ISSN 2669-2023 (print) / ISSN 2538-8959 (on-line) / **https://doi.org/ 10.47459/cndcgs.2026.47**

Road Transport Resilience under Military Threat: Scenario Based Assessment of Strategic Corridors, Civilian Evacuation, and Military Mobility in Lithuania

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Abstract

The changing security environment in Eastern Europe has increased the strategic importance of road infrastructure for national resilience, civilian protection, and allied military mobility. Lithuania occupies a critical position on NATO's north eastern flank, where a limited number of strategic road corridors simultaneously support domestic mobility, freight transport, civilian evacuation, and allied reinforcement. This study assesses the resilience of Lithuania's national road network under four military threat scenarios: blockade of the Suwałki Corridor and attacks from Kaliningrad Oblast, Belarusian territory, and the Latvian direction. The methodological framework combines structured evidence synthesis from public transport and infrastructure data, strategic and policy documents, and scientific literature with spatial road network assessment, scenario analysis, and multicriteria vulnerability scoring. The Scenario Severity Index identified the Belarusian scenario as the most severe, scoring 24 of 25 points and reaching 96 percent. The Suwałki Corridor and Kaliningrad scenarios each reached 80 percent, while the Latvian direction scenario reached 64 percent. The analysis identified A1, A5, the Vilnius to Kaunas axis, the Kaunas transport node, and strategic connections with Poland and Latvia as the most critical network elements. The findings show that simultaneous civilian evacuation and military movements may constrain road functionality even without direct infrastructure loss. Nationally coordinated corridor based resilience management and unified civil military traffic coordination are therefore required. The results also provide a structured vulnerability evidence base for the future development of the National Transport Mobilization Index.

KEY WORDS: *military mobility; road transport resilience; civilian evacuation; NATO reinforcement; critical road infrastructure; strategic transport corridors; Scenario Severity Index; Lithuania.*

Citation: Bekešienė, S., Raslavičius, L. Road Transport Resilience under Military Threat: Scenario Based Assessment of Strategic Corridors, Civilian Evacuation, and Military Mobility in Lithuania. In Proceedings of the Challenges to National Defence in Contemporary Geopolitical Situation, Brno, Czech Republic, 7-10 September 2026. ISSN 2538-8959, https://doi.org/ 10.47459/cndcgs.2026.47

1. Introduction

Russia's full scale invasion of Ukraine in 2022 has fundamentally changed the European security environment and reinforced the strategic role of transport infrastructure in national defence, civil preparedness, and societal resilience. Recent armed conflict has demonstrated that military effectiveness depends not only on combat capability but also on the continuous movement of personnel, equipment, essential goods, humanitarian assistance, and civilian populations. Roads, bridges, border crossing points, logistics facilities, fuel distribution systems, and traffic management infrastructure therefore constitute critical components of national security systems and may be exposed to kinetic attacks, sabotage, cyber incidents, and other forms of hybrid disruption [1,2]. Disruption of a limited number of critical transport links can generate cascading network effects, including congestion, delayed military deployment, interrupted supply chains, and reduced emergency response capacity. These conditions have strengthened the need to integrate transport engineering, infrastructure resilience, civil protection, military mobility, and crisis management within national transport planning [1,3]. Road transport is particularly important because it provides high operational flexibility, supports door to door logistics, and connects population centres, border crossings, military facilities, airports, ports, railway terminals, and logistics hubs. During the initial phases of a crisis, road networks may simultaneously accommodate military convoys, civilian evacuation flows, emergency services, strategic

Peer-review under responsibility of General Jonas Žemaitis Military Academy of Lithuania and University of Defence, Czech Republic

freight, and infrastructure recovery teams. The operational availability of strategic road corridors therefore directly affects Host Nation Support and NATO reinforcement capacity [4,5]. Importantly, physical availability alone does not ensure functional road capacity. An undamaged corridor may become operationally constrained by traffic concentration, uncontrolled evacuation movements, vehicle breakdowns, insufficient route redundancy, or conflicting civilian and military transport priorities.

Lithuania is particularly exposed to these problems because of its geographical position on NATO's northeastern flank and the external border of the European Union. The Lithuanian road network forms part of the principal land transport connection between the Baltic States and Central Europe, supports international freight transport, enables allied reinforcement through the Suwałki Corridor, and forms the main infrastructure base for large scale civilian evacuation. These functions are concentrated on a relatively limited number of strategic corridors. The A1 corridor connects Vilnius, Kaunas, and Klaipėda and forms the principal east west redistribution axis, while the A5 corridor provides the main road connection with Poland and continental allied territory. The A3, A15, and A16 corridors perform important functions in access to and movement from the Vilnius region, whereas the A8 and A10 corridors support northern connectivity with Latvia. The national road system consequently performs civilian, commercial, emergency, and defence functions on many of the same infrastructure links. The Suwałki Corridor is commonly recognised as a strategically sensitive land connection between the Baltic States and other NATO members. Its restriction could impair allied reinforcement, international freight flows, and access to continental Europe. However, a focus on the Suwałki Corridor alone may obscure other forms of structural road network vulnerability. Disruption affecting the Klaipėda region could increase evacuation and logistics pressure on the A1 corridor; pressure on the Vilnius region could generate large westbound population movements while military transport requires access toward eastern Lithuania; and disruption of northern corridors could reduce road connectivity with Latvia. The resilience problem is therefore not limited to the loss of a single corridor. It concerns the capacity of the national road network to redistribute several competing transport flows under spatially different disruption conditions.

Existing research has increasingly addressed transport resilience, critical infrastructure, and military mobility. Transport resilience research indicates that disruption of strategically connected nodes and links may produce system wide effects [6]. At the European policy level, military mobility planning has focused on infrastructure bottlenecks, dual use transport assets, cross border procedures, and the suitability of civilian transport infrastructure for defence requirements [1,7]. Nevertheless, a research gap remains at the national road network scale. Existing studies and policy assessments often examine military mobility, transport infrastructure, logistics, or evacuation as separate problems. Less attention has been given to the simultaneous use of the same road corridors by civilian evacuees, NATO military movements, emergency services, and strategic freight under multiple threat scenarios.

