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Infrastructural solutions for 1,435/1,520 mm railway interoperability in Ukraine

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Abstract. Under martial law and in the context of European integration, improving the interoperability between the 1,435 mm and 1,520 mm railway gauge networks through the development of multimodal transport and logistics hubs has become critically important for ensuring the functioning of Ukraine's export and import supply chains. The aim of this study was to investigate and substantiate infrastructure solutions for enhancing the interaction between the 1,435 mm and 1,520 mm railway systems through the development of a network of dry ports as key elements of Ukraine's multimodal logistics system. To achieve this objective, a systematic approach, structural-functional analysis, as well as infrastructure, logistics, and statistical analyses of freight flows were employed. Current trends in the development of multimodal transport and the operation of dry ports in the European Union and Ukraine were examined. It was found that the development of inland multimodal terminals can reduce pressure on border and port infrastructure, shorten cargo handling times, and improve the efficiency of logistics chains. Based on a synthesis of international experience in the development of multimodal logistics centres, promising directions for integrating Ukraine's transport system into the Trans-European Transport (TEN-T) network and the Solidarity Lanes initiative were identified. The technical and operational parameters of railway terminal functioning were analysed, including requirements for track layout configuration, the length of arrival and departure tracks, shunting operations, and capacity provision for handling full-length container trains. In addition, patterns of container flow imbalance and empty rolling stock accumulation within international transport corridors were identified. The study also examined the issue of container flow imbalance and the role of dry ports in ensuring efficient management of empty containers. The practical value of the research lies in the possibility of applying its findings by public authorities, logistics operators, transport companies, and design organisations in planning the development of multimodal infrastructure, border terminals, and a network of dry ports in Ukraine

Keywords: railway infrastructure; dry ports; multimodality; containerisation; logistics hubs; international freight transport; supply chains

Introduction

The transport sector plays a crucial role in strengthening Ukraine's economic resilience and supporting its integration into the European economic area. Since the beginning of the full-scale Russian invasion, ensuring the continuity of logistics operations, developing alternative export routes, and improving the efficiency of multimodal transportation have become critical priorities. The destruction of transport infrastructure, restricted access to seaports, and the reorientation of foreign trade flows have created an urgent need for new logistics solutions capable of maintaining resilient supply chains. One of the most promising approaches involves the development

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of multimodal transport and logistics hubs, particularly dry ports, which optimise interaction between different modes of transport, increase transport system capacity, and facilitate Ukraine's integration into the European transport network. Dry ports also support the technological synchronisation of railway systems with different track gauges – the European standard gauge (1,435 mm) and the Ukrainian broad gauge (1,520 mm) – thereby helping to overcome existing infrastructural barriers.

Recent studies have examined various aspects of multimodal transportation and dry port development under conditions of geopolitical instability and global logistics transformation. Kh. Prytula *et al.* (2022) analysed changes in freight movements across the Ukraine-European Union border following the outbreak of the war and emphasised the importance of container transportation and intermodal terminal networks for increasing the throughput capacity of Ukraine's logistics infrastructure. O. Nelipovych (2023) investigated the functional role of inland terminals in Ukraine and highlighted the need to redirect freight flows toward the western borders due to the limited operation of seaports during wartime. Several studies have focused on the infrastructural, operational, and environmental dimensions of dry port systems. O. Kyryllova & V. Romakh (2025) proposed a conceptual model of an integrated dry port combining production, customs, and logistics functions. C. Caballini *et al.* (2025) developed a process-oriented approach to evaluating dry port systems and demonstrated that operational efficiency and process synchronisation are more important for competitiveness than physical distance alone. T. Rožić *et al.* (2025) examined the role of inland terminals in strengthening port-hinterland connectivity and improving regional logistics efficiency. G. İnegöl & Y. Arslanoğlu (2024) showed that prioritising railway transport within multimodal logistics systems can significantly reduce greenhouse gas emissions and air pollution. Z. Lu & W. Qiu (2025) analysed the resilience of logistics networks and demonstrated that dry ports can function as dynamic buffers that protect maritime hubs from operational overloads. R. Saha & K. Khalil (2025) investigated policy measures aimed at expanding intermodal infrastructure to improve the productivity and competitiveness of trade corridors.

Recent research has also emphasised the strategic role of dry ports in integrating maritime and inland logistics systems. V. Roso *et al.* (2026) examined the growing congestion of maritime terminals and argued that dry ports can partially assume customs, storage, and cargo consolidation functions traditionally performed by seaports. Their findings indicate that transferring part of freight flows to rail and inland transport corridors can reduce congestion in coastal areas and improve supply chain sustainability. E. Kurtuluş (2023) proposed a multi-criteria optimisation model for inland container logistics and dry port location planning that incorporates environmental considerations, empty container redistribution, railway pricing mechanisms, and cargo consolidation opportunities. Despite the growing body of research on dry ports and multimodal transportation, limited attention has been paid to infrastructural solutions for interoperability between the 1,435 mm and 1,520 mm railway systems under wartime conditions in Ukraine. In particular, insufficient research addresses the technical and operational requirements of inland terminals capable of supporting large-scale multimodal integration within the European transport network.

The scientific novelty of the study lies in substantiating the role of dry ports as strategic multimodal infrastructure elements capable of supporting logistics resilience, technological synchronisation between railway systems with different gauges, and the long-term integration of Ukraine into the European transport area. The study aimed to identify ways to improve international container transport, overcome technical barriers at the border and ensure the integration of Ukraine's transport system into the European TEN-T network under current geopolitical challenges. To achieve this objective, the following tasks had been identified: to investigate the functioning of dry ports as key nodes of multimodal infrastructure to optimise the interaction of railway systems with different track gauge standards; to determine the technical and operational parameters and throughput capacity of terminal infrastructure (track layout configuration, effective length, handling capacity) required for the efficient handling of full-length container trains; justify infrastructure solutions for overcoming the 1,520/1,435 mm "track gauge barrier" through the creation of points for technological synchronisation and cargo transhipment within internal logistics systems.

