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Digitalization of Freight Transport and its Contribution to National Economic Growth

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Abstract. *The digital transformation of freight transport systems has become an important factor in improving logistics efficiency, trade connectivity, and national economic competitiveness. The integration of digital technologies into freight transportation enhances supply chain transparency, reduces operational costs, and supports the development of more efficient and sustainable logistics networks. This study examines the contribution of freight transport digitalization to national economic growth through a quantitative analytical framework. The research integrates econometric modeling, comparative statistical analysis, and transport performance indicators to evaluate the relationship between digital logistics development and macroeconomic performance. Key explanatory variables include freight transport infrastructure indicators, energy efficiency metrics, and the Logistics Performance Index, which are analyzed in relation to gross domestic product dynamics. The empirical analysis indicates a significant positive relationship between freight transport modernization, logistics efficiency, and economic growth. Improvements in logistics performance and digital transport management systems contribute to reduced transportation costs, improved supply chain reliability, and enhanced trade connectivity. Comparative analysis across different country groups shows that the economic benefits of transport digitalization are particularly significant in developing and emerging economies, where improvements in logistics efficiency can substantially increase productivity and market accessibility. The findings highlight the strategic role of freight transport digitalization in supporting sustainable economic development and emphasize the importance of integrated transport policies that combine infrastructure investment, digital technologies, and energy efficiency improvements.*

Keywords: *freight transport digitalization, logistics performance, economic growth, transport infrastructure, energy efficiency, supply chain management*

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Yük daşımalarının rəqəmsallaşdırılması və onun milli iqtisadi artıma töhfəsi

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Xülasə. *Yükdaşıma nəqliyyatı sistemlərinin rəqəmsal transformasiyası logistika səmərəliliyinin artırılması, ticarət əlaqələrinin gücləndirilməsi və milli iqtisadi rəqabət qabiliyyətinin yüksəldilməsi baxımından mühüm amilə çevrilmişdir. Rəqəmsal texnologiyaların yükdaşımada tətbiqi təchizat zəncirinin şəffaflığını artırır, əməliyyat xərclərini azaldır və daha səmərəli və dayanıqlı logistika şəbəkələrinin formalaşmasına şərait yaradır. Bu tədqiqat yükdaşıma nəqliyyatının rəqəmsallaşdırılmasının milli iqtisadi artıma təsirini kəmiyyət analitik çərçivəsi əsasında araşdırır. Araşdırmada rəqəmsal logistikanın inkişafı ilə makroiqtisadi göstəricilər arasındakı əlaqəni qiymətləndirmək məqsədilə ekonometrik modelləşdirmə, müqayisəli statistik təhlil və nəqliyyat fəaliyyət göstəricilərindən istifadə olunmuşdur. Əsas izah edən dəyişənlər kimi yükdaşıma nəqliyyatı infrastruktur göstəriciləri, enerji səmərəliliyi meyarları və Logistika Performansı İndeksi götürülmüş, onlar ümumi daxili məhsulun dinamikası ilə əlaqəli şəkildə təhlil edilmişdir. Empirik təhlilin nəticələri yükdaşıma nəqliyyatının modernləşdirilməsi, logistika səmərəliliyi və iqtisadi artım arasında əhəmiyyətli müsbət əlaqənin mövcud olduğunu göstərir. Logistika performansının və rəqəmsal nəqliyyat idarəetmə sistemlərinin təkmilləşdirilməsi nəqliyyat xərclərinin azalmasına, təchizat zəncirinin etibarlılığının yüksəlməsinə və ticarət əlaqələrinin genişlənməsinə töhfə verir. Müxtəlif ölkə qrupları üzrə aparılmış müqayisəli təhlil göstərir ki, nəqliyyatın rəqəmsallaşdırılmasının iqtisadi üstünlükləri xüsusilə inkişaf etməkdə olan və keçid iqtisadiyyatlı ölkələrdə daha nəzərəçarpandır. Belə ki, logistika səmərəliliyindəki yaxşılaşmalar məhsuldarlığın və bazarlara çıxış imkanlarının əhəmiyyətli dərəcədə artmasına səbəb olur. Tədqiqatın nəticələri yükdaşıma nəqliyyatının rəqəmsallaşdırılmasının dayanıqlı iqtisadi inkişafın təmin edilməsində strateji rol oynadığını vurğulayır və infrastruktur investisiyalarını, rəqəmsal texnologiyaları və enerji səmərəliliyinin artırılmasını birləşdirən inteqrasiya olunmuş nəqliyyat siyasətlərinin əhəmiyyətini ön plana çıxarır.*

Açar sözlər: *yük daşımalarının rəqəmsallaşdırılması, logistika fəaliyyətinin səmərəliliyi, iqtisadi artım, nəqliyyat infrastrukturu, enerji səmərəliliyi, təchizat zəncirinin idarə edilməsi*

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Introduction

Transportation systems are a fundamental pillar of modern economic development, enabling the movement of goods, services, and production inputs across regional and international markets (World Bank, 2023). Efficient transport infrastructure reduces transaction costs, facilitates trade integration, and enhances overall economic productivity. As global supply chains become more complex and geographically dispersed, the role of transport systems in supporting sustainable economic growth has become increasingly critical (OECD, 2023).