This gap is particularly relevant to evacuation planning. Municipal evacuation planning is generally organised within administrative territories and may identify local assembly areas and evacuation routes. However, separate local plans may not fully account for the cumulative traffic demand generated when several municipalities direct population flows toward the same strategic corridor or transport node. Evacuation from a major metropolitan area cannot be assessed solely through the availability of local exit routes. Downstream road capacity, receiving nodes, alternative corridors, fuel availability, incident clearance, and competing military traffic must also be considered. National evacuation preparedness should therefore be assessed as a network wide transport coordination problem rather than as a set of independent municipal movements. The need for such analysis is reinforced by the Baltic security environment. Lithuanian intelligence assessments continue to identify the Russian Federation as the principal long term military threat to national security. Although Russia's continuing war against Ukraine constrains its immediate capacity for large scale conventional aggression against NATO, force regeneration, military industrial expansion, and the rebuilding of strategic reserves may increase pressure on NATO's eastern flank over the medium term [8]. The exact timing and form of a future military crisis remain uncertain. For transport research, however, this uncertainty strengthens the value of scenario based assessment because recurring network weaknesses can be identified without predicting a specific military operation. Against this background, the present study assesses the resilience of Lithuania's national road transport network under four operational scenarios: blockade of the Suwałki Corridor and attacks originating from Kaliningrad Oblast, Belarusian territory, and the Latvian direction. The analytical framework integrates structured spatial road network assessment, strategic corridor dependency, border connectivity, military mobility, civilian evacuation pressure, and multicriteria vulnerability assessment. Five operational impact dimensions are compared using the Scenario Severity Index SSI: military mobility risk, civilian evacuation pressure, supply chain disruption, continuity of government risk, and road network congestion. The study seeks to identify recurring corridor dependencies, critical transport nodes, and competing civilian and military transport demands under distinct spatial disruption conditions and to derive practical priorities for national road transport preparedness.

The remainder of the article is structured as follows. Section 2 presents the data, spatial road network assessment, scenario development, and vulnerability assessment framework. Section 3 reports the national road network analysis and the results of the four operational scenarios, followed by comparative assessment using the Scenario Severity Index. Section 4 discusses the findings, practical implications, and study limitations. Section 5 presents the main conclusions and priorities for strengthening Lithuania's road transport resilience.

2. Materials and Methods

2.1. Study Area

The study was conducted at the national scale, considering the entire territory of the Republic of Lithuania as an integrated road transport system operating under conditions of potential military aggression. The analysis focuses on the national road network because road transport constitutes the primary mode supporting civilian evacuation, military mobility, emergency response, freight distribution, and Host Nation Support (HNS) operations [9]. Particular attention was devoted to the strategic transport corridors connecting Lithuania with neighbouring NATO and European Union Member States, including the Via Baltica corridor, the A1 (Vilnius–Kaunas–Klaipėda), A5 (Kaunas–Marijampolė–Suwałki), A8 (Panevėžys–Aristava–Sitkūnai), A10 (Panevėžys–Pasvalys–Riga), A3, A15 and A16 highways, together with major road junctions, bridges, border crossing points, logistics centres and intermodal terminals. The study area further includes border crossing infrastructure with Poland, Latvia, Belarus and the Russian Federation (Kaliningrad Oblast), which collectively represent the principal gateways for international freight transport, military reinforcement and emergency evacuation [11-13].

2.2. Data Sources

The study integrated quantitative and qualitative data from national and international public sources to support cross source verification and methodological transparency. Road network characteristics, traffic volumes, pavement condition, bridge inventories, and infrastructure maintenance information were obtained from Via Lietuva and the Ministry of Transport and Communications of the Republic of Lithuania [12,13]. Border crossing infrastructure, freight flows, and transport indicators were compiled from the State Border Guard Service, the State Data Agency, and Lithuanian Customs [14,15]. These sources provided the empirical basis for identifying strategic road corridors, critical transport nodes, cross border connections, infrastructure condition, and potential transport bottlenecks.

Strategic and security related information was derived from European Union military mobility policy documents, NATO publications on resilience and logistics, and Lithuanian national threat assessments. These sources informed the assessment of military mobility, allied reinforcement, logistics continuity, civil preparedness, and transport resilience requirements relevant to the four operational scenarios [13,16,17]. Lithuanian legal acts governing transport, mobilisation, crisis management, civil protection, and critical infrastructure were also reviewed to assess the institutional and regulatory context of national transport preparedness [18].

Peer reviewed scientific and policy literature on transport network resilience, critical infrastructure vulnerability, evacuation planning, and scenario based risk assessment was used to support the analytical framework [16,19 to 21]. Road infrastructure, traffic, border connectivity, and strategic transport information were compiled and standardised within a common analytical database to support the spatial road network assessment, corridor comparison, critical node identification, and scenario analysis. The assessment followed a structured corridor and node based approach, with particular attention to network dependency, route redundancy, cross border accessibility, and competing civilian and military transport functions. Recent transport resilience guidance also identifies vulnerability assessment, network dependency, and scenario based stress testing as important approaches for identifying critical transport risks [21]. The collected quantitative and documentary sources were reviewed through a structured evidence synthesis procedure. Information relevant to strategic corridor functions, critical transport nodes, route redundancy, cross border accessibility, civilian evacuation, and military mobility was identified and organised according to the analytical categories defined in the vulnerability assessment framework.

2.3. Spatial Road Network Assessment and Scenario Development

Lithuania's road network was assessed as a spatially structured system composed of strategic corridors, transport nodes, border crossing points, and critical infrastructure assets. The analysis identified corridor dependency, node exposure, route redundancy, cross border connectivity, and potential bottlenecks using structured map based assessment and scenario comparison. Strategic links included motorways, national roads, and regional roads, while nodes included major junctions, logistics centres, border crossings, and multimodal transport points [22]. Connectivity assessment examined the availability of alternative routes under degraded network conditions, while spatial overlay analysis identified areas where civilian evacuation flows, strategic road corridors, and military mobility functions could intersect. This analytical framework provided the spatial basis for identifying critical corridors and nodes and for the subsequent scenario based vulnerability assessment.

Scenario development followed a structured scenario planning approach rather than predictive military modelling. Scenario planning enables the systematic assessment of plausible alternative conditions under uncertainty without assigning probabilities to specific future events [19]. Four operational scenarios relevant to Lithuania's geographical and security context were assessed: blockade of the Suwałki Corridor, attack from Kaliningrad Oblast, attack from Belarusian territory, and attack from the Latvian direction. Each scenario represented a distinct spatial pattern of corridor disruption, pressure on critical transport nodes, and competing civilian and military transport demand. Scenario assumptions were informed by publicly available national security assessments and NATO principles concerning military movement, reinforcement, logistics, civil preparedness, and Host Nation Support. NATO planning emphasises the dependence of collective defence on logistics coordination, civilian infrastructure and services, and the ability to support large scale military movements under crisis conditions [17].

2.4. Road Network Modelling and Military Mobility Assessment

Road network performance was evaluated through a systems approach considering network connectivity, route redundancy, corridor hierarchy and operational capacity [23]. Strategic transport corridors were analysed to identify critical links whose disruption would significantly affect nationwide mobility. Particular attention was devoted to major intersections, bridges, urban bypasses and road sections connecting border crossing points with logistics hubs and metropolitan areas. Rather than modelling individual traffic volumes, the analysis evaluates the structural capacity of the road network to sustain simultaneous civilian evacuation and military transport under emergency conditions [21].

Military mobility was assessed by analysing the compatibility of the national road network with NATO reinforcement requirements. The evaluation considered strategic access routes, road hierarchy, bridge availability, logistics support infrastructure and connectivity with Host Nation Support facilities [2,25]. Special attention was given to potential conflicts between civilian traffic and military convoy movements, recognising that road infrastructure must simultaneously support defence operations and civilian protection during crisis situations [5].

