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A MULTILEVEL ANALYSIS OF STRATEGIC DISRUPTION AND LOGISTICAL COMPLEXITY IN THE MARITIME DOMAIN

Abstract. *The article presents a systematic approach to analyzing the current challenges facing maritime logistics in the context of increasing global turbulence, rising costs, digitalization, and a changing regulatory landscape. The authors provide a comprehensive analysis of the factors that reduce the efficiency and sustainability of supply chains based on a synthesis of international reports (IMO, UNCTAD, OECD), expert surveys, and structural modeling. A methodology for visual risk analysis in four key categories is proposed: economic (rising costs of fuel, freight, insurance), information (fragmentation or lack of digital transparency), technical and operational (complication of ship nominations and routing), and regulatory (tightening of international and national regulatory requirements). For each of these categories, we have developed visualized conceptual approaches that allow us to identify systemic risk nodes, assess scenarios of their spread in the logistics chain, and formulate adaptive response mechanisms at the level of operators and transport policy.*

The proposed approach is focused on integration into strategic planning processes under conditions of high uncertainty and can be used as a decision support tool. The results obtained are of practical value for the implementation of effective principles in the field of sustainable transport development.

Keywords: *maritime logistics, economic efficiency, maritime transport, investment, demurrage, sustainable development, ship nomination, regulatory compliance, safety of transportation, data analytics, logistics transformation, port management, transport services, strategic planning, supply chain, green shipping, maritime cluster, integrated management, port infrastructure, fleet operation, merchant shipping, transport development, cargo carriage.*

БАГАТОРІВНЕВИЙ АНАЛІЗ СТРАТЕГІЧНИХ ЗМІН ТА ЛОГІСТИЧНОЇ НЕВИЗНАЧЕННОСТІ В МОРСЬКІЙ ГАЛУЗІ

Анотація. *У статті представлено системний підхід до аналізу актуальних викликів, що постають перед морською логістикою в умовах посилення глобальної турбулентності, зростання витрат, розвитку інформаційних технологій та зміни регуляторного ландшафту. Здійснено комплексний аналіз чинників, які знижують ефективність та стійкість логістичних ланцюгів, базуючись на синтезі міжнародних звітів (IMO, UNCTAD, OECD), експертного опитування та структурного моделювання. Запропоновано методологію аналізу ризиків у чотирьох ключових категоріях: економічній (зростання витрат на паливо, фрахт, страхування), інформаційній (фрагментованість або відсутність електронної прозорості), техніко-операційній (ускладнення номінацій і маршрутизації суден), та нормативній (посилення міжнародних і національних регуляторних вимог). Для кожної з цих категорій розроблено і візуалізовано концептуальні підходи, що дозволяють ідентифікувати системні вузли ризику, оцінювати сценарії їх поширення в логістичному ланцюзі та формувати адаптивні механізми реагування на рівні операторів і транспортної політики. Запропонований підхід орієнтований на інтеграцію в процеси стратегічного планування в умовах високої невизначеності та може бути використаний як інструмент підтримки прийняття рішень. Отримані результати мають практичну цінність для впровадження ефективних принципів у сфері сталого розвитку транспорту.*

Ключові слова: *морська логістика, економічна ефективність, морський транспорт, інвестиції, демередж, сталий розвиток, фрахтування суден, нормативні вимоги, морські перевезення, аналітика даних, трансформація логістики, управління портами, транспортні послуги, стратегічне планування, ланцюжок поставок, зелене судноплавство, морський кластер, інтегроване управління, портова інфраструктура, експлуатація флоту, торговельний флот, розвиток транспорту, вантажні перевезення.*

Formulation of the problem. Maritime transport and logistics play a key role in global trade and global freight turnover and are the true foundation of the global economy. However, the modern maritime transportation system faces a number of challenges that make it difficult to effectively manage supply chains. Among the industry's most critical issues are persistent cost pressures, limited transparency of operations, complexity of ship nomination processes, and ever-changing regulatory requirements related to environmental responsibility and stakeholder expectations.

Analysis of recent research and publications. Modern maritime transportation systems operate in a complex, multi-level environment where strategic disruption and logistical complexity are increasingly becoming the determinants of performance. There is a growing interest in the relationship between digital transformation, environmental responsibility, risk resilience, and logistics continuity. A review of the literature allows us to trace the scientific evolution of approaches to modeling logistics challenges, assessing sustainability, analyzing technological maturity, and developing multi-level adaptation mechanisms in the maritime domain.

