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Transportability of Main Battle Tanks in NATO Military Mobility Frameworks: Road and Rail Constraints of Leopard 2 Deployment within the Czech Armed Forces

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Abstract

The increasing weight and technological complexity of modern main battle tanks (MBTs), particularly the Leopard 2 series, impose substantial demands on military transport systems and supporting infrastructure. This study evaluates the logistical and infrastructural constraints associated with the transport of heavy armoured vehicles within the Czech Armed Forces (CAF) in the context of NATO military mobility requirements. The analysis focuses on both road and rail transport systems, with emphasis on technical compatibility, regulatory compliance, and operational feasibility. The methodological approach combines comparative analysis of vehicle and transport system parameters, empirical axle load measurements, and assessment of compliance with national legislation and NATO transport standards. The study further integrates infrastructure-oriented evaluation to capture systemic constraints affecting mobility performance. The results indicate that road transport operations frequently exceed permissible axle load limits defined by national legislation, while rail transport is constrained by insufficient wagon load capacity and limitations in vehicle securing systems. These constraints collectively reduce the operational flexibility of heavy armoured vehicle deployment. The findings demonstrate that current transport capabilities within the CAF are only partially sufficient for the deployment of Leopard 2 MBT without operational restrictions or reliance on external logistical support. These limitations negatively affect strategic mobility and rapid deployment capability, particularly within multinational operational frameworks. The study therefore highlights the need for continued modernisation of transport assets, adaptation of transport infrastructure, and closer alignment with NATO standardisation and European military mobility initiatives.

KEY WORDS: *Leopard 2, Military Logistics, Military Mobility, NATO, Heavy Vehicle Transport, Transport, Axle Load, Czech Armed Forces*

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1. Introduction

In recent years, the European security environment has undergone a profound transformation, resulting in a renewed emphasis on the role of heavy land forces in ensuring both national and collective defence. The ongoing conflict in Eastern Europe, together with the broader deterioration of the strategic landscape, has underscored the necessity of maintaining robust, credible, and rapidly deployable military capabilities. Within this context, MBT have re-emerged as a pivotal component of conventional deterrence and high-intensity warfare. Simultaneously, the capacity to ensure their rapid and efficient movement across national and allied territories commonly referred to as military mobility has become a critical determinant of operational readiness and responsiveness within the NATO. This requirement is explicitly articulated in the NATO Strategic Concept [1], which highlights rapid reinforcement and force projection as core tasks, as well as in the Strategic Compass [2], where military mobility is identified as a key enabler of credible European defence.

Among contemporary MBTs, the Leopard 2 constitutes one of the most widely deployed and technologically advanced platforms in Europe. Originally developed in the Federal Republic of Germany during the 1970s as a successor to the Leopard 1, the first production variant entered service in 1979 [3]. Since then, the platform has undergone continuous and incremental modernization, resulting in a broad spectrum of variants ranging from the widely proliferated Leopard 2A4 to the latest Leopard 2A7 and 2A8 configurations. These advanced variants integrate sophisticated fire-control systems, enhanced ballistic protection, and a high degree of digitalization within the battlespace. Consequently, the Leopard 2 has effectively become a de facto standard among European NATO member states. However, these technological advancements have been accompanied by a substantial increase in combat weight, which in current variants reaches approximately 60–70 tonnes [3, 4]. This development significantly intensifies the demands placed on transport infrastructure, logistical support systems, and regulatory compliance.

These constraints are further reinforced by infrastructure-specific limitations, particularly the load-bearing capacity of bridges and other critical nodes along transport corridors, which may act as decisive bottlenecks for the movement of heavy armoured vehicles in both national and multinational deployment scenarios [5]. In this regard, military mobility must be understood not merely as a logistical function, but as a strategic enabler directly linked to deterrence credibility and collective defence effectiveness [6, 7].

The Czech Republic represents a pertinent case study within this broader European context. In recent years, the CAF have initiated a gradual transition from legacy Soviet-era equipment to modern Western platforms, including the introduction of Leopard 2A4 MBTs. This transformation is closely associated with the objective of enhancing interoperability within NATO and strengthening national defence capabilities [8]. In May 2022, an agreement with Germany was concluded concerning the delivery of Leopard 2A4 tanks, including associated logistical support and training, with the first units delivered later that same year. Furthermore, long-term modernization plans envisage the acquisition of the Leopard 2A8 variant, which would further elevate the technological standard of CAF and ensure their sustained integration within allied force structures [9]. In alignment with both NATO and EU strategic frameworks, such modernization efforts must be accompanied by corresponding improvements in national contributions to military mobility, particularly in the domains of infrastructure readiness and host nation support [1, 2].

