

INNOVATION AND INFRASTRUCTURE COMPETITIVENESS IN THE RAILWAY SECTOR: COMPARATIVE INSIGHTS FROM KAZAKHSTAN AND THE V4 COUNTRIES

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Abstract

Kazakhstan's railway sector occupies a strategic position in national economic development. This paper explores the contribution of innovation to strengthening the competitiveness of Kazakhstan's railway sector within the wider framework of regional development and Eurasian transport integration. Kazakhstan's modernization efforts - such as digital transformation, infrastructure upgrades, and international partnerships - have enhanced operational efficiency and service performance, yet their implications reach beyond the domestic level. The study draws a comparison with innovation trajectories in the railway sectors of Central European countries, notably those of the Visegrad Group (V4), where smart mobility initiatives, digital advancement, and sustainable transport policies play a crucial role in driving regional competitiveness. By connecting Kazakhstan's innovation-driven strategies with the European Union's smart and green transport agenda, the paper uncovers potential avenues for technological cooperation and shared development. The results underline that innovation within transport systems serves not only as a catalyst for industrial progress but also as a mechanism for fostering regional connectivity and integration across the broader Eurasian corridor.

Keywords: Kazakhstan, Central Europe, Visegrad Group, Railway Innovation, Competitiveness, Regional Development, Sustainable Mobility, Eurasian Connectivity

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Introduction

The railway industry holds a central position in Kazakhstan's economic progress due to the country's vast geographic scale, its landlocked nature, and its function as a strategic transit link between Europe and Asia. In an era of rapid modernization of global transportation, the competitiveness of railways is increasingly tied to the ability to implement and effectively integrate innovative practices. Developments in digital technologies, logistics optimization, infrastructure renewal, and environmentally sustainable solutions now serve as fundamental drivers of improved efficiency, cost minimization, and better service delivery. At the same time, Kazakhstan's railway sector encounters a dual set of challenges. On the one hand, it must strengthen its role within international transport corridors and withstand intensifying global competition. On the other, it continues to grapple with structural legacies of the Soviet period, including outdated infrastructure and institutional rigidity. In this context, adopting innovation-centered strategies becomes a decisive factor in ensuring the sector's sustainable growth and long-term competitiveness.

Studies on transport competitiveness increasingly underline the decisive role of innovation in reshaping efficiency, management approaches, and regional connectivity. Nevertheless, the specific experience of Kazakhstan has received limited scholarly attention, especially when compared to advanced economies and other transit-oriented states. This gap underlines the necessity for a thorough conceptual and empirical investigation into how innovation can enhance Kazakhstan's railway competitiveness within the framework of globalization.

The objective of this paper is to analyze innovation as a key strategic factor determining competitiveness in Kazakhstan's railway system. The study seeks to identify the main innovation-driven mechanisms, evaluate their economic effects, and propose policy as well as managerial recommendations to guide the modernization of the sector (Kvizda and Jandová, 2015).

At the same time, Kazakhstan's railway sector encounters a dual set of challenges. On the one hand, it must strengthen its role within international transport corridors and withstand intensifying global competition. On the other, it continues to grapple with structural legacies of the Soviet period, including outdated infrastructure and institutional rigidity. In this context, adopting innovation-centered strategies becomes a decisive factor in ensuring the sector's sustainable growth and long-term competitiveness.

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The objective of this paper is to analyze innovation as a key strategic factor determining competitiveness in Kazakhstan compared to the V4 countries' railway system. The study seeks to identify the main innovation-driven mechanisms, evaluate their economic effects, and propose policy as well as managerial recommendations to guide the modernization of the sector (Kvizda and Jandová, 2015).

Innovation and Competitiveness in the Railway Sector

As stated in the EU Smart and Sustainable Mobility Strategy (European Commission, 2023), the transport sector's competitiveness and environmental sustainability are primarily driven by innovation and digitalization.

According to the EU Smart and Sustainable Mobility Strategy (European Commission, 2023), innovation and digitalization are key drivers of competitiveness and environmental sustainability in the transport sector.

Rail transport has the capacity to make a substantial contribution to achieving key social and economic objectives, such as fostering a smart, inclusive, competitive, and environmentally sustainable society connected through seamless mobility systems.

A study carried out by Europe's Rail Joint Undertaking (JU) notes that unlocking this potential requires two essential steps:

- positioning rail as an attractive alternative or complementary mode to road and air transport;
- ensuring affordability of rail services, particularly for travelers and countries with lower income levels.

