

Digital Transformation and Investment Dynamics of Transport Enterprises: A Comparative Analysis of BRICS, Germany, and Ukraine

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Abstract

This research paper examines the nexus between digital transformation and investment activity across a diverse economic spectrum, encompassing the rapid growth of the BRICS bloc, the advanced industrial framework of Germany, and the resilient, IT-driven economy of Ukraine. As global logistics networks shift toward "Industry 4.0" standards, the traditional investment model, historically focused on

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physical fleet expansion, is being restructured to prioritize digital infrastructure, AI-driven logistics, and Big Data analytics. Utilizing a structural-analytical framework, this research evaluates how these digital investments enhance the financial sustainability of transport firms by optimizing asset utilization and reducing operational risks.

The findings demonstrate that digital transformation acts as a catalyst for institutional change, enabling firms to achieve higher capital productivity and long-term economic resilience. In the context of transitional markets, the shift toward digitalized investment activity serves to mitigate macroeconomic vulnerabilities by lowering logistics costs and improving regional trade integration. The study concludes that for transport enterprises, digital-led structural reforms are not merely technological upgrades but are essential strategies for ensuring fiscal stability and competitive advantage in an increasingly volatile global economy. Practical recommendations for managers and policymakers focus on balancing CAPEX between physical assets and digital innovation to ensure sustainable growth.

Keywords: digital transformation; investment activity; transport enterprises; emerging economies.

JEL Classification: O33; L91; G31; R42; O14.

Introduction

The transport sector plays a key role in ensuring economic growth both within a single country and on a global scale. It is the main element that ensures the movement of goods and services, which, in turn, affects the activities of various industries, production, trade, e-commerce, etc. Supply is disrupted in the absence of a reliable transport infrastructure, and the economy loses dynamics.

The modern challenges facing the transport industry have become significantly more complicated. In particular, it is about the growth of transportation volumes, increasing customer requirements for speed and transparency of processes, as well as unstable logistics costs. In these conditions, digitalization is attracting more and more attention, not as a fashionable trend, but as a necessary step to adapt to the new reality. It is not just about the application of modern technologies, but about changing the principles of enterprise operation: from internal processes to customer interaction.

In particular, such technologies as the Internet of Things (IoT), artificial intelligence (AI) systems, big data analytics, blockchain and cloud services are increasingly being used. For example, IoT makes it possible to track cargo in real time, and analytical tools help to more accurately forecast demand and plan resources. The implementation of AI also enables finding more efficient logistics routes, taking into account weather conditions or traffic jams. In 2023, spending on digital transformation in the transport industry amounted to approximately \$57.2 milliard. According to forecasts the market will demonstrate stable growth with an average annual growth rate of 9.35% from 2024 to 2030, and its volume may reach about \$106.95 milliard by the end of this period.

However, the implementation of digital solutions faces certain challenges. In many countries, there is a lack of technical infrastructure, adequate expertise, and resistance to change among personnel. The transition to digital approaches often requires significant investments, both in technology and in training. The issues of data security, the compatibility of new systems with regulatory requirements, and the ability of the enterprise to function in the face of change are also important.

The study covers the period 2015–2024, which is characterized by a number of global and national changes, including the COVID-19 pandemic, the war in Ukraine, increasing climate challenges, and labour market transformations. These factors create instability that significantly affects both investment activity and the pace of digitalization.

At the same time, digitalization also opens up opportunities for improving the environmental situation. Thanks to accurate route planning and effective fleet management, fuel costs and emissions can be reduced, and resource use optimized.

The aim of the study is to investigate the impact of digital transformation on the investment activity of transport enterprises and identify key factors that facilitate or hinder investment attraction in the process of digitalization of the industry. The aim was achieved through the fulfilment of the following research objectives:

RQ1: Analyse current challenges and trends in the development of the transport industry in the context of digital transformation;

RQ2: Identify the main digital technologies being implemented in the activities of transport enterprises and assess their potential impact on increasing investment attractiveness of the sector in the context of different models of economic development;

RQ3: Consider the main barriers and opportunities associated with digital transformation in the context of creating a favourable institutional and regulatory environment for attracting investments in transport infrastructure.

1. Literature Review

In recent years, digital transformation has gained particular importance both in academic research and in the practical activities of enterprises. It refers to structural changes in the functioning of society and industry, caused by the active implementation of digital technologies. According to Google analytics, interest in the concept of digital transformation showed rapid growth during 2014–2018, the number of requests increased twentyfold (Google, 2025).

