ISSN: 1991-3494 (Print)
ISSN: 2518-1467 (Online)

SCIENTIFIC JOURNAL OF PEDAGOGY AND ECONOMICS

№3
2026

ISSN 2518-1467 (Online),
ISSN 1991-3494 (Print)

CENTRAL ASIAN ACADEMIC
RESEARCH CENTER

SCIENTIFIC JOURNAL OF PEDAGOGY AND ECONOMICS

PUBLISHED SINCE 1944

3 (421)

May – June 2026

ALMATY, 2026

Scientific Journal of Pedagogy and Economics
ISSN 2518-1467 (Online),
ISSN 1991-3494 (Print).
Owner: «Central Asian Academic Research Center» LLP (Almaty).
The certificate of registration of a periodical printed publication in the Committee of information of the Ministry of Information and Communications of the Republic of Kazakhstan
№ KZ50VPY00121155, issued on 05.06.2025
Thematic focus: *«publication of the results of new achievements inthe field of fundamental sciences»*
Periodicity: 6 times a year.
http://www.bulletin-science.kz/index.php/en/

Scientific Journal of Pedagogy and Economics
ISSN 2518-1467 (Online),
ISSN 1991-3494 (Print).
Меншіктенуші: «Орталық Азия академиялық ғылыми орталығы» ЖШС (Алматы қ.).
Қазақстан Республикасының Ақпарат және коммуникациялар министрлігінің Ақпарат комитетінде 05.06.2025 ж. берілген **№ KZ50VPY00121155** мерзімдік басылым тіркеуіне қойылу туралы куәлік.
Тақырыптық бағыты: *«іргелі ғылым салалары бойынша жаңа жетістіктердің нәтижелерін жариялау»*
Мерзімділігі: жылына 6 рет.
http://www.bulletin-science.kz/index.php/en/

Scientific Journal of Pedagogy and Economics
ISSN 2518-1467 (Online),
ISSN 1991-3494 (Print).
Собственник: ТОО «Центрально-азиатский академический научный центр» (г. Алматы).
Свидетельство о постановке на учет периодического печатного издания в Комитете информации Министерства информации и коммуникаций и Республики Казахстан
№ KZ50VPY00121155 выданное 05.06.2025 г.
Тематическая направленность: *«публикация результатов новых достижений вобласти фундаментальных наук».*
Периодичность: 6 раз в год.
http://www.bulletin-science.kz/index.php/en/

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SCIENTIFIC JOURNAL OF PEDAGOGY AND ECONOMICS
ISSN 1991-3494
Volume 3.
Number 421 (2026), 564-586

https://doi.org/10.32014/2026.2518-1467.1223

IRSTI 06.73.15
UDC 656.2:339.5
JEL L92, R41, O33, F14

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CHINA–KAZAKHSTAN TRANSPORT CORRIDOR: DIGITALIZATION AND EFFICIENCY IN THE CONTEXT OF GROWING FREIGHT FLOWS

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Abstract. This study examines the functioning of the China–Kazakhstan railway transport corridor as a strategically important component of the Eurasian logistics system. The relevance of the research is determined by the rapid growth of freight flows between China, Kazakhstan, Central Asia and Europe, as well as by the increasing role of Kazakhstan as a transit, distribution and logistics hub in international supply chains. In the context of global supply chain restructuring, growing demand for overland transportation and the need to reduce delivery time, the efficiency of railway corridors depends not only on physical infrastructure, but also on the quality of institutional coordination, customs procedures and digital integration. The aim of the study is to analyze the functioning of the China–Kazakhstan railway transport corridor and assess the impact of digitalization on its efficiency under conditions of increasing freight flows. The research focuses on three interrelated areas: the dynamics and structural characteristics of freight flows, infrastructural and institutional constraints affecting corridor performance, and the role of digital technologies in improving railway logistics. The empirical basis of the study includes statistical data, sectoral reports and analytical materials

for 2023–2025, reflecting the development of railway transportation between China and Kazakhstan. The methodological basis combines systems analysis, comparative analysis, elements of descriptive statistics and the theory of constraints. The results show that the China–Kazakhstan corridor has entered a stage of stable growth, while its efficiency is increasingly limited by border crossing capacity, cargo flow imbalance, concentration of transportation at the Dostyk–Alashankou and Altynkol–Khorgos nodes, differences in railway gauge and procedural inefficiencies in customs and logistics operations. At the same time, digitalization significantly improves corridor performance by reducing cargo processing time, increasing transparency, accelerating document circulation and strengthening coordination among transport participants. The scientific significance of the study lies in developing an integrated approach to assessing transport corridor efficiency based on the interaction of infrastructural, institutional, operational and digital factors. The practical value of the research consists in substantiating the need to combine infrastructure expansion with digital modernization in order to strengthen Kazakhstan's role in Eurasian supply chains.

Keywords: China–Kazakhstan transport corridor; railway logistics; freight flows; infrastructure constraints; transport digitalization; supply chain efficiency; containerization

Financing information: *This research was funded by the Committee of Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan under Grant No. BR27198643 "Development of digital competences of human capital in industry and logistics through cluster collaboration of science, education and industry".*

For citation: Karanova Zh.Y., Kazhmuratova A.K., Chakeyeva K.S. China–Kazakhstan transport corridor: digitalization and efficiency in the context of growing freight flows. Scientific Journal of Pedagogy and Economics, 2026. — No. 3. — P. 564-586. DOI: https://doi.org/10.32014/2026.2518-1467.1223

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ҚЫТАЙ–ҚАЗАҚСТАН КӨЛІК ДӘЛІЗІ: ЖҮК АҒЫНДАРЫНЫҢ ӨСУІ ЖАҒДАЙЫНДА ЦИФРЛАНДЫРУ ЖӘНЕ ТИІМДІЛІК