The research, based on an extensive literature review, expert consultations, and quantitative modeling, analyzed how improvements in railway systems and changes in mobility trends could influence passenger and freight traffic volumes. The model was calibrated using data from European railway lines, covering both freight and passenger operations (Kvizda and Jandová, 2015).

The analysis also explored the role of different innovations, taking into account potential scenarios in competing modes of transport (such as autonomous cars, electric trucks, and e-mobility solutions), and assessing their effects across four segments: high-speed, regional, metro, and freight rail.

Several factors were identified as drivers of passenger rail demand, including more efficient utilization of existing networks, enhanced intramodal competition, the application of yield management practices, and wider adoption of online ticketing systems. At the same time, demand is shaped by broader developments such as market deregulation, the electrification and automation of road transport, and the declining competitiveness of short-haul aviation (particularly flights under 500 km).

Specific findings include:

- The introduction of faster high-speed trains and digital solutions, such as e-ticketing and yield management, is a key driver of demand growth.
- Advances in digital communication technologies tend to stimulate overall travel demand.
- Ride-sharing services affect both public transport usage and traffic congestion, often contributing to the latter.
- Road vehicle automation is expected to influence long-distance passenger and freight transport, though its effects are unlikely to be significant before 2040.
- While innovations in automobile technologies may reduce rail's share of the market, the timely deployment of Europe's Rail innovations could help the railway sector retain or even recover competitiveness.

For freight, the study projects that approximately 30% of road freight will become electrified in the future. Despite road transport continuing to dominate, the share of rail freight is also expected to increase, largely due to reduced logistical costs generated by JU-driven innovations.

The Czech railway industry constitutes a key sector of the national economy, significantly influencing industrial output, technological progress, and export capacity. In recent years, innovation has emerged as a critical factor in sustaining and enhancing the competitiveness of this sector both within the domestic market and on the international stage.

According to data provided by the Association of Czech Railway Industry Companies (ACRI), total industry revenues in 2024 amounted to EUR 5.3 billion, representing a 2.3% annual increase. This growth rate exceeded the overall GDP expansion of the Czech Republic during the same period. Exports accounted for approximately half of total revenues, highlighting the sector's strong external market orientation. These achievements are particularly notable considering the overall decline in industrial output recorded in 2024 – by 1.4% in the Czech Republic and 2.5% across the European Union (ACRI, 2025).

Consistent government backing and continuous investment have been instrumental in maintaining this upward trajectory. The Czech Ministry of Transport continues to emphasize infrastructure modernization,

including the development of high-speed rail, the rollout of the European Train Control System (ETCS), and upgrades to station facilities. These initiatives aim to enhance operational safety, passenger comfort, and integration into the broader European railway network.

Innovation remains a defining driver of success within the Czech railway sector. Leading enterprises such as Škoda Group, BONATRANS, AŽD Praha, CZ LOKO, and DAKO-CZ demonstrate a strong focus on research, development, and technological renewal. For example, Škoda Group secured international contracts totaling CZK 20 billion, while BONATRANS exported wheelsets and axles to over 40 countries. Trinecké železářny introduced advanced heat-treatment technologies for rails, improving durability and performance, and DAKO-CZ presented 11 global innovations at InnoTrans 2024, including digitally integrated braking systems.

Furthermore, innovation in the Czech railway industry extends beyond manufacturing toward digitalization and automation. Companies such as Passengera are piloting autonomous transport connectivity solutions and implementing intelligent passenger information systems, demonstrating the sector's ongoing shift toward smart mobility and digital transformation.

Over the past three decades, ACRI has served as a vital platform for cooperation between businesses, public institutions, and research organizations. As a recognized Technical Standardization Center (CTN ACRI) under the Czech Office for Standards, it actively contributes to the formulation of both national and European railway standards. This institutional collaboration facilitates the dissemination of innovations, enhances market competitiveness, and ensures alignment with EU transport policies.

In conclusion, the Czech railway industry showcases a mature and dynamic innovation ecosystem that underpins competitiveness, export growth, and long-term sustainability. The combination of state support, technological advancement, and international partnerships enables Czech railway manufacturers to maintain a leading position in the European railway modernization landscape.

