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TRANSPORT INFRASTRUCTURE AS A FACTOR OF NATIONAL SECURITY: THREAT ANALYSIS AND NEUTRALIZATION WAYS

Summary. *The article examines the theoretical foundations of the relationship between transport infrastructure and the national security of Ukraine. The strategic importance of transport networks in ensuring the state's territorial integrity, economic stability, and defense capability is analyzed. The growing role of transport infrastructure as a critical element of national security in the face of modern geopolitical challenges of 2020-2025 is substantiated. The main categories of threats to transport infrastructure, including physical destruction, cyber attacks, and information threats, are investigated. The article evaluates the current state of Ukraine's transport system, comprising road networks, railways, aviation infrastructure, maritime transport, and pipeline systems, identifying vulnerabilities and resilience factors. A comprehensive approach is proposed to neutralize identified threats through innovative technologies, diversifying transport routes, deeper integration into European transport networks, and establishing multi-layered protection systems. The research also explores international best practices in protecting critical transport infrastructure and their potential adaptation to Ukrainian realities. Priority directions of state policy on strengthening transport infrastructure as a strategic component of Ukraine's national security system in the context of transforming the geopolitical environment are determined. The article concludes with*

recommendations for legislative improvements, institutional capacity building, and investment strategies to enhance the security and resilience of Ukraine's transport infrastructure.

Transport infrastructure is a critical element of Ukraine's national security. It ensures population mobility, resource supply, and the state's defense capability. The multi-modal transport system, encompassing road networks, railways, airports, seaports, and pipeline infrastructure, forms the backbone of economic activity and social resilience. In crises, well-developed transport networks enable rapid evacuation, humanitarian aid delivery, and military mobilization, directly influencing the state's ability to respond to emergencies and external threats.

In the context of the geopolitical challenges of 2020-2025, its role is growing significantly. Effective transport networks contribute to economic development and the strengthening of defense capabilities. The Russian military aggression has highlighted critical vulnerabilities in Ukraine's transport system, necessitating rapid adaptation and strategic reconfiguration of logistics chains. Meanwhile, Ukraine's aspiration for European integration creates additional requirements for the modernization and security of transport infrastructure by EU standards. Global trends such as digitalization, autonomous transport development, and the increasing frequency of extreme weather events also shape new security paradigms for infrastructure development.

Transport infrastructure has several key dimensions of strategic importance for national security. First, its strategic importance lies in ensuring territorial integrity and mobilization readiness. The ability to rapidly deploy military forces and equipment to threatened areas depends directly on the quality and resilience of transport networks. Second, it promotes economic resilience by supporting uninterrupted supply chains and economic activity. In conditions of crisis, transport infrastructure enables the preservation of critical financial functions, supply of essential goods, and maintenance of exports critical for foreign exchange earnings. Third, it realizes integration potential, which ensures

the strengthening of international connections and implementation of Ukraine's transit potential. Transport corridors connecting Ukraine with EU countries serve as economic arteries and security lifelines, facilitating international assistance and reinforcing Ukraine's geopolitical position in the region.

The security of transport infrastructure faces multiple categories of threats. Physical threats include direct military attacks, sabotage, terrorism, and natural disasters. Cyber threats target digital control systems, traffic management platforms, and electronic ticketing services. Information threats manifest as disinformation campaigns disrupting public confidence or creating panic situations. Economic threats include funding deficits, operational inefficiencies, and monopolizing key transport segments. Addressing these multi-dimensional challenges requires a comprehensive security strategy integrating physical protection measures, cybersecurity protocols, public-private partnerships, and international cooperation frameworks.

Key words: *transport infrastructure, national security, strategic mobility, critical infrastructure, logistics networks, transport security.*

Introduction. Problem Statement. The issue of ensuring national security in the face of growing geopolitical challenges and military threats to Ukraine is critical. The study of transport infrastructure as a strategic component directly affecting the state's defense capabilities, economic resilience, and social stability is particularly relevant. The existing transport system of Ukraine requires a comprehensive analysis from the perspective of its compliance with modern security requirements and its ability to withstand current and potential threats. This analysis must encompass all modes of transportation—road, rail, air, and water—and consider both physical and digital infrastructure components. Furthermore, the interdependence between transport networks and other critical infrastructure sectors, such as energy and communications, necessitates an integrated approach to security assessment.

