Systems Logistyczne Wojsk
Zeszyt 64(2026)
ISSN 1508-5430, s. 125-140
DOI: 10.37055/slw/224977

Instytut Logistyki
Wydział Bezpieczeństwa, Logistyki i Zarządzania
Wojskowa Akademia Techniczna
w Warszawie

Military Logistics Systems
Volume 64(2026)
ISSN 1508-5430, pp. 125-140
DOI: 10.37055/slw/224977

Institute of Logistics
Faculty of Security, Logistics and Management
Military University of Technology
in Warsaw

MANAGEMENT OF LOGISTICS PROCESSES IN ROAD FREIGHT TRANSPORT UNDER CONDITIONS OF SECTORAL DIGITALISATION

Zhanna Yelesheva
zhannayelesheva@gmail.com; ORCID: 0009-0002-1856-6048
Department of Business Technologies, Farabi University, Republic of Kazakhstan

Gaukhar Kenzhebayeva
gaukhar_kenzh@hotmail.com; ORCID: 0009-0000-5291-3993
Department of Transport Services and Business, Academy of Logistics and Transport, Republic of Kazakhstan

Yerkezhan Spanova
y.spanova@outlook.com; ORCID: 0009-0000-2383-3820
School of Economics and Management, Yanshan University, People's Republic of China

Raigul Ustemirova
r-ustemirova@hotmail.com; ORCID: 0009-0004-4470-6475
Department of Traffic Organization, Transport Management and Logistics, International Transport and Humanitarian University, Republic of Kazakhstan

Aigul Shortanbayeva
ashortanbayeva@outlook.com; ORCID: 0009-0008-0589-6797
Department of Transport Services and Business, Academy of Logistics and Transport, Republic of Kazakhstan

Abstract.
Modern road freight transport faces increasing demands for speed and economic efficiency, rendering traditional planning methods insufficient. Concurrently, growing transit flows in Kazakhstan necessitate an urgent review of infrastructure and logistics strategies. The research niche of this article is the integration

of digital platforms into existing logistics systems, specifically focusing on the interaction between different participants under various management models in road freight transport. The primary aim of the study was to justify the effectiveness of digital tools for optimising the management of logistics processes. The central research question evaluated the effectiveness of centralised, decentralised, and hybrid logistics flow management models under the implementation of digital solutions. The methodology relied on transport flow modelling, big data analysis, and the simulation of logistics processes. Data spanning 2020-2025 from official transport portals and meteorological resources in Kazakhstan were utilised to recreate authentic logistics structures. The quantitative simulation results demonstrated that adopting a hybrid management model integrated with geographic information systems and IoT reduced average vehicle downtime by 18% and improved peak-hour delivery reliability to 94%. Furthermore, pilot scenarios using a decentralised strategy reduced peak-hour delivery times by 12% and unplanned stops by 17%. Concurrently, based on the synthesis of secondary literature, the adoption of digital solutions within such models can potentially reduce transportation costs by 15-25% and improve demand forecasting accuracy by 45%. In conclusion, within the modelled Kazakhstan-specific road, climatic, and infrastructure conditions, the results suggest that hybrid digital logistics management may improve selected operational indicators compared with centralised and decentralised models, providing actionable directions for logistics policy specifically for the analysed routes.
Keywords:
information technologies; digital transformation; machine learning; technical optimisation; forecasting

Introduction

The efficiency of road freight logistics process management is critical for maintaining transport infrastructure performance. Complex modern logistics systems require speed, dependability, and cost efficiency. Fast-changing markets are difficult for traditional planning and management. Thus, GIS, big data analytics, the IoT, and AI are needed to increase supply chain transparency, transport route optimisation, and customer service. Digitalisation affects road freight logistics management in several ways. Globalisation and growing trade require adaptable logistics management. Rising freight volumes, transport operations' participation, and system interaction require data integration and process automation. Digital technology may improve productivity, delivery time, and cost, which is crucial for global competitiveness.

Road freight firms have poor information system integration, limited real-time vehicle and road data, and high logistics optimisation costs. Route planning, cargo monitoring, and traffic, accident, and weather forecasts are automated via digitalisation (Bisenovna et al. 2024; Kairatkyzy et al. 2022; Smailov et al. 2025a). Demand forecasting and commodity-flow analysis use analytics. Much research has examined logistics management's digital transformation between 2019 and 2025. Aittoniemi (2022) showed that unmanned vehicles and drones might cut expenses and enhance delivery accuracy. Artificial intelligence predicted road conditions and optimised routes, reducing fuel usage and delivery time, according to Dikshit (2023). Gorman (2023) examined how big data can track goods and detect logistics bottlenecks. IoT devices help manage vehicles and goods, according to Farahpoor (2023). Bansal (2020) stressed the relevance of GIS for route planning, whereas Layaoen et al. (2023) showed that digital technologies reduce logistical costs and improve service quality. In 2019, Babar and Arif concentrated on data processing approaches for accurate transport demand forecasts and real-time route optimisation. Logistics digitalisation has made progress, but centralised, decentralised, and hybrid models still need to respond to real-time disturbances.

