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STUDY OF THE DETERMINANTS OF THE EFFICIENCY OF TRANSPORT TECHNOLOGIES

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The article carries out a comprehensive study of the determinants that determine the efficiency of modern transport technologies in the context of growing requirements for speed, reliability, environmental friendliness and economic efficiency of transport systems. The authors substantiate the need for a systematic approach to assessing efficiency, since transport technologies function in a multifactorial environment, where technical, organizational, economic, infrastructural and digital factors interact with each other and form the final result. The paper identifies key groups of determinants: technical and technological parameters (level of automation, equipment innovation, energy efficiency), organizational and logistical factors (route optimization, integration of traffic flows, flexibility of operations), economic conditions (cost structure, investment attractiveness, cost of technology ownership), infrastructure constraints (state of the transport network, bandwidth, availability of services), as well as digital and information determinants (level of digitalization, use of decision support systems, big data analytics). Particular attention is paid to methods of quantitative and qualitative assessment of the impact of these factors, including multi-criteria analysis, modeling of transport processes, assessment of the life cycle of technologies and approaches to determining integral performance indicators. It is shown that the efficiency of transport technologies is formed not by individual parameters, but by their consistency and ability to adapt to changes in the external environment. The results of the study make it possible to form scientifically based recommendations for improving the efficiency of transport technologies by optimizing technical solutions, improving logistics processes, introducing digital tools and developing infrastructure. The obtained conclusions can be used for strategic planning, modernization of transport systems, development of innovative technological solutions and formation of a policy for sustainable development of the transport industry.

Keywords: *transport technologies, efficiency, determinants, technical and technological factors, logistics optimization, digitalization of transport, innovations.*

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ДОСЛІДЖЕННЯ ДЕТЕРМІНАНТ ЕФЕКТИВНОСТІ ТРАНСПОРТНИХ ТЕХНОЛОГІЙ

У статті здійснено комплексне дослідження детермінант, що визначають ефективність сучасних транспортних технологій у контексті зростаючих вимог до швидкості, надійності, екологічності та економічної результативності транспортних систем. Автори обґрунтовують необхідність системного

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підходу до оцінювання ефективності, оскільки транспортні технології функціонують у багатофакторному середовищі, де технічні, організаційні, економічні, інфраструктурні та цифрові чинники взаємодіють між собою та формують кінцевий результат. У роботі визначено ключові групи детермінант: техніко-технологічні параметри (рівень автоматизації, інноваційність обладнання, енергоефективність), організаційно-логістичні фактори (оптимізація маршрутів, інтеграція транспортних потоків, гнучкість операцій), економічні умови (структура витрат, інвестиційна привабливість, вартість володіння технологією), інфраструктурні обмеження (стан транспортної мережі, пропускна здатність, доступність сервісів), а також цифрові та інформаційні детермінанти (рівень цифровізації, використання систем підтримки прийняття рішень, аналітика великих даних). Особливу увагу приділено методам кількісної та якісної оцінки впливу цих факторів, включно з багатокритеріальним аналізом, моделюванням транспортних процесів, оцінкою життєвого циклу технологій та підходами до визначення інтегральних показників ефективності. Показано, що ефективність транспортних технологій формується не окремими параметрами, а їхньою узгодженістю та здатністю адаптуватися до змін зовнішнього середовища. Результати дослідження дозволяють сформувати науково обґрунтовані рекомендації щодо підвищення ефективності транспортних технологій шляхом оптимізації технічних рішень, удосконалення логістичних процесів, впровадження цифрових інструментів та розвитку інфраструктури. Отримані висновки можуть бути використані для стратегічного планування, модернізації транспортних систем, розроблення інноваційних технологічних рішень та формування політики сталого розвитку транспортної галузі.

Ключові слова: *транспортні технології, ефективність, детермінанти, техніко технологічні фактори, логістична оптимізація, цифровізація транспорту, інновації.*

Introduction. Modern development of the transport industry is taking place in the context of rapid technological changes, growth of global mobility and increased requirements for the efficiency of logistics processes. Transport technologies are becoming a key element of economic infrastructure, determining the competitiveness of enterprises, the stability of supply chains and the level of integration of national economies into world markets. Since the speed of resource movement, cost optimality, environmental impact and quality of service for end users depend on their effectiveness. Transport systems today operate in a complex multifactorial environment, where technical parameters, organizational decisions, digital tools, infrastructure constraints and economic conditions interact with each other and form the final level of efficiency. At the same time, traditional approaches to assessing transport technologies often do not take into account this multidimensionality, which complicates the adoption of informed management decisions [1-11]. This necessitates a systematic study of the determinants of efficiency, capable of comprehensively reflecting the influence of various groups of factors on the effectiveness of transport processes.