2.5. Evacuation and Border Crossing Assessment

Civilian evacuation capacity was evaluated from a nationwide perspective rather than through isolated municipal evacuation plans. The assessment examined the ability of strategic road corridors to accommodate large-scale population movements while maintaining emergency service accessibility and military transport continuity [25]. Border crossing infrastructure was analysed as an integral component of transport resilience because international crossings constitute critical nodes for freight transport, humanitarian assistance, allied reinforcement and potential civilian displacement [1]. Their operational capacity, geographical distribution and connectivity with the national road network were incorporated into each scenario assessment.

2.6. Vulnerability Assessment and Decision Framework

A multi-criteria vulnerability assessment was applied to identify strategic road corridors and transport nodes whose disruption could generate disproportionate effects on national mobility and transport system functionality [26]. The assessment considered seven criteria: strategic importance, network connectivity, infrastructure redundancy, operational flexibility, accessibility, recovery potential, and interaction with military mobility. These criteria were examined through the structured spatial road network assessment and four scenario-based analytical cases described in Sections 2.3–2.5. Particular attention was given to infrastructure elements supporting several transport functions simultaneously, including civilian evacuation, military movements, emergency response, and strategic freight flows.

The identified vulnerabilities were subsequently compared across the four scenarios to determine recurrent corridor dependencies, critical transport nodes, and potential civil-military traffic conflicts. This assessment provided the analytical basis for the five operational impact dimensions and the Scenario Severity Index presented in Section 2.7. The findings were also used to formulate infrastructure, institutional, evacuation, and traffic coordination implications discussed in Section 4. Finally, the results provide a structured vulnerability evidence base for the future development of the National Transport Mobilization Index as a conceptual framework for assessing national road transport preparedness [20].

2.7. Multi Criteria Scenario Severity Scoring

To support systematic cross scenario comparison, the vulnerabilities identified through the spatial road network assessment were classified into five operational impact dimensions: military mobility risk, civilian evacuation pressure, supply chain disruption, continuity of government risk, and road network congestion. These dimensions reflect the main functional consequences associated with strategic corridor exposure, critical node dependency, limited route redundancy, border connectivity, and competing civilian and military transport demands. Each dimension was assessed using a five-point ordinal severity scale ranging from 1, low impact, to 5, critical impact. A score of 1 represented localised disruption with functionally suitable alternative routes and limited national effects; 2 indicated limited regional disruption; 3 represented moderate disruption requiring coordinated interinstitutional response; 4 indicated high disruption affecting strategic corridors, major transport nodes, or national logistics functions; and 5 represented critical system level disruption with nationwide consequences or direct effects on allied military reinforcement, mass civilian evacuation, or continuity of government operations. The scoring criteria and their operational interpretation are presented in Table 1.

Table 1.
Operational impact scoring criteria used in the comparative scenario assessment.

Score	Severity level	Operational interpretation
1	**Low**	Localised disruption; network function maintained; alternative routes readily available.
2	**Limited**	Regional effects; minor capacity reduction; disruption manageable using existing procedures.
3	**Moderate**	Multi regional impact; measurable congestion or capacity reduction; coordinated response required.
4	**High**	Strategic corridor disruption; limited redundancy; major effects on evacuation, logistics, or military mobility.
5	**Critical**	Nationwide or system level disruption; severe network loss; direct threat to mass evacuation, allied reinforcement, or continuity of government.

The structured evidence matrix represented the final synthesis stage of the analytical procedure rather than the primary source of scenario evidence. Evidence was first derived from the road network and infrastructure data, transport and border information, strategic and security documents, and relevant scientific and policy literature described in Section 2.2. The spatial road network and scenario assessments were then used to identify corridor dependencies, critical nodes, route redundancy, cross border accessibility, and potential interactions between civilian and military transport functions. These findings were assessed against the seven vulnerability criteria defined in Section 2.6 and subsequently recorded in the structured evidence matrix. The matrix therefore provided a transparent link between the underlying evidence, vulnerability criteria, operational impact dimensions, and final severity scores. Scores were assigned through a structured evidence matrix linking each operational impact dimension to the underlying vulnerability criteria of strategic importance, network connectivity, infrastructure redundancy, operational flexibility, accessibility, recovery potential, and interaction with military mobility. The final scenario severity score was calculated as the sum of the five operational impact scores. As equal weights were applied, the maximum possible score was 25. The normalised severity index was calculated by dividing the obtained scenario score by the maximum possible score and multiplying the result by 100. The resulting index was used exclusively for relative comparison of the four scenarios and should not be interpreted as a probability of military aggression.

3. Results

3.1. National Road Network Analysis

Lithuania's national road network performs strategic functions extending beyond routine domestic mobility by supporting national logistics, cross border freight transport, emergency response, civilian evacuation, and allied military mobility. Owing to Lithuania's geographical position on the north eastern flank of NATO and the European Union, road infrastructure provides the principal land based connection between the Baltic States and Central Europe and forms an important component of regional reinforcement and Host Nation Support arrangements [1,4]. The operational availability of strategic road corridors is therefore directly relevant to national resilience and regional security.

According to official road inventory data, Lithuania's state road network comprises approximately 21,478 km of roads. Main roads account for approximately 1,948 km, or about 9 percent of the state road network by length, but perform a disproportionate role in long distance, interregional, and cross border connectivity [12,13]. The spatial road network assessment identified a hierarchical structure centred on a limited number of strategic corridors linking major population centres, logistics nodes, and international connections (Fig. 1). This concentration indicates that national road transport resilience is influenced not only by total network extent but also by the operational reliability of a relatively small group of strategically significant links and nodes.

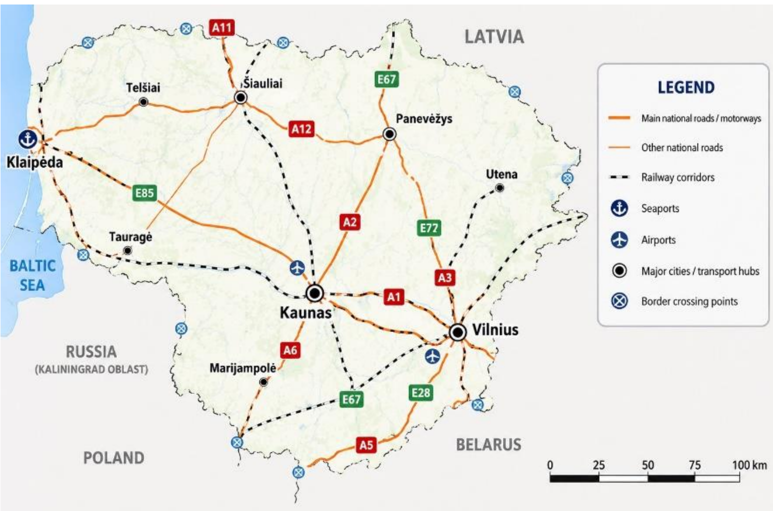


Fig. 1. The Lithuanian national road network, several strategic corridors connecting the country with Poland, Latvia and the port of Klaipėda.