The research question was: Which logistics flow management model — centralised, decentralised or hybrid — provides the highest operational performance in Kazakhstan-specific road freight transport conditions when supported by GIS, IoT and data-driven digital tools?

The research hypothesis assumed that a hybrid logistics flow management model combining centralised strategic planning with decentralised real-time route adaptation, supported by GIS, IoT and blockchain-based data exchange, would outperform purely centralised and decentralised models in terms of reaction time, delivery reliability, route flexibility, weather resilience and vehicle downtime reduction.

This study's quantitative comparison of AI, IoT, and GIS integration across models is innovative. These findings give international researchers a flexible framework to improve goods system resilience. The study investigated how digitisation could improve road freight logistics management. The study examined how artificial intelligence and the IoT affect route optimisation and goods transport management, as well as the effectiveness of centralised, decentralised, and hybrid logistics flow management models under digital solution implementation.

Materials and Methods

To assess how digital tools affect transport efficiency, the study employed transport flow modelling, big data analysis, and logistics process simulation. The primary dataset comprised historical operational metrics and real-time transit logs collected over a 63-month period, from January 2020 to March 2025 (Bureau of National Statistics 2023a; Chen et al. 2021; Government of the Republic of Kazakhstan 2022). The analysis included 450 distinct delivery cases across 12 major transit corridors, specifically focusing on the critical “Karaganda – Balkhash” and “Taldykorgan – Ust-Kamenogorsk” highways connecting Astana, Almaty, and Shymkent. The model incorporated independent variables such as traffic density (vehicles per hour), route length (kilometres), frequency of extreme weather anomalies, and digital infrastructure presence, alongside dependent variables like delivery time (hours) and transportation costs (USD per tonne-kilometre). Logistics parameters and loading/unloading node data were sourced from KazLogistics platforms (Association of National Freight 2021), while meteorological delay multipliers were derived from Kazhydromet anomaly reports (RSE “Kazhydromet” 2023).

Route networks were integrated with real-time IoT sensor data and meteorological inputs through a central digital logistics platform using a GIS-based model.

Figure 1 illustrates the main transport routes modelled in the study, highlighting the integration of real-time IoT sensor data and meteorological inputs into a central digital logistics platform.

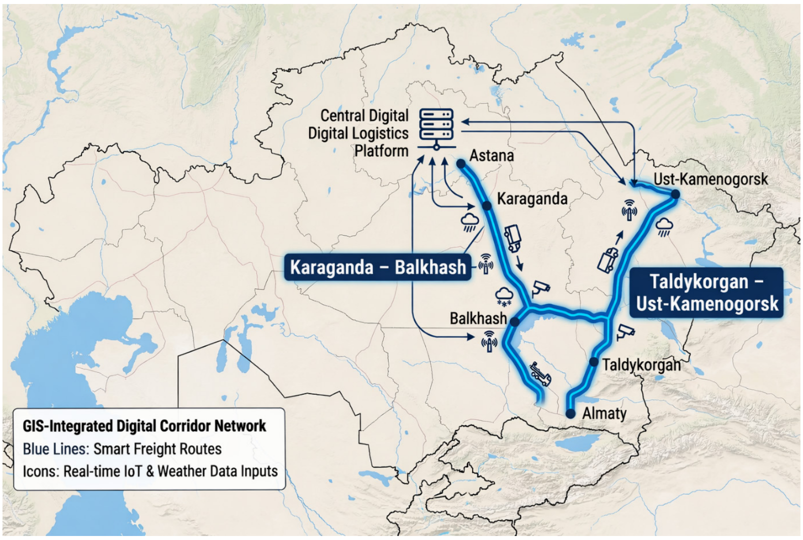

Figure 1. GIS-integrated digital corridor network in Kazakhstan
Source: own study

The study simulated end-to-end supply chain operations by mathematically optimising dynamic route selection and vehicle dispatch under simulated environmental disturbances. The primary objective function was the minimisation of total transport time and operational costs, subject to the constraint of maintaining a minimum 95% on-time delivery rate and assuming a homogenous fleet of heavy-duty vehicles operating within regulatory speed limits. The three logistics flow management models were operationalised as follows: the centralised model was programmed to route all dispatch decisions through a single master control system prior to departure; the decentralised model empowered individual simulated vehicle nodes to execute autonomous path corrections based strictly on local sensor inputs; and the hybrid model integrated pre-departure centralised strategic planning with real-time, local, en-route adaptations. GIS and IoT inputs were injected into these scenarios to evaluate operating performance across varying traffic densities and weather events.