European and Asian Approaches to Railway Competitiveness

International experience demonstrates that in the era of Industry 4.0 and Logistics 4.0, the railway sector is increasingly transforming into a powerful driver of economic development. Its role lies not only in ensuring transport connectivity but also in generating additional revenue streams and expanding the economic space of the service sector. The intensifying competition within the global triad of America–Europe–Japan creates new challenges for system-forming industries that account for a considerable share of GDP. Among these, the railway sector occupies a central place, as its primary function is to provide passenger and freight transportation services at a high level of quality while guaranteeing safety and reliability.

Competition in the global market involves both different modes of transport and rivalry among international manufacturers of railway products. This situation highlights the need for the development of key competencies in the sector, with innovation serving as the main foundation for competitiveness.

The European Union represents one of the largest markets for railway products, especially rolling stock. According to UNIFE, more than 80% of demand from European carriers and infrastructure managers is met by the EU's own rail supply industry. This sector encompasses manufacturers that provide railway operators and the broader transport system with rolling stock, equipment, and components. Demand is shaped by the specific requirements of transport services, particularly their timely and reliable provision across space and time. Consequently, the rail supply industry is recognized as one of the structural pillars of the European Union's economy.

European manufacturers hold more than 45% of accessible foreign markets not protected by trade barriers. The sales turnover of the European rail supply industry approaches €50 billion, with exports accounting for about one-fifth of total sales. As one of the key industrial sectors, it also provides employment to over 400,000 people, which underlines the necessity of integrating socially oriented business models and social innovations into its long-term development strategies.

Maintaining competitiveness in this sector requires strategic management based on innovation, as well as precise identification of marketing geography and objectives of economic actors (suppliers, intermediaries, and end-users). A prominent example of international collaboration in this context is the Shift2Rail program – an EU-funded initiative jointly supported by Horizon 2020 and industry stakeholders. Its main objective is to accelerate the delivery of the European Rail Technical Strategy and promote the development of the Single European Rail Area. Within this framework, consortia of organizations implement interconnected R&D projects covering technical, functional, and process subsystems of the railway system. However, participation among EU member states remains uneven: while Spain is represented by about 40 companies, Poland – despite having a comparable market size – counts only five active participants.

Germany stands out as a leader in the European rail sector, holding an estimated €10 billion (about 15% of the global market). This competitive strength is supported not only by technological innovations but also by structural and organizational reforms. For instance, Deutsche Bahn AG established DB Systemtechnik GmbH in Bavaria as its innovation and development center. To consolidate its global position, Germany

also fostered a Railway Technology Cluster that unites regional partners across the value chain. Its main focus areas include infrastructure and energy, train operation and maintenance, control and security systems, and rolling stock. The cluster is coordinated by CNA e.V., which also manages regional logistics initiatives aimed at enhancing competitiveness in transport and logistics sectors.

Recognition of innovation plays a key role in strengthening the European rail industry. The European Railway Clusters Initiative (ERCI) Innovation Awards annually honor outstanding projects with proven innovative features, economic and social benefits, integration of digital technologies, human capital development, and collaborative networking. For instance, Siemens Mobility GmbH received the Best Large Company Award for developing the world's first autonomous tram equipped with intelligent sensors for environmental monitoring and predictive analysis. Similarly, Bombardier Transportation was awarded for its Obstacle Detection Assistance System (ODAS), designed to improve public transport safety (Aghion and Howitt, 1992).

Despite these achievements, European manufacturers face growing challenges from Asia. China's Belt and Road Initiative, in particular, has accelerated the expansion of its rail transport sector into international markets. The concept of the "Railroad Economic Belt" (REB) reflects China's strategy of exporting rail technology, infrastructure, and high-speed rail systems as tools of regional integration and geopolitical influence. Since the 2013 reform of the Ministry of Railways, the Chinese government has maintained close control over the sector, mobilizing public and private actors to strengthen international competitiveness. This has facilitated rapid technological and industrial development, increased exports of railway infrastructure, and enhanced the global presence of China's high-speed rail (CRH) system, which is now considered both a strategic industry and a transformative factor in the global political and economic landscape of the 21st century.

In parallel, digital technologies are reshaping the sector worldwide. Cloud-to-Edge computing and Platform-as-a-Service (PaaS) models enable manufacturers to provide innovative digital solutions such as Fault Detection as a Service, Predictive Maintenance as a Service (PMaaS), and Simulation as a Service. These services reduce latency, accelerate decision-making, and enhance communication between infrastructures, thereby strengthening the competitiveness of rolling stock manufacturers.