The A1 Vilnius to Kaunas to Klaipėda motorway constitutes the principal east west road axis, linking the country's administrative centre, central transport node, and maritime gateway. The A5 Kaunas to Marijampolė to Suwałki corridor forms a critical section of Via Baltica and provides the principal high capacity road connection with Poland and continental NATO territory. Other strategically important routes include the A2 Vilnius to Panevėžys motorway, A3 toward the Belarusian border, A6 connecting central and eastern Lithuania, A8 and A10 supporting northern connectivity with Latvia, and A11, A12, A14, A15, and A16, which contribute to national accessibility and alternative routing. Collectively, these corridors support civilian mobility, commercial freight, emergency operations, evacuation, and military movement. The assessment identified a marked concentration of strategic transport functions around Vilnius, Kaunas, and Klaipėda (Fig. 1).

Kaunas occupies a central structural position because major north south and east west road corridors intersect within or near the metropolitan area. Its connection with the Rail Baltica corridor and Kaunas Intermodal Terminal further increases its role in national and multimodal transport redistribution. Vilnius, as Lithuania's largest administrative and population centre, represents a major source of routine mobility and potential evacuation demand. Klaipėda, Lithuania's principal seaport, links the national road network with maritime freight, energy related logistics, and international supply chains. Although this spatial organisation supports transport efficiency under normal conditions, it also creates structural dependencies because disruption of a small number of major nodes or connecting corridors may affect transport functions across several regions.

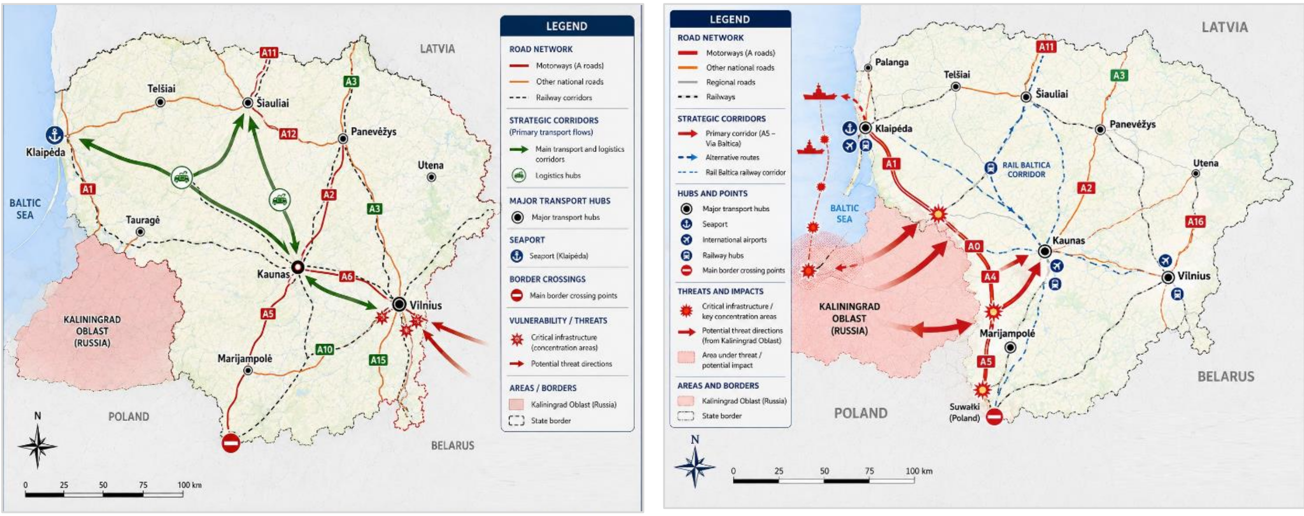
The vulnerability assessment identified limited high capacity route redundancy and concentration of strategic functions as the main structural weaknesses of the national road network. International road connectivity depends strongly on a small number of corridors, particularly A5 toward Poland and A10 toward Latvia. Bridge dependent road sections may create additional vulnerability where disruption of a crossing requires substantial rerouting or transfers transport demand to roads with lower functional capacity. Infrastructure condition may become more operationally significant under crisis conditions, when military vehicles, logistics convoys, emergency services, strategic freight, and civilian evacuation flows simultaneously require access to the same road infrastructure [20,21].

From the perspective of military mobility, Lithuania benefits from an interconnected hierarchy of strategic roads linking major urban centres, border connections, logistics facilities, and multimodal transport nodes. Nevertheless, limited route redundancy and the spatial concentration of transport functions may reduce operational flexibility when several transport demands occur simultaneously. These findings are consistent with European military mobility assessments identifying infrastructure bottlenecks, cross border constraints, and dual use transport capacity as important factors affecting rapid military movement and logistics continuity [16,20].

Overall, the spatial road network assessment indicates that Lithuania's road transport resilience depends primarily on the operational availability of a limited number of strategic corridors, critical transport nodes, bridge crossings, and international connections. The baseline network structure therefore reveals spatially concentrated dependencies that may generate wider transport effects when critical links or nodes are disrupted. These findings provide the analytical basis for the four scenario assessments presented in Section 3.2, in which corridor exposure, transport redistribution, and competing civilian and military mobility demands are examined under distinct spatial disruption conditions.

3.2. Analytical Findings Based on Four Scenario

Four operational scenarios frequently discussed within the Lithuanian national security context were selected and are described in detail in this section: the blockade of the Suwałki Corridor, an attack originating from Kaliningrad Oblast, an attack from Belarusian territory, and an attack from the Latvian direction. Each scenario was defined according to its assumed spatial threat direction, affected strategic road corridors, critical transport nodes, cross border connectivity, expected civilian evacuation pressure, and implications for NATO military mobility. The scenarios were used as structured analytical cases rather than predictive representations of future military operations, allowing the road network response and key vulnerabilities to be assessed under distinct disruption conditions.



a b

Fig. 2. The map illustrates the main strategic corridors, transport hubs, and potential threat directions relevant to: a) Scenario 1 – Suwałki Corridor Blockage; b) Scenario 2 – Attack from Kaliningrad Oblast.