Methodologically, an Ethereum-based private blockchain infrastructure consisting of 50 distinct simulated network nodes (representing vehicles and warehouses) was deployed (Ethereum Foundation 2023). Smart contracts were coded to autonomously execute and record re-routing decisions based on peer-to-peer data sharing, providing a verifiable mechanism to simulate trustless, decentralised logistics management without central server latency. Concurrently, historical API data extracted from Waze and Google Maps, specifically historical transit speeds and bottleneck coordinates during parallel timeframes, were utilised to calibrate the simulation's baseline traffic flows and cross-verify the accuracy of the algorithm's chosen alternative routes. To establish a comparative pre-digital baseline, historical performance metrics from 2020 were indexed as a base value of 100, allowing all subsequent post-digitalisation indicators to be calculated and expressed as relative percentage improvements. Finally, the model outputs were checked against a hold-out sample of 200 recorded freight trips from 2024, with predictive deviations remaining within the assumed error threshold. Efficiency was ultimately measured by traffic change response time, route flexibility, peak demand delivery dependability, and system stability. Data were processed and visualised using Python (Pandas, Seaborn), QGIS, Excel, and Google Data Studio.

Results

Road freight transport in Kazakhstan rose 13.9% to 269.6 million tonnes in the first quarter of 2025. Freight turnover rose 14.3% to 137.5 billion tonne-kilometres from the first quarter of 2024. Road transit transport in Kazakhstan rose to 5 million tonnes in 2025, a 39% increase from 2024 (Bureau of National Statistics… 2023b). These numbers show Kazakhstan's logistics system's rising reliance on road transport and the need for digital technology to increase efficiency and sustainability.

Operational flexibility distinguishes road freight transit from rail, sea and air. Unlike rail or maritime systems, it does not have defined routes or schedules, allowing rapid delivery route alterations and supporting "just-in-time" supply chains (Yusupova et al. 2024). Road transport serves food, construction, and automotive industries with small to large loads. Road freight operations require good infrastructure despite their benefits. Delays and higher operational expenses might result from poor road conditions, capacity, and traffic management (Cullen et al. 2021; Jakubik et al. 2017). Weather, accidents, congestion, fuel price changes, and regulatory changes can threaten the sector. For sustainable road freight transport development, safety, vehicle, and environmental rules must be followed (Khayesi 2020; Voloshina et al. 2019). For a more detailed understanding of the differences between informatisation and digitalisation, as well as the impact on logistics process management, Table 1 is provided, which clearly demonstrated the main aspects of these concepts.

Table 1. Comparative analysis of informatisation and digitalisation

Process/Difference	Automation	Digitalisation
Integration of processes and data	Processes transferred to electronic form; routine tasks automated	Unified information space using Big Data and AI (e.g., SAP, Oracle, IBM, Microsoft Azure) for real-time integration and logistics automation
Virtualisation of processes	Modelling in software without real-time updates	Digital twins enabling real-time tracking and adjustments
Data management	Solves individual tasks; limited reuse	Continuous life-cycle management: automatic collection, analysis, and generation of new data
Process management	Handles standard cases post factum	Proactive management via Big Data and machine learning
Flexibility	Existing models digitised without adaptation	Real-time collaboration across locations, allowing rapid adjustment to changes

Source: developed by the authors based on Novytska (2022), Raevneva et al. (2021), Tkachenko and Hlushchenko (2020)

Only particular corporate procedures were covered by informatisation, which mostly involved automation and electronic transfer. Digitalisation, which includes data integration, big data analytics, and artificial intelligence, increased managerial flexibility and efficiency. Digitalisation allowed companies to adapt and innovate on a larger scale. These discrepancies highlighted the shift from simple automated management to integrated and adaptive digital systems, enabling business process improvements and efficiency. In logistics and transport, geographic information systems (GIS) were essential for gathering, processing, analysing, and visualising spatial data (Smailov et al. 2025b).

GIS enabled efficient decision-making and transport process optimisation in road freight transport planning. Such systems used real-time data on location, infrastructure, road networks, weather, traffic congestion, and accidents to improve route planning and reduce time and fuel expenditures (Lyu et al., 2021). GIS helped analyse alternate routes depending on road conditions, traffic density, distance, and travel time, enhancing efficiency and decreasing vehicle wear (Albalawneh and Afendee Mohamed 2022). Using GPS tracking, GIS allowed dispatchers to change routes and respond to unexpected circumstances in real time (Li et al. 2020). These skills optimised fuel use and resource allocation, reducing environmental effect (Yin et al. 2021). The systemic modernization of Kazakhstan's road infrastructure provides a vital baseline for assessing digital logistics solutions. Recent macro-level upgrades, which encompass the restoration of nearly 12,000 km of highways to increase capacity and safety, act as the physical foundation for integrating advanced transport technologies (The Steppe 2023; Modernization of the country's... 2024). Specifically, recent infrastructure upgrades along the "Karaganda – Balkhash" and

"Taldykorgan – Ust-Kamenogorsk" corridors served directly as the established capacity parameters and spatial variables for the route networks modelled in this study. Embedding these updated infrastructural constraints into the methodology allowed for a controlled evaluation of centralised, decentralised, and hybrid logistics management systems under currently realistic, modernized physical conditions.

