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## THE IMPACT OF ENVIRONMENTAL FLUCTUATIONS ON THE PERFORMANCE OF INTERNATIONAL MARITIME TRANSPORTATION

*This article presents an analytical review of the current state of global maritime fleet development and the impact of environmental fluctuations on the efficiency and effectiveness of international maritime transport. The research objective is to develop information and analytical tools to support maritime transport logistics processes in the face of unpredictable environmental changes, which is essential for improving the efficiency of international maritime transport management. The article notes the dominance of vessels of various functional purposes in maritime trade. China's dominance is supported by the bulk carrier and container ship sector, Japan by refrigerated vessels and liquefied petroleum gas vessels, the United States by cruise ships, and Singapore by vessels transporting liquefied natural gas and supporting offshore fields. The article determines that, against the backdrop of growing international transport, disruptions and interruptions associated with geopolitical conflicts and climate risks are observed. A substantive interpretation of the impact of geopolitical conflicts on the efficiency of maritime transport is offered. An analysis of the components of the influence of the external environment on the efficiency of transport is provided. The paper outlines the key trends in the modern development of maritime freight transportation in the context of dynamic environmental changes, including a 2% growth in global seaborne trade with significant cost fluctuations, regional transport disruptions, and rising consumer prices caused by rising freight rates. Recommendations and prospects for the development of maritime transportation in an uncertain environment are offered, including the use of modern low-carbon fuel technologies, coordinated route planning, and the development of new logistics solutions.*

**Keywords:** transportation, international sea routes, analysis, status, external environment, obstacles, classification, trends, recommendations

### Statement of the problem.

The relevance of this work relates to maritime logistics management processes under conditions of uncertain external disturbances on the operation of shipping facilities. Complex, constantly changing maritime shipping conditions negatively impact their implementation. When preparing shipping plans, it is necessary to consider, in addition to possible navigational and climatic conditions for their duration, intensity, and timing, equipment performance characteristics (fuel consumption, transit speed, main engine loads, etc.), as well as economic factors related to overall shipping costs associated with deviations from planned international routes, additional fuel consumption, and personnel salaries. Planning in advance for possible changes in maritime shipping conditions is virtually impossible, requiring management decisions to be made under conditions of uncertain environmental influences.

**An analysis of recent research and publications on this issue shows that the necessary information on the impact of environmental fluctuations on maritime transport is reflected in estimates contained in statistical compendiums [1, 2]. However, a detailed analysis of the causes of environmental influence on the efficiency of international maritime transport is not provided. Uncertainty in management is associated with insufficient information on the conditions of specific situations during transport transitions, as well as a low degree of predictability and foresight of these conditions. Uncertainty is associated with risk in maritime transport management [3, 4].**

In [5], it is noted that logistics in ports and maritime supply chains has reached such a level of complexity that decision-making under uncertainty requires the use of analytical methods in the form of decision support systems for various operational tasks. The problems and trends of the maritime shipping industry are specified. The rapidly changing external environment forces adaptation to external disturbances and the selection of

appropriate management tools. In [6], the characteristics and patterns of functioning of maritime shipping companies are examined in the context of permanent changes in the economic situation with the expansion of regulatory influences from international maritime organizations. In [7], factors hindering the systemic development and realization of the potential of multimodal transportation from the perspective of logistics and transportation are identified. A single-criteria approach to optimal planning of maritime transportation cannot currently be considered satisfactory, as there is no universal indicator that can be applied as a single criterion of optimality.

Maritime traffic management based on the exchange of digital information and optimization of the maritime transportation chain is considered in [8]. Factors for effective resource management include improved situational awareness on the bridge, timely arrival at port, and shorter routes.

The maritime transport and logistics sector requires intensive data exchange for effective management and decision-making. The integration of Internet of Things (IoT) technologies in the maritime industry [9] includes vessel tracking, emissions monitoring, and cargo delivery security. IoT solutions, adapted to the current needs of the maritime transport sector, are aimed at intelligentizing maritime services. [10] identifies key research challenges and trends in testing external induced loads, humidity, and transparency of bulk cargo during maritime transportation.

An analysis of information on maritime transport management tools under uncertainty allowed us to identify key processes in modern maritime transport information support and determine their focus on improving transport efficiency.

An unresolved aspect of the overall problem of managing the development of international maritime transport includes an assessment of the current state and the degree of influence of the external environment on process efficiency.

**The aim of this work** is to study the impact of environmental fluctuations on the performance and efficiency of international maritime transport and trends in these changes. To achieve this, the following tasks must be completed:

- compilation of an information and analytical database on global maritime transport;
- determining the volume of international maritime transport and its development trends;
- identifying the factors hindering the development of international maritime transport;
- specifying geopolitical conflicts and climate risks;
- drawing conclusions and recommendations.