Materials and Methods

This study was based on a review of academic publications, regulatory documents, reports by international organisations, and statistical data related to the development of multimodal transport infrastructure, the operation of dry ports, and the interaction between the 1,435 mm and 1,520 mm railway systems. In this study, a dry port was defined as an inland logistics facility that acts as a buffer between railway networks with different track gauges. The theoretical framework draws on concepts of multimodal transport, intermodal logistics, TEN-T corridor development, and resilient logistics systems under wartime and crisis conditions. The methodological approach combined systems, structural, functional, and logistics analysis to examine dry ports as integrated elements of the transport network that facilitate interoperability between different railway gauge systems. The study employed the following methods: systems analysis to assess the role of dry ports within multimodal transport systems; comparative analysis to evaluate international experience in the development of inland logistics terminals and its applicability to Ukraine; logistics and infrastructural analysis to determine the technical and operational parameters of terminal infrastructure; generalisation to formulate conclusions regarding Ukraine's integration into the European TEN-T network; statistical analysis to evaluate trends in freight and container traffic.

The literature review primarily focused on publications issued between 2020 and 2026 in order to capture recent transformations in logistics systems related to the war in Ukraine, the development of the Solidarity Lanes initiative, and ongoing European integration processes. This period was selected because it reflects the reorientation of Ukraine's logistics routes under wartime conditions, including recurring disruptions affecting maritime transport corridors. Sources were selected based on their scientific relevance, topicality, analytical value, and relevance to multimodal transport and dry port development. The study used materials published in international and Ukrainian academic journals, European Commission reports, analytical studies on the Solidarity Lanes initiative, and statistical data on maritime and rail transport in EU countries. The literature search used the following keywords: "dry port", "multimodal transport", "intermodal logistics", "railway infrastructure", "TEN-T", "container transportation", "1,520/1,435 mm gauge interoperability", "Solidarity Lanes", and "logistics centres". Searches were conducted using the Scopus, Web of Science, Google Scholar, and ResearchGate databases, as well as open-access analytical sources.

The study followed a progression from a general analysis of global logistics trends and freight imbalances to the examination of technical constraints related to the 1,520/1,435 mm gauge barrier and, finally, to the development of applied infrastructure solutions for Ukraine. The analysis compared the theoretical advantages of the dry port concept with the technical and operational constraints of Ukrainian border and inland railway terminals. This approach made it possible to formulate recommendations for the development of a network of railway terminals capable of strengthening Ukraine's role as a logistics hub in Eastern Europe. The proposed methodology ensured a consistent research framework and supported the formulation of conclusions regarding the development of dry ports as a tool for integrating Ukraine into the European logistics system.

Results and Discussion

Transport constitutes a fundamental component of the economy by ensuring the mobility of people and goods, facilitating access to employment and services, and supporting trade and economic growth. Since 2014, the gradual reorientation of Ukraine's trade flows has significantly reshaped transport patterns. Whereas trade with Russia and transit through Ukrainian territory previously played a major role, the growing share of trade with European Union member states has increased the strategic importance of westbound transport corridors (Ukraine Facility, n.d.). Since the beginning of the full-scale Russian invasion, ensuring the security and resilience of supply chains has become a critical priority, with transport playing a central role in maintaining the stability of the national economy. The rapid restoration of damaged infrastructure and the implementation of the Solidarity Lanes initiative between the European Union and Ukraine enabled the export of nearly 214 million tonnes of goods from May 2022 onward, including approximately 91 million tonnes of grain, oilseeds, and related products.

The Solidarity Lanes have also facilitated the import of nearly 100 million tonnes of essential goods, including military and humanitarian aid, fuel, and other critical commodities. The total trade value supported through the initiative is estimated at approximately EUR 270 billion, including around EUR 198 billion in imports to Ukraine (European Commission, n.d.). Following Russia's withdrawal from the Black Sea Grain Initiative on 17 July 2023 and the subsequent attacks on Ukrainian port infrastructure, the role of the Solidarity Lanes became even more significant for sustaining the Ukrainian economy. In addition to addressing immediate wartime logistics challenges, the initiative creates a foundation for Ukraine's future integration into the EU Single Market and the broader European transport system. Strengthening transport connectivity between Ukraine and the EU is therefore of strategic importance for ensuring secure and reliable trade routes.

Improving export routes, restoring and expanding the capacity of key transport connections, and diversifying logistics systems are essential for maintaining the competitiveness of Ukrainian products in international markets. The wider implementation of multimodal transport solutions and intelligent transport systems can improve the efficiency of transport operations and promote deeper integration into global supply chains, thereby supporting economic recovery and long-term development. Investment in transport connectivity is particularly important in the context of Ukraine's gradual integration into the EU Single Market. Such investments should comply with the principles of sustainable development and decarbonisation in line with the objectives of the European Green Deal. In this regard, Ukraine may also benefit from participation in the EU-supported Transport Community framework. According to the RDNA3 assessment, as of 31 December 2023, the total cost of Ukraine's reconstruction and recovery over the next decade is estimated at approximately USD 486 billion, compared with USD 411 billion estimated a year earlier (World Bank, 2024). Reforms and investments should complement one another and contribute to expanding export logistics capacity. Ukraine's EU candidate status should serve both as an instrument and as a driving force for the development of a modern and efficient transport system aligned with EU standards. In the short term, priority should therefore be given to reforms capable of stimulating economic growth while creating the foundation for further modernisation of transport infrastructure.