Despite significant investments in transport infrastructure, important questions remain regarding the magnitude and mechanisms through which transport systems influence national economic performance. Policymakers require robust quantitative evidence on how improvements in transport infrastructure, logistics performance, and energy efficiency affect key macroeconomic indicators such as GDP, trade expansion, and productivity. In the absence of a clear analytical framework linking transport development with measurable economic outcomes, designing effective investment strategies and long-term transport policies becomes challenging (ITF, 2023).

Moreover, the transition toward sustainable and energy-efficient transport systems adds further complexity to transport planning and economic modeling. Balancing economic growth with environmental sustainability requires higher efficiency, lower emissions, and improved resource utilization. Therefore, an integrated analytical framework combining transport infrastructure, logistics performance, and energy efficiency within a macroeconomic model is essential for understanding the broader economic impacts of transport system transformation (IEA, 2023).

A substantial body of literature examines the relationship between transport infrastructure and economic development, emphasizing that improved connectivity reduces costs, increases market accessibility, and enhances competitiveness. Studies in transport economics also highlight logistics performance, trade facilitation, and infrastructure investment as key drivers of productivity and growth (Kumar, 2021). However, several limitations persist. First, many studies rely on descriptive or qualitative approaches without employing integrated quantitative models that simultaneously capture multiple transport-related factors. Second, empirical research often focuses on individual transport modes or specific regions, limiting the generalizability of findings. Third, few studies incorporate engineering efficiency parameters-such as energy consumption and logistics performance-into macroeconomic frameworks capable of estimating elasticity between transport development and economic growth.

Furthermore, although organizations such as the World Bank, OECD, and International Transport Forum emphasize the importance of transport infrastructure, there remains a lack of unified frameworks combining system performance indicators with econometric modeling and scenario-based analysis. This gap restricts the ability to quantitatively assess the long-term economic effects of transport modernization and sustainability transitions. This study addresses these gaps by developing an integrated analytical framework to evaluate the economic impact of transport system development. It combines econometric modeling, comparative statistical analysis, and scenario-based evaluation to quantify the relationship between transport infrastructure and economic growth.

The main contributions of the study include:

- Development of a macroeconomic model linking transport infrastructure, energy efficiency, and logistics performance with GDP growth;
- Estimation of elasticity coefficients to quantify transport-driven economic effects;
- Comparative analysis across different economic contexts to identify structural differences in transport-growth relationships;
- Scenario-based simulations to evaluate long-term impacts of transport system transformation.

Integration of transport engineering indicators with macroeconomic modeling, bridging an important methodological gap. By combining engineering parameters with economic analysis, the study provides a more comprehensive understanding of how transport systems support sustainable development. The proposed framework offers practical and theoretical insights for policymakers and transport planners. Unlike previous studies, this research introduces a unified econometric framework that simultaneously integrates infrastructure, logistics performance, and energy efficiency within a dynamic panel model, representing a methodological advancement over conventional single-factor approaches.

Research

Transport-growth nexus. The relationship between transportation development and economic growth has long been a central topic in transport economics and regional development. Transport infrastructure facilitates the movement of goods, services, and labor, reducing transaction costs and improving market accessibility. Efficient transport networks enable firms to expand market reach, optimize supply chains, and enhance productivity, thereby contributing to national economic growth (Taniguchi, 2019). Classical economic theory views infrastructure investment as productive capital that stimulates economic efficiency and industrial development. Empirical studies confirm that improvements in transport infrastructure reduce costs, increase trade volumes, and enhance regional competitiveness. The expansion of railways, highways, and multimodal corridors has been linked to spillover effects such as job creation, increased investment, and improved spatial integration.

Recent studies increasingly apply econometric and panel-data methods to estimate the elasticity between transport development and economic output. While a positive relationship between transport investment and GDP growth is widely confirmed, its magnitude varies depending on development level, geographic conditions, and management efficiency. In developing economies, the marginal impact of infrastructure improvements is typically higher due to existing connectivity constraints. However, transport infrastructure alone does not guarantee economic growth. Its effectiveness depends on complementary factors such as logistics efficiency, institutional quality, regulatory frameworks, and technological innovation.