Enhancing the Competitiveness of Railway Sector through Innovation and Partnerships

Kazakhstan's railway sector is actively pursuing modernization and digital transformation to boost competitiveness and strengthen integration into international transit networks. The country's strategy encompasses infrastructure development, technological innovation, and expanded cooperation with global partners.

The national railway network, extending over 16,000 kilometers, represents a cornerstone of Kazakhstan's transport and transit system. Currently, approximately 57% of the tracks are in a worn condition, making modernization a strategic imperative. The Ministry of Transport plans to upgrade 5,000 kilometers of tracks and carry out repairs on 11,000 kilometers by 2030. Key projects under implementation include the Dostyk–Moiynty, Almaty Bypass, Darbaza–Maktaral, Moiyny–Kyzylzhar, and Bakhty–Ayagoz lines. These initiatives aim to expand capacity, enhance efficiency, and optimize operations along major transit corridors.

Kazakhstan is actively introducing digital technologies to improve railway operations. The Ministry of Digital Development, Innovation and Aerospace Industry is focusing on five priority areas:

- Digitizing public services;
- Reengineering internal business processes;
- Developing a national innovation ecosystem;
- Providing satellite internet connectivity for passengers;
- Implementing an online cargo tracking platform.

These measures are intended to streamline operational procedures, increase transparency, and improve service quality for both passengers and freight.

International partnerships are playing a key role in modernizing Kazakhstan's railway sector. In August 2025, Alstom launched its first signaling competencies center in Astana, representing a major step toward digitalizing the national railway network. The center is designed to foster the development of advanced signaling technologies and provide training for local engineers, thereby supporting domestic expertise and strengthening the overall rail ecosystem.

Moreover, Kazakhstan signed a \$4.2 billion agreement with Wabtec, a U.S.-based locomotive manufacturer, to supply 300 Evolution Series ES44Aci heavy-haul locomotives over the next ten years. This collaboration aims to modernize the locomotive fleet, improve fuel efficiency, and reduce maintenance costs, contributing to the long-term sustainability and competitiveness of the railway sector (Akhmedov, 2024).

Kazakhstan is also prioritizing improvements in passenger services through the introduction of technological innovations. The national railway operator, Kazakhstan Temir Zholy (KTZ), has implemented pilot projects that provide satellite internet connectivity on passenger trains. Initially rolled out on the Astana–Almaty route, these initiatives mark an important step in enhancing the travel experience while integrating modern communication technologies into railway operations.

Overall, these efforts highlight Kazakhstan's dedication to modernizing its railway sector through innovation and international cooperation. By embracing cutting-edge technologies and establishing strategic partnerships, the country seeks to boost the competitiveness of its railway industry and reinforce its role as a key participant in global transit networks.

To maintain a strong competitive position in international markets, the Czech railway industry must prioritize the enhancement of its innovation capacity. Traditional advantages such as relatively low labour costs are gradually losing their significance, making technological advancement and research-driven development increasingly critical. According to the European Commission's Country-Specific Recommendations 2020: Research and Innovation Analysis, the Czech Republic still performs below the EU average in several dimensions of innovation and research activity. Productivity growth remains largely associated with foreign-owned companies, while domestic enterprises continue to demonstrate limited progress, particularly regarding research and development (R&D) investments.

The European Innovation Scoreboard 2020 classified the Czech Republic among the “Moderate Innovators,” based on 27 comparative indicators. This assessment underscores both the potential for growth and the need for structural transformation toward innovation-oriented development. For Czech manufacturing firms – especially those in the railway sector – product innovation has become essential to maintaining long-term competitiveness. Achieving this goal requires intensified collaboration between industrial enterprises, universities, and research institutions to foster the introduction of advanced technologies and innovative solutions in production processes.

An important instrument that supports innovation and enhances long-term competitiveness is the Life Cycle Cost (LCC) approach. LCC analysis enables a comprehensive evaluation of all costs associated with a product's life cycle – from design and manufacturing to maintenance and disposal. Studies conducted among leading Czech railway vehicle producers show that the systematic application of LCC principles not only improves innovation performance and product reliability but also significantly reduces operational costs. Furthermore, LCC-based evaluation has become a decisive factor in procurement processes for new rolling stock, motivating manufacturers to develop technologically advanced, efficient, and sustainable solutions.