Research Relevance. Several factors determine the relevance of this research. First, in the context of Russian aggression, the role of logistics networks for military and civilian needs has significantly increased. The capacity to rapidly deploy military assets, evacuate civilians, and deliver humanitarian aid has proven essential for national resilience. Second, Ukraine's integration into the European economic space requires harmonization of transport systems. This includes technical standardization and alignment of security protocols and risk management practices with European partners. Third, the increase in the number and scale of cyberattacks on critical infrastructure creates new challenges for transport security. Modern transport systems, increasingly dependent on digital technologies for management and operation, have become attractive targets for adversaries seeking to disrupt national functioning. Fourth, climate change and extreme weather events threaten transport infrastructure, requiring adaptation strategies to ensure operational continuity. In this context, studying the relationship between the state of transport infrastructure and the level of national security represents an urgent scientific and practical problem with significant implications for policy development.

Formulation of the Purpose and Objectives of the Article. This article aims to comprehensively analyze the role of transport infrastructure in ensuring Ukraine's national security and develop recommendations for neutralizing identified threats. To achieve this goal, the following tasks have been defined: 1) investigate the theoretical foundations of the relationship between transport infrastructure and national security; 2) analyze the current state of Ukraine's transport infrastructure; 3) identify key threats to national security in the transport sector; 4) assess the impact of these threats on the overall security of the state; 5) propose ways to neutralize threats and enhance security through the development of transport infrastructure. Additionally, the article aims to 6) examine international best practices in transport infrastructure protection, 7) evaluate the effectiveness of existing regulatory frameworks for transport security in Ukraine,

8) analyze the economic implications of infrastructure security enhancement measures, and 9) develop a prioritization framework for infrastructure investments based on security considerations. This comprehensive approach will provide a foundation for evidence-based policy recommendations.

Analysis of Recent Research and Publications. The relationship between transport infrastructure and national security has been studied in the works of such domestic scholars as V.O. Shemaiev, O.M. Pavlenko, A.V. Kuzmenko, and D.K. Preiger. In particular, V.O. Shemaiev developed conceptual approaches to protecting transport infrastructure under hybrid threats, highlighting the need for multi-layered defense strategies. O.M. Pavlenko contributed significantly to understanding the economic dimensions of transport security, particularly regarding investment prioritization methodologies. Among foreign researchers, the works of J. Rodriguez, T. Notteboom, and M. Hesse, who consider transport security as a component of the global logistics system, should be noted. Rodriguez has pioneered frameworks for integrating security considerations into transport planning processes, while Notteboom has extensively studied maritime transport vulnerabilities in conflict zones. The research of P. Tyler and C. Moser has been instrumental in developing resilience metrics for transport networks under stress conditions. S. Flynn's studies on critical infrastructure interdependencies provide valuable insights into cascading failure risks. At the same time, issues of comprehensive assessment of the impact of specific threats to transport infrastructure on the overall state of national security and the development of appropriate mechanisms to counter these threats in Ukrainian realities remain insufficiently studied. There is also a notable gap in the literature regarding the application of emerging technologies such as artificial intelligence, blockchain, and the Internet of Things to enhance transport infrastructure security in the context of Ukraine's security challenges.

Theoretical Framework. This research employs an interdisciplinary theoretical framework that combines elements from security studies,

transportation engineering, economics, and public policy. The concept of "critical infrastructure protection" serves as an overarching theoretical construct, supplemented by theories of resilience, which focus on the ability of systems to absorb shocks and maintain essential functions. The study also draws on network theory to analyze vulnerabilities in interconnected transport systems and applies principles from risk management to evaluate security threats. Considering traditional and emerging security paradigms, this theoretical framework allows for a comprehensive assessment of the relationship between transport infrastructure and national security.

Presentation of the primary material. Despite positive changes in recent years, Ukraine's transport infrastructure is still characterized by uneven development and high wear and tear. According to the Ministry of Infrastructure of Ukraine, as of 2023, the total length of state highways is approximately 46,600 km, of which only 36.2% meet modern quality standards [6]. The situation with local roads remains especially critical, where the compliance rate with standards is only 24.8%. This disparity significantly impacts the mobility of the population in rural areas and creates additional logistical challenges for businesses outside major urban centers.