One of the priority tasks is the restoration and development of Ukraine's export logistics potential, particularly within the TEN-T framework. Reforms should focus on improving market conditions in ways that encourage private investment in transport infrastructure, especially in ports and logistics centres, while also facilitating the gradual integration of Ukrainian operators into the EU Single Market under fair and competitive conditions. In this

context, the development of a new generation of inland logistics hubs – dry ports – is becoming increasingly important. These facilities ensure efficient interaction between different transport modes, optimise cargo transshipment processes, and reduce pressure on border crossings and port infrastructure (Euroterminal, n.d.). A dry port can be defined as an inland multimodal logistics centre equipped with advanced infrastructure and cargo-handling facilities that provide services traditionally associated with seaports while operating inland. Under conditions of restricted access to Black Sea ports and continuing attacks on port infrastructure, dry ports are also acquiring strategic importance as secure rear logistics hubs. They enable customs and logistics operations to be relocated away from active combat zones, thereby improving the continuity and reliability of supply chains.

The revision and modernisation of Ukraine's comprehensive transport strategy are therefore essential both for defining priorities during post-war reconstruction and for ensuring the long-term development of the transport sector in accordance with EU standards and objectives. This is particularly important in the context of current geopolitical challenges, which require deeper integration of Ukraine into the European transport area. The strategy should be long-term, financially sustainable, environmentally responsible, and based on the principle of equal territorial accessibility. The transformation of logistics systems with a focus on integration into the European transport network represents one of the key strategic tasks for the coming years. Prior to 2022, seaports accounted for up to 90% of Ukraine's food exports; therefore, current priorities must include the development and modernisation of integrated transport and logistics infrastructure (Table 1).

Particular attention should be given to the development of logistics centres in Western and Southern Ukraine, as well as to increasing transshipment capacity at border crossing points. In this regard, dry ports should be considered key components of the emerging logistics infrastructure. Functioning as inland multimodal terminals, they facilitate the consolidation, handling, and redistribution of cargo flows while also performing customs clearance and transshipment operations between different transport modes. Their development contributes to reducing congestion at seaports and border terminals, shortening cargo handling times, and improving the overall efficiency and resilience of logistics chains.

Table 1. Directions for the development of multimodal transport and logistics infrastructure

Area of development	Key measures	Expected impact
Border infrastructure	Modernisation of border crossing points with the EU and Moldova; simplification of customs and border procedures	Faster border crossing and increased throughput capacity
Port clusters	Development and protection of ports on the Danube, in Greater Odesa, and in eastern regions of the country	Improved security of maritime trade routes and support for export operations
Multimodal solutions	Expansion of container transportation and development of the dry port network	Optimisation of logistics processes through reduced pressure on border crossings and seaports; relocation of logistics operations inland

Source: compiled by the authors

The future transport system should be developed around the TEN-T network, which connects major cities, border crossings, and ports. Modernisation of railway, road, and terminal infrastructure in accordance with EU standards will strengthen regional connectivity and improve the efficiency of freight transportation. In particular, expanding the capacity of logistics centres and dry ports in Western and Southern Ukraine is essential for ensuring efficient cargo transshipment and supporting the reorientation of trade flows. In modern logistics systems, a dry port is an inland rail-road terminal located away from the seacoast but capable of performing many functions traditionally associated with a seaport. Such terminals serve as hubs for container handling and provide customs clearance, cargo consolidation, storage, and onward distribution inland. Cargo arriving at seaports is transferred to rail or road transport and delivered to inland terminals, where the main logistics and cargo-handling operations are carried out. In this sense, dry ports represent an integrated logistics network infrastructure that extends seaport functions inland without requiring direct maritime access. They support the full cycle of container and cargo handling, from customs processing and storage to dispatch to final destinations.

Dry ports have become widely used worldwide, and demand for their services continues to grow. In many countries, regular container shuttle trains connect seaports with inland logistics terminals according to fixed schedules. The presence of a developed network of inland terminals is therefore considered an indicator of the efficient functioning of major seaports and national logistics systems. A single dry port can provide cargo owners with a comprehensive range of logistics and cargo-handling services, including the following: cargo handling and storage; handling and storage of bulk cargo; customs clearance, inspection, packing, and labelling; repair and maintenance of container equipment; freight forwarding services; banking, insurance, and financial services; transport booking and brokerage services; cargo transshipment to other transport modes and delivery to final destinations (Horachek & Horova, 2021). Dry ports located near major cargo-generating areas or trade centres, while remaining distant from seaports, can significantly optimise transport costs. This is achieved through the use of light and medium-duty trucks for local cargo distribution between production or consumption points and inland terminals, while rail or inland waterway transport is used for

long-distance container transportation where applicable. Such transport schemes contribute to lower logistics costs and may stimulate further growth in trade volumes.

One of the key priorities for improving Ukraine's transport and logistics infrastructure is the development of a network of dry ports capable of serving import and export cargo flows for the regions in which they are located. These terminals should facilitate cargo consolidation and the formation of freight trains for subsequent delivery to end consumers and regional distribution centres. The effectiveness of a dry port largely depends on its location. On the one hand, it should maintain strong transport connectivity with seaports; on the other hand, it must provide efficient access to warehousing and distribution infrastructure. Therefore, dry ports should be situated at the intersection of major logistics corridors. At the same time, they must be integrated into transport connections with other inland terminals, border crossing points, customs control facilities, seaports, inland waterway terminals, and airports. Equally important is their operational versatility, meaning the ability to handle different categories of cargo and provide a broad range of logistics services (Fig. 1).