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Аннотация. Бұл зерттеу Қытай–Қазақстан теміржол көлік дәлізінің Еуразиялық логистикалық жүйенің стратегиялық маңызды құрамдас бөлігі ретіндегі қызметін талдауға арналған. Зерттеудің өзектілігі Қытай, Қазақстан, Орталық Азия және Еуропа арасындағы жүк ағындарының қарқынды өсуімен, сондай-ақ Қазақстанның халықаралық жеткізу тізбектеріндегі транзиттік, тарату және логистикалық хаб ретіндегі рөлінің күшеюімен айқындалады. Жаһандық жеткізу тізбектерінің қайта құрылуы, құрлықтық тасымалдарға сұраныстың артуы және жеткізу уақытын қысқарту қажеттілігі жағдайында теміржол дәліздерінің тиімділігі тек физикалық инфрақұрылымға ғана емес, сонымен қатар институционалдық үйлестіру сапасына, кедендік рәсімдердің тиімділігіне және цифрлық интеграция деңгейіне де тәуелді. Зерттеудің мақсаты - Қытай–Қазақстан теміржол көлік дәлізінің қызметін талдау және жүк ағындарының өсуі жағдайында цифрландырудың оның тиімділігіне әсерін бағалау. Зерттеу үш өзара байланысты бағытқа негізделеді: жүк ағындарының динамикасы мен құрылымдық сипаттамалары, дәліз жұмысына ықпал ететін инфрақұрылымдық және институционалдық шектеулер, сондай-ақ теміржол логистикасының тиімділігін арттырудағы цифрлық технологиялардың рөлі. Зерттеудің эмпирикалық базасын 2023–2025 жылдардағы Қытай мен Қазақстан арасындағы теміржол тасымалының дамуын сипаттайтын статистикалық деректер, салалық есептер және аналитикалық материалдар құрайды. Әдіснамалық негіз ретінде жүйелік талдау, салыстырмалы талдау, сипаттамалық статистика элементтері және шектеулер теориясының тәсілдері қолданылды. Зерттеу нәтижелері Қытай–Қазақстан көлік дәлізінің тұрақты өсу кезеңіне өткенін көрсетті. Сонымен қатар оның тиімділігі шекаралық өткелдердің өткізу қабілетіне, жүк ағындарының теңгерімсіздігіне, тасымалдардың Достық–Алашанькоу және Алтынкөл–Қорғас тораптарында шоғырлануына, теміржол табаны айырмашылығына, сондай-ақ кедендік және логистикалық рәсімдердегі ұйымдастырушылық шектеулерге тәуелді болып отыр. Цифрландыру жүк өңдеу уақытын қысқарту, құжат айналымын жеделдету, процестердің ашықтығын арттыру және тасымалдау қатысушылары арасындағы үйлестіруді күшейту арқылы дәліздің тиімділігін арттыратын маңызды фактор ретінде қарастырылады. Зерттеудің ғылыми маңыздылығы көлік дәлізінің тиімділігін инфрақұрылымдық, институционалдық, операциялық және цифрлық факторлардың өзара байланысы негізінде бағалауға мүмкіндік беретін интеграциялық тәсілді ұсынуымен айқындалады. Практикалық маңыздылығы Қазақстанның Еуразиялық жеткізу тізбектеріндегі орнын нығайту

үшін инфрақұрылымды кеңейтуді цифрлық жаңғыртумен ұштастыру қажеттілігін негіздеуден тұрады.

Түйін сөздер: Қытай–Қазақстан көлік дәлізі; теміржол логистикасы; жүк ағындары; инфрақұрылымдық шектеулер; көлікті цифрландыру; жеткізу тізбегінің тиімділігі; контейнеризация

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ТРАНСПОРТНЫЙ КОРИДОР КИТАЙ–КАЗАХСТАН: ЦИФРОВИЗАЦИЯ И ЭФФЕКТИВНОСТЬ В УСЛОВИЯХ РОСТА ГРУЗОПОТОКОВ

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Аннотация. Настоящее исследование посвящено анализу функционирования железнодорожного транспортного коридора Китай–Казахстан как стратегически значимого элемента евразийской логистической системы. Актуальность исследования обусловлена быстрым ростом грузопотоков между Китаем, Казахстаном, странами Центральной Азии и Европой, а также усилением роли Казахстана как транзитного, распределительного и логистического хаба в международных цепях поставок. В условиях перестройки глобальных логистических маршрутов, повышения спроса на сухопутные перевозки и необходимости сокращения сроков доставки эффективность железнодорожных коридоров определяется не только состоянием физической инфраструктуры, но и качеством институциональной координации, таможенных процедур и цифровой интеграции. Цель исследования заключается в анализе функционирования железнодорожного транспортного коридора Китай–Казахстан и оценке влияния цифровизации на его эффективность в условиях роста грузопотоков. В работе рассматриваются три взаимосвязанных направления: динамика и структурные характеристики грузовых потоков, инфраструктурные и институциональные ограничения,

влияющие на работу коридора, а также роль цифровых технологий в повышении эффективности железнодорожной логистики. Эмпирическую основу исследования составили статистические данные, отраслевые отчеты и аналитические материалы за 2023–2025 гг., отражающие развитие железнодорожных перевозок между Китаем и Казахстаном. Методологическая база включает системный анализ, сравнительный анализ, элементы описательной статистики и подходы теории ограничений. Результаты исследования показывают, что транспортный коридор Китай–Казахстан перешел к стадии устойчивого роста, однако его эффективность все в большей степени ограничивается пропускной способностью пограничных переходов, дисбалансом грузопотоков, концентрацией перевозок на узлах Достык–Алашанькоу и Алтынколь–Хоргос, различиями в ширине железнодорожной колеи, а также процедурными ограничениями в таможенных и логистических операциях. Цифровизация рассматривается как важный фактор повышения эффективности коридора, поскольку она способствует сокращению времени обработки грузов, ускорению документооборота, повышению прозрачности процессов и улучшению координации между участниками перевозочного процесса. Научная значимость исследования заключается в разработке интегрированного подхода к оценке эффективности транспортного коридора на основе взаимосвязи инфраструктурных, институциональных, операционных и цифровых факторов. Практическая значимость состоит в обосновании необходимости сочетания расширения транспортной инфраструктуры с цифровой модернизацией для укрепления позиции Казахстана в евразийских цепях поставок.

Ключевые слова: транспортный коридор Китай–Казахстан; железнодорожная логистика; грузопотоки; инфраструктурные ограничения; цифровизация транспорта; эффективность цепей поставок; контейнеризация

Introduction. In the context of the transformation of the global economy and the increasing complexity of international supply chains, transport corridors are acquiring particular importance as strategic mechanisms that ensure the stable and predictable movement of goods between major production, transit and consumption regions. Over the past decade, the importance of land-based transport routes has increased significantly due to the need to reduce delivery times, diversify logistics risks and strengthen the resilience of supply chains. In this regard, railway corridors connecting China, Central Asia and Europe are becoming one of the key elements of the emerging Eurasian transport architecture (Rodrigue, 2020; World Bank, 2023).

The China–Kazakhstan railway transport corridor occupies a special place in this system. Its strategic significance is determined by the geographical position of Kazakhstan, which links the industrial regions of China with the markets of Central Asia, the Eurasian Economic Union, the Caucasus, Turkey and Europe. Within the framework of the Belt and Road Initiative and the development of transcontinental logistics routes, Kazakhstan is gradually moving beyond the role

of a simple transit territory and is becoming a logistics hub where cargo flows are redistributed, consolidated and integrated into broader international supply chains (Asian Development Bank, 2023; Eurasian Development Bank, 2024).

The relevance of the study is further strengthened by the rapid growth of freight flows along the China–Kazakhstan route. The increasing volume of railway transportation reflects the growing demand for faster and more reliable overland logistics solutions. Compared with maritime routes, railway transport provides a shorter delivery cycle and allows companies to diversify transport risks in conditions of global uncertainty. At the same time, the development of containerization has contributed to the standardization of cargo transportation and has increased the operational efficiency of international logistics systems (Christopher, 2016; Notteboom and Rodrigue, 2009).

