Systemy Logistyczne Wojsk
Zeszyt 63(2025)
ISSN 1508-5430, s. 13-34
DOI: 10.37055/slw/218677

Instytut Logistyki
Wydział Bezpieczeństwa, Logistyki i Zarządzania
Wojskowa Akademia Techniczna
w Warszawie

Military Logistics Systems
Volume 63(2025)
ISSN 1508-5430, pp. 13-34
DOI: 10.37055/slw/218677

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Risk assessment of transport companies in Poland and Ukraine in the context of critical infrastructure reorganisation during military conflict

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Abstract. With increasing geopolitical tensions and cross-border operational disruptions, critical transport infrastructure is becoming particularly important for Europe's economic and logistical security. The research niche of the article is the limited number of empirical, comparative studies assessing the resilience of critical transport infrastructure under the direct impact of armed conflict, with a particular focus on intermodal operations between Poland and Ukraine. The aim of this article is to identify and assess risks affecting critical transport infrastructure in Europe in the context of the war in Ukraine, with particular emphasis on the perspective of Polish and Ukrainian companies. The study adopts the hypothesis that infrastructure resilience varies significantly across transport modes and that a systemic risk-management approach supported by international coordination improves the effectiveness of adaptation processes. The study covered companies in the TSL (transport – shipping – logistics) sector that provide road transport services and cooperate with rail, air and maritime transport operators. In the empirical part, an assessment of infrastructure risk and vulnerability was carried out using the FMEA method. The results show significant variation in resilience depending on the type of infrastructure and the need to implement a systemic approach to risk management. Based on the analysis, strategic directions for improvement were identified, including diversification of routes, development of digital competences and increased interoperability of infrastructure. The conclusions of the study indicate that the identification of key risks and vulnerabilities of the transport infrastructure provides the foundation for ensuring the continuity of logistics systems and an effective response to future geopolitical emergencies.
Keywords: military conflict, risk assessment, transport infrastructure, FMEA, supply chain disruption

Introduction

The Russian invasion of Ukraine, which began in February 2022, has led to the largest security crisis in Europe since World War II. Its effects go far beyond the military dimension, destabilizing key areas of the functioning of the European economic and infrastructure space (Georgescu, 2024; Żółtowski, Żółtowski, 2024). The transport sector has been particularly affected, not only experiencing serious operational disruptions but also entering a phase of intensive reorganization (Stasiak-Cieślak, Grabarek, 2023). Previous models of international logistics have been verified in the face of the destruction of Ukrainian infrastructure and the need to quickly redirect strategic cargo to alternative routes, mainly through the territory of Poland, Slovakia, and Romania (Hellberg et al., 2025; Osetrin, et al., 2024). Previous studies on the resilience of critical infrastructure in the context of armed conflicts (Ferdman et al., 2022) have emphasized the need for increased redundancy, system integration, and technological standardization. In war conditions, risk management processes, contingency planning, and the ability to quickly restore the functionality of transport systems are of particular importance.

Against this background, the research niche of this article is the limited number of comparative, company-level risk assessments of critical transport infrastructure resilience under the direct impact of armed conflict, particularly for intermodal operations between Poland and Ukraine. The purpose of the article is to identify and assess key risks affecting critical transport infrastructure in Europe in the context of the war in Ukraine, from the perspective of Polish and Ukrainian TSL companies. The analysis covers TSL sector companies providing road transport services in cooperation with rail, sea and air transport operators. The scope of the study includes an analysis of intermodal transport systems in Central and Eastern Europe, with a special focus on Polish-Ukrainian relations and regulatory activities conducted by the European Union.

The main research questions are:

- How has the military conflict affected the reorganization of critical transport infrastructure in Central and Eastern Europe?
- Which elements of transport infrastructure are most vulnerable to disruption in wartime?
- What risk management and international cooperation mechanisms can increase the resilience of the transport and logistics system?

The study was based on the Failure Mode and Effects Analysis (FMEA) method, which enabled the identification of potential threat scenarios and the assessment of their probability and impact. The case studies included companies from the TSL sector in Poland and Ukraine, due to their key logistical locations and the direct impact of armed conflict on their operations. The FMEA method was adapted to the needs of critical infrastructure analysis, in accordance with the recommendations of the PN-EN IEC 60812 standard.

The research hypothesis assumes that effective reorganisation of critical infrastructure during geopolitical instability requires coordinated international response mechanisms, the implementation of advanced risk management tools, and the harmonisation of operational standards within the framework of the European Union's transport policy.

Reorganization of critical infrastructure in the transport sector

In recent years, the Transport, Forwarding and Logistics (TSL) sector has experienced numerous disruptions resulting from global crises: the COVID-19 pandemic, disruptions in supply chains, the energy and inflation crisis (Raźniewska, et al., 2024; Dymyt, et al., 2024) and the armed conflict in Ukraine (Zheng, 2023). In the face of these dynamic conditions, TSL companies are faced with the need to adapt to economic instability, regulatory changes, labor market challenges and changes in trade directions (Grzeszak, 2022; Piękoś, et al., 2024).

Critical infrastructure in transport refers to key systems, facilities and connections that enable the efficient movement of people and goods, constituting the foundation of economic stability, public safety and social cohesion on a European scale, with particular emphasis on Poland (Dyr, 2014). It includes various means of road, rail, air and water transport, the continuity of operation and operational availability of which are essential for the functioning of supply chains, regional integration and industrial development (Rokicki, 2022; Staniewska, 2023).