The wider adoption of the LCC framework has therefore become a catalyst for improving product quality, safety, and durability. In the railway sector, where vehicles are typically in service for several decades, the cooperation between producers and operators is crucial for optimizing the total cost of ownership (TCO) – the core element of LCC. Empirical studies carried out between 2019 and 2020 with major Czech railway producers confirm that integrating LCC methodologies into product design and production stimulates innovation by fostering long-term planning and continuous improvement.

Given the Czech railway industry's export-oriented nature, it is also vital to adapt to global technological trends, including autonomous control systems, alternative propulsion technologies, and intelligent transport solutions. Realizing this potential depends on sustained coordination among government institutions, research organizations, high-technology firms, and related industries such as energy and ICT.

The Innovation Strategy of the Czech Republic 2019–2030 outlines a national vision to position the country among Europe's leading innovation-driven economies. In the railway industry, aligning with this strategic agenda will reinforce the industrial base, enhance export capacity, and contribute to sustainable growth and improved service quality, strengthening the Czech Republic's role as a competitive player in the European transport landscape (Vogl and Jánešová, 2021).

Innovation and Railway Competitiveness in the Context of Central European Regional Development

The EU aims to make transport more sustainable, smart, and resilient by 2050 (European Commission, 2023).

The Visegrad Group (V4) countries – Poland, the Czech Republic, Slovakia, and Hungary – have been actively promoting innovation in their railway sectors, viewing it as a key instrument for infrastructure modernization and efficiency enhancement. Their strategic priorities include high-speed rail development, digital transformation, environmental sustainability, and improved safety and service quality.

Key Directions of Innovation:

Infrastructure Modernization – V4 countries are implementing large-scale programs to reconstruct and expand their railway networks, including the construction of new lines suitable for high-speed operations. Substantial investments are directed toward the renewal of rolling stock through the purchase of modern, energy-efficient trains and carriages. At the same time, the development of logistics hubs and freight transport terminals is advancing to strengthen the efficiency of regional and international supply chains.

Digitalization and Technological Innovation – major focus lies in the deployment of automated train control and signaling systems, such as the European Rail Traffic Management System (ERTMS). Digital platforms are increasingly used for managing railway operations, ticketing, and passenger information services. The adoption of “smart network” technologies contributes to the optimization of train scheduling, predictive maintenance, and overall operational efficiency.

Environmental Sustainability – railway innovation in the V4 region is also closely linked to the European Green Deal agenda. Efforts include the expansion of electrified railway sections, the introduction of alternative propulsion systems such as hydrogen trains, and the reduction of carbon emissions. In addition, railway networks are being integrated with other modes of public transport to build sustainable, multimodal mobility systems.

Safety and Passenger Experience – modernization of safety systems aims to prevent accidents and improve the reliability of operations. Simultaneously, initiatives are being implemented to enhance passenger comfort, upgrade station infrastructure, and ensure accessibility for people with reduced mobility. These measures collectively strengthen the social dimension of transport innovation (Duleba and Farkas, 2019).

Examples of National Projects:

- Czech Republic: ongoing projects focus on the modernization and electrification of key railway corridors, including the development of new high-speed segments.
- Poland: expanding its high-speed rail network while investing in advanced traffic management systems and logistics centers.
- Slovakia: prioritizing the modernization of cross-border railway connections and freight transport infrastructure.
- Hungary: investing in the construction of new lines and modernization of existing routes to improve both passenger and freight services.

Overall, the Visegrad Group countries aim to create an innovative, efficient, and environmentally responsible railway system aligned with European Union standards. This strategic transformation enhances not only transport connectivity and safety but also the overall competitiveness and sustainability of the Central European region.

European programs such as TEN-T, Shift2Rail, and its successor, Europe's Rail Joint Undertaking (EU-Rail), are pivotal in guiding the modernization and development of the continent's railway sector. The Trans-European Transport Network (TEN-T) establishes a strategic framework for creating integrated, cross-border transport infrastructure, enhancing connectivity, interoperability, and operational efficiency throughout the EU. Building on this foundation, Shift2Rail (2014–2021) and EU-Rail (2021–2027) are designed to accelerate research, innovation, and digitalisation within the railway industry, promoting cohesive solutions across rolling stock, infrastructure, traffic management, and services. These initiatives aim to strengthen the competitiveness of the European rail supply sector while supporting the transition toward a fully interoperable and sustainable railway system.