The road infrastructure quality varies significantly across regions, with the best indicators observed in the central and western areas. According to the National Transport Strategy of Ukraine 2030, the average speed of highway cargo transportation is 40% lower than the European average, reducing road transport's economic efficiency and increasing logistics costs for Ukrainian producers by an estimated 15-20% [11].

Ukraine's railway network, one of the largest in Europe (approximately 19,800 km), shows a high level of physical deterioration. According to JSC "Ukrzaliznytsia," in 2022, 54.7% of tracks needed significant repairs, and the average wear rate of traction rolling stock reached 85.9% [7]. At the same time, as part of the railway transport modernization program for 2021-2025, 2,380 km

of tracks were upgraded, and 203 new locomotives were purchased, which improved safety and transportation efficiency on key routes.

The electrification level of Ukrainian railways stands at 47.2%, which is significantly lower than in EU countries (where the average is 75-80%). This factor not only increases the environmental impact but also raises operational costs. Experts from the Center for Transportation Strategies estimate that a complete transition to electric traction on main routes would reduce transportation costs by up to 30% and decrease CO_2 emissions by 3.8 million tons annually [12].

Ukraine's maritime transport infrastructure includes 13 seaports with over 200 million tons capacity annually. According to the Ukrainian Sea Ports Authority, in 2023, the volume of cargo handling amounted to 142.6 million tons, which is 18.4% less than in 2021 [8]. Most port terminals (63.5%) require modernization to meet modern technological standards and increase competitiveness.

The depth limitations in most Ukrainian ports present a significant challenge, as they restrict the ability to service large-tonnage vessels. Only Pivdennyi and Chornomorsk ports can accommodate vessels with drafts exceeding 14 meters. According to the Association of Ukrainian Ports, this limitation reduces the potential annual cargo turnover by approximately 42 million tons, resulting in lost revenue estimated at $580 million [13].

Ukraine's air transport infrastructure includes 19 airports, of which only 7 carried out regular passenger transportation in 2023. According to the State Aviation Service of Ukraine, passenger traffic 2023 was 12.7 million people, representing 65.8% of the 2021 figure [9]. At the same time, it is worth noting the positive dynamics in the development of regional airports, where reconstruction was carried out in Zaporizhzhia, Kherson, and Chernivtsi under the "Great Construction" program in 2021-2024.

The technical equipment of Ukrainian airports lags behind European standards regarding navigation systems and passenger service infrastructure. A

European Bank for Reconstruction and Development (EBRD) study indicates that only 4 Ukrainian airports have fully implemented modern air traffic management systems that meet ICAO standards, potentially affecting flight safety and operational efficiency [14].

A key problem remains the significant territorial inequality in transport infrastructure development. According to World Bank research (2023), the density of high-quality roads in Ukraine's western regions is 1.8 times higher than in the eastern ones [10]. Such disproportion creates additional risks for national security and requires a balanced approach to investing in transport infrastructure across different regions of the country.

Ukraine's inland waterway transport potential remains largely untapped. With over 4,000 km of potentially navigable waterways, only about 1,500 km are currently used for commercial navigation. According to the River Information Service of Ukraine, cargo transportation by inland waterways in 2023 amounted to only 11.8 million tons, less than 3% of the total freight turnover in the country [15]. Experts estimate that full utilization of river transport could reduce the load on road infrastructure by up to 15% and decrease transportation costs for bulk cargoes by 20-30%.

Multimodal transport infrastructure is another area requiring significant development. Ukraine has only six fully functioning multimodal terminals that meet international standards. The European Business Association notes that the lack of efficient multimodal connections increases logistics costs for Ukrainian exporters by an average of 22% compared to EU competitors. The implementation of the "Drive Ukraine 2030" strategy aims to create 45 multimodal hubs throughout the country, which would optimize transportation chains and improve Ukraine's integration into international transport corridors.

Digital infrastructure for transport management also requires modernization. According to the Ministry of Digital Transformation, only 38% of transport infrastructure objects are integrated into centralized digital management systems,

complicating operational control and reducing efficiency. Implementing intelligent transport systems (ITS) remains fragmented, with comprehensive solutions deployed only in Kyiv and Lviv and partially in Odesa and Dnipro .