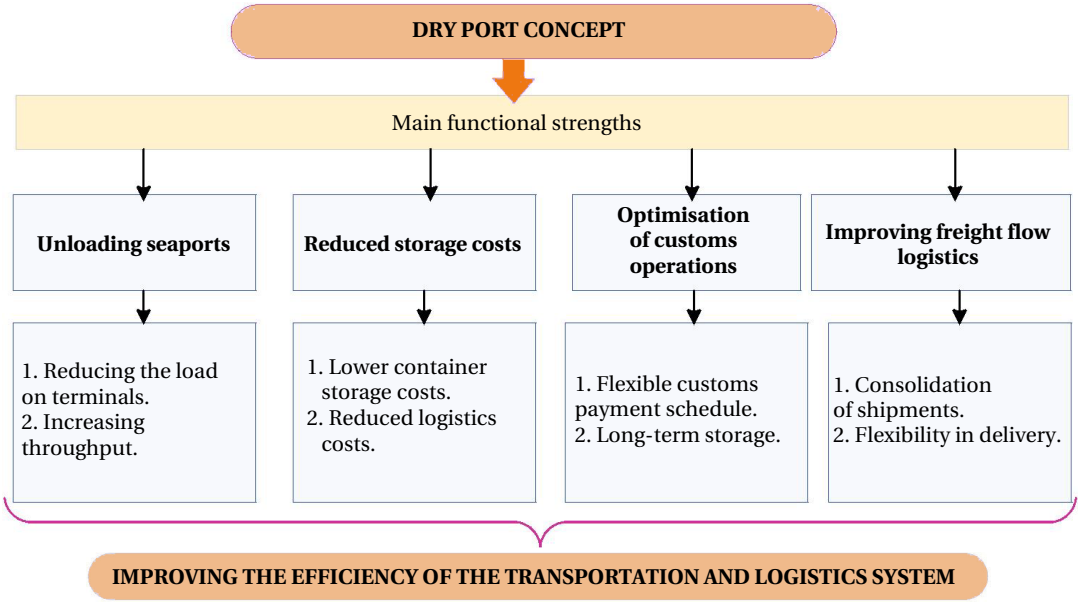

Figure 1. Scheme of the location and functioning of the dry port

Source: compiled by the authors

Such dry ports offer significant advantages for all participants in the transport and logistics sector. First, they help reduce congestion at maritime terminals. Second, the storage of containers and other cargo at inland terminals is generally less expensive than at seaports. Third, customs payments can often be deferred until cargo is released from the dry port, allowing goods to remain in storage for extended periods when necessary. Finally, dry ports improve cargo logistics by enabling the consolidation and redistribution of shipments. International experience demonstrates the growing importance of inland logistics infrastructure. In Western Europe, transport infrastructure is highly developed not only in coastal regions but also deep inland. A particularly high concentration of dry ports can be observed along the Rhine corridor and in Bavaria in southern Germany. Major logistics hubs have also emerged around key economic centres such as Paris, Milan, and Madrid, as well as within the Liverpool-Manchester-Leeds corridor. Another extensive network extends from Austria toward industrial regions in Hungary, the Czech Republic, and southern Poland.

Because many major European industrial regions and the Baltic countries are located far from primary maritime routes, seaports frequently function as intermediate gateways connecting inland markets with global trade networks. Connections between inland terminals and major European seaports – including Rotterdam, Antwerp, Hamburg, Bremerhaven, Le Havre, Barcelona, and Marseille – are supported by medium-distance transport corridors using combined transport technologies, including rail transport, road haulage, and inland waterway shipping. As noted by M. Raimondi (2023), a rail-oriented dry port is planned in Salaspils. The logistics park is expected to integrate both 1,520 mm and 1,435 mm railway systems, together with motorway connections and large-scale warehouse infrastructure. Dry ports are exerting an increasingly important influence on the development of transport infrastructure and supply chain systems by reducing cargo transit times and lowering delivery costs. Four major dimensions of this impact can be identified.

1. Location and surrounding infrastructure. Like any major transport facility, a dry port requires a strategically advantageous location with efficient access to rail transport and, where possible, to other transport modes such as inland waterways. Another important factor is the availability of land reserves for future expansion.

Proximity to economically developed and densely populated regions is particularly significant, since such areas generate stable cargo flows and become integrated into logistics corridors passing through inland terminals. As a result, demand for terminal capacity and adjacent warehouse infrastructure increases. Logistics operators, distributors, and foreign trade participants are often willing to pay higher rents for warehouse facilities in strategically located logistics zones because of the resulting reductions in transport and delivery costs. The development of logistics centres and intermodal terminals also creates a mutually reinforcing effect. Intermodal terminals require logistics centres to consolidate cargo flows and generate sufficient freight volumes, while logistics centres benefit from inland terminals by gaining improved access to multimodal transport networks.

2. Empty container repositioning. As a substantial share of international and domestic freight transportation is containerised, imbalances between export and import flow frequently arise. Under such conditions, dry ports must possess both the physical infrastructure and logistical capacity necessary for the efficient redistribution of empty containers to regions experiencing container shortages. This can be achieved through the organisation of dedicated empty-container repositioning flows and through coordination agreements with shipping companies and freight forwarders regarding available transport capacity. According to the L. Nguyen (2025), approximately 41% of global container transport activity, measured in TEU-miles, is currently associated with empty containers. This represents a significant increase compared with 31% in 2019, prior to the disruptions caused by the COVID-19 pandemic. In practical terms, this means that for every ten miles travelled by a loaded container, empty containers must now be repositioned for an additional 4.1 miles, compared with 3.1 miles in 2019. Over the past five years, this indicator has shown a generally upward trend, with only a slight temporary decline observed in 2022. According to L. Nguyen (2025), these imbalances are primarily driven by uneven trade patterns between regions. Asian ports frequently experience shortages of empty containers due to high export volumes, whereas many ports in North America and Europe accumulate surpluses of empty containers because imports exceed exports. As a result, significant inefficiencies and additional costs emerge throughout the container logistics chain.

For shipping lines and logistics operators, the growth in the share of empty-container movements increases operating costs, lowers equipment utilisation rates, and creates additional challenges for repositioning operations. The management of empty-container flows has therefore become a strategic issue not only for major global carriers but also for regional and feeder shipping operators. In addition, ports that accumulate large volumes of empty containers increasingly face storage and handling constraints. In congested logistics markets, this may affect terminal charges, storage fees, and route-planning strategies. Consequently, balancing empty-container flows is becoming an increasingly important component of logistics system management. According to data published by Eurostat (2025), cargo imports through EU ports reached approximately 2.1 billion tonnes in 2024, whereas exports amounted to only 1.3 billion tonnes (Fig. 2). This imbalance contributes to the accumulation of empty containers within European logistics systems and increases the importance of dry ports as inland hubs for container redistribution.