In addition to technological objectives, these programs advance broader EU priorities, including green mobility and ESG (Environmental, Social, and Governance) standards. By encouraging energy efficiency, decarbonisation, and optimal resource use, they foster a sustainable transport ecosystem, mitigate environmental impacts, and enhance the social and economic resilience of the railway sector. Collectively, TEN-T, Shift2Rail, and EU-Rail provide both a practical policy framework and a technological roadmap for achieving a more sustainable, reliable, and competitive European railway network (Helling, 2023).

Innovations in the railway sector of Central Europe play a significant role in promoting regional cohesion and economic development, contributing to the achievement of Cohesion Policy Objective 3 – “A more connected Europe.” These efforts focus on improving cross-border transport connectivity, eliminating bottlenecks, and reducing disparities in infrastructure development.

Railway innovation in Central Europe significantly contributes to regional cohesion and economic development by enhancing accessibility, competitiveness, and sustainability. Upgrading railway networks, particularly in peripheral regions, improves access to major transport corridors, which is especially vital for countries with less-developed infrastructure, such as Croatia, where EU funding facilitates alignment with European standards. Investments in the modernization of railway stations and freight terminals strengthen trade efficiency and regional competitiveness, positioning Central Europe as a key hub for north–south and east–west transport routes. In Poland, for instance, infrastructure investments have reduced travel times and stimulated higher passenger demand.

Moreover, funding from EU Cohesion Policy instruments, including the Cohesion Fund and the European Regional Development Fund (ERDF), promotes railway infrastructure investment, driving economic growth and job creation. The introduction of energy-efficient rolling stock, as exemplified in the Czech Republic, enhances service quality by ensuring safer, faster, and more comfortable travel, thereby encouraging a modal shift toward rail transport.

These developments align closely with Cohesion Policy Objective 3 – “A more connected Europe” – which emphasizes regional integration through the development of the Trans-European Transport Network (TEN-T) and the elimination of interoperability barriers. Europe's Rail Joint Undertaking (EU-Rail) plays a vital role in addressing interoperability challenges and advancing the full integration of the European railway system. Simultaneously, digital transformation initiatives improve the efficiency, sustainability, and

connectivity of rail networks, while projects financed under the Connecting Europe Facility (CEF) ensure infrastructure development consistent with TEN-T standards.

The ongoing shift toward sustainable transport enhances the attractiveness of rail as a viable alternative to road and air transport, directly supporting EU decarbonization objectives. Furthermore, the deployment of advanced technologies such as the European Rail Traffic Management System (ERTMS) strengthens both safety and interoperability in cross-border operations. Overall, innovations in Central European railways reinforce the EU's strategic goals of building a sustainable, competitive, and integrated transport infrastructure, thereby fostering regional cohesion and long-term economic growth.

Methodology

To evaluate the performance of Kazakhstan's railway sector in comparison with the V4 countries (Czech Republic, Poland, Slovakia, and Hungary), a comparative analysis framework was applied. This approach involves systematically examining multiple countries using a set of shared indicators, integrating both quantitative and qualitative measures to reveal relative strengths and weaknesses.

Indicators and data sources:

- R & D intensity in the rail industry (% of GDP or share of total industrial R & D): a quantitative measure reflecting the level of investment in research and development within the railway sector. Data were sourced from national statistical agencies and international databases.
- Share of electrified railways (%): represents the proportion of infrastructure equipped with electric traction, based on information from UIC and national transport authorities.
- Share of modern signalling systems (ETCS Level 1/2 coverage): indicates the adoption of advanced traffic control and safety technologies across the rail network.
- Participation in EU rail R & I programmes (Shift2Rail, Horizon Europe): a qualitative indicator measuring involvement in European research and innovation initiatives.
- Domestic innovation maturity index (rail subsector): a composite qualitative score (1–5) capturing technology adoption, innovation capacity, and integration of R & D in the sector.

Analytical procedure:

- Quantitative indicators (R & D intensity, electrification share, and signalling coverage) were directly compared across countries to identify performance gaps and relative standings.
- Relative indices were calculated where appropriate to express Kazakhstan's outcomes as a percentage of the V4 average.
- Qualitative measures were assessed descriptively, considering participation in EU programmes and maturity ratings (Tóth, 2020).

