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ANALYSIS OF METHODS FOR OPTIMIZING INTERMODAL TRANSPORT SYSTEMS USING DIGITAL TECHNOLOGIES AND COST ANALYSIS

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This article examines contemporary approaches to optimizing maritime and intermodal transport in the context of economic globalization, rising prices for fuel and energy resources, and increasingly stringent environmental requirements in the transport sector. It analyzes the impact of fuel costs on the configuration of container transport, the economics of intermodal transport, and the reduction of emissions from ship engines. The use of economic-mathematical methods and information technologies to improve the efficiency of transport systems is examined separately. The impact of optimizing ship speeds, implementing energy-efficient technologies, and utilizing intermodal logistics on cost reduction and the sustainable development of the industry has been investigated. In a generalized form, the results obtained can be used to optimize the transportation process and for the general development of system development strategies.

In recent years, the issue of improving maritime and intermodal transport has increasingly become the subject of scientific research in various countries around the world. T. Notteboom and B. Vernimmen conducted studies on the impact of fuel costs on the organization of maritime transport. They noted that rising fuel prices significantly affect the structure of the container fleet. This leads companies to reduce vessel speeds to optimize routes.

M. Issa explores the environmental sustainability of maritime transport and the

economic evaluation of technologies aimed at reducing emissions from ship diesel engines. The authors emphasize the need for an innovative approach in line with international environmental standards.

B. Sahin focuses on a methodological analysis of the economics of intermodal transport. The study presents methods for evaluating the transport system based on relative prices, delivery times, and comprehensive service.

The source of statistical data on the development of international trade and maritime transport is the reports of the United Nations Conference on Trade and Development (UNCTAD). These materials analyze current trends in the global transport market.

A. Algendi studied the optimization of performance indicators in maritime logistics, taking into account the impact of cargo loading on ship speed. Their research confirms that the use of mathematical models significantly contributes to improving the efficiency of transport processes.

Thus, a review of the literature highlights the importance of studying the optimization of maritime and intermodal transport in light of current economic and environmental challenges.

Maritime freight transport has always been and remains the backbone of global trade, as it accounts for over 80% of international goods shipments. Its efficiency provides a significant advantage and contributes to the competitiveness of the national economy and the stability of global logistics chains. Today, this industry faces several challenges, including rising fuel costs, stricter environmental regulations, and the integration of different modes of transport. Thus, the efficient use of intermodal transport—combining different modes—helps optimize logistics processes and reduce transportation costs. Combining sea, rail, and road transport ensures the seamless delivery of goods over long distances. At the same time, increasing environmental safety requirements are driving the adoption of new technologies and energy-efficient solutions.

Thus, the objective is to examine modern methods for optimizing maritime and multimodal transport based on scientific literature and international statistical data.

The main objectives of the study are:

- analysis of the impact of fuel costs on the organization of maritime transport;
- assessment of the economic efficiency of intermodal transport systems;
- study of the environmental aspects of maritime transport operations;
- identification of areas for optimizing logistics processes.

Under current conditions, maritime routes are becoming a key link in international trade, accounting for the majority of cargo movement across the oceans. However, challenges such as high fuel prices and strict environmental protection standards are forcing a reevaluation of how transportation is organized. Logistics efficiency today requires different models and approaches to route management. Analytical reports from the UN and the IMO demonstrate that without technical upgrades, shipping will not meet the required standards. Reducing emissions, conserving resources, and simultaneously accelerating delivery are the main goals of innovative development. The link between transport policy and the principles of sustainable development is of particular importance. Furthermore, the pursuit of progress in the field of shipping must take into account SDGs 8, 9, 12, and 13.

Instead of choosing the shortest shipping routes, shipowners are increasingly factoring fuel costs into their route planning. This reduces expenses by allowing for stops at ports where bunkering prices are lower. As a result, the route may become longer, but overall transportation costs decrease; even a small difference in fuel prices affects the final budget of the voyage. Previously, the most important task was to reduce distances; now, the priority has shifted to overall efficiency. Therefore, logistics systems are now being adapted to actual costs rather than geography.

Thanks to this approach, resource use is more economical, which aligns with SDG 12.2 regarding the rational consumption of natural resources. The possibility of implementing such a model has emerged thanks to the spread of digital technologies, including systems for analyzing data on bunkering, atmospheric conditions, terminal loading, and vessel schedules.

Optimizing the route, speed, and fuel consumption is approached as a mathematical problem aimed at reducing overall costs. It has been found that as fuel

prices rise, shipping companies adjust their service schedules, adapt vessel routes, and reassess delivery times. Flexibility in logistics enables a rapid response to new conditions; however, this approach is not always resilient to economic fluctuations or global events.

Instead of optimizing through logistics, another approach focuses on upgrading the technical condition of vessels. Technological advancements in the fleet help reduce costs in day-to-day operations, meaning the focus shifts from shipping routes to the hull, engines, vessel control systems, and so on. Energy efficiency becomes the result of modifications made directly to the vessel itself. The goal is lower fuel consumption, quieter operations, longer equipment service life, and other benefits, where each improvement reduces environmental impact. These areas of activity align with UN Goals 12.2, 8.4, and 9.4, where resources are used more efficiently where modern solutions are implemented.