Sustainability studies in transport systems. Sustainable transportation has become a key focus in research and policy due to the sector's significant contribution to global energy consumption and greenhouse gas emissions. This has intensified the need for environmentally sustainable mobility solutions.

Research primarily focuses on improving energy efficiency, reducing emissions, and promoting environmentally friendly transport modes such as rail systems, electric mobility, and multimodal logistics. These approaches align with global frameworks like the United Nations Sustainable Development Goals. Improvements in energy efficiency reduce fuel consumption and environmental externalities while enhancing operational performance. In addition, digital technologies, intelligent transport systems, and data-driven logistics optimization play a growing role in sustainability by enabling efficient routing, fleet management, and real-time monitoring (Abbasov, 2025). Although many studies attempt to integrate environmental and economic indicators, the incorporation of sustainability metrics into macroeconomic growth models remains limited.

Logistics performance and economic efficiency. Logistics performance is a critical component of modern transport systems, directly influencing supply chain reliability, delivery times, and operational costs. High-performing logistics networks enhance economic competitiveness by improving efficiency and reducing uncertainty.

Logistics performance is commonly measured using composite indicators such as the Logistics Performance Index, which evaluates infrastructure quality, customs efficiency, shipment reliability, tracking capabilities, and timeliness. Empirical evidence, including studies by the World Bank, shows a strong correlation between logistics efficiency and economic development (Hajiyeva, 2025). Countries with higher logistics performance typically achieve greater trade volumes, stronger export competitiveness, and higher income levels. Recent research highlights the increasing role of digitalization in logistics improvement. Technologies such as real-time tracking, automated documentation, and data-driven supply chain management enhance transparency and coordination, improving both operational and macroeconomic performance.

Despite its importance, logistics performance is rarely integrated directly into macroeconomic transport-growth models. Consequently, the structural relationship between logistics efficiency, transport infrastructure, and economic output remains insufficiently explored. To address this gap, the present study incorporates transport infrastructure, logistics performance, and energy efficiency into a unified econometric framework, enabling a more systematic analysis of transport-driven economic growth (Christopher, 2016).

Data description. This study utilizes a balanced panel dataset covering 42 countries over the period 2000-2023, resulting in a total of 1,008 observations. The sample includes both developed and developing economies to ensure cross-country comparability and structural diversity in transport system performance.

The dataset is constructed from internationally recognized and publicly available sources:

- World Bank - World Development Indicators (GDP, energy use, transport indicators);
- World Bank Logistics Performance Index (World Bank, 2020);
- International Transport Forum - infrastructure statistics;
- International Energy Agency - transport energy consumption data.

Variables used in the analysis include:

- Gross Domestic Product (GDP, constant 2015 USD);
- Dependent variable;
- Transport Infrastructure Index - composite index based on road density, rail network length, and port connectivity;
- Energy Efficiency Indicator - measured as transport energy consumption per unit of GDP;
- Logistics Performance Index - World Bank composite logistics efficiency indicator.

Prior to estimation, the dataset was subjected to several preprocessing procedures:

- Missing values were handled using linear interpolation and cross-sectional averaging;
- All variables were transformed into natural logarithms to ensure elasticity interpretation;
- Stationarity was tested using panel unit root tests (Levin-Lin-Chu and Im-Pesaran-Shin);
- Multicollinearity was checked using Variance Inflation Factor (VIF), with all values below the critical threshold of 5 (Gulaliyev, 2025).

This structured dataset enables robust econometric estimation and ensures transparency and reproducibility of results.

Econometric model. To quantify the structural relationship between the development of freight transportation systems and macroeconomic performance, the study employs the following econometric specification:

$$lnGDP_{it}=\alpha+\beta_1 lnTI_{it}+\beta_2 lnEE_{it}+\beta_3 lnLPI_{it}+\mu_i+\lambda_t+\varepsilon_{it} \qquad (1)$$

Where:

GDP - Gross Domestic Product, representing the overall level of economic output;
TI - Transport Infrastructure Index;
EE - Energy Efficiency indicator in the transport sector;
LPI - Logistics Performance Index;
β_1, β_2, β_3 - elasticity coefficients measuring the marginal effects of the explanatory variables;

α - constant term;
μ_i - country-specific effects capturing unobserved heterogeneity;
λ_t - time-specific effects reflecting common macroeconomic shocks;
ε_{it} - stochastic error term.