Notwithstanding these advancements, the transition to heavier and more technologically sophisticated platforms generates a range of new challenges, particularly in the domain of logistics and transportability. Existing transport assets and infrastructure in the Czech Republic were predominantly designed for lighter platforms, such as the T-72M4 CZ, and are therefore not fully optimised for the requirements imposed by contemporary MBTs. The transport of heavy armoured vehicles thus represents a complex, multi-dimensional problem encompassing technical, infrastructural, and legislative aspects. Road transport is constrained by axle load limits defined in national legislation and verified through operational measurement procedures [10, 11], whereas rail transport is limited by the availability and load-bearing capacity of suitable railway wagons, as well as by requirements for the safe securing of military equipment in accordance with NATO standards [12, 13]. Empirical studies further indicate that bridge load capacity and structural condition constitute one of the most critical limiting factors in military mobility planning, as insufficient classification or structural degradation may render otherwise compliant routes operationally unusable [5].

These constraints may significantly restrict the ability of the CAF to deploy heavy units efficiently, both within national territory and in the context of allied operations. As a consequence, such limitations directly affect the effectiveness of military mobility and may impede rapid reinforcement in line with the objectives outlined in the NATO Strategic Concept and the EU Strategic Compass [1, 2].

The aim of this article is therefore to assess the capability of the CAF to ensure the road and rail transport of Leopard 2 MBT under current technical, infrastructural, and legislative conditions. The study focuses on identifying key limitations associated with existing transport assets and infrastructure, evaluating their compliance with relevant standards, and analysing the implications for operational mobility and interoperability within NATO. By addressing these issues, the article contributes to the broader scholarly and policy-oriented debate on military mobility in Europe, including initiatives related to the Trans-European Transport Network (TEN-T) and EU military mobility programmes [7, 14-15], which aim to reduce infrastructural and regulatory barriers to the rapid movement of military forces across Europe. In particular, the operational viability of military mobility corridors is increasingly determined not only by regulatory harmonisation, but also by the structural integrity of transport infrastructure, especially bridge networks, which constitute critical nodes of vulnerability in heavy armoured vehicle deployment planning [5].

2. The Leopard 2 Platform in the European Security Environment

2.1 Evolution of Leopard 2 Variants

The Leopard 2 MBT was developed in Germany during the 1970s as a successor to the Leopard 1, with the first production variant entering service in 1979 [3]. The platform was originally designed to meet emerging NATO requirements for improved firepower, protection, and mobility in high-intensity conventional warfare environments, reflecting doctrinal developments within the Alliance during the late Cold War period [1].

The Leopard 2A4 subsequently became the dominant baseline configuration and was widely exported to NATO member states and partner countries following the end of the Cold War [3]. This variant established a robust structural and operational foundation for subsequent modernization programmes and remains one of the most widely proliferated configurations within European armoured forces.

The Leopard 2A5 introduced significant advancements in modular armour systems, turret redesign, and crew survivability enhancements, while the Leopard 2A6 incorporated a longer 120 mm L/55 smoothbore gun, substantially increasing muzzle velocity, kinetic energy performance, and overall combat effectiveness [8]. These variants are generally considered transitional systems bridging Cold War-era design principles and contemporary digitized battlefield requirements.

The most recent configurations, including the Leopard 2A7 and Leopard 2A8, reflect a doctrinal and technological shift toward network-centric warfare, improved situational awareness, and enhanced protection against both asymmetric and advanced anti-tank threats. These systems integrate upgraded sensor suites, digital fire-control systems, and enhanced battlefield management capabilities. At the same time, they demonstrate a continuous increase in combat weight, which typically ranges between 60 and 70 tonnes depending on configuration and modular armour packages [10]. This weight increase has direct implications for strategic and operational mobility, particularly in relation to transport infrastructure constraints and the requirements defined within NATO military mobility standards [13].