The main areas of technical optimization are:

- modernization of ship engines;
- improvement of the hull's hydrodynamic characteristics;
- implementation of fuel combustion optimization systems;
- use of alternative fuels;
- installation of exhaust gas cleaning systems;
- adoption of energy-efficient technologies.

It has been proven that fuel consumption depends not only on speed but also on the ship's design. This approach makes it possible to reduce emissions and costs, even if the shipping route remains unchanged. Although upgrading equipment requires significant capital investment, over time these investments pay off in the form of stable profits and a reduced environmental impact, bringing us closer to achieving UN Goals 8.2 and 13.

Digital technologies are increasingly becoming the foundation for optimizing maritime logistics processes, which is linked to Sustainable Development Goals 8.2, 9.1, and 12.6. In addition to automation, the analytical capabilities of new platforms play a key role. Real-time data is obtained through IoT devices installed on ships. Fleet

management systems are gradually replacing traditional monitoring methods. Artificial intelligence helps predict equipment status to avoid downtime. This approach allows for more efficient route planning through the use of Big Data. Furthermore, the economic benefits are complemented by environmental benefits due to reduced emissions.

Instead of high speeds, the concept of slow steaming is adopted; this approach helps ships consume less fuel and emit significantly fewer pollutants into the environment. Digital solutions also ensure that cost savings do not interfere with meeting cargo delivery deadlines.

In addition, digitalization contributes to:

- synchronizing the operations of ships and ports;
- minimizing downtime;
- optimizing transport schedules;
- increasing the reliability of logistics chains.

The use of economic and mathematical models makes it possible to calculate the optimal speed for ships based on their load. This approach saves time and also optimizes the entire intermodal transportation system. Every decision is based on accurate data rather than assumptions, ensuring efficiency through a constant balance between costs and volumes. An effective management system for the maritime segments of intermodal transport relies on a combination of digital, technical, and logistical components.

As bunker fuel prices rise, companies are reevaluating their routes, as cost savings become a priority. Instead of speed, they opt for a slower pace to reduce expenses. As a result, shipping lines frequently adjust schedules or the number of ports along a route. Even a minor adjustment to a vessel’s route can have a significant impact on the entire voyage. Rising fuel costs also affect the frequency of sailings.

Energy savings achieved through modern solutions help the fleet operate more efficiently. Instead of conventional fuel, alternative fuels compliant with International Maritime Organization regulations are being used. This transition mitigates environmental damage, and the benefits of this approach become evident from the very beginning. The market is responding to these changes gradually but irreversibly.

Instead of separate transportation systems, a more efficient cargo route is created. Travel time is reduced through better synchronization, not through increased speed. Unforeseen delays occur less frequently when the links in the chain interact seamlessly. Logistics become more robust thanks to the smooth transitions between modes of transport.

Thanks to mathematical models, ship speed control becomes more precise. Digital systems allow for improved logistics without losing control over routes, and delivery efficiency increases along with the regularity of shipments. The reliability of transport flows is ensured through responsive control mechanisms.

Maritime transport remains the backbone of international trade, underscoring the need for its further modernization and innovative development.

Conclusions The study found that an analysis of scientific research and statistical data from international organizations revealed the important role of maritime routes in the global freight delivery system. An examination of various approaches to improving transportation demonstrates the effectiveness of modern fleet management models, and the data supports the need to integrate new technologies into logistics processes. Practice shows that without a maritime network, it is difficult to imagine a stable exchange of goods in international trade. Furthermore, intermodal schemes are gradually becoming the primary method of moving cargo shipments. A detailed comparison of influencing factors highlighted shipping's key contribution to the overall supply system.

Rising bunker fuel prices are changing the logic of maritime transport, with efficient routes becoming more important than speed. In addition to choosing ports for bunkering, companies are increasingly opting for slower vessel speeds to save on costs and fuel. This approach, though simple, aligns with Sustainable Development Goal 12.2. It is worth noting that costs are rising and the industry is responding with practical adaptations rather than theoretical plans. Such changes demonstrate how the economy directly shapes the environment through technical solutions.

The economic benefits of intermodal transport have been proven in practice: it reduces costs, speeds up delivery times, and makes logistics more stable—all of which

are directly linked to Sustainable Development Goal 8. Although technologies change, the primary advantage lies in the balanced combination of transport modes. Every step toward integrating transport modes yields real savings, not just theoretical improvements. Such systems do not merely adapt to global trends but establish a new level of efficiency. As a result, a number of countries are already seeing progress precisely because they have reimagined transport integration.

It is important to use the latest solutions to reduce harmful emissions from seagoing vessels. This approach helps meet UN goals, particularly 9.4 and 13. Even small changes yield noticeable results; through the gradual modernization of the fleet, we gain economic and environmental benefits. The time for implementing solutions for technical upgrades is becoming increasingly urgent.

The most effective approach is a system that combines logistics, technology, and digital tools. This approach increases productivity in the transportation sector while fulfilling Goals 8.2 and 12.6 of the Sustainable Development Goals.

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