In the context of critical infrastructure resilience analysis, it is worth considering approaches modelling the dynamics of technical degradation (Sierpiński, et al., 2024). Symptom and structural modelling can provide a basis for assessing the functionality of complex systems under conditions of operational disruptions, such as armed conflict (Żółtowski, 2023).

Transport infrastructure plays a special role within the Trans-European Transport Network (TEN-T), which provides connections between the European Union Member States, thus supporting cross-border mobility and economic growth (De Fabiis, et al., 2023). Polish transport infrastructure, especially after joining the EU in 2004, has undergone an intensive transformation phase, driven by long-term financial support from European funds and aimed at meeting Community standards and increasing the competitiveness of the TSL sector (Zamojska, et al., 2017).

Contemporary challenges for critical transport infrastructure result from the dynamically changing security environment, both physical and digital. Growing geopolitical tensions, hybrid threats, as well as potential cyberattacks and acts of terrorism require the implementation of integrated protection mechanisms and the construction of systemic resilience of these structures (Hoterová, et al., 2019). In response to these challenges, Poland has implemented the National Critical

Infrastructure Protection Program, which serves as a strategic document, identifying key entities in the transport sector and defining criteria for their classification (Maciejczyk-Cień, 2019). Cyclic updates of the program allow it to be adapted to new threats and changes in the operational environment, which ensures that the transport infrastructure remains adequately protected and able to respond in crisis situations (Piekarski, et al. 2022).

In conditions of armed conflict, the effectiveness of infrastructure and strategic resources management systems depends largely on their regulatory flexibility, operational transparency and the level of international coordination of activities (Trifunovic, et al., 2025). Strengthening these elements is the foundation for increasing the resilience of critical infrastructure to systemic disruptions, as well as for maintaining the continuity of the transport sector in conditions of geopolitical destabilization (Tsyrfa, et al., 2024). Critical transport infrastructure is a strategic component of state security and economic stability. In conditions of increasing geopolitical and cyber threats (Lymaxis, et al., 2023), (Boratyńska-Karpiej, Engel, 2024; Pawlos, Zadorożny, 2024), the role of transport is gaining importance, becoming a key element of the country's systemic resilience.

Directions for adaptation and strengthening the resilience of the transport system

In the face of growing geopolitical challenges and the need to increase the resilience of the transport system, European countries and EU institutions have undertaken a number of actions aimed at strengthening strategic means of transport (Kovács, et al., 2016). Investments in those branches of logistics that are characterized by high efficiency and the ability to respond quickly to crisis situations have proven to be particularly important.

Particular attention has been paid to the development of railways as a means of transport of strategic importance. Railways not only enable relatively cheap and fast transport of goods over long distances but also support military mobility and evacuation of civilians in situations of military threat (Chekhovska, et al., 2022). Integration of railway infrastructure in Central and Eastern Europe has gained priority within the framework of EU projects, such as the extension of the TEN-T network (Komornicki, et al., 2023).

These changes did not bypass the aviation sector either. The closure of airspace over Ukraine, Russia and Belarus forced carriers to make significant detours, which resulted in increased operating costs and reduced efficiency of many cargo and passenger connections (Chu, et al., 2024). The reconstruction of flight networks required flexibility and additional investments in regional airports, and thus the aviation infrastructure in Poland was transformed. The airports in Warsaw (Chopin) and Rzeszów (Jasionka) began to function as humanitarian and military hubs. They handled aid deliveries from Western countries, which were then directed to Ukraine by land and rail. Poland became a key link in the system of transatlantic logistic support for (Shramenko, et al., 2021).

Maritime transport has not changed significantly, as Ukrainian ports such as Odessa are of limited importance to Western European economies. Nevertheless, Ukraine remains an important link in trade between the East and the West, especially in the field of energy resources, grains, industrial products and food (Mickiewicz, et al., 2023). For Europe, it is crucial to maintain stable supplies of these goods, especially grains and energy, which affects the food and energy security of the region. The structure of transport depends on trade agreements, infrastructure availability and political conditions (Dávid, et al., 2023).

In the face of growing geopolitical threats, the EU member states have begun the process of strategic reconstruction of transport systems. The key elements of these activities have become: diversification of logistics routes, construction of alternative transit corridors and strengthening the redundancy and security of critical infrastructure (Lebedeva, et al., 2024).

One important example of an effective response to changing geopolitical conditions is the growing importance of the Trans-Caspian Corridor, which allows for bypassing Russian territory. This route, which runs through the Caspian Sea, Central Asia, the Caucasus and Turkey to Europe, is part of the New Silk Road and allows for the transport of containers from China to the European Union without passing through sanctioned areas (Hellberg, et al., 2025). In 2024, the number of trains running between China and Europe reached a record level, recording a significant increase compared to the previous year. At the same time, the number of transported containers increased significantly, which indicates the dynamic development of intermodal rail transport on the New Silk Road. This trend underlines the growing role of this route in global supply chains (Wang, et al., 2025).