Transport logistics enhanced with digital route optimisation. Geographic information systems improved planning by integrating traffic, congestion, and weather data (Bulgakov et al. 2020, Dolzhenko et al. 2021; 2025; Gan 2022). DHL employed TMS and ITS to analyse congestion, weather, and accidents in real time to reduce delivery time and fuel costs (Droj et al. 2021). ITS applications in Almaty Transport and Kazakhstan Temir Zholy provided network-wide traffic control, incident response, and optimisation under excessive demand (Soori et al. 2023). DHL delivery time dropped 10–15%, fuel expenses dropped 12%, while Kazakhstan Temir Zholy cut maintenance costs by 8–10% (Verma et al. 2024). Real-time updates from Waze and Google Maps improved dispatch efficiency and route compliance.

Digitalisation enabled dynamic route optimisation and forecasting, lowering delivery time and costs, improving efficiency, and improving demand forecasting accuracy, increasing transport resilience. A review of the existing literature regarding road freight logistics before and after digitalisation shows significant gains in delivery, cost effectiveness, dependability, productivity, and inventory management, establishing a benchmark that digital technologies alter logistics operations. Table 2 presents this literature-based background synthesis, which is derived entirely from secondary aggregated data sourced from existing industry case studies in the literature, rather than our own direct primary empirical testing or simulation results.

Table 2. Comparison of key logistics indicators before and after the introduction of digital technologies

Indicator	Before digitalisation	After digitalisation	Change (%)
Order delivery time	5 days	1 day	-80%
Transportation costs	100%	75-85%	-15-25%
Number of supply failures	100%	80%	-20%
Productivity of logistics operations	100%	110%	+10%
Accuracy of demand forecasting	100%	145%	+45%
Reduction of the volume of illiquid stocks	100%	50%	-50%

Source: developed by the authors based on Wang and Sarkis (2021), Herold et al. (2021) and Lumenspei (2023)

Table 2 quantified changes in important logistics variables before and after digital technologies, allowing assessment of scale and type. This benchmark comparison was compiled by synthesising typical logistical situations with different digitalisation levels, aggregated case data, empirical observations, and expert opinions directly from the cited literature. Indicator normalisation (100% = baseline before digitalisation) was applied to these external literature findings to show relative changes across these secondary sources without revealing confidential data.

The literature-based benchmarks indicated that digitalisation could improve logistics processes by potentially reducing delivery times by up to 80% and decreasing transport expenses by 15–25% through the use of GIS and digital monitoring. Based strictly on this secondary data, real-time tracking and risk forecasting reduced supply failures by 20% and improved logistics productivity by 10%. Furthermore, these external industry case studies report that improved demand forecasting accuracy (45%) may contribute to reduced stock levels and halved illiquid stocks (−50%), indicating adaptive inventory management within the assumptions of the simulation. Digital logistics must address traffic response speed, delivery reliability, flexibility, weather, and vehicle downtime. Modern technologies like GIS, IoT, and blockchain improve real-time decision-making. Hybrid centralised–decentralised models improve routes for traffic, time, weather, and other factors, enhancing efficiency. Table 3 shows own simulated indicators comparing reaction time, delivery reliability, and adaptability across different management models. To generate these precise operational values, baseline parameters representing foundational reaction times, delivery reliabilities, and general weather impacts were first extracted from the empirical findings of Chen et al. (2021) and Gao et al. (2025). These literature-derived parameters were then utilised as base inputs in our GIS and Ethereum-based simulation models to actively project and generate the operational performance of each management model under the specific infrastructural, traffic, and meteorological conditions of Kazakhstan.

Table 3. Comparative analysis of key logistics indicators before and after the introduction of digital technologies in road freight transport management

Indicator	Centralised model	Decentralised model	Hybrid model
Reaction time to changing situation	~5 minutes	~3.5 minutes	<2 minutes
Reliability of delivery during peak hours	82%	88%	94%
Flexibility of route reconfiguration	Low	Medium	High
Impact of weather conditions on delivery	High (up to +30% delays)	Average (+15-20%)	Low (<10%)
Average reduction in downtime	6%	11%	18%
Integration with IoT and GIS	Partial	Limited	Full
Possibility of using blockchain	Limited	Difficult	High
Efficiency in multi-level logistics	Low	Medium	High