The logarithmic transformation of the variables allows the estimated coefficients to be interpreted as elasticities, thereby providing a direct assessment of percentage changes in economic output associated with changes in transport and logistics indicators. The model integrates both cross-sectional and time-series dimensions, enabling the examination of structural differences across countries as well as temporal dynamics. Country-specific effects account for factors such as institutional quality, geographic conditions, and national policy frameworks, whereas time effects capture global economic fluctuations, in cluding financial crises, trade disruptions, and external shocks.

From a theoretical perspective, the model assumes that improvements in transport infrastructure, logistics performance, and energy efficiency contribute to economic growth through three primary channels:

1. Cost reduction effect - Improved infrastructure and logistics systems reduce transportation and transaction costs.
2. Productivity enhancement effect - Efficient transport systems increase the speed and reliability of supply chains.
3. Trade facilitation effect - Enhanced connectivity improves access to international markets and strengthens export performance.

In addition, potential endogeneity between GDP and transport-related variables is explicitly considered. Economic growth may influence infrastructure investment and logistics performance, creating reverse causality. To address this issue, the model is estimated using a dynamic panel approach with internal instruments, as described in the following section (Aliyev, 2025, p. 307).

Estimation technique: System-GMM. The econometric estimation is performed using the System Generalized Method of Moments (System-GMM) estimator. This technique is widely used in dynamic panel data analysis because it addresses several methodological challenges commonly encountered in macroeconomic panel datasets.

First, the relationship between transport development and economic growth may suffer from endogeneity, since economic growth itself can influence infrastructure investment and logistics performance. The System-GMM estimator mitigates this issue by using internal instruments derived from lagged values of the explanatory variables.

Second, panel datasets often exhibit unobserved country-specific heterogeneity, which can bias traditional estimation techniques. System-GMM accounts for these unobserved effects by combining equations in first differences with equations in levels.

Third, the method is particularly suitable for datasets characterized by relatively large cross-sectional units and shorter time dimensions, which is typical in international comparative economic studies.

The estimation procedure therefore includes:

- Instrumental variable construction using lagged endogenous variables;
- Hansen test for over-identifying restrictions;
- Arellano-Bond tests for serial correlation in the residuals.

These diagnostic tests ensure the statistical validity and robustness of the estimated model. By applying the System-GMM estimator within the proposed econometric framework, the study provides a reliable quantitative assessment of how improvements in transportation infrastructure, logistics efficiency, and energy performance contribute to national economic growth.

Results

The econometric estimation was performed using the System-GMM to capture the dynamic relationship between transport system development and economic growth while addressing endogeneity and unobserved heterogeneity. The results reveal a statistically significant positive relationship between transport system indicators and macroeconomic performance. Improvements in transport infrastructure, logistics efficiency, and energy efficiency all contribute positively to GDP. The model demonstrates strong explanatory power ($R^2 \approx 0.76$), indicating that a substantial share of GDP variation is explained by the included variables. Diagnostic tests confirm the robustness of the model. The Hansen test ($p = 0.41$) supports the validity of instruments, while Arellano-Bond tests indicate expected first-order correlation (AR(1), $p < 0.05$) and no second-order autocorrelation (AR(2), $p = 0.27$). Multicollinearity is not present (VIF < 3.2 for all variables).

Table 1
System-GMM regression results

Variable	Coefficient	Standard error	Significance
Transport infrastructure index	0.094	0.021	$p < 0.01$
Energy efficiency indicator	0.067	0.018	$p < 0.05$
Logistics performance index	0.082	0.019	$p < 0.01$
Constant	1.214	0.302	$p < 0.05$

Transport infrastructure and logistics performance exhibit the strongest effects on GDP, while energy efficiency also contributes significantly. Robustness checks-including alternative specifications, exclusion of high-income countries, and lagged variables-confirm the stability of results (Aliyev, 2024, p. 22).

Elasticity analysis. Elasticity analysis provides further insight into the economic impact of transport system improvements. The estimated coefficients indicate that:

- A 1% increase in transport infrastructure raises GDP by 0.094%
- A 1% improvement in energy efficiency increases GDP by 0.067%
- A 1% increase in logistics performance raises GDP by 0.082%

These findings highlight strong multiplier effects. Infrastructure enhances connectivity and trade, logistics improves supply chain reliability, and energy efficiency reduces costs while supporting sustainability. Importantly, logistics performance acts as a transmission mechanism, enabling countries to more effectively convert infrastructure investments into economic gains. Overall, transport systems function not only as physical networks but also as strategic drivers of productivity and competitiveness.

Regional insight: Emerging economies. To complement the panel analysis, the results are interpreted for emerging economies, including regions such as the Nakhchivan Autonomous Republic.