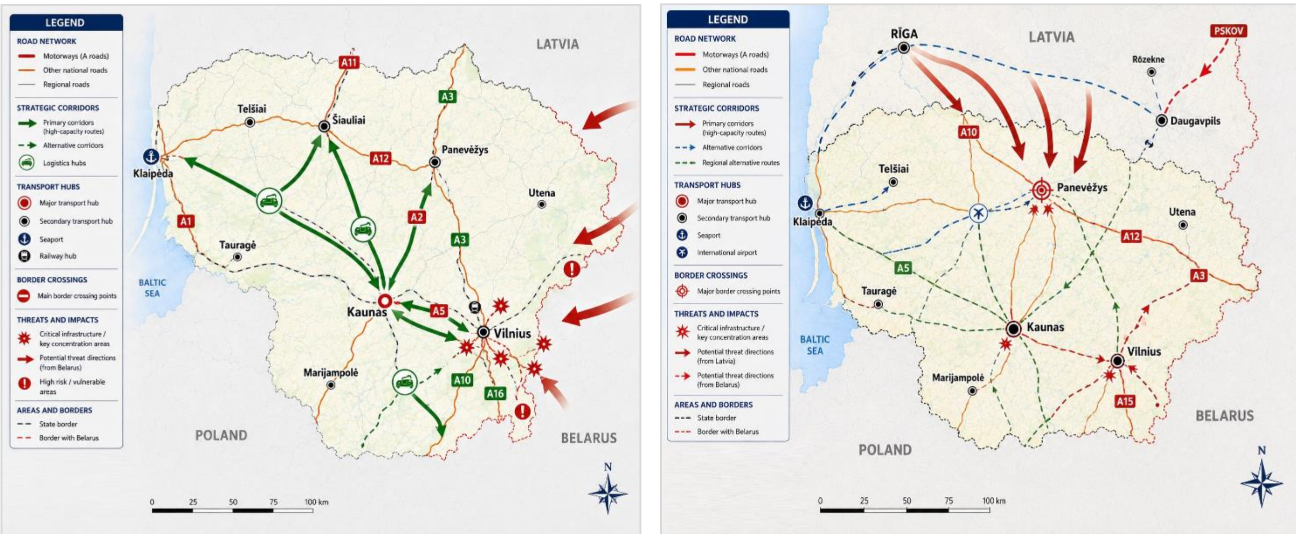
Scenario 1 – Suwałki Corridor Blockade. The spatial road network assessment identified the blockade of the Suwałki Corridor as the most significant threat to Lithuania's international connectivity and NATO military reinforcement capability (Fig. 2A). The simulated disruption of the A5 corridor immediately isolates the Baltic States from the only continuous high-capacity land route connecting Lithuania with Poland and the broader European transport network. Consequently, international freight transport, military mobility, and cross-border logistics become concentrated on a limited number of secondary corridors with substantially lower operational capacity or longer travel distances.

The assessment indicates that traffic redistribution would primarily affect the A1 Vilnius–Kaunas–Klaipėda motorway, the Rail Baltica corridor, and alternative regional routes connecting Kaunas with western Lithuania. The increased concentration of civilian evacuation traffic and military convoy movements around Kaunas creates a high probability of operational conflicts between civilian and defence transport systems. The Marijampolė transport node was identified as the most critical bottleneck because it simultaneously supports international freight transport, military reinforcement, and civilian mobility. The results further demonstrate that disruption of the Suwałki Corridor would significantly increase dependence on Klaipėda Seaport and maritime logistics while simultaneously reducing the flexibility of NATO reinforcement operations. Although alternative routes through the A16 and A7 corridors remain available, their lower capacity and longer travel distances substantially reduce transport efficiency. Therefore, this scenario primarily affects international accessibility, logistics continuity, and military mobility rather than nationwide evacuation capacity.

Scenario 2 – Attack from Kaliningrad Oblast. The second scenario evaluates the consequences of military pressure originating from Kaliningrad Oblast and affecting Lithuania's western transport infrastructure (Fig. 2B). Unlike Scenario 1, which primarily disrupts international land connectivity, this scenario concentrates operational impacts on the country's principal maritime gateway and the western section of the national road network. The spatial analysis identifies Klaipėda as the most vulnerable transport node because it integrates maritime, railway, road, and energy infrastructure within a relatively small geographical area. Disruption of port operations would directly affect container transport, fuel imports, LNG distribution, and strategic logistics supporting both civilian supply chains and military operations.

Road traffic modelling indicates that evacuation flows originating from western Lithuania would rapidly concentrate along the A1 corridor toward Kaunas and Vilnius. This corridor therefore performs two simultaneous functions: it serves as the principal evacuation route while also remaining the primary military mobility axis connecting central Lithuania with Klaipėda. Such overlap substantially increases the probability of congestion and operational interference between civilian and military transport. The scenario also demonstrates the strategic importance of alternative logistics routes through Latvian ports. However, the analysis indicates that rerouting freight transport to northern maritime gateways would increase transport distances and reduce overall logistics efficiency. Consequently, maintaining operational functionality of the Klaipėda–Kaunas corridor represents one of the highest infrastructure protection priorities under this scenario.

Scenario 3 – Attack from Belarusian Territory. Among the four scenarios analysed, the attack originating from Belarusian territory generates the highest level of nationwide transport disruption and represents the most critical challenge for continuity of government operations (Fig. 3A). The analysis indicates that direct military pressure on the Vilnius region simultaneously affects the country's political centre, the largest population concentration, and several strategic transport corridors connecting eastern Lithuania with the national road network.



a **b**

Fig. 3. The map illustrates the main strategic corridors, transport hubs, and potential threat directions relevant to: a) Scenario 3 – Attack from Belarusian Territory; b) Scenario 4 – Attack from the Latvian Direction.

The spatial road network assessment indicates that disruptions affecting the A3, A15 and A16 highways significantly reduce the accessibility of eastern Lithuania and force large-scale evacuation traffic onto the Vilnius–Kaunas corridor. Under these conditions, Kaunas becomes the principal redistribution node for both civilian evacuation and military logistics, creating substantial pressure on the national transport system. The results further indicate that the overlap between evacuation movements and NATO military reinforcement operations is greatest under this scenario. Civilian transport streams moving westward intersect with military convoys entering Lithuania from Poland and moving toward operational deployment areas. Such interactions considerably increase congestion risk, reduce transport efficiency, and complicate traffic management.

Furthermore, because Vilnius contains the principal national governmental and administrative institutions, disruption affecting transport accessibility in the region also has implications for emergency coordination and continuity of government functions. Scenario 3 therefore represents a combined evacuation, road capacity, military mobility, and national governance crisis and was identified as the most severe of the four assessed scenarios.

Scenario 4 – Attack from the Latvian Direction. The fourth scenario analyses military pressure affecting Lithuania's northern transport corridors and cross-border connectivity with Latvia (Fig. 3B). The results indicate that this scenario primarily disrupts regional logistics rather than nationwide transport operations. The Panevėžys transport node emerged as the most critical infrastructure element because it connects the Via Baltica corridor with east-west transport routes leading toward Šiauliai, Klaipėda and Kaunas. Disruption of this junction would significantly reduce connectivity between Lithuania and Latvia while increasing pressure on alternative transport corridors.

The analysis identifies the A10 and A8 highways as the principal vulnerable corridors supporting cross-border freight transport and NATO logistics. Increased transport demand is subsequently redistributed toward the Klaipėda region, placing additional operational pressure on western transport infrastructure. Although Scenario 4 produced a lower relative severity score than the other three scenarios, it remains strategically important because disruption of northern corridors could constrain logistics and military movement from the Latvian direction. Scenario 4 is therefore characterised as a northern corridor and regional military logistics crisis.