An additional challenge for logistics systems in Europe, including Poland, was the rising fuel prices and restrictions on access to some raw materials, which directly affected the increase in road and rail transport costs (Kopiika, et al., 2025). The logistics sector was forced to quickly adapt to dynamically changing market conditions, while increasing the resilience of supply chains (Dashko, et al., 2024). The situation was particularly difficult in the border regions of Poland and Ukraine. Overloaded border crossings and limited capacity of the existing logistics infrastructure led to significant delays, congestion and threats to liquidity. In response to these challenges, there was an urgent need to build new transshipment terminals, increase the number of border crossings and create technology parks supporting the development of goods exchange and strategic transit (Hudzelyak, et al., 2024).

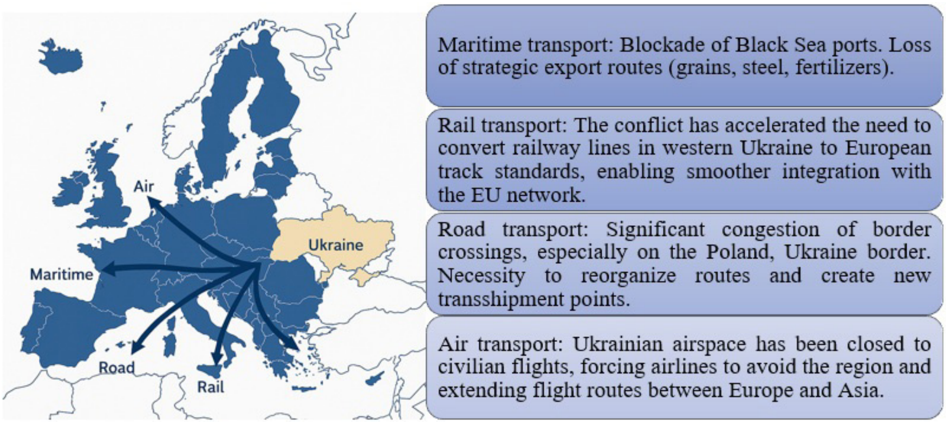

Fig. 1. Key changes taking place in the transport sector in Europe
Source: Own work based on (Cascetta, et al., 2023, Kravchenko, et al., 2024, Yanovska, et al. 2025, Ke, et al., 2024)

The changing geopolitical conditions and the outbreak of armed conflict in Ukraine forced significant changes in the functioning of the TSL sector in Poland (Brahina, 2023). In response to new threats, many companies limited their activity in the eastern direction, focusing resources on maintaining and developing connections with Ukraine (Sim, et al., 2024). This change was not only a market reaction but resulted from the need for operational reorganization in conditions of disrupted logistics routes, uncertain supplies and increased security requirements. The reorganization of critical transport infrastructure requires a comprehensive approach, combining actions at the national and international level, oriented at flexible risk management and long-term strategic planning. The key here is to strengthen cross-border cooperation, implement common technical standards and develop operational transport systems.

Research objects

Twenty-eight companies from the TSL sector participated in the study (sixteen from Poland and twelve from Ukraine). Each had at least several years of experience in international transport. These companies represented all key modes of transport: road, rail, maritime, and air, operating in close cooperation with intermodal transport systems. The purposive sampling was methodologically sound and appropriate to the specific nature of research on critical infrastructure, where access to data and respondents is often limited due to confidentiality and the strategic importance of the business. The selection of companies was based on precise criteria: activity in cross-border supply chains, experience in managing operational disruptions, and business continuity during a crisis. Participants represented both operational and strategic levels, enabling a multidimensional assessment of the vulnerability and resilience of transport systems. The comparable scale of operations and operational diversity of companies from both countries ensured sample consistency.

Materials and Methods

Text The study was conducted using an electronic questionnaire, which was distributed directly to the management staff of transport enterprises operating during the period 2022–2024. The questionnaire included a set of both closed- and open-ended questions, allowing for the collection of qualitative and quantitative data concerning the adaptive measures undertaken by companies, the identification of risk factor sources, and changes in cost structures and transport routes.

The adopted methodology was developed to analyse the impact of the armed conflict in Ukraine on the transport sector in Europe, with particular emphasis on operational and strategic adjustments implemented by logistics enterprises in response to emerging market conditions and disruptions to supply chain functioning. The methodological framework was based on a mixed-method approach, integrating empirical research with elements of comparative analysis.

The primary research method employed was a survey aimed at obtaining data directly from representatives of companies engaged in road transport as well as those operating within intermodal and multimodal transport models. The questionnaire included a set of questions addressing key operational areas of the enterprises, such as modifications to transport routes, changes in cost structures, adaptation of operational strategies, and identification of risk factors arising from the conflict situation.

The collected data were subjected to detailed comparative analysis with reference to the functioning of the TSL sector under stable conditions, i.e., prior to the outbreak of the armed conflict. This enabled the identification of adaptive changes, organizational shifts, and modifications to operational strategies. On this basis, an in-depth interpretation of the sector's transformation dynamics was conducted, taking into account both external factors and internal adaptation mechanisms. The results of the analysis were compared with existing literature, which made it possible to place the observed phenomena within a broader context of critical infrastructure functioning under crisis conditions.

Comparative analysis of the impact of the armed conflict on the activities of companies in Poland and Ukraine

A comparative analysis of the data collected from enterprises operating in Poland and Ukraine is presented below. The findings are illustrated with charts (Fig. 2-7) highlighting the differences in the extent to which the conflict has affected operational activities and organizational adaptability.