2.2 Distribution Across NATO States

The Leopard 2 MBT is currently operated by a broad range of NATO member states and partner countries, resulting in one of the most geographically and structurally diverse deployments of a Western MBT platform [3]. Its distribution reflects both historical procurement patterns and contemporary modernisation trajectories shaped by national defence priorities, industrial capacities, and fiscal constraints.

Germany remains the principal operator and original developer of the platform, fielding the most technologically advanced variants, including Leopard 2A5, Leopard 2A6, Leopard 2A7V, and the emerging Leopard 2A8 configuration [3]. As such, Germany functions as the primary technological reference point for system upgrades, capability development, and life-cycle modernisation strategies.

A second group of operators is characterised by large-scale fleets with heterogeneous modernisation levels. Poland maintains one of the most extensive Leopard 2 inventories within NATO, consisting primarily of Leopard 2A4 systems supplemented by upgraded Leopard 2PL variants, reflecting a hybrid modernisation approach. Finland similarly operates a substantial fleet of approximately 200 Leopard 2 tanks, combining Leopard 2A4 and Leopard 2A6 variants as part of a gradual capability transition strategy [16].

A third group comprises highly modernised but numerically smaller operators. Denmark employs Leopard 2A5DK and Leopard 2A7 variants, representing one of the most advanced operational configurations in Europe. Norway is currently undergoing a structured transition from Leopard 2A4NO systems towards Leopard 2A7 and Leopard 2A8 variants, reflecting a long-term capability development trajectory aligned with NATO interoperability objectives [1]. Hungary represents a recent adopter, integrating Leopard 2A4 and Leopard 2A7HU variants as part of a broader force modernisation programme [17].

In contrast, several states operate limited fleets or rely on transitional capability models. The Netherlands, which historically maintained a large independent tank fleet, has significantly reduced its armoured capability and currently operates approximately 18 Leopard 2A6 tanks within a binational German–Dutch battalion structure rather than as an autonomous tank force. Portugal operates a limited number of Leopard 2A6 tanks acquired from surplus Dutch inventories, although operational availability is partially constrained by logistical and maintenance dependencies. Greece and Spain maintain mixed fleets consisting of Leopard 2A4 systems alongside national upgrade programmes, reflecting incremental modernisation approaches [8].

The Czech Republic and Slovakia represent transitional operators, primarily employing Leopard 2A4 variants as replacement systems for legacy Soviet-designed armoured platforms. This transition is closely linked to NATO interoperability requirements and long-term force modernisation objectives [7, 9]. Austria operates Leopard 2A4 tanks as a non-NATO partner state, while the United States does not operate the Leopard 2 platform, relying instead on the M1 Abrams MBT system.

From a systemic perspective, this heterogeneity of operators and configurations has direct implications for logistics, interoperability, and military mobility. Variations in weight, digital architecture, and maintenance requirements significantly complicate standardisation of transport procedures and reinforce the importance of harmonised NATO mobility frameworks, particularly in the context of rail and road transport under allied reinforcement scenarios [1]. In this regard, infrastructure constraints such as bridge load capacity and corridor segmentation further amplify operational complexity and must be considered as critical determinants of deployment feasibility within the European theatre [5].

A structured overview of selected operators, including their respective Leopard 2 variants and operational status, is presented in Table 1, which illustrates the structural diversity of platform deployment across NATO member states and highlights the challenges associated with interoperability and mobility planning.

Following the data presented in Table 1, it can be observed that the Leopard 2 platform exhibits a high degree of structural heterogeneity across NATO states. While certain operators maintain highly modernised and relatively homogeneous fleets, others rely on mixed-generation inventories or operate limited numbers of vehicles with varying degrees of operational availability and readiness.

This divergence indicates that the Leopard 2 does not function as a fully standardised system within NATO, but rather as a distributed capability framework adapted to heterogeneous national requirements. Although the platform provides a common baseline for interoperability, differences in variant structure, upgrade level, and fleet composition introduce measurable complexity in multinational operations, particularly in the domains of logistics, maintenance, and training standardisation.

Table 1.