Kazakhstan's role in this process is not limited to the physical transit of goods. The country acts as a key overland gateway for Chinese freight flows directed toward Central Asia and further westward. The main railway flows pass through the Dostyk–Alashankou and Altynkol–Khorgos border crossings, which have become critical nodes of the China–Kazakhstan transport corridor. These crossings concentrate a substantial share of freight operations and determine the overall capacity and stability of the corridor. However, the growing concentration of cargo at a limited number of nodes increases the vulnerability of the transport system and creates risks of congestion, delays and rising logistics costs (Eurasian Development Bank, 2024; Sheffi, 1985).

At the present stage, the growth of transportation volumes is accompanied by a number of infrastructural and institutional constraints. These include limited capacity at border crossings, differences in railway gauge, uneven distribution of freight flows, insufficient development of logistics infrastructure in some directions and administrative barriers in customs and transport procedures. Such constraints reduce the predictability of deliveries and limit the ability of the corridor to process increasing freight volumes without operational losses (Woxenius, 2010; Goldratt, 1990).

In this context, digitalization is becoming a decisive factor in improving the efficiency of transport corridors. Digital technologies make it possible to reduce transaction costs, accelerate the processing of transport and customs documents, increase transparency and improve coordination among participants in the logistics chain. The implementation of electronic documents, automated transit procedures and digital platforms contributes to the transformation of railway logistics from a fragmented system into an integrated and more predictable transport environment (OECD, 2022; ITF, 2021; UNECE, 2023).

Despite the growing number of studies devoted to transport corridors, railway logistics and digital transformation, the issue of the integrated impact of digitalization on the efficiency of the China–Kazakhstan transport corridor remains insufficiently explored. Most existing studies focus either on infrastructure development, trade connectivity or digital transport procedures separately. However, the interaction

between freight flow growth, infrastructure constraints, institutional barriers and digital solutions requires a more comprehensive analytical approach (World Bank, 2023; UNESCAP, 2019).

The purpose of this study is to analyze the functioning of the China–Kazakhstan railway transport corridor and to assess the impact of digitalization on its efficiency under conditions of increasing freight flows. To achieve this purpose, the study examines the dynamics and structure of freight transportation, identifies key infrastructural and institutional constraints, and evaluates the role of digital technologies in improving operational coordination and reducing processing time.

The scientific contribution of the study lies in developing an integrated approach to assessing the efficiency of an international transport corridor by combining infrastructural, institutional, operational and digital factors. The practical significance of the research is related to the possibility of using its findings in the development of transport policy, logistics infrastructure planning and the implementation of digital solutions aimed at strengthening Kazakhstan's position in Eurasian supply chains.

Literature Review. Modern studies in the field of transport logistics and international freight transportation consider transport corridors as complex systems in which infrastructural, institutional, technological and spatial factors interact. In this approach, a transport corridor is not limited to a physical route connecting two points. It is understood as a functional system that includes railway lines, border crossings, logistics hubs, dry ports, customs procedures, information flows and institutional coordination mechanisms (Rodrigue, 2020).

Rodrigue (2020) emphasizes that transport corridors play a key role in the spatial integration of economic regions, since they connect production centers with consumer markets and distribution networks. This interpretation is particularly relevant for Eurasian land corridors, where the effectiveness of transportation depends not only on distance, but also on the quality of infrastructure, the level of logistics services and the degree of coordination between states and transport operators.

A similar approach is presented by Notteboom and Rodrigue (2009), who developed the concept of logistics regionalization. According to this concept, transport nodes gradually transform from simple transit points into logistics centers where cargo redistribution, consolidation, warehousing and value-added operations take place. This means that the development of a transport corridor creates not only a transport effect, but also an economic effect, since logistics activity begins to generate additional value within the territory of transit countries.

For landlocked countries, this approach is of particular importance. Kazakhstan, having no direct access to the sea, uses its geographical position as a competitive advantage in the development of railway transit. The transformation of Kazakhstan from a transit territory into a logistics hub corresponds to the logic of dry port development, in which inland logistics centers perform part of the functions traditionally associated with seaports. Roso (2009) defines dry ports as inland

intermodal terminals directly connected with seaports or international corridors, capable of handling, storing and distributing cargo flows.

The development of dry ports and logistics hubs is closely connected with the growth of containerization. Container transport makes it possible to standardize cargo handling, reduce transshipment time and improve the reliability of international transportation. Christopher (2016) notes that modern supply chains require not only low transport costs, but also speed, flexibility and predictability. Therefore, countries participating in international corridors must develop not only railway infrastructure, but also logistics services and digital coordination mechanisms.

In the Eurasian context, the importance of transport corridors is confirmed by analytical studies of international organizations. The World Bank (2023) emphasizes that transport connectivity in Central Asia is one of the key conditions for expanding trade, reducing logistics costs and increasing the competitiveness of landlocked economies. The Asian Development Bank (2023), within the CAREC framework, also highlights the importance of corridor performance measurement, since delays at borders and inconsistencies in procedures can significantly reduce the benefits of infrastructure investments.

The Eurasian Development Bank (2024) considers Eurasian transport corridors as a strategic direction for the development of regional connectivity. In its analytical materials, Kazakhstan is identified as one of the key transit countries connecting China with Europe, Russia, the Caucasus and Central Asia. This confirms the growing role of the China–Kazakhstan corridor not only as a bilateral route, but also as a segment of a broader Eurasian logistics system.

A significant part of the literature focuses on infrastructure constraints and their impact on transport system efficiency. Sheffi (1985), within the framework of transport network analysis, shows that when the load on a transport system approaches its maximum capacity, waiting time and operational costs increase disproportionately. This principle is important for understanding the functioning of border crossings, where even moderate growth in freight flows can lead to substantial delays if capacity is limited.

Woxenius (2010) draws attention to the problem of interoperability in intermodal transport systems. Differences in technical standards, railway gauge, documentation procedures and operational rules increase the complexity of international transportation. In the case of the China–Kazakhstan corridor, the difference in railway gauge creates the need for additional operations at border crossings, including transshipment or bogie exchange, which increases processing time and affects the overall efficiency of the route.

The theory of constraints proposed by Goldratt (1990) is also applicable to the analysis of transport corridors. According to this approach, the performance of the entire system is determined by its weakest element. In the context of the China–Kazakhstan corridor, such bottlenecks may include border crossings, customs procedures, terminal capacity and limited coordination between logistics

participants. Therefore, increasing total infrastructure length does not automatically improve corridor efficiency unless the most critical constraints are addressed.

