resilience assessment algorithm that constitutes the base for future development of decision support system in the area of seaports risk management performance.

2. *Development of algorithm for vulnerability and resilience assessment for logistic processes performed in the corridor to the seaport and in the seaport.*

This research task is aimed at the development of assessment algorithm for vulnerability and resilience of seaport supply chain. The assessment method is to be developed based on the *What if?* approach and Bow-Tie method.

3. *Verification of the developed algorithm for vulnerability and resilience assessment for logistic processes performed in the corridor to the seaport and in the seaport.*

This research task is aimed at practical application of the developed assessment algorithm, with an indication of the possibility of improving the future performance of the real-life system. The obtained results are to be the base for knowledge database development.

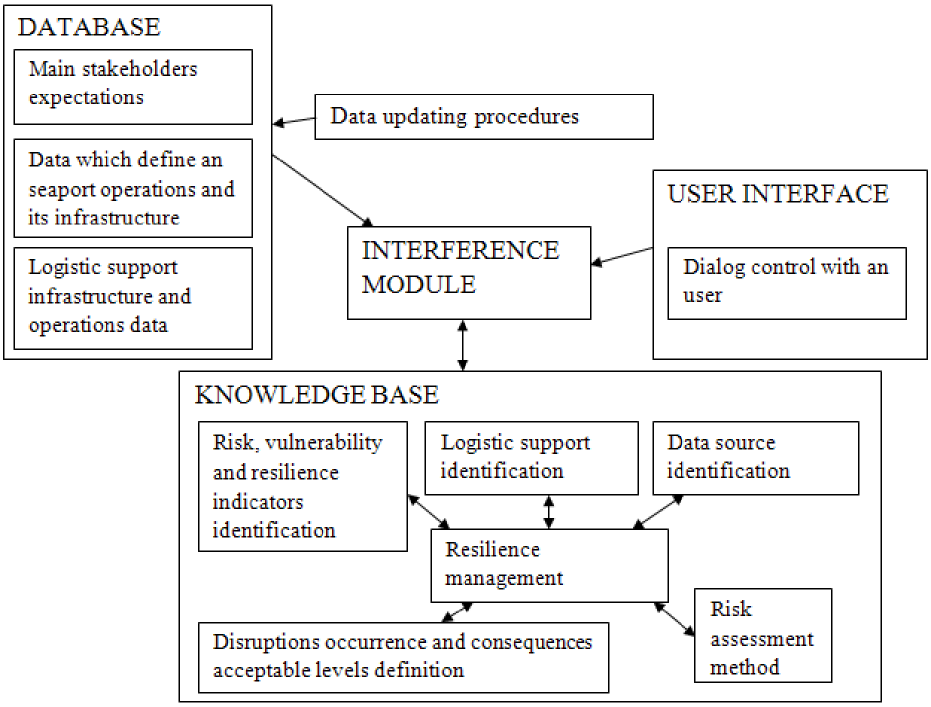

Figure 2. Decision support system for seaport supply chain vulnerability and resilience assessment preliminary structure

4. *Development of decision support system for seaports supply chain risk management in the aspect of vulnerability and resilience engineering.*

The decision support system in the field of seaport supply chain risk management preliminary conception is given at Figure 2. The main DSS elements are database that includes the main information necessary to conduct the decision-making procedures, and knowledge database for seaport supply chains performance.

3.3. The current research project's sub-tasks

The investigated research project is at his preliminary working stage. Following this, the main sub-tasks that are currently performed include:

1. Identification of the main stakeholders in the logistic system performed in the seaport and investigation of law regulations for logistic support performance.
2. Identification and analysis of logistic processes focused on material and information flows performance in the seaports.
3. Analysis of used infrastructure of logistic systems that supports the performance of the seaports.
4. Development of the classification for hazard events that may occur in the seaport supply chain.
5. Definition of guidelines for assessment algorithm of vulnerability and resilience of seaport supply chain performance.

These guidelines are to be based mostly on stakeholders expectation, law regulation limitations/requirements and available operational data on the one hand. On the other, they take into account the risk assessment tools that are to be defined as the most suitable for seaport supply chain performance investigation.

4. Conclusion and perspective

Seaports play a strategic role in international trade and transport. This is mostly due to the fact that they are an important link in the land - maritime transport chains, which can handle at one time the largest amount of cargo. Port is also a center of information on cargo, transport, potential transshipment port capabilities on cargo to/ from the port. Consequently, the development of the port functions is determinant of the development of cities and coastal regions [19]. For several years, Poland has taken actions aimed at restoring the importance of its seaports in the world arena and the European Union. In the "*Program of development of Polish seaports by 2020 (with the prospect of 2030)*" [58], there are formulated two specific objectives for the implementation: (1) to adjust seaports' service offer to changing market needs, and (2) to create a safe and environmentally friendly port system. One of the priority directions, beside safety improvement, there is indicated the improvement of maritime management that may be support by DSS in the area of decision making processes performance of managers and main groups of stakeholders.

It should therefore be noted that presented in the article assumptions about the direction of future research work fit in with the current development trends. Results of planned research study will constitute important contributions to the science, but they also can become an interesting material for decision makers responsible for policy development of seaports in Poland. Identification of risk sources and support processes related to managing constitutes an important element of the 4th. priority defined in the "*Program of development of Polish seaports by 2020 (with the prospect of 2030)*" [58], namely "*to ensure the safety of participants in port traffic*".

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