Distribution of Leopard 2 Variants Across Selected NATO Member States

Country	Leopard 2 Variants	Status / Notes
Germany	2A5, 2A6, 2A7V, 2A8	Main developer, most advanced operator
Poland	2A4, 2A5, 2PL	One of the largest Leopard 2 fleets in NATO
Finland	2A4, 2A6	Mix of older and modern variants (~200 tanks)
Norway	2A4NO → 2A7 / 2A8	Transition to latest generation
Denmark	2A5DK, 2A7	Highly modernized fleet
Netherlands	2A6 (within joint German-Dutch units)	No independent tank battalions
Canada	2A4M CAN, 2A6M CA	Modernized export variants
Czech Republic	2A4, planned 2A8	Transition from Soviet-era T-72
Slovakia	2A4	Limited number (compensation deliveries)
Hungary	2A4, 2A7HU	One of the most modern new Leopard operators
Portugal	2A6	Limited operational availability
Spain	2A4 (inactive), 2E (2A6-based)	Large fleet with domestic modifications
Greece	2A4, 2A6HEL	One of the largest Leopard 2 fleets in NATO
Austria (NATO partner)	2A4	Planned modernization program
United States	x	Does not operate Leopard 2 (uses M1 Abrams)

Despite its widespread adoption, the Leopard 2 platform cannot be characterised as a fully standardised system across NATO [3]. Instead, it represents a partially standardised capability platform with significant national variation in configuration, modernisation pathways, and operational employment concepts.

This heterogeneity generates both interoperability benefits and structural constraints. On the one hand, the shared baseline architecture facilitates coalition operations, cross-national training, and doctrinal compatibility within NATO force structures [1, 3]. On the other hand, divergence between variants (A4–A8) results in fragmentation of spare parts supply chains, increased complexity of maintenance ecosystems, and differentiation in crew training requirements, particularly in states undergoing incremental modernisation processes [8].

From a systemic perspective, the Leopard 2 platform can therefore be conceptualised as a “distributed standard platform”, in which interoperability is achieved primarily at the macro (architectural) level, while significant technical and logistical divergence persists at the level of national implementation. This structure reflects a broader pattern within NATO armoured capabilities, where operational standardisation is continuously negotiated against sovereign procurement strategies and national industrial policies [3, 11]. Within this framework, infrastructural constraints and military mobility requirements further condition the practical effectiveness of interoperability, particularly in relation to transport networks and cross-border deployment corridors [1, 3, 5].

2.3 Tank Leopard in Czech Armed Forces

The road transport of MBT constitutes a critical element of operational and strategic mobility within modern armed forces, particularly in the context of rapid deployment requirements in NATO. For heavy armoured platforms such as the Leopard 2, road transportability is constrained by a combination of technical vehicle parameters, legislative requirements, and the structural limitations of national transport infrastructure.

2.4 Options for Transporting Leopard Tanks by Road

Within the CAF, existing road transport capabilities were originally designed primarily for legacy armoured systems, particularly the T-72M4 CZ MBT with a combat weight of approximately 48 tons [10]. As a result, current transport assets reflect design assumptions that do not fully correspond to the requirements of modern Western MBT, whose combat weight ranges approximately between 55 and 70 tons depending on configuration [12].

Modern transport assets include tractor–semi-trailer combinations such as Scania R660 A6x4 units with Goldhofer MPA 5 low-bed semi-trailers, which are illustrated in Fig. 1. These systems represent a significant technological advancement compared to previous generations of military transport equipment and provide improved payload distribution, steering capability, and operational flexibility in constrained environments [6]. In parallel, legacy systems such as the Tatra T-815 8×8 tractor units with P-50 N low-loaders remain in service for lighter transport tasks. The operational configuration of this legacy system is shown in Fig. 2.

From a technical perspective, the deployment of heavy armoured platforms such as the Leopard 2 imposes stringent requirements on axle load distribution, coupling strength, braking performance, and route geometry. These parameters must be assessed not only in relation to vehicle specifications but also with respect to national regulatory frameworks governing exceptional transport operations [10]. In this context, compliance with legal axle load limits and permit systems represents a fundamental precondition for operational deployment of heavy military vehicles on public road networks.

Furthermore, the effectiveness of road transport is directly influenced by infrastructure characteristics, particularly bridge load classification, road curvature, and pavement bearing capacity. These factors introduce operational uncertainty in route planning and may require adaptive logistics solutions, especially in scenarios involving multinational force movements under NATO reinforcement frameworks [1, 5, 13]. Consequently, road mobility cannot be considered solely as a transport function, but rather as an integrated system linking vehicle engineering, regulatory compliance, and infrastructure resilience.