Another important research direction concerns the relationship between transport costs and international trade. Hummels (2007) shows that transportation costs and delivery time remain significant factors influencing global trade patterns. Limao and Venables (2001) demonstrate that poor infrastructure and geographical disadvantage increase trade costs and reduce competitiveness. For Kazakhstan, these findings are particularly relevant, since the country's ability to use its geographical location depends on the quality of transport connectivity and logistics services.

Korinek and Sourdin (2011) also emphasize that high-quality logistics services facilitate trade by reducing uncertainty, delays and transaction costs. This argument supports the idea that the efficiency of the China–Kazakhstan corridor should be assessed not only through physical infrastructure indicators, but also through the quality of logistics management, documentation procedures and digital integration.

In recent years, digitalization has become one of the most important areas of transport research. OECD (2022) notes that digital transformation of transport systems can significantly improve efficiency by reducing administrative costs, increasing transparency and enabling real-time data exchange. Digital tools help synchronize the actions of customs authorities, railway operators, logistics companies and border services, which is especially important for international corridors involving several jurisdictions.

The International Transport Forum (2021) emphasizes that transport innovation contributes to sustainable development by improving the use of existing infrastructure and reducing inefficiencies in logistics operations. This is important because digital solutions may increase system capacity without immediate large-scale capital investment in new infrastructure. In this sense, digitalization can act as a mechanism for increasing the effective capacity of transport corridors.

UNECE (2023) highlights the role of digital transport documents, including electronic railway consignment notes, as a key element of international transport digitalization. The transition from paper-based procedures to electronic documentation reduces processing time, lowers the risk of errors and increases the transparency of cargo movement. UNESCAP (2019) also notes that digitalization of transport documents in Asia and the Pacific is essential for simplifying cross-border transport operations and improving regional connectivity.

At the same time, the literature indicates that digitalization produces the greatest effect only when it is implemented systematically. Fragmented digital solutions may improve individual procedures, but they do not necessarily change the overall efficiency of the transport corridor. Therefore, the integration of digital platforms, harmonization of data exchange and institutional coordination are necessary conditions for achieving a sustainable effect (OECD, 2022; ITF, 2021).

The review of the literature shows that existing studies provide a strong theoretical and empirical basis for analyzing transport corridors, but several gaps remain. First, many studies examine infrastructure, logistics hubs or digital

technologies separately, while the functioning of a specific corridor depends on the interaction of these factors. Second, the China–Kazakhstan transport corridor is often considered within the broader framework of Eurasian connectivity, but its internal structure, border node concentration and digital transformation are not always analyzed in an integrated way. Third, the role of digitalization as a factor that can partially compensate for infrastructure constraints remains insufficiently developed in the academic literature.

Thus, the present study seeks to fill this gap by examining the China–Kazakhstan railway transport corridor as an integrated system. In this study, digitalization is considered not as an auxiliary element of logistics modernization, but as a systemic factor that affects capacity, processing time, transparency and the resilience of freight flows under conditions of increasing transportation volumes.

Materials and Methods. The empirical basis of the study consists of statistical and analytical materials reflecting the development of railway freight transportation between China and Kazakhstan in 2023–2025. The research uses aggregated data on freight volumes, transit flows, border crossing capacity, cargo processing time and the implementation of digital solutions in railway logistics. In addition, the study relies on analytical reports of international organizations and development institutions, including the World Bank, Asian Development Bank, OECD, International Transport Forum, UNECE, UNESCAP and the Eurasian Development Bank, as well as academic studies on transport corridors, logistics hubs, infrastructure constraints and digital transformation of transport systems (World Bank, 2023; Asian Development Bank, 2023; OECD, 2022; ITF, 2021; UNECE, 2023; Eurasian Development Bank, 2024).

The methodological basis of the study is a systems approach, according to which the China–Kazakhstan transport corridor is considered not as a single railway route, but as an integrated logistics system consisting of several interrelated components. These include physical infrastructure, border crossings, logistics hubs, customs procedures, operational coordination mechanisms and digital platforms. This approach makes it possible to assess the corridor as a complex system in which efficiency depends on the interaction between infrastructure capacity, institutional regulation and technological modernization (Rodrigue, 2020; Sheffi, 1985).

The study applies several complementary methods. First, statistical analysis was used to examine the dynamics of railway freight flows between China and Kazakhstan. This method allowed identifying the scale and direction of changes in transportation volumes, including total freight flows, export-import asymmetry and projected growth for 2025. Second, comparative analysis was applied to compare the functional role of key border crossings, including Dostyk–Alashankou and Altynkol–Khorgos. Third, system analysis was used to identify bottlenecks and to assess how local constraints at border nodes can influence the performance of the entire corridor (Goldratt, 1990; Woxenius, 2010).

Particular attention was paid to the assessment of digitalization as a factor influencing transport corridor efficiency. Digitalization was analyzed through its

impact on cargo processing time, transparency of procedures, automation of transit declarations and coordination between participants in the logistics chain. This corresponds to the approach of OECD and UNECE, according to which digital transport documents, automation and real-time data exchange reduce transaction costs and improve the operational performance of international transport systems (OECD, 2022; UNECE, 2023).

Within the framework of the study, an analytical model was developed to assess the efficiency of the China–Kazakhstan transport corridor. The model includes four groups of factors: transport-operational, infrastructural, institutional and digital. Such a classification makes it possible to identify not only the sources of efficiency, but also the factors that limit the development of the corridor under conditions of growing freight flows.

Table 1 – Analytical framework for assessing the efficiency of the China–Kazakhstan transport corridor

Factor group	Indicators	Substantive interpretation
Transport and operational	freight volume, transit speed, delivery reliability	reflect the actual performance of the corridor
Infrastructural	capacity, border crossings, logistics hubs, network development	determine the physical constraints of the system
Institutional	customs procedures, regulation, coordination between participants	characterize administrative barriers and governance quality
Digital	automation, electronic documents, digital platforms, system integration	reflect the level of digital maturity and transparency
Note: Compiled by the authors based on relevant sources (Rodrigue, 2020; OECD, 2022; UNECE, 2023).		

The presented framework performs a methodological function and establishes the logic of the subsequent analysis. It demonstrates that the efficiency of the China–Kazakhstan transport corridor cannot be explained by one indicator alone. Freight volume growth may indicate demand for the route, but it does not automatically mean that the corridor operates efficiently. If infrastructure capacity, customs procedures and information exchange mechanisms do not develop at the same pace, increasing freight flows may lead to congestion, longer processing times and declining system stability (Sheffi, 1985; Goldratt, 1990).

To assess the relationship between freight flow growth and operational load, the study uses a comparative analytical approach. It compares the dynamics of transportation volumes with changes in processing time, node load and system stability. This approach is important because transport systems often demonstrate nonlinear behavior: when utilization approaches maximum capacity, even a relatively small increase in freight volume can lead to a disproportionate increase in delays and costs (Sheffi, 1985).