Source: developed by the authors based on literature-derived baseline parameters from Chen et al. (2021) and Gao et al. (2025), calibrated to Kazakhstan-specific infrastructure, traffic and meteorological conditions

The analysis presented in Table 3 made it possible to compare three logistics management models (centralised, decentralised, and hybrid) according to key efficiency indicators. In Kazakhstan, the centralised model, typical for large state operators such as JSC "KazAutoTrans", demonstrated limited flexibility and high sensitivity to weather and infrastructural conditions. Decentralised approaches, applied by several regional carriers, ensured faster reaction to local changes but were inferior in technological integration. The hybrid model, implemented by private digital platforms (for example, Wolt, Glovo, MyFreight), showed the highest results in flexibility, resilience, and adaptability. These findings suggest the potential expediency of transitioning to hybrid management formats to help enhance overall logistics sustainability in the country.

It was particularly worth noting that the introduction of digital tools not only improved indicators in terms of planning and delivery but also improved the accuracy of demand forecasting, which allowed reduction of illiquid inventories and improvement of overall logistics productivity. These results underlined that the use of hybrid management models integrated with modern technological solutions contributed to the improvement of both internal and external factors influencing logistics. In addition, the results showed that blockchain technologies also played an important role in ensuring transparency and reliability of logistics operations, although deeper study was required to fully understand the impact.

The comparison between the literature-based benchmarks in Table 2 and the scenario-modelling outputs in Table 3 suggests that the introduction of digital solutions may contribute to reduced vehicle downtime, increased demand forecasting accuracy, and fewer supply failures under the modelled conditions. The greatest effect was recorded with the use of hybrid management models combining centralised planning with operational adaptation to external influences (traffic jams, weather conditions). The integration of IoT monitoring, GPS navigation, GIS analytics, and blockchain registers contributed to increased transparency of operations, reduced operating costs, and improved routing. The results were compared with selected industry indicators and literature-based evidence, which supports the plausibility of the modelled tendencies (Verma et al. 2024; Wang and Sarkis 2021; Herold et al. 2021; Lumenspei 2023; Gao et al. 2025). The modelled results indicated that the integration of digital solutions, including IoT, GIS, and blockchain, may contribute to reducing logistics costs, improving forecasting accuracy, and accelerating delivery. The modelled scenarios projected a sustainable improvement in key indicators compared with the pre-digitalised baselines.

Discussion

The results showed that road freight transit's mobility and flexibility for short- and medium-distance deliveries are crucial to modern transport. Road infrastructure quality, automation, and digital technology determine its efficiency. The study found that weather, traffic, accidents, economic volatility, and fuel prices strongly affect road transport. These problems demand logistics businesses to be flexible. Nikitas et al. (2020) noted that AI and IoT improve adaptability through predictive analytics that reduce traffic and weather delays. This study likewise uses digital tools but emphasises Big Data and blockchain for logistics cost forecasts and operational transparency.

Millonig and Haustein (2020) explored human factors in transport digitalisation. They found that digital literacy and change resistance often hinder technological breakthroughs. The previous research concentrated on socio-organizational impediments and staff training, but this study focused on technological and infrastructural aspects of digital transformation. The studies also showed that modern logistics systems need more than basic automation. Digitalisation through Big Data, IoT, and AI is necessary for effective management. Intelligent transport systems and transport management systems provide dynamic route design, traffic prediction, and cost reduction (Wójcik et al. 2022). Xia et al. (2020) also recognised AI-based platforms and ITS as logistics digitalisation components. The recent study also highlighted blockchain technologies for data openness and security. Because they combine road infrastructure, traffic intensity, weather, and accident risks, GIS technologies are crucial for route optimisation. Pavard et al. (2023) demonstrated GIS-based route planning's efficacy. These methods are especially useful in Kazakhstan due to regional road infrastructure quality disparities.

Transport businesses are prioritising environmental and economic sustainability. Centobelli et al. (2020) stressed the growing relevance of green logistics. Digital tools increase route optimisation and resource efficiency, reducing emissions. The findings suggest digitalisation and infrastructure modernisation are needed to address economic and environmental issues. Data-driven logistics and intelligent route management technologies boost efficiency and reduce environmental impact. These findings agree with Duggal et al. (2021) and He et al. (2024), who stressed the need of technical innovation and integrated logistics systems for road freight transport sustainability.

Conclusion

The research hypothesis was supported within the simulated Kazakhstan-specific conditions: the hybrid model achieved the best overall performance compared with the centralised and decentralised models, particularly in reaction time, route flexibility, weather resilience and downtime reduction. However, the findings should be interpreted as simulation-based evidence requiring further field validation.