The relevance of a topic is determined by several key aspects. First of all, global logistics challenges – the growth of transportation volumes, the instability of supply chains, the need to quickly adapt to market changes – require high flexibility and resilience from transport technologies. Without understanding the determinants of efficiency, it is impossible to ensure their optimal functioning. Secondly, the digital transformation of transport (the introduction of IoT, decision support systems, automation, big data analytics) creates new opportunities, but also puts forward new requirements for methods of evaluating efficiency. There is a need to rethink traditional approaches and integrate digital factors into the system of determinants. Thirdly, environmental and energy challenges increase the need to transition to energy-efficient and low-carbon transport solutions. This makes the study of the factors that affect the environmental performance of technologies especially important. Fourthly, the infrastructure constraints of many countries, in particular Ukraine, require optimization of the use of available resources. Determining the determinants of efficiency allows you to form priorities for modernization and investment. Fifth, the growth of competition in the transport market requires operators and logistics companies to implement innovative technologies that can provide higher productivity and lower costs.

Thus, the study of the determinants of the efficiency of transport technologies is relevant both from a scientific and practical point of view. It allows for the formation of a holistic methodological basis for evaluating and improving the efficiency of transport systems, contributes to the development of innovative solutions and supports strategic planning in the transport industry.

Materials and methods. The issue of determining the determinants of the efficiency of transport technologies occupies an important place in modern scientific research, but the available publications demonstrate fragmentary approaches and focus mainly on certain aspects of the functioning of transport systems. In the Lithuanian scientific tradition, considerable attention is paid to macro-level factors of the development of the transport industry. Thus, in the work of Matijošius, Čižiūnienė and Zautra [3] economic, infrastructure and regulatory factors that determine the sustainability of the

transport system of Lithuania. The authors investigate in detail the relationships between these factors, but their approach does not cover the technical and technological parameters of transport technologies and digital determinants, which today are key to improving the efficiency of transport processes. Similarly, the study by Čižiūnienė and Vaičiūnas [1] focuses on trends in sustainable transport development, in particular environmental aspects and innovative approaches to the modernization of the industry. However, here, too, attention is focused mainly on the macro level, while microlevel technological determinants remain outside the scope of analysis.

Ukrainian studies demonstrate a wider range of approaches, but are also characterized by a certain fragmentation. The work of Nikonchuk, Vakulenko, Pashkevych and Sokolova [4] considers the problems of development of the transport and logistics infrastructure of Ukraine, outlines the key challenges and prospects for its modernization, and emphasizes the importance of integrating intelligent transport systems. At the same time, the authors do not analyze the determinants of the efficiency of specific transport technologies, which limits the possibility of applying their conclusions in the context of technological efficiency. The study [10; 11] focuses on technological tools to improve the efficiency of transportation operations, such as GPSmonitoring, automated fleet management, and digital scheduling platforms. Despite the detailed analysis of individual instruments, the work does not form a systematic vision of the interaction of different groups of determinants.

A number of Ukrainian publications pay attention to logistics optimization and digital transformation of transport processes. In particular, Ivanov analyzes trends in the digitalization of logistics systems, emphasizing the role of information technology in improving the accuracy of planning and optimizing routes. However, the study focuses on digital aspects and does not cover technical and infrastructural factors, which limits its comprehensiveness. In the work of Butko and Hrytsenko [5] the management of the efficiency of transport processes in logistics systems is considered, attention is focused on organizational and logistic determinants. However, the technical, technological and digital aspects remain insufficiently exposed. Melnyk and Kovalchuk analyze innovative technologies in the transport industry and their impact on productivity and safety, but the work focuses mainly on technical innovations and does not take into account economic and infrastructure factors.

Dykan and Zubenko [6] explore the development of intelligent transport systems in Ukraine, outlining their potential to improve transportation efficiency. However, the authors focus on the conceptual aspects of ITS, without offering a methodology for evaluating their effectiveness in the context of interaction with other groups of determinants. The work of Kirdina and Lomotko [8] considers approaches to assessing the effectiveness of transport technologies in logistics supply chains, which brings their analysis closer to the problems of this article. However, the study does not cover the digital and infrastructural aspects that are critical today. Pashchenko and Kozak [11] analyze the modernization of transport infrastructure as a factor in improving transportation efficiency, but their approach focuses on infrastructure determinants and does not take into account technological and organizational factors.