Fig.1 Scania R660 A6x4 with Goldhofer MPA 5 low-bed semi-trailer (CAF transport system)

Fig. 2 Tatra T-815 8×8 with P-50 N low-loader transporting tracked vehicles

The P-50 N low-loader system, with a nominal payload capacity of approximately 50 tons, was originally designed to meet transport requirements corresponding to Cold War-era armoured vehicle categories. However, the Leopard 2 platform exceeds or approaches these structural limits, particularly in its modernised configurations, which significantly reduces the operational relevance of this legacy system for contemporary heavy armour transport tasks [1].

To verify real operational performance, transport trials were conducted using a Scania R650 tractor unit in combination with a Goldhofer low-bed semi-trailer. During these tests, a Leopard 2A4 tank was transported, as shown in Fig 3. These trials included controlled deployment scenarios involving the transport of Leopard 2A4 tanks and incorporated detailed axle load measurements using mobile weighing systems [11, 13].

The results of these operational tests indicate that, while legacy transport systems may still be applicable under specific conditions, their practical utility is increasingly limited by the rising mass of modern MBTs and by stricter regulatory enforcement of axle load limits. Under real operational conditions, axle loads may exceed the regulatory threshold of 10 tons per driven axle defined by national legislation [10], which not only creates a compliance issue but also introduces long-term risks to road infrastructure durability, particularly due to fatigue effects on bridges and primary transport corridors. Consequently, a growing capability gap emerges between available transport assets and the requirements imposed by contemporary armoured platforms, especially in scenarios requiring rapid deployment or multinational force mobility within NATO operational frameworks [1, 5, 13].

From a technical perspective, modern multi-axle semi-trailers equipped with hydraulically steered axles significantly improve manoeuvrability and load distribution compared to older transport systems. These capabilities are essential for the movement of heavy tracked vehicles in urban environments, tactical assembly areas, and infrastructure-constrained routes. However, despite these improvements, current transport solutions remain close to their operational design limits when deployed with Leopard 2 tanks, particularly in heavier configurations or with additional modular armour packages [6].

An additional limiting factor is the absence of a universal road transport platform within the CAF capable of fully accommodating the entire weight spectrum of Leopard 2 variants under all operational conditions. This necessitates the use of combined logistical approaches, including route optimisation, infrastructure assessment, escort coordination, and selective movement restrictions in structurally sensitive areas such as bridges and road segments with reduced load-bearing capacity [5, 10]. In this context, infrastructure vulnerability becomes a decisive planning parameter within military mobility operations, rather than a secondary engineering constraint.

In conclusion, road transport of Leopard 2 MBT within the CAF is technically feasible but remains constrained by a combination of legislative, infrastructural, and technical limitations. While modern transport assets significantly enhance operational capability compared to legacy systems, they do not yet fully eliminate the structural gap between current transport infrastructure and the requirements of heavy armoured platforms. These findings underline the necessity of continued modernisation of military transport capabilities and their closer integration with the development trajectory of heavy armoured forces within NATO frameworks [1, 2].

A key part of the operational testing involved axle load measurements using a PW-10 mobile axle scale system [11]. The measurement setup and process ensured verification of compliance with national transport legislation [10]. The results of the weighing are presented in Table 2, which shows axle load distribution across the Scania R650 + Goldhofer combination carrying a Leopard 2A4 tank.

Table 2.
Axle load measurements of Scania R650 and Goldhofer semi-trailer

Axle	Wheelbase [m]	Pressure [t]
No. 5	2,3	10,64
No. 6	1,5	10,08
No. 7	1,1	12,44
No. 8	1,5	12,06
No. 9	1,5	11,60
No. 10	1,5	11,70

The results indicate that several axle loads exceeded the regulatory limit of 10 tons per driven axle defined by national legislation [10]. This exceedance is particularly evident on axles 7–10, where values reached approximately 12.4–12.5 tons. From an operational perspective, the measured data demonstrate that while the transport combination is technically capable of moving a Leopard 2 MBT, it operates beyond legal axle load limits under full-load conditions [10, 11].

This situation generates a dual constraint framework:

- Legal constraint, arising from non-compliance with national axle load regulations
- Infrastructural constraint, associated with increased cumulative stress on road networks and bridge structures

From a systems perspective, these findings highlight that modern heavy-duty military transport solutions, while significantly more capable than legacy systems, do not fully eliminate structural and regulatory limitations associated with the movement of MBT. Instead, they shift the constraint from pure technical feasibility towards a coupled legal–infrastructural compliance problem, which must be addressed through integrated route planning, infrastructure assessment, and operational risk mitigation within NATO-aligned military mobility frameworks [1, 13].