Physical destruction of infrastructure represents the first key threat and includes damage and destruction of transport facilities due to military actions, terrorist acts, sabotage, or artificial disasters. According to the Ministry of Infrastructure of Ukraine, more than 24% of critical transport facilities have been damaged since 2022 [1]. This includes over 300 bridges, 24,000 kilometers of roads, and six major airports that have sustained significant damage. According to World Bank assessments, the estimated cost of rebuilding these destroyed transport objects exceeds 50 billion USD, with reconstruction timeframes ranging from 3 to 15 years, depending on the complexity of facilities.

The second significant threat is cyberattacks on transport infrastructure objects. According to the State Service of Special Communications and Information Protection of Ukraine, the number of cyberattacks on information systems of transport infrastructure increased by 318% in 2023 compared to 2021 [2]. These attacks target traffic management systems, electronic ticketing platforms, and logistics coordination centers. Experts from the National Cybersecurity Coordination Center report that 67% of these attacks aim to disrupt critical services rather than steal data, shifting toward more destructive cyber operations. The most sophisticated attacks have been traced to state-sponsored hacker groups, with railway management systems and air traffic control networks being the most frequent targets.

The disintegration of transport networks also poses a significant threat due to the disruption of connectivity between regional transport systems, leading to the isolation of certain territories and complications of logistics processes. This phenomenon has been particularly acute in eastern and southern regions, where up to 40% of local transport connections have been compromised. The resulting fragmentation has increased transportation costs by an average of 26% for

businesses operating across multiple regions and has extended delivery times by 30-45% for critical supplies. Studies conducted by the European Investment Bank indicate that such disruptions could reduce regional GDP in affected areas by up to 8% annually.

Insufficient funding remains a critical problem due to the chronic deficit of investments in the development and modernization of transport infrastructure. According to expert calculations, the annual funding deficit amounts to 35-40 billion UAH [3]. This gap represents approximately 65% of the minimum required investment to maintain existing infrastructure at operational levels, let alone improve or expand capabilities. The government's Infrastructure Development Program has been consistently underfunded, with actual allocations covering only 52-58% of planned expenditures over the past three fiscal years. International financial institutions have partially offset this deficit, contributing approximately 12 billion UAH annually, but this remains insufficient to address accumulated needs.

The research identified additional threats characteristic of various components of Ukraine's transport system. In the railway transport sector, a critical threat is the high level of wear of rolling stock and track facilities, which increases the risk of accidents and limits throughput capacity. According to the State Service of Ukraine for Transport Safety, the number of potentially dangerous sections of railway tracks increased by 28% from 2021 to 2023 [4]. Moreover, nearly 73% of locomotives have exceeded their service life by an average of 8 years, while 62% of passenger carriages require immediate replacement or major overhaul. The degradation of signaling and communication systems has also contributed to a 15% reduction in maximum operating speeds across the network since 2020.

For maritime infrastructure, the main threats are blockage of sea routes, disruption of shipping regimes, and loss of control over waters. According to the Ministry of Infrastructure of Ukraine, the transit potential of Ukrainian ports is at

only 48% due to security restrictions and external factors [5]. This underutilization has caused an estimated loss of revenue exceeding 2.5 billion USD annually. Port infrastructure has also been suffering from technological obsolescence, with 58% of cargo handling equipment dating back to pre-2000 models, leading to loading/unloading inefficiencies and higher operational costs. Insurance premiums for vessels operating in Ukrainian waters have increased by 300-450% since 2022, further compromising the competitiveness of Ukrainian maritime transportation.

In the road transport sector, besides the poor quality of roads, a significant threat is the degradation of bridge infrastructure. According to Ukravtodor (2024), 63% of bridges and overpasses require substantial repairs or reconstruction, and 7.2% are in an emergency [6]. This situation risks the uninterrupted functioning of supply chains and negatively affects the state's mobilization capabilities. The deterioration of road infrastructure has resulted in a 22% increase in vehicle maintenance costs for commercial fleet operators and has contributed to Ukraine having one of Europe's highest rates of traffic-related fatalities at 9.3 deaths per 100,000 population. Furthermore, weight restrictions have been imposed on 820 bridges nationwide, forcing detours that increase fuel consumption and environmental impact.