Generalization of scientific developments shows that despite significant interest in the problems of efficiency of transport systems, research remains fragmented. Some works mainly analyze macro-level and environmental aspects, while others analyze individual technological, logistical, or infrastructure factors. There is no integrated approach that would simultaneously take into account technical, organizational, economic, infrastructural and digital determinants. This creates a scientific gap, which necessitates a comprehensive study aimed at systematizing the determinants of the efficiency of transport technologies and developing methodological tools for their integral assessment.

The article is aimed at a comprehensive scientific substantiation and systematization of the determinants that determine the effectiveness of modern transport technologies, as well as in the development of a methodological approach to their comprehensive assessment. The study is aimed at identifying key technical, organizational-logistic, economic, infrastructural and digital factors that form the effectiveness of transport processes, and at determining ways to increase the efficiency of transport systems in the conditions of dynamic changes in the external environment.

Results. In the structure of modern transport technologies, efficiency cannot be explained only by the technical characteristics of equipment or the organization of transportation. The functioning of transport systems takes place in a multidimensional environment, where technical solutions are intertwined with logistics approaches, economic constraints, the state of infrastructure and the level of digital maturity. This necessitates the identification and scientific substantiation of five key groups of determinants of efficiency: technical-technological, organizational-logistic, economic, infrastructural and digital (Fig. 1).

Such a classification allows, on the one hand, to systematize heterogeneous factors, and on the other hand, to ensure the possibility of their integral

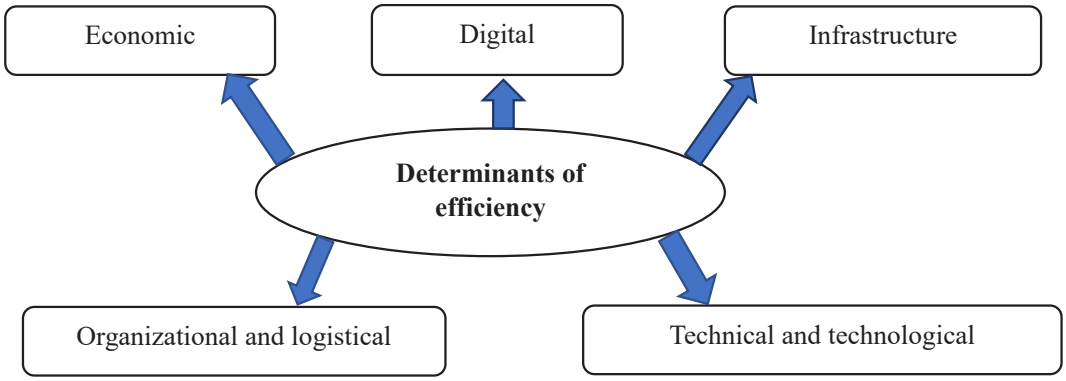


Fig. 1. Determinants of the efficiency of transport technologies

Source: compiled by the authors

consideration when assessing the effectiveness of transport technologies.

Technical and technological determinants form the basic level of potential efficiency of transport technologies. This group includes the design characteristics of vehicles and technical means of service, the level of automation and mechanization of operations, the innovativeness of the applied technical solutions, energy efficiency, reliability and reliability of equipment operation, technological compatibility with the existing infrastructure. When determining the efficiency of transport technologies Technical and technological determinants should be taken into account through a system of quantitative indicators, such as equipment performance, specific energy consumption, load capacity and mileage utilization rates, downtime indicators, and the level of automation of operations. The assessment of this group involves comparing the actual parameters with the normative or target values, analyzing the compliance of technical solutions with the requirements of safety, environmental friendliness and quality standards, as well as studying the possibilities of modernizing the technical base to achieve a higher level of efficiency.

Organizational and logistic determinants reflect the way in which the processes of planning, coordination and management of transport operations are built. These include the principles of route formation, the choice of transport service schemes, the level of integration of transport and warehouse processes, methods of managing transport flows, the system of interaction with participants in the logistics chain, the flexibility and adaptability of operations to fluctuations in demand. When evaluating efficiency, it is necessary to analyze the duration of logistics cycles, the level of vehicle loading, the degree of compliance with delivery deadlines, the frequency of schedule violations, the level of service for customers, as well as coordination indicators between different modes of transport. It is advisable to evaluate organizational and logistic factors on the basis of modeling transport and logistics processes, analysis of scenarios for the functioning of the system, identification of «bottlenecks» in the organization of transportation and their impact on integral performance indicators.