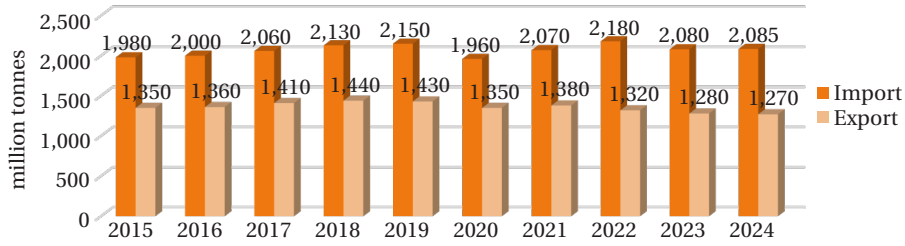

Figure 2. Volumes of maritime freight transport in the EU

Source: developed by the authors based on Eurostat (2025)

The total volume of cargo handled by EU ports in 2024 was estimated at approximately 3.4 billion tonnes, remaining relatively stable compared with 2023 (-0.2%) (Fig. 2). The decline in cargo volumes observed in 2023-2024 relative to 2022 can largely be attributed to restrictions on trade with Russia following the invasion of Ukraine. Although freight volumes partially recovered after the sharp decline recorded in 2020, which was mainly associated with the COVID-19 pandemic and related restrictions, cargo turnover in 2024 still remained somewhat below the levels observed in 2018-2019.

3. Cargo turnover. Despite imbalances in global container flows, dry ports play an important role in improving the coordination of import and export operations. In practice, containers used for imports are often subsequently reused for export shipments after unloading and reloading procedures have been completed. For container owners – including shipping lines, leasing companies, and terminal operators – rapid container turnover represents one of the key indicators of operational efficiency, as it ensures the continuous utilisation of container assets. Effective strategies for managing container circulation and cargo turnover therefore contribute to improving the operational performance of both container owners and dry port operators.

4. Trade facilitation. Dry ports also serve as important instruments for supporting regional import and export

activity. By reducing transport and logistics costs, they expand economic opportunities for inland regions and improve access to international markets. This is especially important for small and medium-sized enterprises, which often cannot independently achieve the economies of scale required for efficient participation in global supply chains. At the same time, the effective performance of dry port functions largely depends on the quality and capacity of inland transport infrastructure, particularly the railway component. Rail transport ensures high cargo throughput, service reliability, and economically efficient connections between seaports and inland terminals. Consequently, the design and organisation of railway infrastructure within dry ports are of particular importance, as such infrastructure must comply with the requirements of modern intermodal transport systems and ensure uninterrupted logistics operations.

Dry ports served by rail transport should be connected to the nearest main railway line through a short access track, which is typically designed and managed by the relevant railway infrastructure authorities. Rail-served inland terminals must also possess infrastructure capable of handling full-length freight trains. The railway infrastructure of dry ports should allow the reception and handling of full-length container trains operating directly between origin and destination terminals without the need for train splitting or regrouping outside the terminal area (Fig. 3).

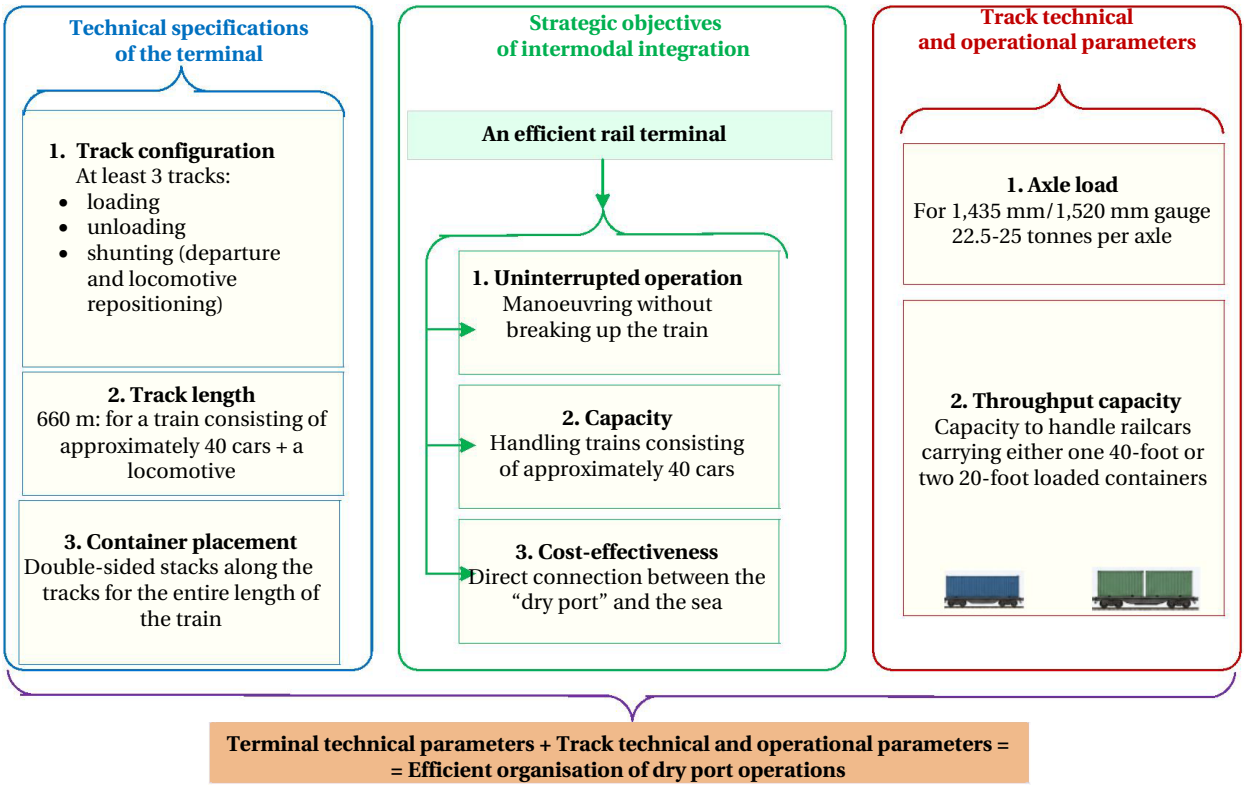

Figure 3. Scheme of organisation of the work of a railway terminal in the dry port system
Source: compiled by the authors