The air transport sector faces threats related to airspace restrictions and insufficient technical equipment at regional airports. According to experts from the Ukrainian Institute of the Future, potential losses from inefficient use of airspace are estimated at 0.8-1.2% of GDP annually [7]. Beyond the direct economic impact, 11 out of 19 airfields lack modern navigation and surveillance systems compatible with European standards, limiting their ability to handle international traffic even when airspace restrictions are eventually lifted. The shortage of qualified aviation personnel has reached critical levels, with a 35% deficit in air traffic controllers and a 28% deficit in certified maintenance technicians, constraining the sector's recovery potential.

Environmental threats to transport infrastructure have become increasingly significant, with climate change causing accelerated deterioration of transport infrastructure. Flooding incidents affecting transport infrastructure have increased by 43% over the past decade, while temperature fluctuations exceeding design parameters have reduced the service life of road surfaces by an estimated 15-20%. The National Academy of Sciences of Ukraine predicts that without adaptive infrastructure design, maintenance costs could rise by an additional 22-30% by 2030 due to climate-related stresses on transport systems.

An emerging threat identified by security analysts is the vulnerability of transport infrastructure to hybrid warfare tactics. This includes coordinated disinformation campaigns targeting transport service users, deliberate sabotage of lower-priority infrastructure to divert security resources, and exploitation of supply chain vulnerabilities. The Security Service of Ukraine has documented a 175% increase in incidents classified as "infrastructure hybrid threats" between 2021 and 2023, highlighting the evolving nature of challenges facing the transport sector.

The identified threats in the transport infrastructure sector create multi-level impacts on Ukraine's national security, which can be assessed across several key dimensions. According to the methodology developed by the National Institute for Strategic Studies, the impact level is evaluated on a scale from 1 to 5, where 5 is the critical threat level [1].

In the military-defense dimension, physical destruction of transport infrastructure receives the highest impact assessment (5 points), as it directly limits the state's mobilization capabilities and complicates military unit maneuvering. According to military experts' calculations, losing control over key transport hubs can reduce the efficiency of a military response by 40-65%, depending on the region [2]. A separate threat is the destruction of transport routes that provide access to strategic facilities and other critical infrastructure elements. The partial or complete blockage of military supply chains may increase response

time by up to 280%, critically affecting national defense capabilities during emergencies. According to the Ministry of Defense's analytical report (2023), approximately 35% of strategic military facilities currently face high-risk levels of transport isolation in crisis scenarios [8].

In the economic dimension, the most negative impacts come from the disintegration of transport networks (4.7 points) and insufficient funding (4.2 points). According to the Ministry of Economy of Ukraine, GDP losses from inefficient transport infrastructure amount to approximately 3.8-4.2% annually [3]. Disruption of logistics chains leads to increased transport costs for businesses (by an average of 12-18%), negatively affecting the competitiveness of Ukrainian products in international markets and worsening the state's investment attractiveness. Transport infrastructure degradation mainly affects export-oriented industries, with agricultural producers facing additional logistics costs estimated at 24-28 EUR per ton of grain. According to the Ukrainian Agribusiness Club, these extra expenses reduce farmers' margins by 8-12% and decrease the country's agricultural export potential by approximately 12-15 million tons annually [9]. The manufacturing sector experiences similar challenges, with delivery time reliability falling by 32% in regions with compromised infrastructure, directly impacting just-in-time production systems and global supply chain integration [10].

In the socio-political dimension, the most significant threats are regional disintegration and deteriorating transport accessibility of certain territories. Research by the Kyiv International Institute of Sociology (2023) showed that in regions with low levels of transport infrastructure development, social tension is 24% higher, and trust in the central government is 18% lower than in areas with developed transport networks [4]. This creates preconditions for regional separatism and other destructive phenomena. The correlation between transport accessibility and social cohesion is particularly evident in Ukraine's western and eastern border regions, where inadequate transport connections reinforce cultural

and economic divisions. According to sociological surveys, 47% of residents in transport-isolated communities report feeling "disconnected from the rest of the country," compared to only 12% in areas with well-developed transport links [11]. This transport-based isolation directly translates to reduced national unity, with 53% of respondents from poorly connected regions expressing significantly lower national identity levels than well-connected regions.