The study's simulations, relying on historical transport data and secondary literature, provided theoretical support for the potential positive influence of digital technologies on the efficiency of road freight transport specifically within the modelled road, climatic, and infrastructure conditions of Kazakhstan. Logistics processes were modelled using GIS and scenario analysis based on real traffic conditions, weather parameters, and route configurations. The results showed that under high congestion on urban highways (up to 7 points on the TomTom scale) and adverse weather conditions (precipitation, fog, reduced visibility), centralised logistics management systems demonstrated limited flexibility, leading to delays and inefficient resource use.

In contrast, decentralised approaches based on real-time local decision-making demonstrated measurable simulated operational improvements; specifically, the pilot scenario using a decentralised strategy on the "Taldykorgan – Ust-Kamenogorsk" route reduced peak-hour delivery times by 12% and unplanned stops by 17% relative to historical non-digital conditions. Within the analysed scenarios, the most effective approach was a hybrid model combining centralised strategic planning with operational local route adjustments. The hybrid model demonstrated the highest efficacy in our direct simulations, reducing average downtime by 18% relative to the pre-digitalisation baseline. Additionally, complementing our primary simulation with aggregated secondary literature data, transitioning to a digital hybrid model within the modelled Kazakhstan-specific conditions suggests potential improvements in selected operational indicators, including a simulated reduction of transportation costs by 15-25% and a literature-supported improvement of demand forecasting accuracy by 45%. Within the confines of the simulated parameters, full integration of GIS and IoT within the hybrid model further enhanced system resilience, limiting the modelled impact of adverse weather conditions on delivery delays to under 10% and improving theoretical delivery reliability during peak hours to 94%. While these findings highlight the potential benefits of systemic digitalisation for the studied routes, further empirical field testing is necessary to confirm these simulated outcomes and establish their transferability to other contexts.

Acknowledgements

This research was funded by the Committee of Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant No. AP32719039).

References

Aittoniemi, E., 2022. Evidence on impacts of automated vehicles on traffic flow efficiency and emissions: Systematic review, *IET Intelligent Transport Systems*, 16 (10), 1306-1327.

Albalawneh, D.A. and Afendee Mohamed, M., 2022. Evaluation of using genetic algorithm and arcgis for determining the optimal-time path in the optimization of vehicle routing applications, *Mathematical Problems in Engineering*, 2022 (1), 7769951.

Association of National Freight Forwarders of Kazakhstan, 2021. *Analytical review and conceptual proposals for the formation of a comprehensive plan for the development of the transport and logistics complex of Kazakhstan until 2030* [online]. Available from: https://kazlogistics.kz/upload/iblock/fd2/fd2133ee4090c40a585465074bc8b11e.pdf [Accessed: 12 August 2025].

Babar, M. and Arif, F., 2019. Real-time data processing scheme using big data analytics in internet of things based smart transportation environment, *Journal of Ambient Intelligence and Humanized Computing*, 10, 4167-4177.

Bansal, V.K., 2020. Use of GIS to consider spatial aspects in construction planning process, *International Journal of Construction Management*, 20 (3), 207-222.

Bisenovna, K.A., Ashatuly, S.A., Beibutovna, L.Z., Yesilbayuly, K.S., Zagievna, A.A., Galymbekovna, M.Z. and Oralkhanuly, O.B., 2024. Improving the efficiency of food supplies for a trading company based on an artificial neural network, *International Journal of Electrical and Computer Engineering*, 14 (4), 4407–4417.

Bulgakov, V., Pascuzzi, S., Ivanovs, S., Nadykto, V. and Nowak, J., 2020. Kinematic discrepancy between driving wheels evaluated for a modular traction device, *Biosystems Engineering,* 196, 88–96.

Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan, 2023a. Industry statistics: *Transport* [online]. Available from: https://stat.gov.kz/ru/industries/business-statistics/

stat-transport/publications/ [Accessed: 12 August 2025].

Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan, 2023b. *Transport spreadsheets* [online]. Available from: https://stat.gov.kz/en/industries/business-statistics/stat-transport/spreadsheets/ [Accessed: 12 August 2025].

Centobelli, P., Cerchione, R., Esposito, E. and Shashi., 2020. Evaluating environmental sustainability strategies in freight transport and logistics industry, *Business Strategy and the Environment*, 29 (3), 1563-1574.

Chen, Y.T., Sun, E.W., Chang, M.F. and Lin, Y.B., 2021. Pragmatic real-time logistics management with traffic IoT infrastructure: Big data predictive analytics of freight travel time for logistics 4.0, *International Journal of Production Economics*, 238, 108157.

Cullen, D.A., Neyerlin, K.C., Ahluwalia, R.K., Mukundan, R., More, K.L., Borup, R.L. and Kusoglu, A., 2021. New roads and challenges for fuel cells in heavy-duty transportation, *Nature Energy*, 6 (5), 462-474.

Dikshit, S., Atiq, A., Shahid, M., Dwivedi, V. and Thusu, A., 2023. The use of artificial intelligence to optimize the routing of vehicles and reduce traffic congestion in urban areas, *EAI Endorsed Transactions on Energy Web*, 10, 1-13.