For example, [1] proposed a theoretical framework for assessing the sustainability of maritime logistics, taking into account indicators and methodology. The authors of [2] developed a three-tiered digital maturity model for the introduction of blockchain in the maritime industry. In [3], they focused on the challenges of achieving zero emissions in ports, highlighting political and infrastructure barriers. Article [4] examines the potential of hydrogen energy in ports on the example of New York and New Jersey.

The authors of [5] presented a blockchain solution to solve logistics problems in supply chains. In [6], they emphasized the threats of maritime terrorism as a factor in the strategic destabilization of logistics processes. Research paper [7] introduced an intelligent logistics model with knowledge graphs and AI agents to optimize mooring, [8] reviewed the use of machine learning in maritime risk assessment.

In [9], a correlation analysis of risk factors in automated container terminals was performed using a sustainability approach. Source [10] investigates the impact of environmentally oriented supplier management on value creation in maritime transport. In [11], a model for predicting changes in the seaworthiness of a ship under the influence of various factors is proposed. Paper [12] highlights the concept of renewable energy in shipping as a strategic response to environmental challenges, and [13] develops a method for assessing the quality of risk management of ship operations based on an expert approach. Works [14][15] revealed the regulatory and service aspects of customs logistics, which are important for reducing logistical complications, and [16] proposed an improved algorithm for interaction during customs and logistics services for cargo. In [17], the Agile model was adapted to the management of project-oriented transport companies in conditions of instability, and [18] presents the concept of the dynamics of the energy entropy of organizations, which allows modeling adaptability in logistics systems.

Given the growing complexity of maritime operations, the lack of a single integrated information base makes it impossible to make prompt management decisions. Ineffective interaction between supply chain participants, outdated IT systems and fragmented display of logistics processes lead to delays, financial losses and increased risks. Particular attention is drawn to the problems associated with compliance with IMO decarbonization regulations and emissions monitoring requirements, which require the introduction of new generation digital solutions.

The purposes of the article. The purpose of this paper is to provide a comprehensive analysis of current challenges in the field of maritime transport and logistics, followed by visual modeling of key issues based on thematic categories: costs, transparency, ship nomination, and regulatory restrictions. The proposed approach combines a structured description of current issues with the construction of graphical models that allow for the presentation of the relationships between factors in an easy-to-understand manner. This ensures both scientific novelty and practical value of the results for developers of solutions in the field of maritime logistics systems management.

Research methodology. The study uses a combination of qualitative analysis of industry challenges and a visual analytics approach aimed at systematizing key problems in the functioning of maritime logistics. The main goal of the methodology is to build a generalized visual profile of the challenges that have the greatest impact on the efficiency and sustainability of logistics processes in maritime transport.

The analysis is based on four critical categories of challenges identified through a literature review, technical industry reports, and recommendations from key international organizations (IMO, BIMCO, UNCTAD). For each category (rising costs, lack of transparency, complexity of nominations, regulatory requirements), we identified the impact factors, implications for logistics processes, and possible areas of response.

Data Sources and Expert Assessment. The information base of the study was formed by the following sources:

- reports of international organizations (IMO, OECD, UNCTAD);
- industry analytical reports of shipping companies and port operators (Maersk, MSC, Hapag-Lloyd);
- scientific publications for the period 2020-2025 related to supply chain sustainability, digitalization of maritime logistics and risk assessment;
- expert assessment (n = 12), which involved maritime logistics system experts, ensuring normalization of the impact parameter estimates.

Thus, the proposed methodology allows not only to identify the main problems, but also to assess their relative position in the "risk space", which is an important tool for strategic planning in the field of maritime transport.

Materials and Methods. Rising Cost Pressure. In today's environment of global instability, rising costs are one of the key challenges affecting the efficiency of maritime logistics operations. The main factors driving cost growth in the industry are higher freight rates, significant demurrage costs, port congestion, and external circumstances, including weather anomalies and geopolitical risks.

Particular attention should be paid to demurrage, which is a payment for vessel demurrage in ports, which has increased significantly due to chronic congestion in port infrastructure and disruptions in supply chains. Taking some of the larger carriers into consideration, such as Maersk and Hapag-Lloyd, massive losses of revenue amounting to millions of dollars are incurred each year due to delays engendered by congestion at some of the major ports in Asia, Europe, and the United States. Ships may also be called late due to weather conditions or storm warnings, which include high winds and fog. Such situation increases downtime and coordination complexity and therefore additional costs.