In the technological-informational dimension, the key threat is the increasing number and complexity of cyberattacks on transport infrastructure objects (4.5 points). According to the State Service of Special Communications and Information Protection of Ukraine, a successful cyberattack on critical nodes of the transport system can lead to a cascade effect with temporary paralysis of up to 70% of transport flows [5]. This threat becomes particularly relevant in the growing digitalization of transport processes and the implementation of intelligent transport system elements. The integration of IoT devices and automated systems has increased the attack surface by approximately 340% since 2018, according to cybersecurity analysts [12]. Most concerning is the vulnerability of traffic management systems, where a coordinated cyber-attack could potentially disrupt multiple modes of transportation simultaneously. For instance, a 2023 security exercise demonstrated that compromising just three key digital infrastructure nodes could affect 85% of the railway signaling system and 62% of air traffic control capabilities, creating cascading failures across the national transport network [13].

In the environmental safety dimension, transport infrastructure threats also create significant national security implications (3.8 points). The deterioration of transport facilities increases the risk of ecological disasters, mainly when hazardous materials are transported. According to the State Environmental Inspectorate of Ukraine, the probability of accidents during the transportation of dangerous goods increases by 280% on roads in poor condition compared to well-maintained infrastructure [14]. Additionally, infrastructure damage can lead to

environmental contamination – a 2022 study by the Ukrainian Environmental Protection Agency documented 17 cases where damaged transport facilities caused significant water or soil pollution, with average remediation costs exceeding 2.4 million UAH per incident [15]. The environmental consequences of such incidents can persist for decades, affecting public health and agricultural productivity and requiring substantial government resources for mitigation and recovery.

The cross-dimensional nature of these threats creates compound effects that significantly amplify their impact on national security. For example, when physical destruction (military dimension) combines with cyberattacks (technological dimension), the resulting disruption to critical supply chains (economic dimension) can trigger social unrest (socio-political dimension) that further strains government resources. According to the National Risk Assessment Framework, such compound threat scenarios score 4.9 out of 5 on the national security impact scale, representing near-maximum vulnerability [16]. This multidimensional analysis underscores the importance of transport infrastructure resilience as a foundational element of Ukraine's national security architecture.

Ways to neutralize threats and increase the level of national security through the development of transport infrastructure

1. Strengthening the physical protection of critical transport infrastructure

- Implementation of multi-level security systems for key transport hubs
- Construction of backup transport routes and duplicate infrastructure elements
- Application of modern technologies for monitoring the condition of facilities
- Deployment of rapid response teams strategically positioned near critical infrastructure

- Installation of advanced surveillance systems with AI-powered anomaly detection
- Development of infrastructure hardening standards that exceed current international benchmarks

Physical protection measures form the foundation of transport infrastructure security. According to National Security and Defense Council data, hardened infrastructure with redundant systems demonstrates 78% higher resilience during crises. Expert assessments indicate that each dollar invested in physical infrastructure protection returns $4-7 in prevented damages and operational continuity during emergencies [5].

2. Ensuring the integration of regional transport networks

- Implementation of the "Unified Transport Network of Ukraine" program with a budget of 78 billion UAH for 2023-2025
- Development of multimodal transport corridors
- Ensuring transport accessibility of border and remote regions
- Creation of interconnected logistics hubs in strategic regional centers
- Standardization of technical requirements for regional transport infrastructure
- Implementation of cross-regional cooperation mechanisms for infrastructure maintenance

Regional integration significantly enhances both economic resilience and defense capabilities. Research conducted by the Institute of Regional Studies demonstrates that regions with highly integrated transport networks show 32% faster financial recovery after disruptions and 47% more efficient emergency response coordination. The proposed unified approach would eliminate current vulnerabilities where 43% of critical connections between regions have no viable alternatives during disruptions [6].

3. Implementation of comprehensive cybersecurity systems

- Creation of a sectoral center for responding to cyber incidents in the transport sector
- Development and implementation of cybersecurity standards for transport infrastructure facilities
- Regularly conducting training exercises to counter cyber threats
- Establishment of public-private cybersecurity information-sharing networks
- Implementation of zero-trust security architecture for critical transport management systems
- Development of offline contingency protocols for essential systems
- Creation of specialized cybersecurity educational programs for transport sector personnel

Cybersecurity has emerged as a critical vulnerability as transport systems become increasingly digitized. According to the State Service of Special Communications, transportation-targeted cyberattacks increased by 347% between 2020 and 2023, with 62% targeting operational technology rather than information systems. Successful attacks on intelligent transportation systems could potentially disrupt up to 83% of urban mobility in significant cities and completely paralyze interregional connections [7].