The works of numerous Kazakh and international scholars and practitioners address a wide range of scientific and methodological issues related to logistics, transit and multimodal transportation, innovation, and the development of transport and logistics systems. The information base for this study includes materials from state target programs for the development of Kazakhstan's transport complex, resolutions of the Government of the Republic of Kazakhstan on transport and economic policy, as well as data from NC KTZ JSC, the Agency for Statistics, the Customs Committee, and the Ministry of Industry and Infrastructure Development of the Republic of Kazakhstan. Additionally, resources from the Research Institute of Transport and Communications and survey-based studies of cargo flows were utilized.

To provide a broader comparative and analytical perspective, international sources and databases were also employed, including the World Bank, the Organisation for Economic Co-operation and Development (OECD), the United Nations Conference on Trade and Development (UNCTAD), and the International Union of Railways (UIC). These sources offer valuable insights into global trends in transport infrastructure, logistics efficiency, railway innovation, and best practices in transit-oriented development. The integration of both national and international data allows for a comprehensive assessment of Kazakhstan's transport sector within the context of global economic and technological trends.

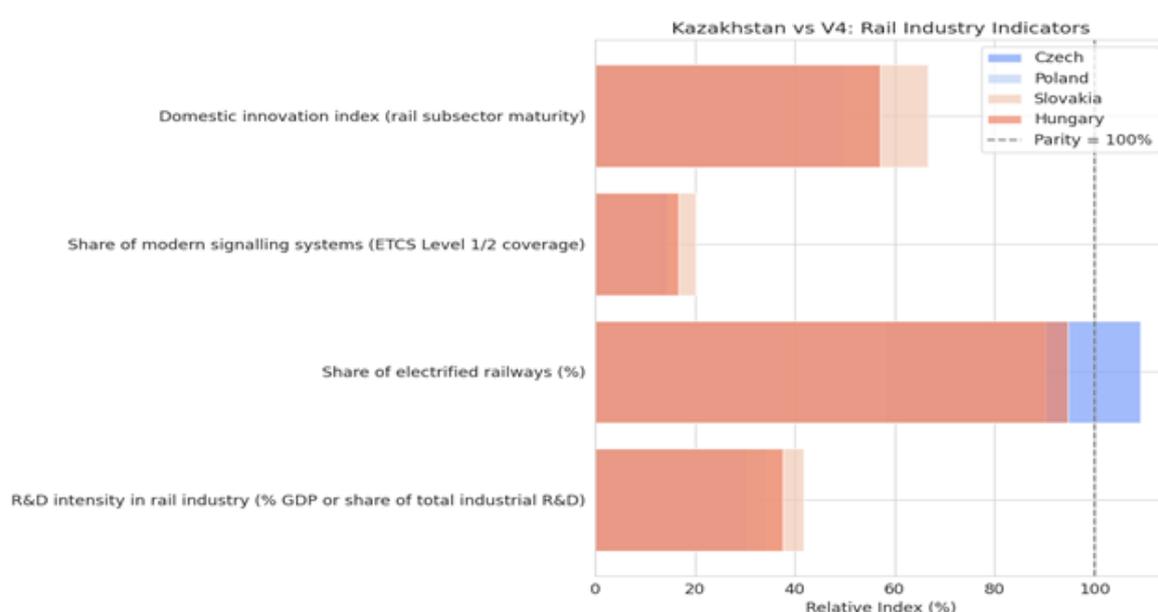
Results

The comparative analysis indicates notable disparities between Kazakhstan and the V4 countries in terms of railway innovation and infrastructure indicators. Kazakhstan's investment in railway research and development is very low, estimated at 0.05–0.1% of GDP or total industrial R & D, while the V4 countries invest between 0.18% and 0.25%, highlighting limited domestic capacity for technological innovation. Approximately 36% of Kazakhstan's railway lines are electrified, which is similar to Slovakia (40%) and Hungary (38%), but substantially below Poland (62%) and slightly above the Czech Republic (33%),

I: Comparative Indicators of Innovation and Technological Development in the Railway Sector in Kazakhstan and Central European Countries