Other external causes exist, such as he price volatility in the fuel market, changes in tax legislation, or political conflicts, also have a direct impact on costs. All of these challenges combine to place a significant burden on shipping companies and logistics operators, reducing the profitability of transportation and making it more difficult to achieve sustainable development goals.

Figure 1 shows a comparative visualization of the dynamics of cost growth by key factors in 2021-2025.

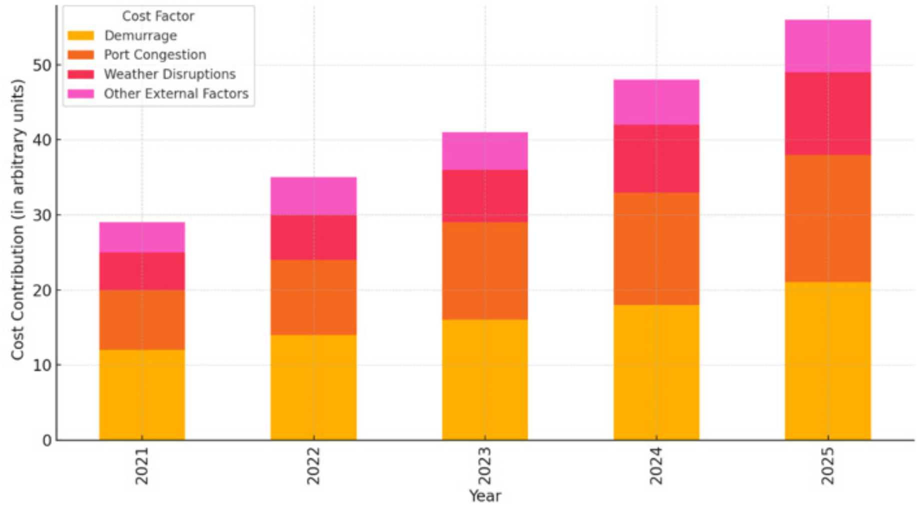

Fig. 1. Rising Cost Pressure in Maritime Logistics by Factor (2021-2025)
Source: compiled by the authors

The diagram illustrates the dynamics of growth of cost components in maritime logistics for 2021-2025. The chart shows the main cost factors: demurrage (vessel delays), port congestion, weather disturbances, and other external factors. Each category is shown in a different color, which allows you to visually compare the contribution of each factor to the overall cost structure by year. The figure shows that the total amount of expenses in the industry is growing from year to year, with demurrage and port congestion consistently making the largest contribution. The growth of costs associated with weather disturbances and other external factors in 2024-2025 is particularly noticeable, indicating an increasing role of external risks in modern maritime logistics. This trend underscores the need to implement adaptive risk management strategies and digital technologies to increase supply chain resilience.

Incomplete Visibility and Information Gaps. One of the critical problems in maritime logistics is the fragmentation of information flows and the lack of a single integrated system for data exchange between all supply chain participants. Due to the involvement of a large number of stakeholders - shipping companies, port operators, agents, customs, cargo owners, and regulators - numerous delays and gaps in communication arise. Each participant often uses its own information system, making it impossible to create a single source of truth.

Lack of prompt access to up-to-date information makes it impossible to accurately predict delays, increases the risk of underloading/overloading, and complicates monitoring of environmental and contractual obligations. To solve this problem, it is necessary to implement integrated monitoring systems based on data-sharing principles to ensure transparent interaction between all parties.

The sketch in Figure 2 illustrates the integrated multi-level architecture of information interaction in modern maritime logistics, which covers the strategic, operational, and governmental levels.

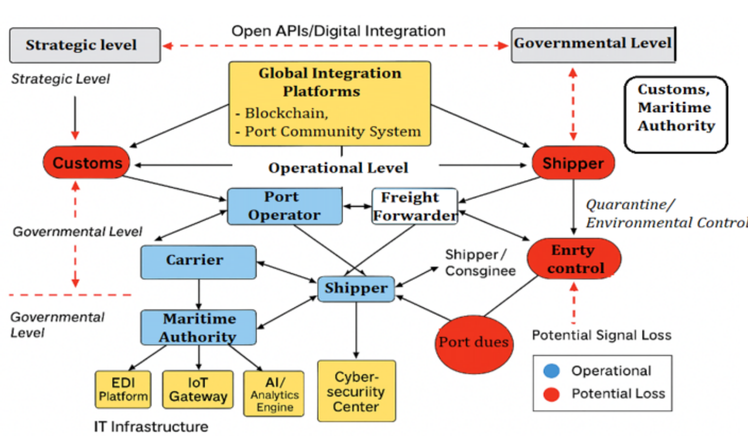

Fig. 2. Multilevel structure of information integration and potential loss points in maritime logistics chains
Source: compiled by the authors