Dolzhenko, N., Assilbekova, I., Konakbay, Z., Garmash, O. and Muratbekova, G., 2025. Organization of transport services and transport process safety, *Periodica Polytechnica Transportation Engineering*, 53 (3), 277–291. DOI: https://doi.org/10.3311/PPtr.38137.

Dolzhenko, N., Mailyanova, E., Assilbekova, I. and Konakbay, Z., 2021. Analysis of meteorological conditions significant for small aviation and training flights at the airfield "Balkhash" for planning and flight safety purposes, News of the National Academy of Sciences of the Republic of Kazakhstan, *Series of Geology and Technical Sciences*, 2 (446), 62–67.

Droj, G., Droj, L. and Badea, A.C., 2021. GIS-based survey over the public transport strategy: An instrument for economic and sustainable urban traffic planning, *ISPRS International Journal of Geo-Information*, 11 (1), 16.

Duggal, A.S., Singh, R., Gehlot, A., Gupta, L.R., Akram, S.V., Prakash, C., Singht, S. and Kumar, R., 2021. Infrastructure, mobility and safety 4.0: Modernization in road transportation, *Technology in Society*, 67, 101791.

Ethereum Foundation, 2023. *Ethereum development documentation* [online]. Available from: https://ethereum.org/en/developers/docs/ [Accessed: 12 August 2025].

Farahpoor, M., Esparza, O. and Soriano, M., 2023. Comprehensive IoT-driven fleet management system for industrial vehicles, *IEEE Access*, 11, 148044-148057.

Gan, Q., 2022. A logistics distribution route optimization model based on hybrid intelligent algorithm and its application, *Annals of Operations Research*, 1-13.

Gao, X., Ci, Y., Yuen, K.F., Wu, L. and Li, R., 2025. Hybrid traffic flow prediction

model for emergency scenarios with scarce historical data, *Engineering Applications of Artificial Intelligence*, 145, 110219.
Gorman, M.F., Clarke, J.P., de Koster, R., Hewitt, M., Roy, D. and Zhang, M., 2023. Emerging practices and research issues for big data analytics in freight transportation, *Maritime Economics and Logistics*, 25, 28-60.
Government of the Republic of Kazakhstan, 2022. *On approval of the Concept for the development of transport and logistics potential of the Republic of Kazakhstan until 2030* [online]. Available from: https://adilet.zan.kz/rus/docs/P2200001116#z374 [Accessed: 12 August 2025].
He, J., Zhang, Z., Tan, Z. and Zheng, S., 2024. Analyzing the transportation infrastructure-rural industry integration relationship in China, *Chinese Journal of Population, Resources and Environment*, 22 (2), 157-166.
Herold, D.M., Ćwiklicki, M., Pilch, K. and Mikl, J., 2021. The emergence and adoption of digitalization in the logistics and supply chain industry: an institutional perspective, *Journal of Enterprise Information Management*, 34 (6), 1917-1938.
Jakubik, P., Kerimkhulle, S. and Teleuova, S., 2017. How to anticipate recession via transport indices, *Ekonomický časopis,* 6 5(10), 972–990.
Kairatkyzy, G., Karsybayev, Y.Y., Abzhapbarova, A.Z., Deryugin, O.V. and Bas, I.K., 2022. Improving the reliability of trucking in the conditions of a mining enterprise, *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu,* 3, 125–130.
Khayesi, M., 2020. Vulnerable road users or vulnerable transport planning? *Frontiers in Sustainable Cities*, 2, 25.
Layaoen, H.D.Z., Abareshi, A., Abdulrahman, M.D.A. and Abbasi, B., 2023. Sustainability of transport and logistics companies: An empirical evidence from a developing country, *International Journal of Operations and Production Management*, 43 (7), 1040-1067.
Li, W., Batty, M. and Goodchild, M.F., 2020. Real-time GIS for smart cities, *International Journal of Geographical Information Science,* 34 (2), 311-324.
Lumenspei, 2023. *How a logistics company digitally transformed their business – Case study* [online]. Available from: https://lumenspei.com/digital-transformation-logistics-case-study/ [Accessed: 12 August 2025].
Lyu, Z., Pons, D., Zhang, Y. and Ji, Z., 2021. Freight operations modelling for urban delivery and pickup with flexible routing: Cluster transport modelling incorporating discrete-event simulation and *GIS, Infrastructures*, 6 (12), 180.
Millonig, A. and Haustein, S., 2020. Human factors of digitalized mobility forms and services, *European Transport Research Review*, 12, 46.
Modernization of the country's key road facilities is nearing completion [online], 2024. Available from: https://ortcom.kz/ru/novosti/1725450153 [Accessed: 12 August 2025].