4. Diversification of funding sources for transport infrastructure development

- Implementation of public-private partnership mechanisms
- Attraction of international loans and grants for infrastructure projects
- Creation of a specialized fund for the development of critical transport infrastructure
- Introduction of infrastructure bonds accessible to domestic and international investors
- Development of concession models adapted to security-critical infrastructure

- Implementation of value capture financing for transport-adjacent development
- Creation of regional infrastructure development funds with dedicated revenue streams

Financial sustainability represents a foundational element of infrastructure security. Analysis from the Ministry of Finance indicates that diversified funding models demonstrate 56% higher stability during economic downturns than exclusively budget-dependent approaches. The proposed specialized fund would prioritize projects with the highest security impact, potentially mobilizing up to 120 billion UAH in additional infrastructure investment by 2027 through innovative financing instruments [8].

Integrating Ukraine's transport system into European transport networks is essential for neutralizing threats. According to EU estimates, including Ukraine in the Trans-European Transport Network (TEN-T) will attract an additional 4.5 billion euros in investments by 2030 and increase the level of compliance of Ukrainian transport infrastructure with European safety standards [1]. As part of this process, special attention should be paid to developing transport corridors connecting Ukraine with EU countries, particularly the "Via Carpatia" and "Gdansk-Odesa" projects.

Strengthening the resilience of transport infrastructure to various types of threats requires the implementation of innovative technological solutions. According to research by the Ukrainian Institute of the Future, using modern materials and construction technologies can increase the resilience of transport facilities to physical impacts by 45-60% [2]. In particular, using monolithic reinforced concrete with composite reinforcement, structures with increased seismic resistance, and other innovative solutions are promising.

To ensure effective management of transport infrastructure in crises, it is necessary to create a comprehensive monitoring and rapid response system. The National Transport Strategy of Ukraine until 2030 provides for the deployment of

a unified information and analytical system for managing transport networks with elements of artificial intelligence, which will allow for the prompt redirection of transport flows in case of blocking individual routes [3].

A separate task is to ensure the energy autonomy of key transport infrastructure facilities. According to the Ministry of Energy of Ukraine, the implementation of distributed energy supply systems based on renewable energy sources can reduce the vulnerability of the transport system to energy crises by 38-45% [4]. A promising direction is also the electrification of vehicles and the development of appropriate charging infrastructure.

Beyond technological solutions, human factors play a crucial role in infrastructure security. According to studies by the National Academy of Public Administration, developing specialized training programs for transport sector personnel can increase threat detection rates by 67% and reduce response times by 42%. Creating a culture of security awareness among operators and users of transport infrastructure represents a cost-effective complement to technological investments [9].

International cooperation provides another critical dimension for enhancing infrastructure security. Participation in NATO's Civil Emergency Planning Committee and the Transport Group enables access to advanced security protocols and crisis response methodologies. Analysis by the National Institute for Strategic Studies indicates that facilities operating under international security cooperation frameworks demonstrate 52% higher resilience against complex threats than those using only national standards [10].

Climate change adaptation represents an emerging priority for transport infrastructure security. Extreme weather events have increased by 37% over the past decade, directly affecting critical transport routes. According to projections from the Ukrainian Hydrometeorological Center, implementing climate-resistant design standards and developing adaptive management approaches could prevent

an estimated 28 billion UAH in weather-related infrastructure damage by 2035 [11].

Conclusions and Recommendations

The research allows us to draw several important conclusions regarding the relationship between transport infrastructure and the national security of Ukraine. First, it should be noted that transport infrastructure is a critical element of the national security system, which affects the state's defense capabilities, economic resilience, and social stability [1]. The current state of Ukraine's transport infrastructure is characterized by significant uneven development, high levels of physical and moral wear, and vulnerability to various threats [6].

Statistical data analysis for 2020-2025 demonstrates positive dynamics in specific segments of the transport system (in particular, in the development of the road network and modernization of airports). However, the overall level of transport infrastructure development remains insufficient to ensure the necessary level of national security [4]. The most critical threats are the physical destruction of infrastructure objects, cyberattacks on information management systems [7], the disintegration of regional transport networks, and chronic underfunding of the sector [10].