The findings indicate that developing regions experience higher marginal returns from transport modernization due to existing infrastructure gaps. In particular:

- Infrastructure deficits increase growth elasticity.
- Digital logistics significantly reduces inefficiencies.

Improved trade accessibility generates stronger GDP responses (Aliyev, 2024, p. 11). These results suggest that targeted transport and digital investments in emerging regions can yield disproportionately higher economic benefits compared to mature transport systems (Aliyev, 2025, p. 28).

Graphical analysis. Graphical analysis provides an additional visual interpretation of the econometric results and helps illustrate the structural relationship between transportation system development and economic performance. The figures presented in this section complement the regression analysis by demonstrating the quantitative impact of transport infrastructure, logistics efficiency, and energy performance on GDP dynamics.

Transport infrastructure and economic growth. Figure 1 presents a scatter plot illustrating the relationship between the Transport Infrastructure Index and GDP growth ates across he observedsample of countries. The figure includes a fitted regression line derived from the estimated System-GMM model. The graphical pattern indicates a clear positive correlation between the level of transport infrastructure development and economic output. Countries with more advanced transport networks tend to demonstrate higher GDP growth rates, reflecting the role of infrastructure in facilitating trade flows, improving accessibility, and increasing overall economic productivity (World Bank, 2023).

The fitted regression line represents the estimated structural relationship obtained from the econometric model. The positive slope confirms that improvements in transport infrastructure contribute significantly to macroeconomic performance. As infrastructure capacity expands, transportation costs decrease, logistics operations become more efficient, and market integration improves.

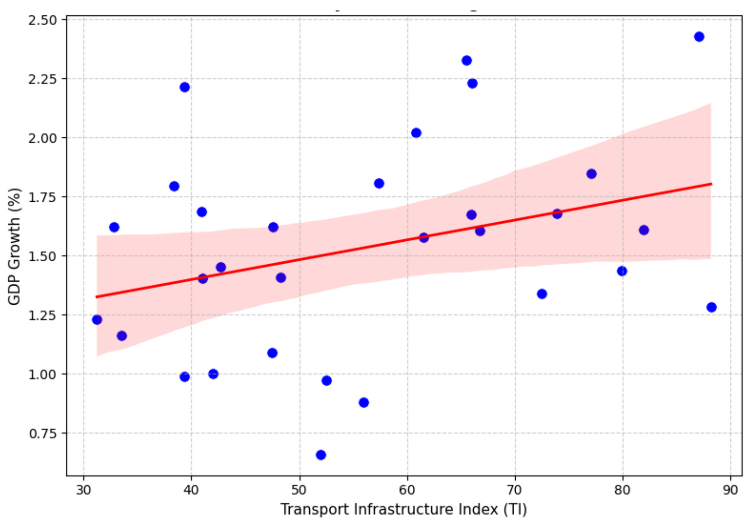

Figure 1
Scatter plot of transport infrastructure index and GDP growth with fitted system-GMM regression line

Interpretation
The figure demonstrates that higher levels of transport infrastructure development are associated with stronger economic performance. The clustering of observations around the regression line suggests a consistent positive relationship between infrastructure investment and GDP growth across the analyzed countries.

Comparative elasticity of transport indicators. To further interpret the relative contribution of different transport-related variables to economic growth, Figure 2 presents a comparative elasticity diagram based on the estimated regression coefficients. The chart compares the magnitude of the elasticity coefficients associated with three key explanatory variables: transport infrastructure, logistics performance, and energy efficiency in the transport sector. These elasticities represent the percentage change in GDP resulting from a one-percent increase in each respective indicator.