3.3. Comparative Assessment of Military Threat Scenarios

The comparative assessment shows that the four military threat scenarios produce different spatial and operational patterns of road network disruption, although their effects repeatedly converge on a small set of strategic corridors and transport nodes. To permit systematic cross scenario comparison, five impact dimensions were assessed using a five-point ordinal scale, where 1 indicates a low impact, 2 a limited impact, 3 a moderate impact, 4 a high impact, and 5 a critical impact. The assessed dimensions were military mobility risk, civilian evacuation pressure, supply chain disruption, continuity of government operations, and road network congestion. The scores represent scenario based analytical ratings derived from the spatial network assessment, identified corridor dependencies, concentration of transport functions, and expected interaction between civilian and military traffic. They should therefore be interpreted as relative scenario severity scores rather than direct probabilities of military events (see Table 1).

Table 1.
Comparative Scenario Severity Index assessment of the four military threat scenarios affecting the Lithuanian road transport network.

Assessment dimension	**Scenario 1 Suwałki Corridor**	**Scenario 2 Kaliningrad**	**Scenario 3 Belarus**	**Scenario 4 Latvia**
Military mobility risk (M_s)	5	4	5	4
Civilian evacuation pressure (E_s)	3	4	5	3
Supply chain disruption (C_s)	5	5	4	4
Continuity of government risk (G_s)	3	3	5	2
Road network congestion (R_s)	4	4	5	3
Total Scenario Severity Score (S_s)	**20 of 25**	**20 of 25**	**24 of 25**	**16 of 25**
Scenario Severity Index (SSI)	80 percent	80 percent	96 percent	64 percent
Principal corridor at risk	A5	A1	A3, A15, A16	A10, A8
Principal critical node	Marijampolė and Kaunas	Klaipėda and Kaunas	Vilnius and Kaunas	Panevėžys and Šiauliai
Dominant operational effect	NATO reinforcement restriction	Maritime and energy logistics disruption	Nationwide evacuation and governance disruption	Northern logistics disruption

For each scenario, the total severity score (S_s) was calculated as the sum of the five operational impact ratings:

$$S\_s = M\_s + E\_s + C\_s + G\_s + R\_s \quad (1)$$

where S_s denotes the total severity score for scenario s, M represents military mobility risk, E civilian evacuation pressure, C supply chain disruption, G continuity of government risk, and R road network congestion. Because five dimensions were assessed on a scale from 1 to 5, the maximum possible severity score was 25. The normalised Scenario Severity Index was calculated as:

$$SSI\_s = S\_s / 25 \times 100 \quad (2)$$

Equal weighting was applied to all five impact dimensions. This approach was selected to avoid imposing an unsupported hierarchy between military, civilian, logistics, governance, and road network effects and to maintain transparency of the comparative assessment. The Scenario Severity Index was used solely to compare the relative transport consequences of the four defined threat scenarios.

The numerical ratings presented in Table 1 were assigned using the scenario specific evidence summarised in Table 2. The evidence matrix links the observed spatial and functional characteristics of each scenario with the ordinal severity criteria defined in the methodology. This procedure was used to maintain consistency between the spatial road network assessment, the identification of critical transport nodes, and the final comparative scenario scores.

Table 2.

Evidence basis for ordinal severity score assignment under the four military threat scenarios.

Impact dimension	Scenario 1: Suwałki Corridor	Scenario 2: Kaliningrad	Scenario 3: Belarus	Scenario 4: Latvia
Military mobility	A5 and the principal NATO land reinforcement route are severely restricted. Score 5, support [9, 11 to 13, 16, 17].	Western military logistics and A1 access are affected, while inland redistribution remains partly available. Score 4, [9, 16, 17, 24].	Eastern access and Vilnius deployment corridors are disrupted and intersect with westbound evacuation flows. Score 5, support [9,12,13,16, 17, 24].	Reinforcement from Latvia is restricted through A10 and A8. Score 4, support [9,12,13,16, 17, 20].
Civilian evacuation	Evacuation pressure is concentrated mainly in southwestern Lithuania. Score 3, [12, 13, 15, 21,25].	Large population movements from Klaipėda and Western Lithuania concentrate on A1. Score 4, [12, 13, 21, 25].	Potential mass evacuation from the Vilnius metropolitan region creates the highest national evacuation pressure. Score 5, [12, 13, 15, 21, 25].	Population displacement remains mainly regional in northern Lithuania. Score 3, [12, 13, 21, 25].
Supply chain disruption	Principal land access to Poland and continental Europe is restricted. Score 5, [9,11 -16,20].	Klaipėda port, fuel logistics, maritime freight, and A1 inland distribution are directly affected. Score 5,[9, 13-16, 20].	Eastern supply routes are disrupted, while western logistics remain partly functional. Score 4, [12 – 15, 21, 27 -30].	Northern Baltic supply chains and connections with Latvia are significantly affected. Score 4, [11- 15].
Continuity of government	Major national security effects occur without direct exposure of the main government centre. Score 3, [8, 18].	Government functions are affected indirectly through energy and logistics disruption. Score 3, [8, 18, 21].	Vilnius and central government functions are directly exposed. Score 5, [8, 18].	Direct exposure of central government institutions is limited. Score 2, [8, 18].
Road congestion	A5 traffic is redistributed toward lower capacity routes and Kaunas. Score 4, [12, 13, 15,21,27,30].	Evacuation, freight, emergency, and military flows concentrate on A1. Score 4, [12, 13, 15, 21, 27-30].	Mass evacuation and military movements concentrate on the Vilnius to Kaunas axis. Score 5, [12, 13, 15, 21, 27-30].	Redistribution around Panevėžys and northern corridors causes regionally concentrated congestion. Score 3, [12, 13, 15, 21, 27-30].

The evidence matrix demonstrates that identical total SSI values may result from different operational impact structures. Scenarios 1 and 2 both reached an SSI of 80 percent; however, Scenario 1 was dominated by military mobility and international land accessibility constraints, whereas Scenario 2 was driven primarily by maritime logistics, energy supply, and A1 corridor dependency. Scenario 3 reached an SSI of 96 percent because four of the five impact dimensions were rated as critical. Scenario 4 recorded the lowest comparative SSI of 64 percent, reflecting the more regionally concentrated nature of the expected transport disruption.

Scenario 1, achieved a total severity score of 20 out of 25 and an SSI of 80 percent. Its impact profile was dominated by critical military mobility and supply chain effects, both rated at 5. The scenario therefore represents primarily an international accessibility and allied reinforcement crisis. The moderate evacuation score of 3 distinguishes this scenario from Scenario 3, as the principal pressure originates from the concentration of military, freight, and regional traffic around A5, Marijampolė, and Kaunas rather than from mass displacement of a major metropolitan population.

Scenario 2 also reached an SSI of 80 percent but displayed a different impact structure. Critical supply chain disruption, rated at 5, resulted from the functional dependence of maritime freight, fuel logistics, and inland distribution on Klaipėda and the A1 corridor. Military mobility, evacuation pressure, and congestion were each rated at 4. The scenario is therefore characterised as a maritime logistics and west to east road capacity crisis, with A1 serving simultaneously as an evacuation, freight redistribution, emergency response, and military transport corridor.