At the strategic level, global integration platforms (e.g., blockchain, Port Community System) are represented, which ensure openness and digital integration through Open API. At the operational level, the key participants are port operators, freight agents, shipping companies, shippers, and control authorities (customs, sanitary and epidemiological, environmental control). Interaction between these entities takes place through the IT infrastructure: EDI platforms, IoT gateways, artificial intelligence analytical modules, and cybersecurity centers. The red circles in the diagram indicate potential signal loss points or information gaps that can lead to slower processes or increased operational risks (for example, duplication of procedures, delays in control, or loss of data on port dues payments).

Complexity of the ship nomination process. The process of vessel nominations in maritime logistics is multifactorial and extremely complex, as it requires consideration of a number of technical, commercial and regulatory criteria. When selecting a vessel for a particular transportation, it is necessary to assess its technical suitability, compliance with environmental standards, availability at a certain time, freight cost, and the specifics of the contract between the parties.

One of the significant complications is the lack of unified nomination procedures. Different companies apply their own approaches to vessel valuation, which leads to discrepancies in requirements, delays in approvals, and increased transaction costs. In addition, there is often a lack of complete information about the technical characteristics of ships (e.g., emissions or compliance with the latest IMO regulations), which makes it impossible to objectively assess whether a ship meets the customer's requirements.

Fig. 3 shows a decision tree that demonstrates the typical logic of vessel selection depending on key criteria: type of cargo, route, environmental restrictions, technical availability and cost parameters. This approach allows for a structured and transparent analysis of nomination scenarios, reducing subjectivity in decision-making.

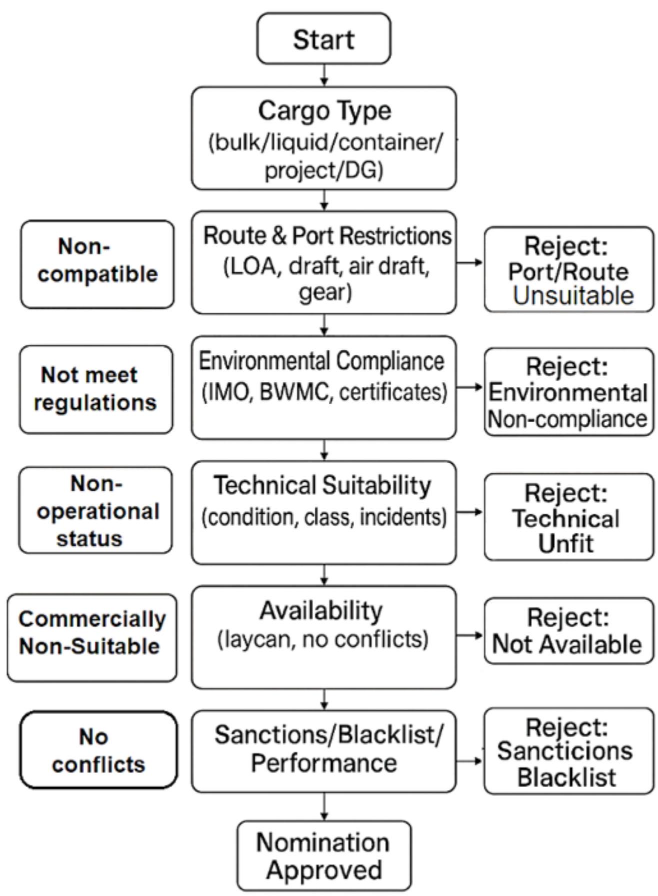

Fig. 3. Decision Tree for Vessel Nomination
Source: compiled by the authors

The nomination process can be made more efficient by automating decision-making, integrating databases on vessel characteristics, and introducing standardized conformity assessment templates. This will not only reduce response time but also increase the objectivity and environmental compliance of logistics solutions.

Changing regulatory requirements and stakeholder expectations. The modern maritime logistics industry is facing increasing regulatory pressure, primarily related to decarbonization, supply chain transparency and environmental reporting. The International Maritime Organization (IMO) has been consistently implementing standards such as EEXI (Energy Efficiency Existing Ship Index), CII (Carbon Intensity Indicator), and ballast water and sulfur emissions requirements. These regulations oblige shipowners not only to technically modernize their fleet, but also to ensure continuous monitoring and reporting of environmental performance.