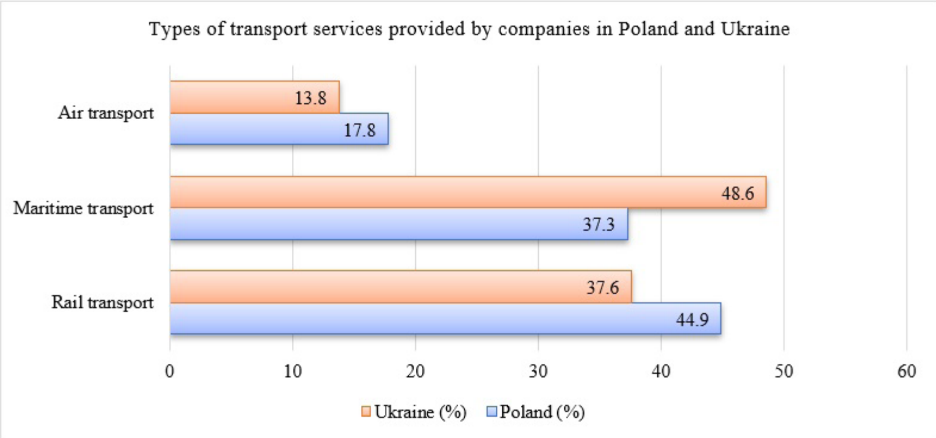

Fig. 2. Types of transport services provided by companies
Source: Own study

The chart illustrates the distribution of transport modes offered by surveyed companies in Poland and Ukraine. Polish firms reported a greater involvement in rail transport (44.9%) compared to their Ukrainian counterparts (37.6%), while Ukrainian companies demonstrated a higher share of maritime transport services (48.6%). Air transport had the lowest share in both countries, reflecting its limited role in freight operations in the context of the ongoing conflict.

The chart shows the level of operational adjustments made by transport companies in Poland and Ukraine following the outbreak of the war. Most Ukrainian enterprises (64.1%) had to reorganize their routes entirely, reflecting the direct impact of the conflict on transport corridors. In contrast, Polish companies mainly introduced minor adjustments (58.4%) or maintained existing routes (39.6%), indicating a lower level of disruption in their logistics operations.

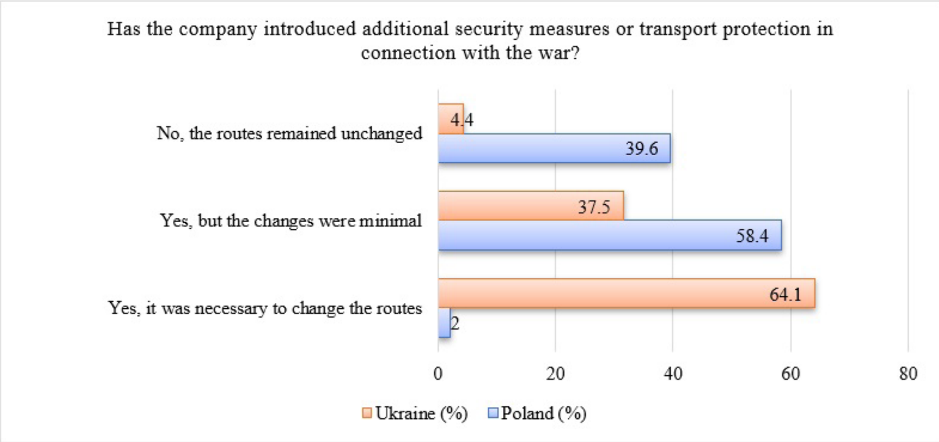

Fig. 3. Was it necessary to adjust transport routes due to the war situation in Ukraine?
Source: Own study

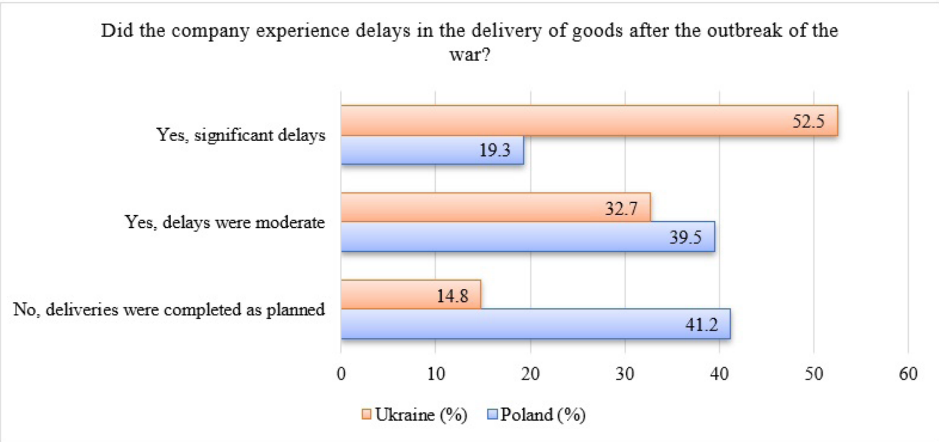

Fig. 4. Did the company experience delays in the delivery of goods after the outbreak of the war?
Source: Own study

The figure illustrates the extent of delivery delays reported by transport companies in Poland and Ukraine. Over half of Ukrainian companies (52.5%) experienced significant delays, reflecting severe disruptions in logistics chains due to the ongoing conflict. In contrast, Polish companies reported fewer disruptions, with (41.2%) stating that deliveries were completed as planned and only (19.3%) indicating significant delays.