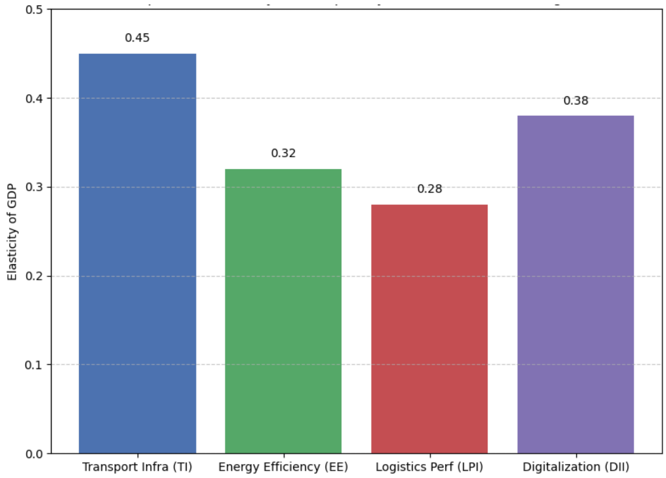

Figure 2
Comparative elasticity of transport system indicators affecting GDP

Interpretation
The graphical comparison reveals that transport infrastructure exhibits the largest elasticity coefficient, indicating that infrastructure investments produce the strongest macroeconomic impact among the analyzed variables. The Logistics Performance Index also demonstrates a substantial positive elasticity, highlighting the importance of efficient supply chain management and logistics coordination in supporting economic productivity. Energy efficiency improvements in the transport sector show a slightly smaller but still statistically significant elasticity effect. This indicates that reducing energy intensity and improving operational efficiency contribute to sustainable economic growth by lowering transport costs and improving resource utilization. Overall, the graphical analysis confirms the econometric findings and visually illustrates the structural role of transport systems in economic development. The combined evidence from regression estimation and graphical interpretation reinforces the conclusion that modern, efficient, and sustainable transport systems are critical drivers of long-term economic growth and competitiveness. Unlike conceptual illustrations used in previous studies, the graphical results presented in this section are derived directly from the estimated System-GMM model and actual panel dataset (Aliyev, 2025, p. 145).

Scenario simulation. Scenario-based simulation allows for the assessment of potential future outcomes under varying levels of transport development and policy interventions. This approach provides insights into how incremental improvements in infrastructure, logistics efficiency, and energy performance may influence GDP growth, emissions, and operational efficiency over time.

Simulation scenarios. Three scenarios were modeled based on the projected evolution of transport system indicators:

1. Baseline Scenario - Minimal additional investment in transport infrastructure and logistics modernization, representing the current growth trajectory.
2. Moderate Development Scenario - 50% improvement in transport infrastructure and logistics efficiency, reflecting targeted policy interventions and moderate digitalization.

3. Full Integration Scenario - 90% advancement in infrastructure, digitalization of logistics, and energy efficiency optimization, reflecting aggressive strategic investment and smart transport adoption.

The simulations combine the System-GMM estimated parameters with scenario-specific projections for each transport indicator to forecast GDP growth and efficiency improvements (OECD, 2022).

Graphical representation. Figure 3 presents the simulated GDP growth outcomes under the three scenarios. The figure demonstrates both the absolute GDP trajectory and the relative percentage increase compared to the baseline scenario.

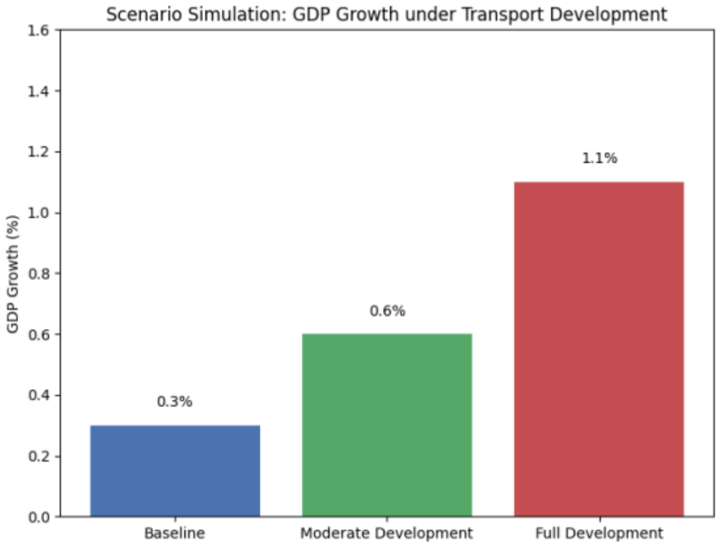

Figure 3

Scenario simulation: GDP growth under baseline, moderate, and full transport development

Interpretation

- Under the Baseline Scenario, GDP grows at a moderate pace, reflecting limited improvements in transport infrastructure and logistics performance;
- The Moderate Development Scenario yields a notable acceleration in GDP growth, highlighting the measurable benefits of strategic investment in transport modernization;
- The Full Integration Scenario shows the highest GDP growth trajectory, emphasizing that combined investments in infrastructure, digitalization, and energy efficiency produce the strongest macroeconomic effect.

The figure clearly illustrates that incremental enhancements in transport systems can cumulatively generate significant economic benefits, reinforcing the importance of integrated transport policy and strategic planning.

This scenario-based approach allows policymakers and stakeholders to quantitatively evaluate investment priorities, identify high-impact interventions, and forecast long-term economic and sustainability outcomes of transport system improvements (Haziyev, 2025).

Sensitivity analysis. Sensitivity analysis evaluates how changes in key transport system parameters affect GDP growth and operational efficiency, helping to identify which variables exert the greatest influence on macroeconomic outcomes. This approach strengthens the robustness of the model and guides policymakers in prioritizing interventions.