The study also uses elements of the theory of constraints. According to this approach, the overall efficiency of a system is determined by its weakest element.

In the case of the China–Kazakhstan corridor, the most important constraints are concentrated at border crossings, where differences in railway gauge, customs procedures, transshipment operations and document processing are combined within one limited operational space (Goldratt, 1990; Woxenius, 2010).

The limitations of the methodology should also be noted. The available data are aggregated and do not allow conducting a full econometric analysis at the level of individual trains, stations or logistics operators. Therefore, the study does not claim to provide a micro-level operational simulation of the corridor. Instead, it focuses on identifying systemic patterns and developing an integrated analytical interpretation of the relationship between freight flow growth, infrastructure constraints and digitalization.

Thus, the chosen methodology makes it possible to combine quantitative indicators of freight flow dynamics with qualitative and system-based analysis of infrastructural, institutional and digital factors. This provides a basis for assessing the China–Kazakhstan transport corridor as an integrated transport and logistics system.

Results. The results of the conducted analysis show that the China–Kazakhstan railway transport corridor has entered a stage of stable growth and has become one of the key overland routes in the Eurasian logistics system. Previously, this route was mainly considered as an element of bilateral trade between two neighboring countries. At the present stage, however, it performs a broader function by ensuring transit connectivity between China, Central Asia, the Eurasian Economic Union, Russia, the Caucasus, Turkey and Europe. This confirms the transformation of Kazakhstan from a transit territory into a logistics hub that redistributes and organizes freight flows within the Eurasian transport system (Eurasian Development Bank, 2024; World Bank, 2023).

The first important result is the sustained increase in railway freight transportation between China and Kazakhstan. According to available analytical data, in 2024 the total volume of railway freight transportation reached approximately 32 million tons, which is about 13% higher than in 2023. In 2025, further growth is expected, with projected volumes reaching 33–35 million tons. This indicates that the China–Kazakhstan route is developing not as a temporary alternative, but as a stable and systemically significant corridor in Eurasian logistics (Asian Development Bank, 2023; Eurasian Development Bank, 2024).

Table 2 – Dynamics of railway freight transportation between China and Kazakhstan

Indicator	2023	2024	2025 forecast
Total freight volume, million tons	~28	32	33–35
Growth rate compared to previous period, %	–	+13	+10
Freight volume from Kazakhstan to China, million tons	~20	21–22	~22
Freight volume from China to Kazakhstan, million tons	~8–10	12–13	>13
Note: Compiled by the authors based on analytical materials on railway transportation between Kazakhstan and China (Eurasian Development Bank, 2024; Asian Development Bank, 2023).			

The data presented in Table 2 show that freight flow growth is stable and

sustained. This growth can be explained by several factors. First, demand for the delivery of Chinese goods to Central Asia, the Eurasian Economic Union and Europe remains high. Second, Kazakhstan continues to act as the most important overland channel for westbound transportation. Third, in conditions of global uncertainty and disruption risks in maritime logistics, railway transport is becoming a competitive alternative due to shorter delivery times and greater predictability (Christopher, 2016; Hummels, 2007).

However, the increase in total freight volume does not fully reflect the internal structure of transportation. A more detailed analysis shows that freight flows between China and Kazakhstan are asymmetrical. Freight flows from Kazakhstan to China are larger in tonnage terms, but they are mainly represented by raw materials and semi-processed goods, including coal, iron ore, metals and grain. In contrast, flows from China to Kazakhstan and further westward mainly consist of manufactured goods, machinery, equipment, electronics and consumer products. This means that the corridor serves cargo flows with different economic characteristics and different logistics requirements (World Bank, 2023; Korinek and Sourdin, 2011).

The asymmetry of freight flows has important implications for corridor efficiency. Uneven cargo distribution complicates the planning of rolling stock, increases the risk of empty or partially loaded return movements and creates additional pressure on logistics coordination. Therefore, the same increase in total freight volume may be associated with different levels of operational efficiency depending on the structure of cargo flows and the balance between directions.

The second important result concerns the spatial concentration of freight flows. The main load is concentrated at two key border crossings: Dostyk–Alashankou and Altynkol–Khorgos. These nodes form the backbone of railway interaction between China and Kazakhstan and determine the overall performance of the corridor. From the perspective of transport network theory, such concentration increases system vulnerability because congestion or delays at one node can quickly affect the functioning of the entire route (Sheffi, 1985; Rodrigue, 2020).

Table 3 – Distribution of freight flows across key railway border crossings between China and Kazakhstan

Border crossing	Estimated volume in 2024, million tons	Functional characteristics	Analytical significance
Dostyk–Alashankou	≈18	the oldest and most heavily loaded crossing	the main backbone channel for bulk freight flows
Altynkol–Khorgos	≈14	a newer node associated with container operations and dry ports	a growing center of containerization and cargo redistribution
Bakhty–Chuguchak / Tacheng	under development	prospective additional crossing	potential instrument for relieving congestion at existing nodes
Note: Compiled by the authors based on materials on the structure of cross-border railway transportation (Eurasian Development Bank, 2024; World Bank, 2023).			

The data in Table 3 demonstrate that the two existing crossings perform complementary but different functions. Dostyk–Alashankou remains the historically established and most heavily loaded channel, especially for bulk freight. Altynkol–Khorgos is more closely connected with container transportation, dry port infrastructure and modern logistics services. Together, these crossings form a dual-node framework of the corridor, but their high load also creates a bottleneck effect. This confirms the theoretical assumption that the efficiency of the entire system is determined by the capacity of its most constrained elements (Goldratt, 1990).

The third result is related to the geographical scope of the corridor. Kazakhstan acts not only as a bilateral partner of China, but also as a transit gateway for a broad group of countries. Cargo flows from China to Uzbekistan, Kyrgyzstan, Tajikistan, Turkmenistan and other Central Asian destinations are largely routed through Kazakhstan. In addition, the corridor is integrated with routes leading to Russia, Europe, the Caucasus, Turkey and Iran. This means that the China–Kazakhstan railway corridor functions as the initial overland segment of a broader Eurasian logistics system (Eurasian Development Bank, 2024; World Bank, 2023).

Table 4 – Geographical coverage of the China–Kazakhstan transport corridor

Level of coverage	Directions	Logistical significance
Direct service	Kazakhstan	domestic distribution, consolidation, warehousing and processing of flows
Regional service	Uzbekistan, Kyrgyzstan, Tajikistan, Turkmenistan	Kazakhstan as a transit gateway for Central Asia
Extended Eurasian service	Russia, Europe, Caucasus, Turkey, Iran	integration of the corridor into international overland supply chains
Integration with TITR / Middle Corridor	Caspian direction	diversification of access to Europe and increased multimodality
Note: Compiled by the authors based on materials on route geography and the development of the Trans-Caspian International Transport Route (Eurasian Development Bank, 2024; Asian Development Bank, 2023).		