Economic determinants determine the financial feasibility of the use of certain transport technologies and the limits of their development. They include the structure of costs for the introduction and operation of technologies, the level of capital investments, the cost of owning equipment throughout the entire life cycle, the pricing policy for transport services, the availability of financial resources, economic incentives for the introduction of innovations. Determinants are taken into account through the analysis of the cost of transportation, profitability of operations, payback periods, net income from the introduction of new technological solutions, sensitivity of economic results to changes in tariffs, energy prices and other external conditions. It is economic factors that allow you to translate technical and logistical advantages into financial results and determine to what extent the use of a certain technology is not only technically possible, but also economically justified.

Infrastructure determinants have a system-forming character, since they determine the possibility of practical implementation of transport technologies in a specific space. These include the state and density of the transport network, the throughput and processing capacity of infrastructure facilities (ports, terminals, logistics centers, stations), the level of technical equipment of the infrastructure, the availability of integrated transport and logistics hubs, the degree of interaction of different modes of transport. In determining the efficiency of transport technologies, infrastructure determinants are taken into account through the analysis of capacity utilization rates, the level of congestion of infrastructure facilities, the duration of downtime due to infrastructure restrictions, the availability of key logistics services in the right places and at the right time. It is also important

to assess the compliance of the infrastructure with the requirements of the transport technologies used or planned for implementation, since even high-tech solutions can be ineffective in the conditions of an underdeveloped or worn-out infrastructure base.

Digital determinants reflect the level of penetration of digital technologies in transport processes and the degree of use of data for managerial decision-making. They include the use of decision support systems, transportation and logistics management platforms, intelligent transport systems, real-time monitoring tools, big data analytics, integration of information flows between participants in the transport and logistics chain. Determinants When assessing efficiency, it is necessary to analyze the degree of automation of information and management processes, the speed and accuracy of data exchange, the ability to forecast demand and capacity utilization, the level of transparency of transport operations for customers and partners. In quantitative terms, this can be reflected in a reduction in order processing time, a decrease in the number of errors, an increase in the stability of schedules, a decrease in non-production costs associated with information inconsistency.

The rationale for distinguishing these five groups of determinants is based on the fact that they cover all the main dimensions of the functioning of transport technologies: from technical capacity and organization of processes to economic efficiency, spatial and infrastructural constraints and digital management environment. Each group can be formalized through a system of indicators, which allows you to build an integral model for evaluating performance. At the same time, it is important not only to have a separate analysis of each group of determinants, but also to take into account their interaction, since changes in the technical, organizational or digital subsystem are necessarily reflected in economic results and infrastructure requirements. It is this system logic that creates the methodological basis for the further development of a comprehensive toolkit for assessing the effectiveness of transport technologies in modern conditions.

The efficiency of transport technologies is formed under the influence of heterogeneous factors that belong to the technical, organizational, economic, infrastructure and digital spheres. For a systematic analysis of their impact, it is advisable to present a generalized characteristic of each group of determinants, determining their economic essence, the mechanism of influence on the effectiveness of transport processes and methods of consideration when assessing efficiency. This allows you to form a holistic vision of the structure of factors and provide the possibility of their integral analysis (Table 1).

Generalization of determinants in tabular form (Table 1) allows us to clearly trace that the efficiency of transport technologies is the result of the interaction of different groups of factors, each of which has its own economic nature and specific mechanism of influence.

Technical and technological determinants determine the technical potential of the system and its ability to provide the required level of performance and reliability. They are the foundation on which all other aspects of efficiency are based, since even the best organization of processes does not compensate for the technical imperfection of the equipment.

Organizational and logistical factors shape operational efficiency by determining how efficiently resources are used, how routes are optimized, how consistently schedules are adhered to, and how quickly the system responds to changes in demand. It is this group of determinants that provides flexibility and adaptability of transport technologies.

Economic determinants play the role of a limiter or stimulator of the development of technology. They determine whether the implementation of a particular solution is financially feasible, how quickly the investment will pay off, and whether the technology is able to provide a competitive advantage in the market. Thus, economic factors translate technical and logistical advantages into the plane of financial results.

Infrastructural determinants set the spatial and technological framework for the functioning of transport systems. Even the most modern technologies can demonstrate low efficiency in the event of insufficient network bandwidth, deteriorating infrastructure, or lack of necessary logistics services. Therefore, infrastructural interoperability is a critical condition for the implementation of technological solutions.

Digital determinants ensure the integration of all other groups of factors into a single management system. They increase the accuracy of planning, speed up the exchange of information, reduce risks and ensure transparency of transport processes. In modern conditions, digitalization is becoming a key driver of increasing efficiency, as it allows you to optimize both technical, organizational and economic aspects of activities.

Thus, Table 1 demonstrates that the efficiency of transport technologies is a multidimensional category that is formed under the influence of interrelated determinants. Their comprehensive consideration is a prerequisite for an objective assessment of the effectiveness of transport systems and the development of strategies for their modernization.