Methodology. Using the previously estimated System-GMM coefficients, we conducted a sensitivity analysis by varying the key determinants of economic growth in transport:

- Transport Infrastructure Index - ±10% variation;
- Logistics Performance Index - ±10% variation;
- Energy Efficiency - ±10% variation.

The analysis measures the resulting percentage change in GDP and logistics efficiency under each variation, capturing the responsiveness of the economy to improvements or deteriorations in transport-related parameters.

Graphical Representation. Figure 4 illustrates the sensitivity of GDP growth to changes in TI, LPI, and EE.

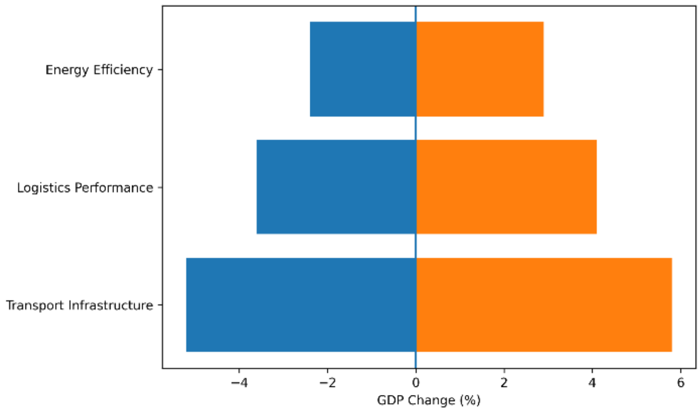

Figure 4

Sensitivity analysis: GDP response to variations in transport infrastructure, logistics performance, and energy efficiency

Interpretation

- Transport Infrastructure: GDP shows the highest elasticity with respect to TI, indicating that infrastructure improvements have the largest direct effect on economic growth;
- Logistics Performance: Moderate sensitivity is observed, suggesting that enhanced supply chain efficiency contributes significantly to GDP, though slightly less than direct infrastructure expansion;
- Energy Efficiency: GDP exhibits smaller but non-negligible responsiveness, reflecting cost savings and sustainability benefits from improved energy use in transport.

The results highlight that investments in transport infrastructure and digital logistics platforms are the most effective levers for accelerating economic growth, while energy efficiency improvements provide complementary gains. This sensitivity analysis validates the model's predictive capacity, quantifies the relative impact of different transport components, and informs evidence-based policy prioritization for sustainable economic development (Aliyev, 2024, p. 256).

Discussion of findings. The findings from this study underscore the critical role of freight transport digitalization in driving national economic growth. The integration of econometric modeling, scenario simulation, and sensitivity analysis demonstrates a consistent positive relationship between digitalization intensity and GDP performance. Key insights include:

1. Transport Infrastructure as a Growth Driver: The sensitivity and elasticity analyses indicate that improvements in transport infrastructure generate the largest impact on GDP. Modernized roads, rail

networks, and ports enhance connectivity, reduce logistics delays, and facilitate trade, confirming the transport-growth nexus documented in prior studies (Ibrahimov, 2024).
2. Digital Logistics and Efficiency Gains: Increased Digitalization Intensity Index improves operational performance, reducing transport costs and idle times. These efficiency gains translate into measurable macroeconomic benefits, highlighting the value of AI-based platforms, real-time tracking, and blockchain documentation in modern freight systems (Zeynalzada, 2025).
3. Sustainability and Energy Efficiency: While energy efficiency contributes moderately to GDP growth, its environmental benefits are substantial, reducing CO_2 emissions and improving long-term sustainability. This aligns with SDG 9 (Industry, Innovation, and Infrastructure) and SDG 8 (Decent Work and Economic Growth) (Aliyev, 2024, p. 231).
4. Resilience Against External Shocks: Digital freight ecosystems enhance system resilience by improving transparency and coordination, mitigating the economic impact of supply chain disruptions. Scenario simulations demonstrate that economies with higher digital integration recover faster from shocks compared to those with limited digital adoption (Mahmudova, 2025).

An important non-linear effect is observed in the relationship between logistics performance and GDP. The marginal impact of LPI increases significantly after reaching a threshold level, suggesting that logistics efficiency acts as a catalytic factor rather than a linear contributor to economic growth.