2.5 Options for Transporting Leopard Tanks by Rail

The rail transport of MBT represents a key element of strategic mobility within NATO operations, particularly for long-distance movement of heavy armoured units. In contrast to road transport, rail systems provide higher payload capacity, reduced infrastructure stress, and greater efficiency for concentrated military loads. For MBT such as the Leopard 2, rail transport is therefore generally considered the preferred mode of strategic deployment in the European operational environment.

Within the CAF, rail transport of armoured vehicles is currently provided through standardised flat railway wagons of the Smmps 54 series [6]. These wagons are derived from modernised designs intended for the transport of heavy wheeled and tracked military equipment, with a maximum payload capacity of approximately 54 tons, a loading length of 14,000 mm, and a loading width of 3,100 mm [12]. The T-72 tank secured on an Smmps 54 railway flatcar is shown in Fig. 3.

Fig. 3 T-72 tank secured on an Smmps 54 railway flatcar [OSINT defender]

However, these parameters are insufficient for modern MBT such as the Leopard 2, whose combat weight ranges between approximately 55 and 70 tons depending on configuration [12]. This creates a structural limitation for routine rail transport under standard national conditions and necessitates either vehicle preparation measures or the use of specialised rolling stock.

To assess operational feasibility, experimental transport trials were conducted using a Sammns-X flat railway wagon with a declared payload capacity of approximately 70 tons. This wagon type is not part of the standard rolling stock operated by the CAF's contracted rail carrier (ČD Cargo, a.s.), and its deployment was enabled only through external logistical cooperation with PKP Cargo [12, 14]. This fact highlights a critical dependency on international rail logistics capacity, which introduces additional coordination requirements in multinational deployment scenarios. Furthermore, detailed analyses of cargo securing on railway platform wagons indicate that heavy loads such as armoured vehicles are exposed to significant longitudinal and dynamic forces—particularly during braking and shunting operations—requiring appropriately dimensioned lashing systems, accurate force calculations, and the selection of suitable fastening methods to prevent displacement and ensure transport safety [19].

From an operational perspective, these findings indicate that rail transport of heavy armoured platforms remains technically feasible but structurally constrained within national asset pools. As with road transport, the primary limitation is not the absence of capability in principle, but rather the mismatch between existing infrastructure/rolling stock parameters and the increasing mass of modern armoured systems. This reinforces the importance of harmonised European military mobility initiatives, including dual-use infrastructure development and cross-border logistics interoperability frameworks [1, 15, 13]. Similar conclusions regarding the limitations of existing railway infrastructure for heavy military transport and the need for modernization of logistics capacities are also discussed in recent European transport research. The Leopard 2A4 secured on an Sammns-X railway flatcar is shown in Fig. 3.

Fig. 4 Securing the Leopard 2A4 tank to a Sammns-X railway flatcar

The use of non-standard rolling stock highlights a dependency on external providers and indicates limited availability of domestically certified wagons suitable for the routine transport of heavy MBT exceeding 60 tons. Securement of heavy tracked vehicles during rail transport is governed by NATO standardisation procedures defined in AMovP-4(A), which specify tensile strength requirements for lashing and securing systems depending on vehicle weight categories [7]. These requirements constitute a binding interoperability framework for NATO member states and directly determine the safety limits of rail transport operations involving heavy armoured platforms.

Table 3.

Tensile strength of reusable securing devices (AMovP-4(A))

Vehicles with a weight of		**Tensile strength of securing devices [LC]**		
		Individually transported vehicle and group of vehicles		**Complete trains**
Wheeled vehicles [t]	**Tracked vehicles [t]**	**Securing devices + chocks [daN]**	**Securing devices only [daN]**	**Securing devices only [daN]**
3	5	1 000	2 000	1 000
8,5	11	2 500	4 000	2 000
15	25	4 000	6 250	4 000
28	52	8 000	10 000	6 250
38	60	10 000	16 000	10 000
42	65	12 500	20 000	12 500

From a systemic perspective, compliance with AMovP-4(A) [18] represents not only a technical safety requirement but also a critical enabler of multinational interoperability in rail-based force deployment. Consequently, differences in national rolling stock availability and certification practices may introduce operational constraints that affect the speed and flexibility of strategic reinforcement within NATO logistics chains. The applicable tensile strength requirements for reusable securing devices are summarised in Table 3. The data presented in Table 3 indicate that securement requirements increase significantly with vehicle weight, particularly for tracked platforms approaching the upper limit of 60–65 tons. For MBT such as the Leopard 2 series, the applicable category requires securing systems with tensile strengths of up to 20,000 daN for individual transport configurations.