Table 4 shows that the corridor cannot be analyzed only as a bilateral China–Kazakhstan route. Its function is multi-level. At the first level, it supports domestic distribution in Kazakhstan. At the second level, it provides access to Chinese cargo flows for Central Asian countries. At the third level, it becomes part of broader Eurasian routes connecting China with Europe and the Middle East. This strengthens Kazakhstan's geo-economic role, but at the same time increases the requirements for infrastructure resilience, operational coordination and digital integration.

The fourth result concerns the relationship between transit growth and operational load. The increase in freight flows has a dual effect. On the one hand, it confirms the competitiveness of the route and the growing demand for railway logistics. On the other hand, it increases pressure on border crossings, customs procedures, transshipment operations and information exchange systems. This means that the corridor is moving from a stage of quantitative growth to a stage of operational strain.

Table 5 – Comparative analysis of transit growth and operational load

Indicator	2024	2025	Change	Interpretation
Transit volume, million tons	9.93	11.04	+11%	growth in demand for the route
Average load on nodes	baseline	high	↑	increase in congestion and queues
Processing time	stable	increasing	↑	overload effect
System stability	medium	decreasing	↓	risk of disruptions
Note: Compiled by the authors based on analytical data on transit transportation dynamics and system load indicators for the China–Kazakhstan transport corridor (Eurasian Development Bank, 2024; Sheffi, 1985).				

The results presented in Table 5 demonstrate that freight growth is not a purely positive factor. As transportation volumes increase, the system begins to operate closer to its capacity limits. Under such conditions, processing time and the risk of delays may increase disproportionately. This finding is consistent with transport system theory, according to which congestion effects intensify as system utilization approaches maximum capacity (Sheffi, 1985).

The fifth result concerns the multilevel nature of infrastructural and institutional constraints. These constraints do not arise at one level only. They are formed simultaneously in physical infrastructure, technological procedures, customs processes and the spatial organization of freight flows.

Table 6 – Multilevel model of infrastructural and institutional constraints

System level	Type of constraint	Mechanism of occurrence	System effect
Physical	capacity limitations	constraints of tracks, terminals and stations	accumulation of trains
Technological	railway gauge difference	transshipment and bogie exchange operations	increase in processing time
Process-related	customs clearance	manual or weakly integrated procedures	delays and uncertainty
Systemic	concentration of flows	limited number of border nodes	bottleneck effect
Note: Compiled by the authors based on the analysis of infrastructural and institutional constraints within the China–Kazakhstan transport corridor (Woxenius, 2010; Goldratt, 1990; UNECE, 2023).			

The key conclusion from Table 6 is that the constraints generate not isolated problems, but an interconnected system of delays. A cascading effect emerges: freight growth increases pressure on infrastructure; infrastructure pressure leads to congestion; congestion overloads customs and logistics procedures; and procedural delays reduce the overall capacity of the corridor. As a result, even localized constraints at border nodes can become systemic constraints affecting the entire route.

The sixth result relates to the role of digitalization. The analysis shows that digital solutions can significantly reduce cargo processing time and increase the effective capacity of the corridor. In particular, automation of transit procedures and electronic documentation can reduce processing time per train from approximately 180 minutes to 30 minutes. This creates a substantial increase in potential throughput

without immediate physical expansion of infrastructure (OECD, 2022; UNECE, 2023; UNESCAP, 2019).

Table 7 – Estimation of the impact of digitalization on system capacity

Indicator	Before digitalization	After digitalization	Change
Processing time per train	180 min	30 min	–83%
Trains per day, estimated	8	48	+6 times
System capacity	baseline	significantly higher	↑↑
Time losses	high	minimal	↓
Note: Compiled by the authors based on analytical assessment of the effect of digitalization on cargo processing time (OECD, 2022; UNECE, 2023).			

The data in Table 7 show that the reduction of processing time has a nonlinear effect on system capacity. If the time required to process one train is reduced from three hours to 30 minutes, the number of trains that can be processed within the same time frame increases significantly. Therefore, digitalization can be interpreted as a form of "virtual infrastructure expansion," since it increases the effective capacity of the corridor without constructing new tracks or terminals.

The seventh result is based on the comparison of two models of corridor development: the traditional infrastructure-based model and the digital model. Infrastructure expansion remains necessary in the long term, but it requires large investments and long implementation periods. Digitalization, by contrast, can provide a faster and more scalable effect, especially in the reduction of administrative and operational delays (ITF, 2021; OECD, 2022).

Table 8 – Comparison of transport corridor development models

Criterion	Infrastructure-based approach	Digital approach
Implementation time	long-term	short-term
Investment requirements	high	moderate
Effect	gradual	rapid
Scalability	limited	high
Impact on efficiency	partial	systemic
Note: Compiled by the authors based on a comparative analysis of transport corridor development models (OECD, 2022; ITF, 2021).		

The comparison shows that the traditional infrastructure-based approach cannot fully respond to the rapid growth of freight flows in the short term. New railway lines, terminals and border crossings are necessary, but their construction takes time. Digitalization provides a faster mechanism for increasing efficiency by reducing processing time, improving transparency and synchronizing the actions of logistics participants.

Thus, the results of the study demonstrate that the China–Kazakhstan transport corridor has reached a stage at which its efficiency is determined not only by the availability of physical infrastructure, but also by the quality of flow management. Freight flow growth increases pressure on the system and reveals infrastructure

constraints, while digitalization acts as a mechanism for compensating these constraints and improving the resilience of the corridor. This supports the conclusion that the future development of the China–Kazakhstan route should be based on the formation of an intelligent logistics system integrating infrastructure, institutions and digital technologies.

Discussion. The results obtained in the course of the study make it possible to move beyond a descriptive analysis of freight flow dynamics and to identify the mechanisms that determine the efficiency of the China–Kazakhstan railway transport corridor. In contrast to approaches in which transport corridors are interpreted mainly as physical infrastructure, the present study shows that their performance depends on the interaction of infrastructure, institutional procedures, operational coordination and digital technologies. This corresponds to the modern understanding of transport corridors as integrated logistics systems rather than simple linear routes (Rodrigue, 2020; Notteboom and Rodrigue, 2009).

The first important discussion point concerns the nonlinear relationship between freight flow growth and corridor efficiency. The results show that an increase in transportation volumes strengthens Kazakhstan's role in Eurasian logistics, but at the same time creates additional pressure on border crossings, terminals, customs procedures and rolling stock management. This means that growth itself cannot be considered an unconditional indicator of efficiency. If infrastructure capacity and operational coordination do not expand at the same pace as freight flows, the system begins to experience congestion and delays. This conclusion is consistent with transport network theory, according to which the closer a system comes to its capacity limit, the faster waiting time and operational costs increase (Sheffi, 1985).