**Contribution to the main material of the investigation.**

The global merchant fleet plays a key role in the global economy, transporting goods over long intercontinental distances. Countries with developed maritime fleets can export their goods and import necessary resources. Maritime transport accounts for up to 80% of all global shipping. In 2025, the global order book amounted to 5,404 vessels with a total deadweight of 346 million tonnes, a 15% increase over 2023 figures [2]. The development of the global maritime fleet is characterized by an increase in orders for vessels with increased transport volumes.

Today, the main categories of vessels—bulk carriers, tankers, container ships, and gas carriers—account for more than 90% of the total maritime fleet by tonnage. China has the largest fleet by number of vessels. China's dominance is supported by the development of the bulk carrier and container ship sectors, valued at US\$68.4 billion. Japan is the leader in the liquefied petroleum gas and refrigerated cargo segment, with a vessel value of \$49.9 billion. Greece has the largest tanker fleet, exerting strategic influence on global shipping lanes and enabling it to capitalize on geopolitical shifts. The United States continues to dominate the cruise sector, valued at \$58.6 billion. Singapore serves the petroleum gas and offshore support market, with a fleet valued at \$107.2 billion. Singapore's strategic location and developed port infrastructure have made it a maritime hub.

The sharp rise in ship prices is due to disruptions to maritime transport in the Red Sea, as ships divert their routes around the Cape of Good Hope to avoid military action. In December 2023, the political situation in the Middle East escalated, leading to attacks on cargo vessels transiting the Bab el-Mandeb Strait, which connects the Red Sea and the Gulf of Aden. Shippers are forced to seek alternative routes.

The dynamics of international maritime transport per ton of cargo, with a shift toward longer routes, is presented in Figure 1 [2].



Fig. 1 – International Sea Transport Dynamics

Bypassing the African continent around the Cape of Good Hope adds 14-15 days to the Red Sea voyage on the China-Europe route. Bypassing Africa increases the distance and time of crossings, which in turn increases demand for vessels by 3% and container ships by 12% [1]. The increased route lengths have led to an increase in the number of port calls. This has complicated the maritime operational environment and exacerbated environmental problems associated with additional carbon dioxide emissions caused by increased fuel consumption and faster vessel speeds. The challenging operational environment for maritime transport, driven by geopolitical conflicts and climate risks, is hampering the stability of maritime trade. The increased route lengths have led to congestion, particularly in Asia, which accounts for 60% of global container trade. By mid-2024, vessel transit through the Suez Canal had declined: throughput through the Gulf of Aden had fallen by 76%, while transit through the Cape of Good Hope had increased by 85%. Lengthening the routes had led to increased costs for fuel, wages, and insurance, and had caused an increase in atmospheric emissions. Rising trade costs and shipping tariffs had led to an increase in global consumer prices. Simulation calculations show a 0.9% increase in consumer prices. This will have the greatest negative impact on the development of small island developing states, as these countries depend on maritime transport, particularly on the import and export of food products. Due to global changes and disruptions in strategically important shipping lanes, real GDP is projected to decline by 0.06%, and in these countries, the decline may be nearly halved, as meteorological factors such as air temperature, wind speed, direction, and precipitation intensity are the determining factors.

According to the UN Conference on Trade and Development, they will grow by 0.6% in 2025 due to rising shipping costs. The dynamics and trends in maritime trade demonstrate the continued focus on international maritime transport.

The concept of risk is associated with an assessment of the probability of occurrence of events, while the concept of uncertainty does not have such an assessment of probability. There are differences in the cause-and-effect relationships of both concepts. Uncertainty is generated by incomplete information, the randomness of the manifestation of external unstable connections, the result of the intersection of independent processes and events. Risk is directly related to decision-making. The concept of uncertainty is ambiguous, while risk has a quantitative dimension. In this case, risks should first be identified, and then a number of precautionary measures should be taken to reduce or eliminate them.

The war in Ukraine and restrictions on shipping in the Black Sea forced Egypt to purchase grain from Brazil. In September 2023, Turkey implemented additional technical safety protocols, which resulted in delays in adapting to the new regulations.

Climate change is among the factors that determine the impact of external conditions on the functioning of the international maritime shipping sector. Storms, hurricanes, fog, and ice are the causes of disruptions to shipping schedules due to low water levels in the Panama Canal, and sometimes even transport accidents due to tsunamis in countries such as Japan and South Korea.

There is no universally accepted definition of geopolitical conflicts due to the diversity of political, economic, and international legal aspects. The semantic content of the term geopolitical conflict is understood as a manifestation of interstate contradictions at a stage of significant escalation.

In their most obvious interpretation, geopolitical conflicts result from the interaction of parties to pursue their interests, using all available means within the relevant international relations. They exhibit characteristics of perceived necessity, increasing tension, and pressure without the use of external force. Based on these definitions, a general description and specific use of geopolitical conflict in maritime transport is presented in Table 1.