At the same time, expectations from customers, investors, and society are growing in terms of sustainable development. Logistics companies are increasingly required to demonstrate responsibility for the entire supply chain, from the nomination of a vessel to the arrival of cargo at the final destination. It is especially important to ensure transparency of data on emissions, fuel consumption and compliance with environmental standards.

In the current maritime logistics environment, there is a gradual increase in regulatory influence from international bodies, primarily the IMO. The introduction of new standards, such as EEXI (Energy Efficiency Index for Existing Ships), CII (Carbon Intensity Index) and requirements for ballast water treatment and sulphur emission limits, directly affects the technical suitability of ships for further operation. Ships that do not meet the requirements are subject to temporary or permanent withdrawal from the market, which reduces the available tonnage of the fleet.

At the same time, there is growing pressure from stakeholders - cargo owners, investors and regulators - who expect full transparency regarding the environmental behavior of the vessel, in particular in terms of CO_2 emissions, fuel consumption and compliance with the principles of sustainable development at all stages of the supply chain. This requires the implementation of digital monitoring systems, automated reporting and strategic fleet planning.

Fig. 4 shows the impact of regulatory changes on available fleet tonnage.

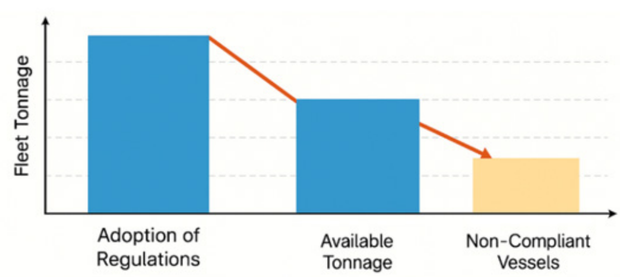

Fig. 4. Impact of Environmental Regulatory Changes on Fleet Tonnage Availability
Source: compiled by the authors

The figure shows the reduction in available fleet tonnage due to the introduction of international environmental regulations (EEXI, CII, SOx emission limits, BWMC). The adoption of more stringent environmental requirements leads to the temporary or permanent decommissioning of vessels that do not meet these requirements, which affects the availability of tonnage on the market and causes volatility in freight rates.

This leads to the temporary or permanent withdrawal of vessels found non-compliant with environmental standards, limiting the available tonnage supply on the market and causing fluctuations in freight rates, as well as delays in logistics.

One clear instance of regulatory challenges was offered by the introduction of the energy efficiency indices of CII (Carbon Intensity Indicator) and EEXI (Energy Efficiency Existing Ship Index), which have caused considerable tonnage reductions on intra-European routes and led to the berthing of certain vessels at Chinese ports for being non-compliant with the regulation. These changes are encouraging shipowners to modernize their fleets, introduce new types of fuel and revise their logistics strategies.

Thus, adaptation to the new regulatory environment requires strategic planning, investments in fleet modernization, digital solutions for environmental monitoring and transparent data management. This is becoming a key factor in competitiveness in the maritime transportation market.

Limitations and directions for further research

The study has certain limitations related to the expert assessment of impact parameters, which may contain subjective components. In addition, the model covers only the key challenges and does not take into account the specifics of individual regional markets or types of cargo.

Further research could focus on developing digital response scenarios for individual port hubs, modeling the impact of regulatory changes on the ship fleet, and integrating ESG indicators into logistics performance measurement systems. It is also advisable to expand the empirical data base by drawing on the practical experience of container and ferry operators.

Conclusions. The study identifies and systematizes the key challenges affecting the functioning of maritime transport and logistics systems: rising operating costs, lack of transparency, complexity of nomination procedures, and increased regulatory pressure. The proposed visual and analytical approach allowed us to create a multidimensional threat model that reflects their impact on the efficiency and sustainability of logistics processes.

The results can be used to increase the strategic flexibility of shipping companies and port operators, in particular through integration into digital decision support systems. The application of the proposed model allows for timely identification of risks and development of adaptive response scenarios in the field of maritime logistics.

The key is that the results obtained have the potential to be integrated into port sustainability policies, in particular by supporting the digitalization of environmental monitoring, developing digital twins of port operations, and ensuring compliance with ESG principles. This will contribute to the implementation of the green ports strategy and the transformation of logistics chains in line with global sustainable development goals.

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