The China–Kazakhstan corridor demonstrates this effect quite clearly. The increase in total railway freight volume to approximately 32 million tons in 2024 and the forecasted growth to 33–35 million tons in 2025 indicate the high demand for this route. However, the concentration of flows at the Dostyk–Alashankou and Altynkol–Khorgos crossings shows that the system's efficiency depends not on the total length of the railway network, but on the performance of its most loaded nodes. This confirms the relevance of the theory of constraints, according to which the total performance of a system is determined by its weakest or most overloaded element (Goldratt, 1990).

The second discussion point is related to the structural asymmetry of freight flows. The analysis demonstrates that transportation from Kazakhstan to China is dominated by raw materials and semi-processed goods, whereas freight flows from China toward Kazakhstan and further westward consist mainly of manufactured goods, machinery, equipment and consumer products. This asymmetry affects the organization of logistics processes because different types of cargo require different handling, storage, documentation and delivery conditions. As a result, the efficiency of the corridor depends not only on tonnage indicators, but also on the structure and balance of freight flows (Christopher, 2016; Korinek and Sourdin, 2011).

This finding is significant because many assessments of transport corridors focus

primarily on total volumes. However, the case of the China–Kazakhstan corridor shows that two corridors with similar freight volumes may differ substantially in operational efficiency if their cargo structures are different. The imbalance between directions increases the probability of empty or partially loaded return movements, complicates rolling stock planning and reduces the predictability of logistics cycles. Therefore, transport policy should consider not only the expansion of freight volumes, but also the qualitative structure of transportation.

The third discussion point concerns the role of Kazakhstan as a logistics hub. The results show that the China–Kazakhstan corridor cannot be analyzed only within the framework of bilateral trade. In practice, Kazakhstan acts as a gateway for Chinese cargo flows directed to Central Asia, Russia, the Caucasus, Turkey, Iran and Europe. This confirms the concept of logistics regionalization, according to which transport nodes gradually transform from simple transit points into centers of cargo redistribution and value creation (Notteboom and Rodrigue, 2009). In this context, Kazakhstan's strategic task is not only to ensure transit passage, but also to develop logistics services, warehousing, consolidation, multimodal operations and digital flow management.

The development of dry ports and logistics hubs is especially important in this regard. The Altynkol–Khorgos node demonstrates the potential of a new logistics model based on containerization, terminal operations and integration with international supply chains. This corresponds to the concept of dry ports, which are considered inland logistics centers capable of performing part of the functions of maritime ports and strengthening the position of landlocked countries in international trade (Roso, 2009). For Kazakhstan, this approach creates an opportunity to transform geographical location into an economic advantage.

The fourth discussion point concerns infrastructure constraints. The results indicate that the most significant limitations are concentrated at border crossings and in procedures associated with gauge change, transshipment, customs clearance and document processing. These constraints are not isolated. They interact with each other and create a cumulative effect. For example, limited terminal capacity increases waiting time; longer waiting time creates additional pressure on customs and logistics services; procedural delays reduce system stability; and instability affects delivery reliability. This mechanism corresponds to the logic of bottlenecks in complex systems (Goldratt, 1990; Woxenius, 2010).

Therefore, solving infrastructure problems requires not only the construction of new railway lines or terminals, but also the synchronization of all operational processes. If new physical infrastructure is created without improving customs procedures, digital documentation and data exchange, the effect of investment may be limited. This is why the development of the China–Kazakhstan corridor should be based on a combined model that integrates infrastructure expansion with institutional and digital modernization.

The fifth and most important discussion point concerns the role of digitalization. The results of the study show that digital technologies can significantly reduce cargo

processing time and increase effective system capacity. The reduction of processing time from 180 minutes to 30 minutes demonstrates that digitalization affects not only individual procedures, but also the overall performance of the corridor. In this sense, digitalization performs the function of "virtual infrastructure expansion," since it allows the system to process more trains and cargo flows without immediate large-scale capital construction (OECD, 2022; UNECE, 2023).

This result expands the traditional interpretation of digitalization in transport logistics. In many studies, digital technologies are considered mainly as instruments for improving transparency, simplifying documentation or reducing administrative costs. The present study shows that under conditions of infrastructure overload, digitalization becomes a systemic factor of capacity management. It reduces the negative effect of bottlenecks, increases the speed of cargo clearance, improves coordination between participants and strengthens the resilience of the transport corridor (ITF, 2021; UNESCAP, 2019).

Based on the results obtained, the efficiency of the China–Kazakhstan transport corridor can be represented through a conceptual model in which freight flow growth acts as an external driver, while infrastructural capacity, institutional environment, operational logistics and digital ecosystem form the internal structure of the system. The interaction of these elements determines cargo processing time, delivery reliability and overall corridor performance.

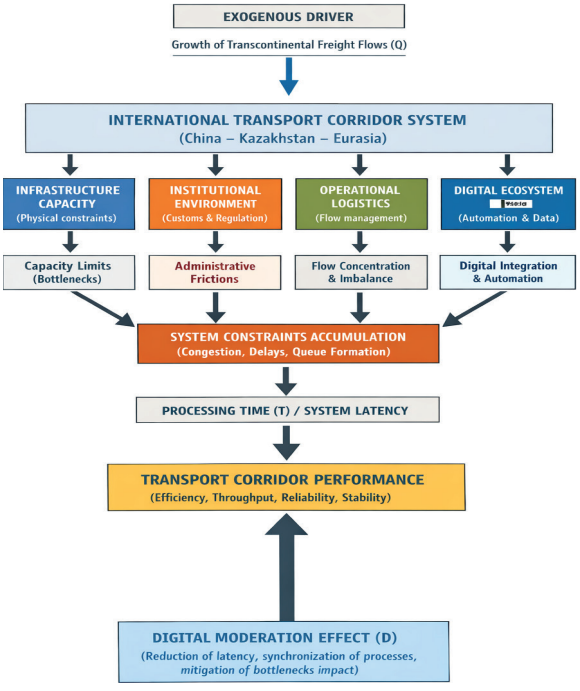

Figure 1 – Conceptual model of the efficiency of the China–Kazakhstan international transport corridor considering the moderating effect of digitalization

Note: Compiled by the authors.

The proposed conceptual model includes several analytical levels. At the first level, the growth of transnational freight flows increases pressure on the transport corridor. At the second level, this pressure is absorbed or intensified by four internal components: infrastructure, institutions, logistics operations and digital systems. At the third level, the interaction of these components produces specific outcomes, including processing time, congestion, reliability and system capacity. Digitalization performs a moderating function because it reduces the negative impact of infrastructure and institutional constraints on overall efficiency.

This interpretation contributes to the development of transport corridor theory. In the works of Rodrigue (2020), corridors are primarily analyzed as spatial and infrastructural systems. In this study, the approach is expanded by including institutional and digital dimensions. In OECD and ITF studies, digitalization is often considered as a separate area of transport modernization (OECD, 2022; ITF, 2021). In the present study, digitalization is integrated into the overall model of corridor efficiency and is interpreted as a mechanism for compensating infrastructure constraints.