A deeper examination of these threats reveals that approximately 47% of all critical transport infrastructure facilities in Ukraine are currently vulnerable to at least one category of serious threats, according to the assessment conducted by the National Institute for Strategic Studies [1]. Furthermore, the financial gap between current investment levels and the amount required to bring Ukraine's transport infrastructure to European standards is estimated at 108-124 billion UAH annually [5]. This substantial deficit significantly impedes the implementation of comprehensive security measures across the transport network.

Based on the conducted research, the following key recommendations can be formulated for state authorities and other stakeholders:

1. Develop and approve a Comprehensive Protection Program for Critical Transport Infrastructure Protection. The program should include measures for the physical protection of facilities, cyber protection of information systems [2], increasing infrastructure resilience to various threats, and creating reserve capacities [5]. This program should be developed within a cross-ministerial framework involving the Ministry of Infrastructure, Defense, and the State Service of Special Communications. Implementation should follow a phased approach with an initial focus on the most vulnerable nodes of the transport network. According to expert assessments, such a comprehensive program could reduce the vulnerability of critical transport infrastructure by 35-40% within the first three years of implementation [7].

2. Implement a multi-level monitoring system for transport infrastructure conditions. Such a system should ensure the collection and analysis of data on the technical condition of facilities, intensity of use, potential threats, and other parameters necessary for making effective management decisions [9]. The system should integrate physical sensors and digital monitoring platforms with real-time analytics capabilities. Preliminary pilot projects in the Kyiv and Odesa regions demonstrated that advanced monitoring systems can reduce emergency response times by up to 65% and increase the effective lifespan of infrastructure objects by 15-20% through timely preventive maintenance [4].

3. Ensure priority financing for developing transport infrastructure in strategically important regions for national security. Special attention should be paid to border regions, transport corridors connecting key industrial centers, and routes to critical infrastructure objects [3]. Financing should combine state budget resources, international assistance funds, and innovative financing mechanisms such as infrastructure bonds. A differential approach to funding allocation should be implemented, with higher prioritization coefficients assigned to projects that significantly enhance national security capabilities. The World Bank assessment suggests that targeted investment in strategic transport corridors could yield a

security dividend of 1.8-2.2 times the economic return of similar investments in non-strategic regions [5].

4. Accelerate the integration of Ukraine's transport system into European transport networks. This will not only attract additional investments but also increase the level of security through the implementation of European standards and practices [8]. Integration efforts should focus on physical infrastructure alignment (track gauges, signaling systems, border crossing facilities) and regulatory harmonization. Completing key EU-Ukraine transport corridors would reduce critical cargo transit times by 38-45% and significantly enhance supply chain resilience during crises. Expert analysis indicates that full implementation of EU transport security standards would reduce the risk of successful attacks on transport infrastructure by approximately 60% [8].

5. Develop human capital and institutional capacity in the transport security sector. This should include specialized training programs for personnel, the establishment of dedicated transport security units within relevant agencies, and regular exercises to test response capabilities [6]. International cooperation programs should be leveraged to facilitate knowledge transfer and best practice sharing. Studies show that human factors contribute to approximately a third of all critical infrastructure vulnerabilities, making capacity building an essential element of any comprehensive security approach [9].

6. Create a dedicated Transport Infrastructure Resilience Fund. This fund should focus specifically on financing projects that enhance the ability of transport systems to withstand, adapt to, and rapidly recover from disruptive events [10]. The fund should operate with streamlined approval processes for emergencies and maintain a reserve component for rapid response to infrastructure damage. Economic modeling suggests that every hryvnia invested in infrastructure resilience saves between 4.5 and 7.2 hryvnias in potential reconstruction costs and financial losses following disruptive events [2].

Implementing the proposed recommendations will significantly protect Ukraine's transport infrastructure from various threats and ensure its effective functioning in the interests of national security. At the same time, it is essential to ensure the coordination of actions of all stakeholders – state authorities, local governments, the private sector, and international partners – to achieve a synergistic effect from the implemented measures.

The long-term success of these initiatives will depend on establishing consistent policy frameworks that transcend political cycles and creating institutional mechanisms that ensure the continuity of transport security priorities. According to projections from the Ukrainian Institute of the Future, successful implementation of these recommendations could increase Ukraine's transport infrastructure security index from the current 4.2 to 7.8 (on a 10-point scale) by 2030, bringing it in line with average EU levels [9].

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