Loading and unloading operations should be performed on centrally located terminal tracks consisting of at least three railway tracks: one loading track, one unloading track, and one track intended for locomotive movements and shunting operations. The required number of loading and unloading tracks depends on traffic intensity and terminal throughput. Container stacks within the paved terminal yard should be arranged along both sides of the railway tracks throughout their full length in order to ensure continuous operation of handling equipment along the entire train formation. The required length of loading and unloading tracks is determined by the number and length of wagons within the train formation. For example, a train consisting of 40 wagons and one locomotive may require track lengths of approximately 660 m between switch points. The design axle load of terminal sidings should correspond to the axle load standards of the adjacent main railway lines. For 1,435 mm and 1,520 mm gauge systems, this typically ranges from 22.5 to 25 tonnes per axle. Even on less intensively used sections, the infrastructure must be capable of accommodating heavy locomotives and wagons carrying either two fully loaded 20-foot containers or one fully loaded 40-foot container.

When designing the layout and infrastructure of dry ports, particular attention should therefore be paid to ensuring uninterrupted railway connectivity between inland terminals, seaports, and other dry ports. Rail infrastructure must support reliable and continuous freight

operations within multimodal transport corridors. The concept of the dry port as an inland logistics hub is highly relevant for Ukraine under conditions of war and European integration. Such terminals perform many functions traditionally associated with seaports, including cargo handling, storage, customs clearance, and the formation of container trains, while simultaneously strengthening the resilience and flexibility of national logistics systems. These facilities are becoming particularly important in the context of the development of the Solidarity Corridors. Given restricted access to deep-water Black Sea ports and continuing attacks on port infrastructure, dry ports are increasingly functioning as secure inland logistics hubs (Fig. 4).

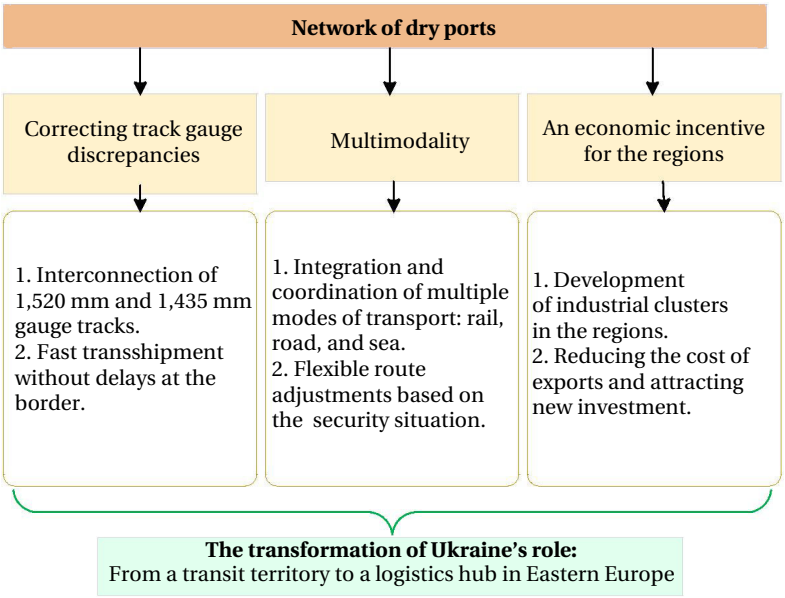

Figure 4. Model of the impact of the development of the dry ports network on Ukraine's integration into TEN-T
Source: compiled by the authors

The implementation of such a strategy makes it possible to overcome the incompatibility between Ukrainian and European railway gauge systems through the rapid integration of 1,520 mm and 1,435 mm railway infrastructure, thereby accelerating cargo transshipment processes. Through multimodal integration, these logistics hubs combine different modes of transport and provide greater route flexibility under unstable security conditions. At the same time, the development of dry ports stimulates the emergence of regional industrial and logistics clusters, reduces export-related costs, and attracts new investment. Ultimately, this contributes to Ukraine's integration into the European TEN-T network and strengthens its position as a major logistics hub in Eastern Europe.

Recent studies demonstrate growing academic and practical interest in the development of dry ports as key elements of multimodal transport systems, particularly in the context of increasing containerisation, logistics disruptions, and the need to improve supply chain resilience. I. Lovrić *et al.* (2020) examined the operations of the Port of Rijeka, the largest seaport in Croatia and an important component of the EU TEN-T Mediterranean Corridor. Due to the steady growth of container traffic over the last two decades, the authors analysed the potential role of dry ports in expanding terminal capacity and improving logistics efficiency. In this study, a dry port is defined as an inland intermodal terminal directly connected to a seaport by rail or road infrastructure and capable of performing logistics and cargo handling functions for inland destinations. Simulation results demonstrated that transferring part of logistics operations inland can significantly reduce container dwell time and improve the efficiency of freight transportation. The study also confirmed the strategic importance of rail transport as a core element of sustainable freight mobility within the European transport system.