The practical implications of the study are also significant. First, the results show that Kazakhstan's transport policy should not rely only on the physical expansion of infrastructure. Although new railway lines, border crossings and terminals remain necessary, they cannot fully solve the problem of efficiency without digital integration. Second, the implementation of electronic documents, automated transit declarations and integrated data exchange platforms can provide a faster effect than large-scale construction projects. Third, digitalization creates the conditions for Kazakhstan to move from the role of a transit country to the role of an active logistics operator capable of managing freight flows and generating added value.

From a policy perspective, the development of the China–Kazakhstan corridor requires the simultaneous implementation of three groups of measures. The first group includes infrastructure measures aimed at increasing the capacity of border crossings, terminals and connecting railway lines. The second group includes institutional measures related to simplifying customs procedures, harmonizing documentation and strengthening coordination between railway, customs and logistics operators. The third group includes digital measures aimed at creating integrated platforms for cargo tracking, electronic documentation, data exchange and operational decision-making (UNECE, 2023; UNESCAP, 2019).

The scientific novelty of the study lies in the fact that it interprets digitalization not as an auxiliary element of transport modernization, but as a central factor in improving corridor efficiency under conditions of increasing freight flows. The study also identifies the nonlinear effect of freight growth on system stability and demonstrates that the concentration of cargo at a limited number of border nodes creates systemic vulnerability. These findings make it possible to develop a more comprehensive approach to the assessment of international transport corridors.

At the same time, the discussion should acknowledge several limitations. The study is based on aggregated statistical and analytical data, which limits the

possibility of conducting detailed econometric modeling. The available data do not allow assessing the exact processing time at each station, the behavior of individual logistics operators or the micro-level structure of delays. Therefore, future research should focus on building quantitative models based on operational data, including train-level information, terminal processing time, customs clearance duration and digital platform usage indicators.

Thus, the discussion confirms that the China–Kazakhstan transport corridor has reached a stage where its development cannot be assessed only through freight volume indicators. The decisive factor is the system's ability to process increasing flows quickly, transparently and reliably. Under these conditions, digitalization becomes a key mechanism for increasing effective capacity, reducing bottlenecks and strengthening Kazakhstan's position in the Eurasian logistics system.

Conclusion. The conducted study was aimed at analyzing the functioning of the China–Kazakhstan railway transport corridor and determining the role of digitalization in improving its efficiency under conditions of increasing freight flows. The results made it possible to identify the key patterns of corridor development and to reveal the mechanisms that shape its operational performance within the broader Eurasian logistics system.

First, the study established that the China–Kazakhstan transport corridor has entered a stage of stable and sustained growth. The increase in freight volumes in 2023–2025 confirms the growing importance of this route for overland transportation between China, Central Asia and Europe. Kazakhstan performs not only a transit function, but also increasingly acts as a logistics hub where cargo flows are consolidated, redistributed and integrated into international supply chains (Eurasian Development Bank, 2024; World Bank, 2023).

Second, the study showed that the growth of freight flows is accompanied by increasing pressure on infrastructure and logistics procedures. The main load is concentrated at the Dostyk–Alashankou and Altynkol–Khorgos border crossings, which form the dual-node framework of the corridor. This concentration strengthens the strategic role of these nodes, but also creates a bottleneck effect, where the performance of the entire system depends on the capacity and stability of a limited number of border points (Sheffi, 1985; Goldratt, 1990).

Third, the analysis revealed the asymmetrical nature of freight flows. Cargo moving from Kazakhstan to China is dominated by raw materials and semi-processed goods, while flows from China to Kazakhstan and further westward consist mainly of manufactured goods, machinery, equipment and consumer products. This asymmetry complicates the planning of rolling stock, increases the risk of empty or partially loaded return movements and affects the overall efficiency of the corridor (Christopher, 2016; Korinek and Sourdin, 2011).

Fourth, the study demonstrated that infrastructural and institutional constraints are interconnected and form a system of cumulative delays. Capacity limitations, differences in railway gauge, transshipment operations, customs procedures and insufficient digital integration create a cascading effect in which local delays

can influence the entire transport corridor. This confirms that the efficiency of the corridor is determined not by one factor, but by the interaction of physical, institutional, operational and digital components (Woxenius, 2010; UNECE, 2023).

Fifth, particular importance was given to digitalization. The results show that digital solutions, including automated transit procedures, electronic documentation and integrated information platforms, can significantly reduce cargo processing time and increase the effective capacity of the system. The reduction of processing time from 180 minutes to 30 minutes demonstrates that digitalization can function as a mechanism of "virtual infrastructure expansion," allowing the corridor to process greater freight volumes without immediate large-scale capital investment (OECD, 2022; ITF, 2021).

The scientific contribution of the study lies in the development of an integrated approach to assessing transport corridor efficiency. In contrast to studies that examine infrastructure, logistics or digitalization separately, this research considers the China–Kazakhstan corridor as a complex system in which efficiency is determined by the interaction of freight flows, infrastructure capacity, institutional procedures and digital technologies. The proposed conceptual interpretation shows that digitalization acts as a moderating factor that reduces the negative impact of infrastructure constraints and improves system resilience.

The practical significance of the study lies in the possibility of using its results in transport policy and logistics planning. The findings confirm that Kazakhstan's transport strategy should combine long-term infrastructure expansion with short- and medium-term digital modernization. Priority should be given to the development of electronic documentation, automated customs and transit procedures, real-time cargo tracking, integrated data exchange platforms and coordinated management of border crossing operations.

At the same time, the study has several limitations. The analysis is based on aggregated data and does not include detailed operational information at the level of individual trains, stations, terminals or logistics operators. This limits the possibility of conducting econometric modeling or simulation of specific bottlenecks. Future research should therefore focus on micro-level operational data, quantitative assessment of the effect of digital tools, modeling of border crossing capacity and analysis of multimodal integration with the Trans-Caspian International Transport Route.

In conclusion, the China–Kazakhstan transport corridor should be viewed as a strategic element of Eurasian logistics whose future development depends not only on the expansion of physical infrastructure, but also on the quality of digital and institutional coordination. Under contemporary conditions, digitalization becomes one of the key factors ensuring the competitiveness, resilience and sustainable development of the corridor. The transition from a transit model to an intelligent logistics management model can strengthen Kazakhstan's role in global supply chains and increase the long-term efficiency of its transport system.

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ISSN 2518–1467 (Online),
ISSN 1991–3494 (Print)
http://www.bulletin–science.kz/index.php/en

Managing Editor: A.Shormakova
Editors: D.S. Alenov, M.Konyrbekov
Computer layout: G.D. Zhadyranova

Signed for print: June 30, 2026
Format: 70×90 1/16. 48.0 printed sheets. Order No. 3

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