Nikitas, A., Michalakopoulou, K., Njoya, E.T. and Karampatzakis, D., 2020. Artificial intelligence, transport and the smart city: Definitions and dimensions of a new mobility era, *Sustainability*, 12 (7), 2789.

Novytska, M., 2022. Comparative analysis of definitions of the term "digital economy", *Economics and Management Organization*, 2 (46) 183-189.

Pavard, A., Dony, A. and Bordin, P., 2023. Road modelling for infrastructure management - The efficient use of geographic information systems, *Journal of Information Technology in Construction*, 28, 438-457.

Raevneva, O., Aksyonova, I. and Brovko, O., 2021. Comparative rating analysis of the state and trends of digitalization of Ukrainian society and economy, *Economic Problems*, 4, 56-66. Available from: http://repository.hneu.edu.ua/handle/123456789/27415 [Accessed: 12 August 2025].

RSE "Kazhydromet", 2023. *Annual bulletin of monitoring the state and change of climate in Kazakhstan* [online]. Available from: https://www.kazhydromet.kz/ru/klimat/ezhegodnyy-byulleten-monitoringa-sostoyaniya-i-izmeneniya-klimata-kazahstana [Accessed: 12 August 2025].

Smailov, N., Nussupov, Y., Taissariyeva, K., Kuttybayev, A., Baigulbayeva, M., Turumbetov, M., Hryhoriev, Y. and Lutsenko, S., 2025a. Identification of dangerous situations in the road infrastructure using unmanned aerial vehicles, *Technology Audit and Production Reserves,* 6 (2), 97–102.

Smailov, N., Tsyporenko, V., Ualiyev, Z., Issova, A., Dosbayev, Z., Tashtay, Y., Zhekambayeva, M., Alimbekov, T., Kadyrova, R. and Sabibolda, A., 2025b. Improving accuracy of the spectral-correlation direction finding and delay estimation using machine learning, *Eastern European Journal of Enterprise Technologies*, 2 (5(134)), 15–24.

Soori, M., Arezoo, B. and Dastres, R., 2023. Artificial intelligence, machine learning and deep learning in advanced robotics, a review, *Cognitive Robotics*, 3, 54-70.

The Steppe, 2023. *How the growth of the logistics industry allows Kazakhstan and Kazakhstanis to earn money* [online]. Available from: https://the-steppe.com/razvitie/kak-rost-logisticheskoj-otrasli-dajot-zarabotat-kazahstanu-i-kazahstancam [Accessed: 12 August 2025].

Tkachenko, I. and Hlushchenko, Y., 2020. Comparative analysis of the current state of digitalization of the economy of Ukraine and the EU, *Black Sea Economic Studies*, 50, 106-111.

Verma, S.K., Verma, R., Singh, B.K. and Sinha, R.S., 2024. Management of intelligent transportation systems and advanced technology. In: R.K. Upadhyay, S.K. Sharma, V. Kumar (eds.), *Intelligent Transportation System and Advanced Technology*, 159-175. Singapore: Springer.

Voloshina, A., Panchenko, A., Panchenko, I., Titova, O. and Zasiadko, A., 2019. Improving the output characteristics of planetary hydraulic machines, IOP Conference Series: *Materials Science and Engineering,* 708 (1), 012038. DOI:

https://doi.org/10.1088/1757-899X/708/1/012038.

Wang, Y. and Sarkis, J., 2021. Emerging digitalisation technologies in freight transport and logistics: Current trends and future directions, Transportation Research Part E: *Logistics and Transportation Review*, 148, 102291.

Wójcik, W., Kalizhanova, A., Kulyk, Y.A., Knysh, B.P., Kvyetnyy, R.N., Kulyk, A.I., Sichko, T.V., Dumenko, V.P., Bezstmertna, O.V., Adikhanova, S., Zhassandykyzy, M., Junisbekov, M., Smailov, N. and Yussupova, G., 2022. The method of time distribution for environment monitoring using unmanned aerial vehicles according to an inverse priority, *Journal of Ecological Engineering*, 23 (11), 179–187.

Xia, W.H., Zhou, D., Xia, Q.Y. and Zhang, L.R., 2020. Design and implementation path of intelligent transportation information system based on artificial intelligence technology, *The Journal of Engineering*, 2020(13), 482-485.

Yin, X., Wu, G., Wei, J., Shen, Y., Qi, H. and Yin, B., 2021. Deep learning on traffic prediction: Methods, analysis, and future directions, *IEEE Transactions on Intelligent Transportation Systems*, 23 (6), 4927-4943.

Yusupova, G., Dootaliev, A., Belek uulu, E. and Melis uulu, D., 2024. Infrastructure of national automobile transport systems as a factor in the development of international supply chains. *Bulletin of the Kyrgyz National Agrarian University*, 22 (6), 285-291.