Conclusions. The study made it possible to form a comprehensive idea of the system of determinants that determine the effectiveness of modern transport

Table 1

Characteristics of the determinants of the efficiency of transport technologies

Determinants	Economic characteristics	Impact on the efficiency of transport technologies	Methods for taking into account impact when evaluating effectiveness
Technico-Technological	Determine operating costs, energy efficiency, the level of wear and tear of equipment, and the need for modernization	Form basic performance potential; affect speed, reliability, reliability, power consumption and technological compatibility	Analysis of technical parameters; comparison with standards; calculation of productivity, capacity utilization rates; technical audit; Energy Efficiency Assessment
Organizationally Logistics	Determine operating costs, resource efficiency, time losses, costs from downtime and inconsistency	They affect the duration of logistics cycles, transport loading, stability of schedules, quality of service and adaptability of the system	Modeling of logistics processes; route analysis; assessment of the level of load; measurement of delivery time; analysis of "bottlenecks"; Logistics Efficiency KPIs
Economic	They form the cost of transportation, profitability, return on investment, financial stability and competitiveness	Limit or stimulate the introduction of technologies; determine the scalability and economic feasibility of innovations	Calculation of the cost price; Life Cycle Analysis (LCC); NPV, IRR, payback period; sensitivity to tariffs and prices for resources; Economic modeling
Infrastructure	Determine the costs associated with downtime, bandwidth limitations, availability of services, and the need for infrastructure investments	They affect the possibility of implementing technologies, the speed of cargo handling, the stability of traffic flows, the level of delays	Bandwidth analysis; assessment of infrastructure workload; audit of infrastructure compatibility; modeling of transport hubs; Service Availability Assessment
Digital	Reduce operating costs, increase planning accuracy, reduce error losses, optimize resource management	Increase transparency, speed and accuracy of control; ensure the integration of processes; reduce risks and uncertainty	Assessment of the level of automation; digital maturity analysis; measurement of data accuracy; assessment of the effect of ITS; analysis of information processing time; Audit of information flows

Source: compiled by the authors

technologies, as well as to identify the patterns of their interaction in a multifactorial environment. Based on the analysis of scientific sources, generalization of practical approaches and systematization of theoretical provisions, a number of important results were obtained. First of all, it was established that the efficiency of transport technologies is formed under the influence of five key groups of determinants: technical-technological, organizational-logistic, economic, infrastructural and digital. Each of these groups has its own structure and a specific mechanism of influence on the effectiveness of transport processes, but it is their interaction that determines the integral level of efficiency. It has been proved that an isolated analysis of individual factors does not allow obtaining an objective assessment, since transport technologies function in a complex system of interdependencies. Secondly, the study showed that technical and technological determinants (level of automation, innovation of equipment, energy efficiency, reliability of technical solutions) are of a basic nature and determine the potential productivity of transport technologies. At the same time, their impact is largely moderated by organizational and logistical factors, such as route optimization, integration of traffic flows, flexibility of operations, and quality of management decisions. Thirdly, it has been established that economic determinants – the structure of costs, the level of investment, the cost of technology ownership, the economic feasibility of introducing innovations – play the role of a limiting or stimulating factor. They determine the scalability of technologies and their competitiveness in market conditions. Fourthly, it has been confirmed that infrastructural determinants have a system-forming character. The state of the transport network, throughput, availability of services and the level of integration of infrastructure elements directly affect the possibility of implementing technological solutions. Even high-tech systems show low efficiency in the event of infrastructure constraints. Finally, digital determinants – the level of digitalization, the use of decision support systems, big data analytics, intelligent transport systems – turned out to be key to increasing the adaptability and efficiency of transport processes. The study showed that digital tools not only optimize individual operations, but also ensure the integration of all other groups of determinants into a single management system. Sixthly, on the basis of system analysis, a generalized model of interaction of determinants of the efficiency of transport technologies was developed. The model demonstrates that efficiency is not formed linearly, but through a multi-level system

of interdependencies, where a change in one factor can significantly affect others. This confirms the need for an integrated approach to performance evaluation. Seventh, the study made it possible to identify the most critical determinants for modern transport systems. These include: the level of digital integration, the degree of automation of technological processes, the quality of logistics planning, infrastructure compatibility and the economic feasibility of introducing innovations. It is these factors that have the greatest impact on the final performance indicators.

The results obtained create a scientific basis for the further development of methodological tools for a comprehensive assessment of the effectiveness of transport technologies, and can also be used to form strategies for the modernization of transport systems, optimization of logistics processes and the introduction of innovative solutions in the transport industry.

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