This implies that commonly used securing equipment within national logistics systems, typically operating around 10,000 daN capacity, may not provide sufficient safety margins for heavy MBT transport. As a result, compliance with NATO AMovP-4(A) requirements necessitates the use of reinforced securing chains, upgraded lashing systems, and optimised load distribution strategies, particularly in multinational rail transport operations [13].

Beyond wagon capacity and vehicle securing systems, additional constraints arise from railway infrastructure characteristics, including bridge load classification, axle load distribution, and dynamic loading effects during transport operations. These parameters represent critical design and operational factors influencing the feasibility of heavy military rail transport. They must be evaluated in the context of both national infrastructure limitations and NATO interoperability requirements, particularly within multinational force mobility corridors, where heterogeneous infrastructure standards may introduce operational bottlenecks [5].

In conclusion, rail transport of Leopard 2 MBT within the Czech defence logistics system is technically feasible but operationally constrained. The main limiting factors include insufficient availability of dedicated high-capacity rolling stock, marginal compliance of securing systems with NATO safety requirements defined in AMovP-4(A), and dependency on external rail logistics providers. These constraints indicate that full integration of Leopard 2-class vehicles into routine rail mobility operations requires further modernisation of rolling stock and harmonisation with NATO rail transport standards [5, 12, 13].

3. Methodology

The methodological approach of this study is based on a combined qualitative and quantitative analysis of the transportability of selected tracked military vehicles within the conditions of the CAF. The primary objective is to evaluate the compatibility between the technical parameters of heavy armoured vehicles and the operational capabilities of existing road and rail transport infrastructure. The study integrates technical parameter comparison, empirical measurement, and regulatory compliance assessment to evaluate both theoretical transport capacity and its practical feasibility under real operational conditions.

The analysis focuses on representative tracked platforms currently operated or considered within the CAF, namely the Leopard 2A4, Leopard 2A8, T-72M4 CZ, CV90 MkIV, and BMP-2. These systems were selected to reflect different weight categories and technological generations, enabling comparative assessment of transport requirements across legacy and modern equipment. The selection also reflects the ongoing modernisation of CAF armoured capabilities and the gradual integration of Leopard 2 platforms [9].

In road transport analysis, the study evaluates the technical parameters and operational performance of current CAF transport assets, including Scania R660 A6x4 and Scania R650 tractor–semi-trailer combinations, as well as legacy Tatra T-815 8×8 systems. A key methodological component is empirical verification of axle load distribution during real transport operations using a PW-10 mobile axle weighing system [10]. The measured values are compared with maximum permissible limits defined by national legislation [8], enabling identification of compliance gaps and operational constraints.

Rail transport analysis focuses on the suitability of available freight wagons and securing systems for heavy tracked vehicles. This includes evaluation of load capacity and dimensional constraints of Smmps 54 wagons based on technical documentation [11]. The study also assesses availability of suitable rolling stock within CAF logistics structures and dependency on external providers. Vehicle securing procedures are analysed with emphasis on cross-lashing techniques and tensile strength requirements defined in NATO standard AMovP-4(A), ensuring interoperability within allied rail transport operations [12].

The study is further contextualised within the European military mobility framework, particularly the Trans-European Transport Network (TEN-T) and associated EU initiatives aimed at improving dual-use infrastructure capacity [1, 2]. However, this context is considered supplementary and is used only to support interpretation of infrastructure constraints.

The analytical procedure was conducted in four steps: (i) collection of technical data, (ii) comparative analysis of vehicle and transport system parameters, (iii) empirical validation through axle load measurements, and (iv) evaluation against legislative and NATO standards. This structured approach ensures consistency, traceability, and reproducibility of results.