Scenario 3 generated the highest SSI of 96 percent, corresponding to 24 out of 25 points. Military mobility risk, civilian evacuation pressure, continuity of government risk, and road congestion were all rated at the critical level of 5. The result reflects the concentration of population, government institutions, and strategic road functions in the Vilnius region. Simultaneous westbound evacuation and military access requirements would place exceptional pressure on the Vilnius to Kaunas axis and the Kaunas redistribution node. Scenario 3 therefore represents the most severe system level road transport disruption among the four assessed cases.

Scenario 4 Scenario 4 reached an SSI of 64 percent, corresponding to 16 out of 25 points. The scenario produced high military mobility and supply chain impacts, both rated at 4, but lower effects on continuity of government, rated at 2. Its transport consequences are concentrated mainly around A8, A10, Panevėžys, and Šiauliai. Scenario 4 therefore represents a northern regional connectivity and military logistics crisis rather than an immediate system level governance crisis.

These numerical comparisons reveal a clear structural pattern. Three of the four scenarios produce a Scenario Severity Index of at least 80 percent, with Scenario 3 reaching the highest value of 96 percent. Network vulnerability is concentrated within a limited set of strategic corridors: A5 supports southern military mobility and land connectivity with Poland, A1 forms the principal east west redistribution axis, A3, A15, and A16 determine access to and evacuation from the Vilnius region, while A8 and A10 maintain northern connectivity with Latvia. Kaunas emerges as the only transport node exposed to major secondary pressure across all four scenarios, functioning as a central redistribution point for southern, western, eastern, and northern traffic flows. This repeated functional dependence identifies the Kaunas transport node as the most systemically important element of the national road network. The comparative results further demonstrate that civilian evacuation and NATO military mobility cannot be assessed as separate transport functions. In three scenarios, the same strategic corridors are required simultaneously for evacuation, military convoys, emergency services, and freight transport. Consequently, network functionality depends not only on physical road capacity but also on the coordinated allocation of capacity among competing transport flows. Without centralised traffic prioritisation, even physically operational corridors may become functionally constrained by congestion, uncontrolled evacuation movements, vehicle breakdowns, and civil military traffic conflicts.

Overall, Lithuania's road transport resilience depends less on total network length than on the operational availability of a limited number of critical corridors and nodes. Scenario 3 was identified as the most severe, scoring 24 out of 25, followed by Scenarios 1 and 2 with 20 out of 25 and Scenario 4 with 16 out of 25. These results provide a structured vulnerability evidence base for the future development of the National Transport Mobilization Index. The Scenario Severity Index and the NTMI should be treated as distinct measures: a higher SSI indicates greater expected transport disruption, whereas a higher NTMI should indicate stronger infrastructure, institutional, and operational preparedness. The findings identify A1, A5, the Vilnius to Kaunas axis, the Kaunas transport node, and the principal connections with Poland and Latvia as priority elements for road resilience planning, evacuation management, and civil military traffic coordination.

4. Discussion

The results confirm the study's central premise that the resilience of Lithuania's road transport system under military threat is determined less by total network length than by the functional availability of a limited number of strategic corridors and transport nodes. This finding is consistent with network based resilience research, which shows that transport systems may remain physically extensive while becoming functionally weak when disruption affects highly connected links or nodes with limited substitution capacity [27,28, 29]. Recent work on strategic highway networks similarly indicates that shared civilian and military infrastructure creates specific risks because targeted disruption of critical links may reduce logistics performance even where much of the wider network remains operational [30]. The present results extend this argument to Lithuania by identifying A1, A5, the Vilnius to Kaunas axis, and the Kaunas transport node as recurrent sources of system level dependency.

The initial analytical assumption that the four military threat scenarios would produce different transport effects was supported. However, the comparative assessment also revealed a stronger degree of spatial convergence than initially expected. Scenario 1 primarily generated an international accessibility and military reinforcement problem, whereas Scenario 2 was dominated by maritime logistics, energy supply, and A1 corridor dependency. Scenario 3 produced the highest Scenario Severity Index, SSI, of 96 percent because the direct exposure of the Vilnius region combines evacuation pressure, government continuity risk, road congestion, and military mobility requirements. Scenario 4 generated a lower SSI of 64 percent, but exposed the dependence of northern connectivity on A8, A10, Panevėžys, and links with Latvia. Despite these differences, three scenarios reached an SSI of at least 80 percent. This indicates that geographically distinct threats may generate similar national transport stress when they affect strategically important corridors characterised by high functional dependency and limited route redundancy.

The results are consistent with the growing European policy emphasis on transport bottlenecks and dual use infrastructure. The European Union's Military Mobility Action Plan 2.0 stresses the need to identify gaps between existing civilian transport infrastructure and military requirements and to prioritise infrastructure investments accordingly [1]. More recently, the European Court of Auditors concluded that obstacles and infrastructure bottlenecks continue to limit effective military movement across the EU and that geopolitical relevance has not always been sufficiently reflected in project prioritisation [7]. The Lithuanian results support this concern. Conventional road investment criteria based primarily on average traffic volumes, travel time, and routine economic efficiency may fail to identify infrastructure whose national security importance becomes visible only under disrupted operating conditions.

Kaunas represents the clearest example of this difference between conventional transport importance and systemic crisis criticality. The comparative scenario assessment identified Kaunas as the only major node exposed to significant secondary pressure in all four scenarios. Its importance derives from its redistribution function between southern, western, eastern, and northern transport flows. This result is consistent with transport resilience studies indicating that disruption or capacity reduction at strategically connected transport nodes may generate effects extending beyond the immediate disruption area [27,30]. The finding also supports research arguing that protection and rapid recovery of critical nodes may provide greater network resilience benefits than uniform investment across all road segments [28]. In the Lithuanian case, this suggests that the Kaunas road system should be assessed as a single strategic mobility node rather than as a collection of independently managed roads, bridges, and junctions.

A second major finding concerns the interaction between civilian evacuation and military mobility. The analysis indicates that these functions cannot be treated as independent planning problems because they repeatedly rely on the same road capacity. NATO defines resilience as the capacity to prepare for, resist, respond to, and recover from major disruptions while maintaining essential Alliance functions. NATO also stresses the importance of civil preparedness, host nation support, and the ability of civilian systems to support military operations [17]. The findings of this study show the practical transport implications of this principle. Under Scenarios 2 and 3 in particular, civilian traffic would move along corridors that are also required for military convoys, emergency services, strategic freight, and logistics support. Therefore, physical road availability does not necessarily imply operational availability.

This finding extends predominantly infrastructure focused approaches to military mobility. European policy has placed strong emphasis on bridge capacity, road geometry, port access, and other physical requirements for the movement of military equipment [1,7,9]. These factors remain essential; however, the Lithuanian scenario results indicate that traffic allocation, movement prioritisation, and operational traffic control are also critical determinants of road network functionality under crisis conditions. A physically intact A1 or A5 corridor may become functionally constrained by uncontrolled evacuation movements, congestion, disabled vehicles, or competing civilian and military transport priorities. NATO's recent logistics work has similarly emphasised lessons from large scale deployments and the need for coordination with civilian authorities and industry to support military movements at scale and speed [17]. The present study therefore supports a broader interpretation of road transport resilience that combines infrastructure condition and route redundancy with traffic management, communication, institutional coordination, and recovery capacity.