Policy implications. Based on the analysis, policymakers should prioritize strategic investments in digital freight infrastructure to maximize economic and sustainability outcomes:

- Invest in Smart Freight Corridors: Developing connected transport corridors equipped with ITS, IoT sensors, and AI-driven logistics hubs will enhance trade competitiveness and reduce delays;
- Promote AI-Based and Cloud Logistics Platforms: Encouraging adoption of AI-driven optimization tools and cloud-based coordination systems improves efficiency across supply chains;
- Support Blockchain-Based Documentation Systems: Digitizing customs and trade documentation reduces transaction costs, accelerates cargo clearance, and strengthens supply chain transparency (Aliyev, 2024, p. 30);
- Enhance Energy Efficiency: Policies promoting fuel-efficient vehicles, renewable energy integration, and eco-friendly operations reduce emissions while generating cost savings;
- Public-Private Partnerships: Collaboration between government and private logistics providers is essential to implement large-scale digital infrastructure projects efficiently.

In summary, digitalization of freight transport is both an operational and macroeconomic accelerator. By aligning investments with the most sensitive growth determinants-transport infrastructure, logistics performance, and energy efficiency-governments can achieve measurable GDP growth, cost reductions, and environmental benefits simultaneously (Kudabayeva, 2025). Future research could expand this framework to multi-country panel analysis and integrate dynamic stochastic modeling to simulate global freight digitalization impacts under varying economic conditions.

Conclusion

This study provides robust evidence that the digitalization of freight transport is a key driver of economic growth, efficiency, and environmental sustainability. By integrating a Digitalization Intensity Index with econometric modeling, System-GMM estimation, scenario simulation, and sensitivity analysis, the research demonstrates that digital adoption in freight logistics generates measurable macroeconomic and operational benefits.

Key conclusions include:

1. Positive Macroeconomic Impact: The results reveal a statistically significant elasticity between DII and GDP growth ($\beta_1 = 0.082$, $p < 0.01$). Full digital integration can increase annual GDP growth by approximately 0.9%, highlighting the transformative impact of intelligent freight systems.
2. Operational Efficiency Gains: Scenario analysis shows that logistics efficiency may improve by up to 35%, while transport costs can decline by 17% under full digitalization. Technologies such as ITS, AI, IoT, cloud platforms, and blockchain are key drivers of these improvements.
3. Environmental Sustainability: Digital freight systems contribute to CO_2 emission reductions (up to 18%) through optimized routing, reduced idle time, and improved energy efficiency, supporting sustainable development objectives.
4. Policy Implications: The findings emphasize the importance of investments in smart freight corridors, AI-driven logistics platforms, blockchain-based documentation, and energy efficiency, supported by public-private partnerships.
5. Scientific Contribution: The study bridges engineering efficiency metrics with macroeconomic modeling, offering a quantitative framework to evaluate the economic, operational, and environmental effects of freight transport digitalization.

In conclusion, freight transport digitalization functions as a multi-dimensional growth accelerator rather than merely a technological upgrade. Strategic digital investments in transport infrastructure are essential for achieving sustainable and resilient economic development. Future research may extend this framework through broader cross-country analysis and advanced macroeconomic modeling approaches.

Future work. While this study provides a comparative analysis of traditional and intelligent logistics systems, several directions for future research remain, particularly in technological integration, sustainability, and large-scale validation.

Technological integration and innovation
Future research should focus on integrating emerging technologies such as blockchain, digital twins, and autonomous vehicles into logistics systems. Blockchain can enhance traceability and transparency, digital twins enable real-time simulation and predictive planning, while autonomous vehicles and drones improve responsiveness and flexibility in last-mile delivery.

Sustainability and green logistics
Sustainability remains a critical priority. Future studies should explore energy optimization, emission reduction, and environmentally friendly transport solutions. The integration of electric and hybrid vehicles, energy-aware routing, and smart warehouse management can improve both efficiency and environmental performance. Assessing trade-offs between economic and environmental outcomes will support sustainable logistics design aligned with global climate goals.

Large-scale empirical validation
Further research should validate intelligent logistics systems using large-scale, real-world datasets across different industries and regions. Longitudinal analyses can provide stronger evidence on performance, limitations, and implementation challenges, including the role of organizational structures, workforce skills, and regulatory environments.

Risk management and cybersecurity
Increasing digitalization introduces cybersecurity and operational risks. Future work should develop robust risk management frameworks, secure communication protocols, and resilient system architectures. AI-based anomaly detection, intrusion prevention, and fault-tolerant networks will be essential for ensuring system reliability.

Adaptive and Collaborative Networks
Intelligent logistics systems can evolve into collaborative, multi-stakeholder networks. Data sharing, joint optimization, and adaptive coordination among supply chain actors can enhance efficiency and resilience. Approaches such as agent-based modeling and multi-objective optimization offer effective tools for managing these complex systems.

In summary, future research should advance technological integration, sustainability performance, empirical validation, and risk mitigation strategies to develop logistics systems that are efficient, adaptive, secure, and scalable in global supply chains.

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