R. Saha & K. Khalil (2025) investigated policy strategies for expanding dry port infrastructure in Bangladesh to improve the competitiveness and efficiency of maritime trade hubs. Against the background of rapidly growing cargo volumes at the Port of Chittagong, the authors highlighted the insufficient development of intermodal transport infrastructure. Their findings indicate strong expert support for the establishment of new inland terminals, particularly outside major port cities, in order to reduce congestion, improve regional connectivity, and lower logistics costs and emissions. The integration of advanced digital technologies into dry port systems has also attracted growing research attention. S. Rekabi & Z. Sazvar (2026) proposed a multi-stage stochastic model of a flexible logistics network based on Industry 5.0 principles and machine learning tools to optimise interaction between maritime and inland terminals. Their study emphasises the increasing importance of digitalisation and intelligent logistics management in multimodal transport

systems. Several studies have focused on the infrastructural and economic dimensions of multimodal transportation development in Ukraine. V. Sytnik & O. Pikulina (2025) emphasised the need to modernise Ukraine's border and terminal infrastructure in accordance with EU standards and identified priority directions for the development of logistics centres within the TEN-T network. A. Dalivand & S. Torabi (2024) demonstrated that integrating dry ports into transport and logistics systems can reduce congestion at seaports, optimise container transportation, and mitigate the environmental impact of freight operations.

The resilience of transport and logistics systems under crisis conditions has become another important research direction. K. Węcel *et al.* (2024) analysed the impact of the COVID-19 pandemic and the war in Ukraine on maritime freight flows and concluded that diversified logistics routes and inland multimodal hubs are essential for maintaining the stability of international transportation. S. Karakas *et al.* (2024) further highlighted the importance of alternative transport corridors and inland terminals for minimising supply chain disruption risks in Ukrainian agricultural exports. Environmental sustainability and supply chain resilience are increasingly considered key criteria in dry port planning. G. İnegöl & Y. Arslanoğlu (2026) developed a hybrid FR-SWARA model for evaluating dry port location criteria and demonstrated the growing importance of spatial and infrastructural factors compared with purely financial considerations. Their findings redefine dry ports as strategic infrastructure buffers capable of absorbing systemic shocks within logistics networks.

Recent Ukrainian studies have also examined the transformation of port logistics systems under wartime conditions. I. Smyrnova *et al.* (2026) analysed changes in the operation of seaports, dry ports, and multimodal transport systems during martial law. The authors identified several major transformation trends, including the spatial decentralisation of port functions, the diversification of logistics routes, the adaptation of operational procedures to heightened security requirements, and the increasing importance of resilient supply chains. Their study highlights the strategic role of inland logistics terminals in maintaining continuity of freight transportation under conditions of infrastructure disruption and geopolitical instability. These findings are consistent with the conclusions of A. Nechyporuk *et al.* (2023), who emphasised that maintaining export operations under martial law required the rapid reorganisation of logistics chains, the expansion of alternative transport corridors, and the increased use of multimodal transport solutions.

N. Shayan & N. Mohabbati-Kalejahi (2026) analysed the contribution of inland ports to sustainable development through a structured review of academic literature. Their study demonstrated that inland ports play a significant role in advancing sustainable logistics, regional development, and the achievement of the United Nations Sustainable Development Goals, particularly SDGs 9 and 11. Despite the extensive body of research on dry ports, multimodal transportation, and logistics resilience, insufficient attention has been devoted to infrastructural solutions for interoperability between the 1,435 mm and 1,520 mm railway gauge systems in Ukraine. In particular, limited research addresses the technical and operational requirements of inland multimodal terminals capable of supporting efficient cargo transshipment, full-length container train operations, and technological synchronisation between railway systems with different gauge standards under wartime and European integration conditions.

In Ukraine, dry ports are gradually becoming a key component of the modern transport and logistics system, operating as inland multimodal terminals that partially assume functions traditionally performed by seaports. They provide cargo transshipment, storage, customs clearance, and cargo consolidation services, thereby reducing pressure on port infrastructure and improving the efficiency of freight handling operations. The primary driver behind the development of dry ports has been the need to optimise logistics processes under conditions of growing containerisation and limited seaport capacity. International and domestic experience demonstrates that transferring part of logistics operations to inland terminals helps reduce cargo dwell times in ports and lowers handling costs. In the Ukrainian context, dry ports primarily function as multimodal logistics centres located near major transport junctions and railway stations. They integrate transport, warehousing, and customs infrastructure while providing a comprehensive range of cargo-handling services. A particularly important feature is the availability of railway connections, which enable the formation of container trains and ensure regular freight operations (Port Clearance, 2020).

April 2026 became an important milestone for Ukrainian logistics development. Following a prolonged period of border congestion and instability of transport routes, the launch of new multimodal terminals and dry ports began to systematically transform the structure of export flows. According to the Zakarpattia Regional State Administration, the Chornotysiv Terminal became one of the most significant additions to this emerging network (Kurta, 2024). Located in the Berehove district, the project involved investments of approximately UAH 282 million and demonstrated the advantages of geographical proximity to Hungary and Romania. The terminal supports the transshipment of both agricultural products and energy resources, thereby providing Ukrainian businesses with more direct access to international markets. Alongside the western border regions, inland logistics hubs in central Ukraine are also gaining strategic importance. According to O. Yavorskyi (2024), construction of a railway terminal in Vinnytsia region has been completed, establishing transport connections between the region, the ports of Greater Odesa, and the European Union. Total investment in the project exceeded USD 15 million. The first development phase of the Vinnytsia dry port includes modern railway infrastructure and a container terminal with an annual capacity of 30,000 TEU. Through its connection with the Mostyska terminal,

exporters obtained a more predictable transport route toward the Polish border. This development is particularly important given that, according to the Ukrainian government, the maritime corridor has already facilitated cargo turnover exceeding 60 million tonnes, while inland terminal development further strengthens the resilience of national logistics systems (Yavorskyi, 2024). These developments reflect not only infrastructure expansion but also the emergence of a fundamentally new approach to freight transportation. Whereas border crossing congestion previously represented one of the main logistical bottlenecks, businesses are now able to plan deliveries with significantly greater predictability. Such operational stability is critically important for fulfilling contracts with European partners, where compliance with delivery schedules directly affects financial performance and business reputation.

Ukrainian logistics systems has gradually begun transitioning from emergency adaptation toward more strategic optimisation, with dry ports becoming one of the foundations for integration into global supply chains. One of the key functions of inland terminals is the relocation of customs procedures away from border crossings and seaports, which contributes to reducing congestion and accelerating container turnover. This approach corresponds to international logistics practices and improves the transparency and manageability of supply chains (Delo.net.ua, 2026).