Table 1 Geopolitical conflicts in maritime transport

General features and characteristics	Features of manifestation in maritime transport
Rising tensions	Manifestation of interstate contradictions
Pressure without resorting to military action	Protective measures
Changing the rules of conduct for interacting parties	Timely response to changes in transportation conditions
Interstate discrepancy and inconsistency	Agreements and protocols
Fulfilling one's own interests at the expense of other countries	Adequacy of responses
Pirate attacks	Changing routes and transition plans

Geopolitical conflict in maritime transport exacerbates the destructive effects of international relations. The causes of conflict include:

- competition between states;
- conflicting national interests;
- territorial claims.

A diagram of the environmental impact on maritime transport performance, compiled based on the information presented, is presented in Figures 2 and 3.

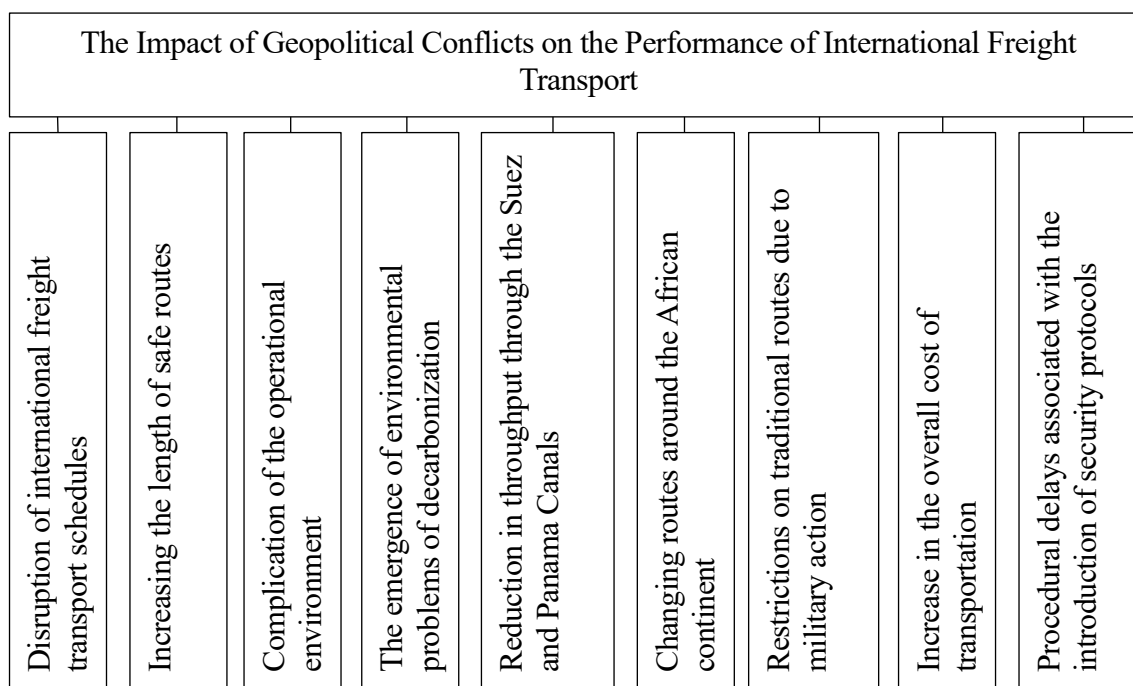


Fig. 2 – The impact of geopolitical conflicts on the performance of international freight transport

Global climate change is associated with long-term weather fluctuations caused by both natural conditions of increased solar activity, melting glaciers, shallowing of riverbeds and water areas, and anthropogenic human

activity associated with deforestation, drainage of wetlands, and an increase in the greenhouse effect from the combustion of fuel in international maritime transport. The consequences of this are global changes in sea level, extreme changes in weather conditions, hurricanes, tornadoes, and tsunamis. Climate change has led to an imbalance in natural systems: melting glaciers, rising sea levels, changing precipitation patterns, and an increase in the frequency of extreme events. Recommendations from analysts at the UN Conference on Trade and Development [2] propose joint action, because climate change affects every country, as a link is observed between climate change and the occurrence of natural disasters. It is noted that with rising sea levels, low-lying areas of the United States, Great Britain, Italy, Germany, and Denmark will be flooded. Urgent and ambitious action is needed to support the sustainability of climate change and risk reduction measures in the use of transport technologies.

Artificial intelligence and machine learning will be potentially transformative technologies in predicting changes in navigation and weather conditions. Various insights from advanced satellite technologies, Internet of Things innovations, and digitalization can be used not only to detect climate change but also to proactively address environmental impacts on the performance of international transport.