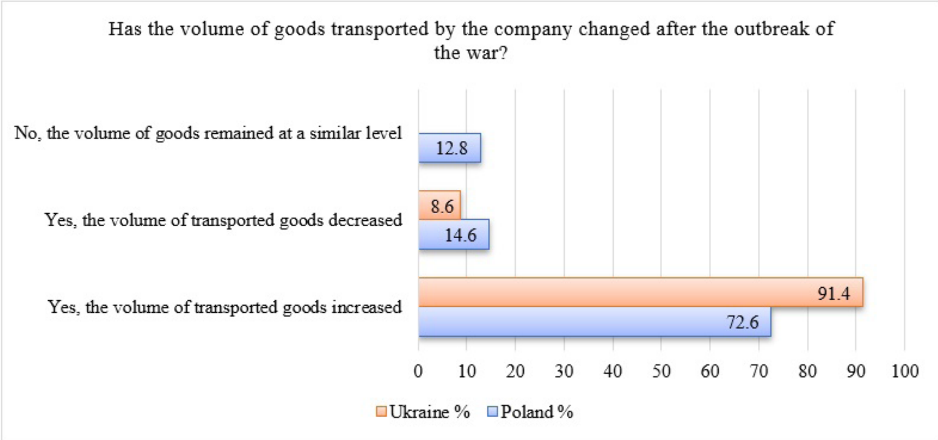

Fig. 5. Has the volume of goods transported by the company changed after the outbreak of the war?
Source: Own study

This figure compares changes in transported cargo volumes in Poland and Ukraine. A significant majority of Ukrainian companies (91.4%) reported an increase in the volume of transported goods, likely reflecting the redirection of trade flows and intensified logistics demand. Similarly, 72.6% of Polish companies also noted an increase, indicating heightened transport activity due to geopolitical shifts and reorganization of supply chains.

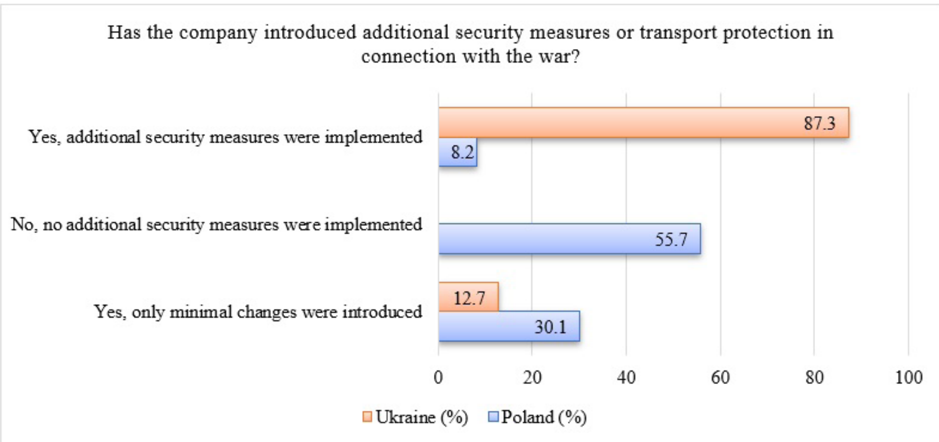

Fig. 6. Has the company introduced additional security measures or transport protection in connection with the war?
Source: Own study

This figure illustrates the contrasting approaches to transport security enhancements in Poland and Ukraine. A substantial majority of Ukrainian companies (87.3%) implemented additional security measures, reflecting their immediate exposure to war-related threats. In contrast, most Polish companies (55.7%) did not introduce significant changes, suggesting a perception of lower direct risk or reliance on existing protective protocols.

The analysis conducted showed clear differences in the impact of the armed conflict on the operational activities of transport companies in Poland and Ukraine. In all cases, road transport remains the dominant mode of operation, but Ukrainian companies were much more likely to use intermodal models, particularly involving rail and maritime transport. This indicates the need to respond flexibly in a high-risk environment with limited infrastructure availability.

Ukrainian operators were much more likely to declare the implementation of additional transport security measures, including cargo and personnel security. In Poland, these measures were limited and mainly taken in the context of cross-border operations. Delays in deliveries also affected Ukrainian companies to a greater extent, due to infrastructure damage, blockades and security checks.

In both countries, modification of transport routes was necessary, but in the case of Ukrainian companies it was systemic and permanent, as a response to the immediate operational threat and instability of logistics routes.

Failure Mode and Effects Analysis in critical transport infrastructure

In order to further analyse the impact of the armed conflict on the transport sector, a risk and vulnerability assessment of critical transport infrastructure was carried out using the Failure Mode and Effects Analysis (FMEA) method, an established technique used in the risk and security management of critical infrastructure operations.

The Failure Mode and Effects Analysis (FMEA) method was selected due to its established role in critical infrastructure risk assessment, as recommended by the PN-EN IEC 60812:2019 standard. This approach enables a structured identification of potential failure modes, their causes, and consequences, which is essential in ensuring the operational continuity of transport systems under conditions of military conflict.