Indicator	Kazakhstan	Czech Republic	Poland	Slovakia	Hungary
R & D intensity in rail industry (% GDP or share of total industrial R&D)	0.05–0.1% (est.)	0.25	0.22	0.18	0.20
Share of electrified railways (%)	36	33	62	40	38
Share of modern signalling systems (ETCS Level 1/2 coverage)	< 5%	~35%	~40%	~25%	~30%
Participation in EU rail R & I programmes (Shift2Rail, Horizon Europe)	low	high	medium	low	medium
Domestic innovation index (rail subsector maturity)*	2/5	4/5	3.5	3	3.5/5

Source: Indicative evaluation compiled from UNIFE (2024), OECD R&D data, Eurostat, ACRI, and World Bank infrastructure statistics



1: Evaluation of technological and innovation indicators in Kazakhstan's railway sector vs. V4 benchmark

Source: Author's compilation based on data from UNIFE (2024), OECD R&D data, Eurostat, ACRI, and World Bank infrastructure statistics

reflecting moderate progress in infrastructure modernization. Coverage of modern signalling systems (ETCS Level 1/2) in Kazakhstan remains under 5%, significantly lower than in the V4 countries, where adoption ranges from 25% to 40%, pointing to a considerable technological gap in traffic control and safety systems. Kazakhstan exhibits minimal involvement in European rail research and innovation initiatives, whereas the V4 countries show medium to high engagement, indicating a strategic disadvantage in international collaboration and knowledge exchange. The domestic innovation index for Kazakhstan's rail subsector is 2/5, reflecting low maturity in terms of innovation adoption and R&D integration, while the V4 countries achieve scores of 3–4/5, demonstrating higher technological sophistication and readiness for innovation-driven development.

The table provides a comparative overview of Kazakhstan's railway sector relative to the V4 countries (Czech Republic, Poland, Slovakia, Hungary) across key quantitative and qualitative indicators. Quantitative measures include R&D intensity in the rail industry, the share of electrified railway lines, and the coverage of modern signalling systems (ETCS Level 1/2).

Qualitative measures include participation in European rail R&I programmes (Shift2Rail, Horizon Europe) and a domestic innovation index assessing rail subsector maturity. This combination of indicators allows for an evaluation of technological capacity, innovation adoption, and infrastructure modernization, highlighting both the strengths and relative gaps of Kazakhstan's rail sector compared to European benchmarks.

The figure offers a comparative evaluation of Kazakhstan's railway sector in relation to the V4 countries (Czech Republic, Poland, Slovakia, and Hungary) using a relative index framework. Performance for each indicator is expressed as a percentage of the V4 average, with horizontal bars illustrating the relative position of each country. Key indicators include the domestic innovation index, which captures the technological maturity and innovation capacity of the rail subsector; the share of modern signalling systems (ETCS Level 1/2 coverage), reflecting the implementation of advanced train control technologies; the share of electrified railways, representing the proportion of the network utilizing electric traction; and R&D intensity in the rail industry, measured as a percentage of GDP or industrial R&D to indicate investment in sector-specific research and development. By comparing Kazakhstan against the V4 benchmark, the analysis highlights relative strengths and weaknesses, revealing gaps in innovation adoption, infrastructure modernization, electrification, and R&D investment. The use of differentiated colors for the V4 countries and a vertical line at 100% facilitates clear benchmarking and emphasizes areas where Kazakhstan may prioritize strategic improvements.

Discussion and Conclusion

Innovation within the railway sector serves not only as a catalyst for technological progress but also as a mechanism for enhancing regional competitiveness, fostering employment, and promoting sustainable mobility. In the Visegrad Group (V4) countries, advancements in railway systems contribute directly to the EU Cohesion Policy Objective 3 – “A More Connected Europe,” by improving regional accessibility, mitigating peripheral disadvantages, and facilitating the integration of territories into the single market. Similarly, in Kazakhstan, modernization and digital transformation initiatives strengthen spatial cohesion, enhance connectivity with remote areas, and stimulate the development of local industrial capacities.

The alignment of innovation priorities between Kazakhstan and Central European nations highlights significant opportunities for cross-regional policy learning. Both contexts emphasize sustainable transport, energy efficiency, and integration into broader transcontinental networks as strategic objectives. When investment strategies are guided by ESG criteria and smart mobility principles, railway innovation emerges as a key driver of balanced regional development.

Consequently, fostering collaborative efforts between Kazakhstan and the V4 countries should be viewed not merely as a transport-focused endeavor but as an overarching regional development strategy that enhances competitiveness, connectivity, and socio-economic resilience across Eurasia.

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