The findings also indicate a scale mismatch between municipal evacuation planning and national road network operation. Local evacuation plans are generally organised within administrative boundaries, whereas evacuation flows may extend across several municipalities and converge on the same strategic corridors and transport nodes. Evacuation from Vilnius, Klaipėda, or several neighbouring municipalities may therefore generate cumulative transport demand on national road corridors and downstream redistribution nodes. From a road network perspective, the relevant analytical unit is the complete origin to destination movement and its interaction with strategic corridors rather than an individual municipal road section. This interpretation is consistent with transport resilience research that considers connectivity, alternative routing, node capacity, and system recovery as interdependent network properties rather than isolated infrastructure characteristics [29]. The findings consequently support a shift from fragmented local evacuation route designation toward nationally coordinated, corridor based evacuation planning and future national scale evacuation flow modelling.

The scenario results should also be interpreted within Lithuania's current security context. The National Threat Assessment 2026 identifies Russia as the principal long term military threat to Lithuania and indicates that the future security environment will depend partly on the course of the war against Ukraine, Russian force regeneration, and the availability of military resources (State Security Department of the Republic of Lithuania & Second Investigation Department under the Ministry of National Defence [8]. The four scenarios examined in this study should therefore not be interpreted as forecasts of specific military operations. Their analytical value lies in assessing how the national road network may respond to geographically distinct forms of strategic disruption. Scenario based assessment is used to identify recurring corridor dependencies, critical transport nodes, limited route redundancy, and competing transport demands under uncertainty rather than to predict the location, timing, or operational form of future military aggression.

4.1. Practical Implications

The findings have direct implications for Lithuanian transport, defence, civil protection, and infrastructure policy. First, strategic road investment should include a national security criticality criterion in addition to conventional traffic and economic indicators. A1, A5, the Vilnius to Kaunas axis, the Kaunas transport node, and the principal connections with Poland and Latvia should be assessed according to their combined roles in civilian evacuation, freight continuity, emergency response, and allied military movement. This recommendation is consistent with the European shift toward protected and resilient dual use transport infrastructure and faster cross border military movement.

Second, the systemic role of Kaunas requires a dedicated strategic mobility resilience plan. Such a plan should assess junction and bridge capacity, alternative bypass routes, traffic control arrangements, heavy vehicle recovery capacity, temporary staging areas, and communication redundancy. The objective should not be limited to protecting individual infrastructure assets. It should maintain the redistribution function of the Kaunas node when one or more incoming corridors are degraded.

Third, municipal evacuation plans should be assessed within a nationally coordinated road network framework. Population departure assumptions, vehicle availability, evacuation timing, destination areas, and expected corridor demand should be aggregated across municipalities to identify cumulative transport pressure on strategic corridors and downstream transport nodes. Future dynamic traffic modelling could estimate corridor saturation, queue formation, and evacuation times under alternative departure and route allocation assumptions. Phased evacuation planning should be linked to empirically measured or modelled road capacity rather than administrative boundaries alone.

Fourth, Lithuania should establish a unified civil military traffic coordination framework. NATO logistics policy emphasises interoperability, Host Nation Support, logistics coordination, and cooperation with civilian actors [17]. A national coordination mechanism should support real time corridor status assessment, convoy scheduling, evacuation sequencing, priority freight allocation, and incident clearance. Private logistics operators should be included because military mobility may depend partly on civilian transport capacity and contracted logistics services.

Finally, the scenario findings provide a structured vulnerability evidence base for the future development of the National Transport Mobilization Index. The SSI and NTMI should remain conceptually distinct. The SSI measures the relative severity of transport disruption under a defined scenario, whereas the NTMI is intended to measure infrastructure, institutional, and operational preparedness. Future research should define measurable NTMI indicators, test alternative weighting methods, and conduct sensitivity analysis using expert elicitation or the Analytic Hierarchy Process. Further work should incorporate dynamic traffic assignment, time dependent evacuation demand, bridge specific military load requirements, border processing capacity, fuel availability, and simultaneous multi corridor disruption. These extensions would permit the current comparative vulnerability framework to support quantitative assessment of network performance and recovery under crisis conditions.

4.2. Limitations

Several limitations should be considered when interpreting the findings. First, the four military threat scenarios represent structured analytical cases rather than predictions of the location, timing, probability, or operational form of future military aggression. The scenarios necessarily simplify the uncertainty and dynamic conditions associated with armed conflict.

Second, the Scenario Severity Index uses a five-point ordinal scale and equal weighting of five operational impact dimensions. Although this approach supports transparent cross scenario comparison, the resulting scores represent structured analytical assessments of relative scenario severity rather than direct measurements of road network performance. Future studies should test alternative weighting structures using expert elicitation, Delphi methods, the Analytic Hierarchy Process, and sensitivity analysis.

Third, the spatial road network assessment focuses on corridor dependency, critical transport nodes, route redundancy, cross border connectivity, and expected interactions between civilian and military transport demands. Dynamic traffic assignment, routing algorithms, and microsimulation were not applied. Consequently, exact evacuation times, queue lengths, corridor saturation times, and vehicle specific delays were not estimated.

Fourth, the analysis relies on publicly available data and excludes classified information concerning NATO reinforcement plans, mobilisation routes, military convoy schedules, infrastructure protection measures, and Host Nation Support arrangements. Finally, the study focuses primarily on road transport. Future research should integrate rail, maritime, air, energy, fuel distribution, and communication systems to assess interdependent infrastructure failures and cascading effects across national transport and critical service systems.

5. Conclusions

This study assessed the resilience of Lithuania's national road transport network under four military threat scenarios, focusing on strategic corridors, border connectivity, civilian evacuation, and military mobility. The results demonstrate that national road transport resilience depends primarily on the operational availability of a limited number of critical corridors and transport nodes rather than on the overall extent of the road network. The A1 and A5 corridors, the Vilnius to Kaunas axis, the Kaunas transport node, and cross border connections with Poland and Latvia were identified as the most systemically important network elements.

The comparative assessment identified the scenario involving an attack from Belarusian territory as having the highest relative severity, with a Scenario Severity Index SSI of 96 percent. The Suwałki Corridor blockade and Kaliningrad scenarios each reached 80 percent, while the Latvian direction scenario reached 64 percent. Across all four scenarios, competing civilian evacuation and military mobility demands emerged as a major source of pressure on strategic road capacity.

The findings support a shift from fragmented local evacuation planning toward nationally coordinated, corridor based road resilience management. Priority measures include strengthening strategic corridor resilience, improving preparedness of the Kaunas transport node, developing phased evacuation arrangements, strengthening cross border coordination, and establishing unified civil military traffic management. The results also provide a structured vulnerability evidence base for the future development of the National Transport Mobilization Index as a national road transport preparedness assessment framework.

Acknowledgements. This research was funded by the Research Council of Lithuania under the project "*Impact Assessment of the Lithuanian Transport Sector in the Case of a Military Threat to the Country*", Project No. S-REP-26-3, 2026 to 2027.

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