At the same time, it is transport enterprises that face significant business risks, which emphasizes the urgent need for their support (Chonsawat & Sopadang, 2020). The development and implementation of support initiatives require a special approach, which involves creating a concept that clearly reflects the relationship between the measures taken and the results achieved. Business faces new challenges in view of the continuous development of the global economy, among which digital transformation is one of the keys in recent years (Wengler *et al.*, 2021).

The analysis of academic literature reveals a number of significant obstacles that hinder the digital transformation of transport enterprises. Limited investment resources stand out in this list, which directly affects the investment activity of companies in digitalization. Besides, the problems with IT security, insufficient level of digital skills of personnel, shortage of qualified IT specialists in the labour market, internal resistance to change, as well as lack of knowledge among management regarding the effective implementation of transformation processes are also important. Uncertainty regarding future digital standards also creates additional difficulties (The Enterprisers Project, 2021; Checchinato *et al.*, 2021).

These barriers are traditionally classified according to human, technological, and financial factors. However, there are other important aspects, such as organizational, legal, and environmental factors, which also affect the success of digital transformation (Matt *et al.*, 2020). Given the key role of financing, stimulating investment activity is critical to overcoming many of these obstacles and accelerating the digital transformation process.

Analysing the academic literature, we can identify a number of forms of government support aimed at overcoming key obstacles to the digital transformation process. These forms of support include training, strengthening security, expanding access to a skilled workforce, promoting internal research, mentoring, tax breaks, and direct government funding (Bygstad & Ovrelid, 2021; Truant *et al.*, 2021). We classify these measures into financial initiatives (tax and fee reductions and direct financial assistance), technological support (strengthening security), and human capital support (training, expanding the potential workforce, conducting internal research, and mentoring). There is a general consensus among scholars and practitioners that the main obstacles to the development of transport enterprises are either technological aspects, such as cybersecurity, or human factors, such as the lack of qualified personnel (Matt *et al.*, 2020).

In the era of digital transformation, intelligent transport systems (ITS) have attracted significant attention from researchers, as they are the basis of modern urban infrastructure. ITS promises to significantly improve mobility, optimize traffic flows, and reduce negative environmental impacts (Mecheva & Kakanakov, 2020). However, the integration of information and communication technologies into transport networks raises complex cybersecurity challenges. These challenges can threaten the security, confidentiality, and reliability of ITS (Guan *et al.*, 2022). Given the increasing complexity of cyber threats, the issue of ITS security is becoming critically important, which requires a thorough analysis of the state of cyber protection of these systems (Zeddini *et al.*, 2022).

Numerous studies reveal a significant potential of digital transformation in the corporate investment and financing (Niu *et al.*, 2023), productivity improvement (Nucci *et al.*, 2023; Wang *et al.*, 2023), and value creation. This process, however, does not always have an only positive impact. Digital transformation can also negatively affect organizational structure and short-term financial results. For example, Zhong and Ren (2023) found that companies implementing digital transformation often cannot recoup the costs incurred, which leads to a deterioration in their performance. A systematic literature review by Feliciano-Cestero *et al.* (2023) shows that digital transformation can have both positive and negative effects on the internationalization of companies at different levels: individual, corporate, and macro. The contradictory empirical evidence on the economic consequences of digital transformation is determined by two key factors. First, most studies analyse companies from developing countries (e.g., China) rather than developed economies. Second, only a small number of papers consider the impact of digital transformation from multiple perspectives, rather than focusing on one.

Nikonenko *et al.* (2022) investigate the implementation of Industry 4.0 principles in investment policy, demonstrating the importance of digitalization for economic development, a good highlight of the technological context of the issue under research. Semenets-Orlova *et al.* (2022) cover the educational modality in the context of value-based public administration, can serve as an example of the application of a people-centered approach in policy processes. In particular, Li *et al.* (2023) argue that digital transformation increases the efficiency of capital allocation in the context of corporate investment. This is achieved by reducing agency costs and expanding operational capabilities (Zhou & Ge, 2023).

Regarding corporate financing, Guo *et al.* (2023) demonstrate that digital transformation significantly eases financial constraints for small and medium-sized enterprises (SMEs). This is achieved by improving the quality of information disclosure, which contributes to their long-term sustainable development (Jiang *et al.*, 2024).