FMEA is particularly useful in the transport sector because it allows for the simultaneous evaluation of multiple dimensions of risk, including occurrence, severity, and detectability. The resulting Risk Priority Number (RPN) facilitates transparent classification and prioritisation of vulnerabilities. This proved especially valuable in identifying high-risk scenarios related to border operations, energy shortages, and cyber disruptions across all transport modes.

The relevance of FMEA in this context is supported by previous studies, such as Pac (2024), who successfully applied this method in maritime infrastructure assessments. Its adaptability and clarity make it an effective tool for guiding corrective actions and reinforcing resilience in cross-border logistics during geopolitical instability.

This method makes it possible to identify potential failure modes and to assess their effects on the operational continuity of transport systems, taking into account their degree of detection and their probability of occurrence. In the context of the analysed case of transport infrastructure in Central and Eastern Europe under conditions of armed conflict in Ukraine, the FMEA allows for a structured assessment of the vulnerability of individual components of the transport system (road, rail, air and maritime) to threats of a strategic nature.

The inclusion of the FMEA method at the stage of assessing the resilience of critical infrastructure makes it possible to identify critical risk areas and recommend corrective and preventive actions. This approach not only reinforces the effectiveness of systemic risk management in the transport sector but is also an important element in enhancing logistics resilience under conditions of transnational and wartime disruption.

The table below shows the results of the analysis covering the four main modes of transport: road, air, sea and rail. Ten key risk factors were identified for each, together with the assignment of values for the significance (S), frequency (O) and detection (D) indicators, from which R was calculated (Zhongyi, et al., 2021).

$$R = S \cdot O \cdot D \tag{1}$$

The R-values form the basis for prioritising risks and selecting appropriate preventive or corrective actions (Table 1), as included in the risk analysis table for each transport mode (Table 2).

Table 1. Level of risk acceptability in the FMEA method

Risk *R*	**Risk acceptability**	**Risk class**
$R \le 110$	Acceptable (green)	1
$111 < R \le 160$	Tolerable (yellow)	2
$R > 161$	Unacceptable (red)	3

Source: Own study

The analysis revealed that the greatest risk to critical road infrastructure stemmed from physical damage (e.g., bridge destruction) and disruptions at border crossings. These issues impact supply chain continuity and require the implementation of flexible rerouting systems and automation of customs procedures. High risk indicators were also noted for cyber threats and fuel shortages, underscoring the need for investment in IT security and energy diversification.

Table 2. Risk analysis table for air transport

Means of transport: Air transport					
No.	**Potential type of defect**	**Severity (S)**	**Occurrence (O)**	**Detection (D)**	**R**
1	Drone attacks on airports	9	4	5	**180**
Potential effect of the defect: Damage to airport infrastructure results in flights having to be diverted, which destabilises schedules and affects security of supply.					
Corrective action: Implementation of radar-based UAV detection systems and active neutralisation measures in airport operational areas.					
2	Airspace closure	9	6	3	**162**
Potential effect of the defect: Airspace closure changing flight routes increases fuel consumption and operational times, generating costs and delays in critical logistics.					
Corrective action: Reorganisation of air routes using dynamic airspace optimisation algorithms and regional coordination.					
3	Lack of ground staff	7	6	4	**168**
Potential effect of the defect: Staff shortages lead to operational inefficiencies in ground cargo handling, causing downtime and handling delays.					
Corrective action: The use of modular ground support teams and the introduction of robotisation solutions for selected handling processes.					
4	Failure of the radar system	10	3	4	**120**
Potential effect of the defect: Radar failure prevents air traffic management, forcing temporary space closures and diversions of operations.					
Corrective action: Introduction of redundant radar modules supported by satellite observation systems and artificial intelligence.					
5	Cargo congestion	8	7	3	**168**
Potential effect of the defect: Overloaded cargo zones limit handling capacity, resulting in cargo accumulation and an increased risk of damage.					
Corrective action: Improving terminal logistics by implementing congestion prediction and cargo slot optimisation tools.					
6	Errors in customs clearance	7	5	4	**140**
Potential effect of the defect: Procedural errors in customs clearance generate delays and financial consequences in the form of penalties and refunds.					
Corrective action: Integration of clearance procedures with the single customs information system within the European logistics data space.					
7	Attack on air traffic control systems	10	2	5	**100**

Potential effect of the defect: Disturbances in the flight control system threaten the safety of air operations and lead to the need for emergency landings.					
Corrective action: Segmentation of flight control systems and implementation of adaptive safety protocols with autonomous threat detection.					
8	Lack of cold storage at the cargo terminal	8	5	3	**120**
Potential effect of the defect: Lack of proper refrigeration conditions results in a loss of quality and safety for the products being transported.					
Corrective action: Construction of multi-segment cooling zones with variable capacity, controlled by adaptive algorithms.					
9	Riots at the airport	8	3	4	**96**
Potential effect of the defect: The unrest is disrupting access to the airport and could lead to a complete shutdown.					
Corrective action: Securing strategic airports through security corridors and integration with emergency response services.					
10	High handling charges	7	6	2	**84**
Potential effect of the defect: Excessive cargo handling costs are causing an exodus of customers and the need to restructure the freight offering.					
Corrective action: Implement flexible handling fee models linked to service quality and objective performance indicators.					