At the same time, the technical level of Ukrainian dry ports remains uneven. Alongside modern logistics complexes equipped with advanced technologies, some facilities still possess limited operational and technological capabilities. This creates a need for further infrastructure modernisation, the introduction of advanced cargo-handling technologies, and the implementation of digital solutions for transport and logistics flow management (Port Clearance, 2020). Under current geopolitical and economic conditions, particularly the transformation of logistics routes and the reorientation of export flows, dry ports are acquiring strategic importance for Ukraine's economy. They increase the resilience of the transport system, facilitate integration into European transport corridors, and create the foundation for the further development of multimodal transportation (Delo.net.ua, 2026).

Consequently, the formation of an interconnected network of dry ports transforms these facilities from isolated infrastructure elements into integrated coordinators of Ukraine's foreign trade logistics system. The combined development of western border terminals and inland multimodal hubs enables the country to reduce geopolitical risks, optimise empty-container management, and improve the stability of cargo flows. In the long term, the systematic modernisation of inland terminals will not only help overcome the technical constraints associated with dual-gauge railway operations but will also serve as one of the key drivers of Ukraine's full integration into the European TEN-T transport network.

Conclusions

The findings of this study demonstrate that the development of a network of dry ports represents one of the most promising directions for the modernisation of Ukraine's transport and logistics system under wartime conditions, changing international trade patterns, and the country's ongoing integration into the European transport area. The research confirms that inland multimodal terminals can significantly improve interoperability between the 1,435 mm European standard gauge and the 1,520 mm broad-gauge railway systems by reducing the negative effects of infrastructural incompatibilities and facilitating more efficient international container transportation. The analysis of international experience in the operation of dry ports showed that inland logistics hubs contribute to the optimisation of freight flows, reduce congestion at seaports and border crossing points, shorten cargo handling times, and increase the resilience of supply chains. For Ukraine, the formation of a network of inland terminals in the western and central regions is particularly important because such facilities support the functioning of the Solidarity Lanes initiative and strengthen integration into the TEN-T transport network. Under conditions of restricted access to Black Sea ports and continuing geopolitical instability, dry ports increasingly perform the role of secure inland logistics centres capable of maintaining the continuity of export and import operations. The study of the technical and operational parameters of railway terminal infrastructure demonstrated that the efficient functioning of dry ports depends on appropriate track layout configurations, sufficient receiving and departure track lengths, the capability to handle full-length container trains, and the uninterrupted execution of shunting operations. The development of such infrastructure creates the conditions necessary for increasing the throughput capacity of multimodal transport corridors and improving the predictability and reliability of international logistics routes.

Particular attention was devoted to the imbalance of container flows and the management of empty containers. The research established that dry ports can function as logistics buffers that facilitate cargo consolidation, container redistribution, and the optimisation of transport costs. These functions contribute to improving the operational efficiency of logistics systems and increasing the competitiveness of Ukrainian exporters in international markets. Overall, the establishment of an interconnected dry port network should be considered a strategic component of Ukraine's long-term transport policy. The implementation of multimodal infrastructure projects in this field will support export-oriented economic development, attract investment, strengthen transport security, and accelerate Ukraine's integration into the unified European transport system. Future research should focus on the development of economic and mathematical models for the optimal location of dry ports, the assessment of their influence on transport network capacity and supply chain resilience, and the application of digital technologies,

intelligent transport systems, and advanced container flow management tools within the framework of Ukraine's integration into the European logistics space.

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Conflict of Interest

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Інфраструктурні рішення взаємодії залізничних систем колії 1435/1520 мм в Україні

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Анотація. В умовах воєнного стану та євроінтеграції удосконалення взаємодії залізничних мереж колій 1435 мм та 1520 мм через розбудову мультимодальних транспортно-логістичних вузлів набуває критично важливого значення для забезпечення функціонування експортно-імпортних ланцюгів постачання України. Метою роботи було дослідження та обґрунтування інфраструктурних рішень щодо забезпечення взаємодії залізничних систем колії 1435 мм та 1520 мм через розвиток мережі «сухих портів» як ключових елементів мультимодальної логістичної системи України. Для досягнення поставленої мети було використано системний підхід, структурно-функціональний аналіз, а також інфраструктурний, логістичний та статистичний аналіз транспортних потоків. Проаналізовано сучасні тенденції розвитку мультимодальних перевезень та функціонування «сухих портів» у країнах Європейського Союзу й Україні. Встановлено, що розвиток внутрішніх мультимодальних терміналів дозволяє зменшити навантаження на прикордонну та портову інфраструктуру, скоротити час обробки вантажів та підвищити ефективність логістичних ланцюгів. На основі узагальненого міжнародного досвід розвитку мультимодальних логістичних центрів визначено перспективні напрями інтеграції транспортної системи України до мережі TEN-T та «Шляхів солідарності». Досліджено техніко-технологічні параметри функціонування залізничних терміналів, зокрема вимоги до конфігурації колійного розвитку, довжини приймально-відправних колій, організації маневрової роботи та забезпечення пропускної спроможності для обслуговування повносоставних контейнерних поїздів. Також виявлено закономірності накопичення дисбалансу контейнерних потоків і порожнього рухомого складу в межах міжнародних транспортних коридорів. Проаналізовано проблему дисбалансу контейнерних потоків та роль «сухих портів» у забезпеченні ефективного управління порожніми контейнерами. Практична цінність роботи полягає у можливості використання отриманих результатів органами державного управління, логістичними операторами, транспортними компаніями та проєктними організаціями при плануванні розвитку мультимодальної інфраструктури, прикордонних терміналів і мережі «сухих портів» в Україні

Ключові слова: залізнична інфраструктура; «сухий порт»; мультимодальність; контейнеризація; логістичний хаб; експортний потенціал; ланцюги постачання