Climate change impacts integrated socio-ecological systems [11], disrupting their sustainable functioning and causing irreversible changes. Sea ice is declining, permafrost is melting faster, heat waves and heavy precipitation are increasing, and water resources are depleting. These impacts are changing lifestyles, management strategies, technological solutions, and implementation measures. It is necessary to develop, integrate, and adjust strategies for interaction between economic actors in the context of changing climate conditions and climate adaptation over time.

The combination of geopolitical tensions, the impacts of climate change, and armed conflicts has led to disruptions and interruptions in trade and supply chains.

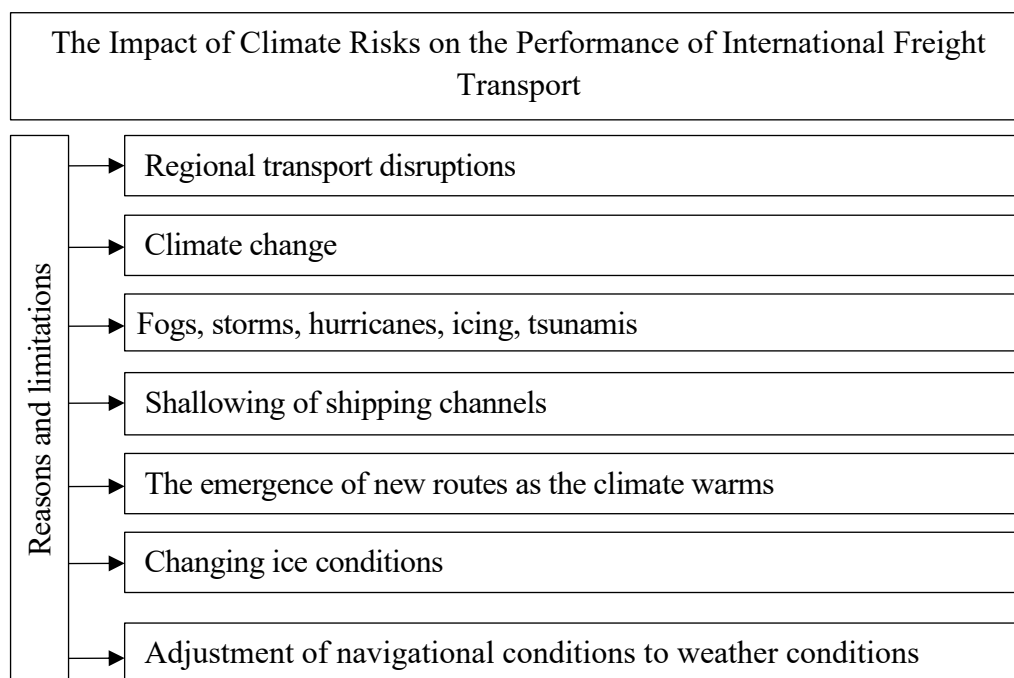


Fig. 3 – The impact of climate risks on the performance of international freight transport

The key trends in global maritime freight transport are:

- 2% growth in global seaborne trade, with significant cost changes;
- regional transport disruptions related to the refinement of the Suez and Panama Canals, port congestion, and increased operating costs;
- freight growth associated with increased distances and higher insurance premiums;
- rising consumer prices driven by rising freight rates.

According to UNCTAD forecasts [1], global seaborne trade will grow by an average of 2.4% in 2029.

The recommendations of the United Nations Conference on Trade and Development are aimed at coordinated action in the areas of navigation and adaptation, increased investment in low-carbon fuels, the use of modern technologies in forecasting, more precise route planning through the development of software and hardware for managing uncertain external influences, and the development of flexible logistics solutions.

To improve safety, reliability, and resilience, the maritime logistics sector must embrace new digital technologies. As maritime logistics overcomes the challenges, priority must be given to developing management tools to cope with the uncertain impact of external disturbances, helping to withstand disruptions and adapt to their sources. The external environment is becoming increasingly fluid and unpredictable, adding new challenges and tasks to maritime transport performance. It's important to maintain focus not on the final goal, but to apply a specific set of knowledge to achieve it and implement it in specific conditions.

#### **Evidence and prospects for further exploration in this direction.**

The novelty of this work lies in its systematization and classification of the impact of geopolitical conflicts and climate risks on the efficiency of maritime transport. It outlines the key trends in the modern development of maritime freight transport in the context of dynamic environmental changes, including a 2% growth in global seaborne trade with significant cost fluctuations, regional transport disruptions, and rising consumer prices caused by rising freight rates. Recommendations and prospects for the development of maritime transport in an uncertain environment are offered, including the use of modern information-intelligence technologies for managing low-carbon fuel development, coordinated route planning, and the development of new logistics solutions. This allows for the discovery of new directions for the further development of international transport.

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