Source: Own study

For air transport, key risks included drone attacks, airspace closures, and cargo terminal congestion. Issues related to staff shortages and the need for robotic ground operations were also identified. Integrating customs clearance systems within a single EU logistics space is crucial, as it can reduce disruptions and improve on-time delivery.

Table 3. Risk analysis table for maritime transport

Means of transport: Maritime transport					
No.	**Potential type of defect**	**Severity (S)**	**Occurrence (O)**	**Detection (D)**	**R**
1	Closure of seaports in Ukraine	9	7	3	**189**
Potential effect of the defect: Port closures have the effect of breaking logistics chains, forcing costly relocation of cargo and overloading other ports.					

Corrective action: Relocation of trade routes to EU ports with the implementation of interoperable intermodal chains.					
2	Attack on a merchant ship	10	4	5	**200**
Potential effect of the defect: The threat of attack results in the need to reduce the number of vessels operating in the waters concerned, leading to a reduction in the capacity of sea lanes and an increase in freight costs.					
Corrective action: The use of integrated protection for merchant vessels through coordination with naval forces and implementation of AIS+ tracking systems.					
3	Lack of container availability	8	6	4	**192**
Potential effect of the defect: A shortage of containers increases costs and disrupts delivery schedules, making it difficult to transport critical shipments.					
Corrective action: Extension of container infrastructure including resource caching and use of hybrid containers.					
4	Crane/port terminal failure	7	5	4	**140**
Potential effect of the defect: Failure of handling equipment leads to operational stagnation and prolonged downtime in the operation of units.					
Corrective action: Transformation of maintenance policy towards a predictive approach and automation of technical inspection of equipment.					
5	Storms and high waves	8	5	3	**120**
Potential effect of the defect: Unpredictable sea conditions lead to material losses and increased risks in the transport of high-value cargo.					
Corrective action: Application of high-resolution meteorological prediction systems and adaptive cruise schedule management.					
6	Contamination of port waters	9	3	4	**108**
Potential effect of the defect: Environmental contamination limits port accessibility and necessitates lengthy decontamination processes.					
Corrective action: Installation of multi-layered harbour water treatment systems and integration with environmental monitoring systems.					
7	Cyber attack on marine terminal	9	4	5	**180**
Potential effect of the defect: Digital paralysis of terminals leads to a complete loss of handling capacity and errors in vessel traffic management.					
Corrective action: Segmentation of seaport IT systems and their isolation from public networks, supported by TAPA security certification.					
8	Port access blocked due to accumulation of sediment or objects	8	3	4	**96**

Potential effect of the defect: Blocking access to the port has the effect of shifting maritime traffic to other routes, disrupting regional logistics.					
Corrective action: Introduction of adaptive algorithms for vessel traffic management and continuous hydrological monitoring.					
9	Leakage of hazardous substances	9	3	4	**108**
Potential effect of the defect: Spills of hazardous substances lead to damage to ecosystems and international sanctions against operators.					
Corrective action: Establishing regional environmental incident response centres and building marine contamination response reserves					
10	Lack of interoperability of IT systems	7	5	3	**105**
Potential effect of the defect: The lack of consistency in IT systems makes it difficult to exchange data, resulting in logistical errors and operational downtime.					
Corrective action: Standardisation of operational data formats and construction of a common interoperability platform for port operators.					

Source: Own study

The highest risk level in maritime transport stemmed from attacks on merchant ships and the closure of Ukrainian ports. The shortage of containers and limited interoperability of IT systems point to the need for standardization and development of container infrastructure. These findings underscore the need to build EU–Ukraine solidarity maritime corridors and interoperable digital solutions for ports.

Table 4. Risk analysis table for rail transport

Means of transport: Rail transport					
No.	**Potential type of defect**	**Severity (S)**	**Occurrence (O)**	**Detection (D)**	**R**
1	Train derailment by sabotage	10	5	4	**200**
Potential effect of the defect: A train derailment leads to severe damage to infrastructure and the temporary suspension of key transport links.					
Corrective action: Construction of railway line monitoring systems using UAVs and AI in continuous mode and automated hazard analysis.					
2	Damage to tracks by attack	9	5	3	**135**
Potential effect of the defect: Track damage disrupts the flow of services and causes traffic to be diverted to less efficient routes.					
Corrective action: Introduction of smart structural sensors and development of mobile inspection teams for strategic trackways.					

3	Lack of rolling stock	8	6	3	**144**
Potential effect of the defect: The shortage of rolling stock prevents the planned services from being implemented and results in under-utilisation of available infrastructure resources.					
Corrective action: Increasing the flexibility of rolling stock supply through dynamic leasing and the establishment of strategic rolling stock reserves.					
4	Too few intermodal terminals	8	6	3	**144**
Potential effect of the defect: The lack of a sufficient number of terminals limits transhipment capacity, leading to congestion and lost time.					
Corrective action: Expansion of the network of intermodal terminals with preference for cross--border locations and EU-AU logistics hubs.					
5	Cyber attack on traffic control system	10	3	5	**150**
Potential effect of the defect: Cyber-attacks can disrupt traffic control systems, posing an immediate security risk.					
Corrective action: Deployment of SIL4 class protection and IT segmentation systems in rail traffic control systems with anomaly detection.					
6	Operational disorders caused by ice and snowfall	7	7	3	**147**
Potential effect of the defect: Extreme weather conditions lead to infrastructure failures and traffic being held up on sensitive sections.					
Corrective action: Winter infrastructure development: installation of active turnout heating and digital track weather prediction tools.					
7	Train drivers' strike	8	5	3	**120**
Potential effect of the defect: Staff strikes bring rail traffic to a complete halt and cause serious disruption to the supply chain.					
Corrective action: Creation of a compensation fund for train drivers and dynamic management of the route network in crisis situations.					
8	Congestion at railway junctions	7	6	3	**126**
Potential effect of the defect: Congestion at nodes leads to delays and misuse of infrastructure capacity.					
Corrective action: Optimisation of depot flow through adaptive traffic control algorithms and node load modelling.					
9	Failure of refrigerated wagons	8	4	3	**96**
Potential effect of the defect: Failure to control the temperature in refrigerated wagons results in damage to sensitive goods and financial losses.					