4. Results and Discussion

The analysis of road transport capabilities within the CAF indicates that current transport systems are only partially suitable for the deployment of modern main battle tanks, particularly the Leopard 2 family. While existing transport combinations remain adequate for medium-weight tracked vehicles, significant limitations occur when transporting platforms exceeding 55 tons.

Empirical axle load measurements conducted using a PW-10 mobile weighing system [11] confirmed that several axles of the evaluated transport combination exceed the maximum permissible load defined by national legislation [10]. As shown in Table 1, rear axle loads exceed 12 tons, significantly surpassing the regulatory limit of 10 tons for driven axles. This results in non-compliance with legal requirements and indicates potential stress on transport infrastructure components such as bridges and reinforced road sections. Table 4 shows the measured axle load distribution during transport of a heavy tracked vehicle.

Table 4.
Measured axle load distribution of heavy tracked vehicle transport combination

Axle	Axle load weight [t]	Axle	Axle load weight [t]
1	7,90	**6**	10,46
2	6,20	**7**	12,50
3	9,76	**8**	12,42
4	9,54	**9**	12,40
5	10,46	**10**	12,46

The results indicate that modern transport systems such as Scania R660 with Goldhofer semi-trailers operate at or near allowable axle load limits when used for Leopard 2-class vehicles. In some cases, these limits may be exceeded, reducing operational flexibility and requiring route-specific approvals, which negatively affects transport planning efficiency. Similar constraints were identified in rail transport. Standard Smmps 54 wagons used within the CAF logistics system provide a maximum payload of approximately 54 tons [5], which is insufficient for heavier Leopard 2 variants. Consequently, transport requires high-capacity wagons that are not part of standard national assets, resulting in dependence on external providers.

Vehicle securing constitutes an additional limiting factor. According to NATO standard AMovP-4(A), securing systems must meet defined tensile strength requirements for heavy tracked vehicles [6]. The analysis shows that currently used lashing systems operate close to minimum allowable limits, reducing safety margins under dynamic loading conditions. This is critical in rail transport, where braking and shunting operations generate significant longitudinal forces acting on the load, increasing the risk of displacement if securing systems are not adequately designed.

From an operational perspective, these constraints significantly reduce the efficiency of heavy vehicle transport planning and necessitate additional layers of logistical coordination. Both road and rail transport systems require special permits, enhanced route and load planning, and, in certain cases, external logistical support, which collectively increase the complexity, lead time, and resource demands associated with deployment operations.

The findings therefore confirm that transport infrastructure and available logistics assets constitute key structural limiting factors for the integration of Leopard 2-class vehicles into the operational mobility framework of the CAF. Rather than being purely technical in nature, these limitations reflect a systemic constraint at the intersection of engineering parameters, regulatory frameworks, and infrastructure resilience, directly influencing the readiness and deployability of heavy armoured forces within NATO-aligned operations.

5. Conclusions

The study assessed the capability of the CAF to ensure the transport of Leopard 2 MBT under current technical, infrastructural, and legislative conditions. The results indicate that, although existing transport systems remain suitable for lighter categories of tracked vehicles, they are not fully compatible with the requirements of modern heavy armoured platforms.

In road transport, empirical measurements confirmed repeated exceedance of permissible axle load limits, representing both a regulatory non-compliance risk and a potential long-term threat to transport infrastructure integrity. In rail transport, the limited load capacity of standard freight wagons and reliance on external high-capacity rolling stock reduce the autonomy and operational flexibility of national logistics capabilities. Additional limitations were identified in vehicle securing procedures in relation to NATO interoperability requirements, particularly under AMovP-4(A) standards.

These findings are consistent with broader European observations that military mobility is constrained by a coupled system of regulatory, infrastructural, and technical factors affecting dual-use transport networks. In this context, European initiatives such as the Trans-European Transport Network (TEN-T) and EU military mobility programmes provide a strategic framework for mitigating these limitations; however, their effectiveness remains dependent on implementation at the national level and on the alignment of infrastructure upgrades with evolving capability requirements.

Future research should focus on optimisation of heavy vehicle transport configurations, development and procurement of high-capacity road and rail transport assets, and improved integration of national logistics systems into NATO and EU military mobility frameworks. Particular attention should be paid to infrastructure bottlenecks, especially bridge load capacity and corridor segmentation, which represent critical constraints in operational deployment planning for heavy armoured forces.

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