Corrective action: Implementation of IoT in wagon cooling systems and automatic alerts for maintenance units.					
10	Lack of track gauge interoperability between Ukraine and EU countries	9	7	3	**189**
Potential effect of the defect: Track width mismatches result in the need for time-consuming and costly transhipment operations or the replacement of bogies in transition zones. This results in a significant reduction in throughput at the borders and a decrease in operational efficiency, especially in the context of military transports and strategic humanitarian supplies.					
Corrective action: The construction of high-capacity transhipment terminals at the rail systems' interfaces, the development of automatic bogie gauge change technology and the implementation of cross-border operational plans to improve the exchange of rolling stock and the organisation of intermodal transport.					

Source: Own study

The study revealed a significant need to harmonize IT systems in ports and terminals, including the creation of a common, interoperable data platform. It is also crucial to increase investment in cross-border intermodal hubs, particularly on the Poland-UA axis, and to support digital risk management tools within the TEN-T.

The results highlight the need to implement route diversification mechanisms and contingency plans, especially in the context of geopolitical instability. Operators should also invest in the automation and cybersecurity of traffic management systems. Although the study focused on relations between Poland and Ukraine, the identified resilience mechanisms and risk management tools are universal. They can be adapted to other regions of Europe vulnerable to instability, especially in the context of hybrid threats and energy crises.

The study's findings could contribute to future EU policies on critical infrastructure, including the update of the CER (Critical Entities Resilience) Directive guidelines and the strategy for supply chain resilience in the transport sector.

Limitations and Directions for Future Research

Despite the broad scope of the analysis and the use of the FMEA method, the study encountered certain methodological limitations that should be considered when interpreting the results. Primarily, the research sample was limited to companies from Poland and Ukraine, two countries directly involved in cross-border logistics activities in the context of the ongoing military conflict. While this allowed for a deep understanding of the phenomenon from a local operational perspective, it limits the ability to fully generalize the results to all European Union member states.

Further research should be expanded to include representative samples from other Central and Eastern European countries and key EU logistics hubs. Comparative studies that consider the differences in the response capabilities of critical infrastructure systems to disruptions and their level of systemic resilience would be particularly important.

Additionally, the use of advanced simulation tools, such as transport flow modelling, stress-testing analyses, and scenario-based assessments of infrastructure vulnerability to extraordinary events (e.g., hybrid attacks, blackouts, linear destructions), is recommended. This would allow for a better representation of disruption dynamics in real time and support the design of more effective crisis response and contingency planning mechanisms.

Conclusions

The research confirms that the armed conflict in Ukraine represented a significant test of the resilience and adaptability of Europe's transport infrastructure. The disruption of traditional logistics routes, the overloading of critical nodes and the need to reorganise operational models in the TSL sector highlighted the scale of the challenges faced by those responsible for maintaining continuity of supply.

Empirical data obtained from companies in Poland and Ukraine indicate that the reorganisation of transport networks required multi-level actions, including optimising routes, implementing risk management procedures and strengthening cross-border cooperation. Road and rail transport systems played a special role in ensuring the continuity of the flow of strategic cargo and humanitarian aid. The closure of airspace and the blockade of seaports further highlighted the importance of diversification and interoperability within intermodal and multimodal transport.

The application of the FMEA method enabled a structured identification of critical areas and assessment of the vulnerability of specific components within the transport infrastructure. The highest risk levels were observed in cross-border operations and infrastructure bottlenecks—particularly in locations where reserve capacity was limited or where advanced digital integration solutions were lacking. These findings confirm the initial hypothesis that the resilience of critical infrastructure in the context of geopolitical crises is directly dependent on the systemic implementation of risk analysis tools and the harmonisation of regulatory and operational standards.

In light of the above, it becomes imperative to build long-term infrastructure resilience based on threat forecasting, the development of adaptive technologies, and the strengthening of international cooperation. The conclusions drawn from this study may serve as a substantive foundation for further academic research and for shaping regulatory policies in the field of transport infrastructure security under conditions of armed conflict and geopolitical instability.

Despite the broad analytical scope and the application of the FMEA method, the study is subject to certain methodological limitations. The inclusion of enterprises exclusively from Poland and Ukraine constrains the potential to fully extrapolate the findings to the entire European Union. Moreover, the complexity and volatility of the geopolitical environment make it difficult to capture the long-term dynamics of the phenomena under investigation. Future research should consider expanding the sample to include additional EU member states and employing advanced simulation tools to assess the capacity and vulnerability of critical infrastructure systems.

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