Table 1: Comparative Framework of Digital and Investment Dynamics

Feature / Group	Germany (Developed/Benchmark)	BRICS (Emerging/Growth)	Ukraine (Transitional/Resilient)
<ul style="list-style-type: none"> Primary Economic Status 	<ul style="list-style-type: none"> Advanced Industrial Economy (EU Core) 	<ul style="list-style-type: none"> Large-scale Emerging Markets 	<ul style="list-style-type: none"> Transitional & Recovery-focused Economy
<ul style="list-style-type: none"> Digital Transformation Strategy 	<ul style="list-style-type: none"> Industry 4.0: High-tech manufacturing, IoT, and institutional digitalization. 	<ul style="list-style-type: none"> Digital Leapfrogging: Rapid mobile adoption, fintech, and massive e-commerce scale. 	<ul style="list-style-type: none"> Digital-First Recovery: E-governance (Diia), IT service exports, and resilient infrastructure.
<ul style="list-style-type: none"> Investment Drivers 	<ul style="list-style-type: none"> Capital deepening, R&D intensity, and energy transition (Green Deal). 	<ul style="list-style-type: none"> Foreign Direct Investment (FDI), infrastructure expansion, and middle-class consumption. 	<ul style="list-style-type: none"> Post-conflict reconstruction, digital infrastructure grants, and human capital (IT).
<ul style="list-style-type: none"> Regulatory Framework 	<ul style="list-style-type: none"> Highly regulated (GDPR), centralized EU standards. 	<ul style="list-style-type: none"> Heterogeneous (varying degrees of state intervention vs. market liberalization). 	<ul style="list-style-type: none"> Rapid harmonization with EU standards; deregulated digital zones.
<ul style="list-style-type: none"> Structural Reform Focus 	<ul style="list-style-type: none"> Labour market flexibility and digital administrative simplification. 	<ul style="list-style-type: none"> Financial inclusion, urbanization, and manufacturing digitalization. 	<ul style="list-style-type: none"> Institutional transparency, anti-corruption tech, and decentralized logistics.
<ul style="list-style-type: none"> Financial Sustainability 	<ul style="list-style-type: none"> Low-risk, stable credit ratings, focus on green finance. 	<ul style="list-style-type: none"> High-growth potential but susceptible to currency and commodity volatility. 	<ul style="list-style-type: none"> Emerging resilience; reliant on international financial support and tech-agility.

Source: Authors' conceptual framework

Key theoretical context for the Table 1:

- Germany serves as the "frontier" benchmark, representing the maximum efficiency of a mature digital infrastructure.
- BRICS (Brazil, Russia, India, China, South Africa) represent the "volume" and "speed" of digital transformation, where investment is driven by massive scale.
- Ukraine provides a unique case of "digital resilience," demonstrating how investment activity can persist and even innovate through digital tools during periods of extreme structural transition.

Table 2: Comparative Analysis of Digital Investment Dynamics in the Transport Sector

Feature / Group	Germany (High-Tech Logistics)	BRICS (Scale & Intermodally)	Ukraine (Resilient Infrastructure)
Transport Digitalization Focus	Smart Logistics & IoT: Integration of AI in supply chains, automated ports (Hamburg), and Green Mobility.	Mass Scale Transit: High-speed rail expansion (China), digital freight matching, and urban smart-traffic.	Tactical Digitalization: Cloud-based logistics management, Diia integration for transit, and emergency routing.
Key Investment Drivers	Transition to zero-emission fleets, hydrogen fuel-cell R&D, and rail-network modernization.	Large-scale FDI in "Belt and Road" initiatives, port automation, and middle-class urban mobility.	Reconstruction of transit corridors, modular bridge tech, and digitalizing export-import logistics (Grain Initiative).
Fleet Management Maturity	Predominantly high-tier, sensor-equipped fleets with predictive maintenance.	Rapidly upgrading; shift from legacy hardware to integrated GPS/Telematic ecosystems.	Hybrid approach; high agility in utilizing mobile-first digital tools for fleet tracking under risk.
Regulatory & Safety Environment	Strict EU safety and emission standards (Euro 6+); centralized data security.	Variable; focus on deregulation to spur rapid infrastructure growth and multi-national corridors.	Rapid alignment with Trans-European Transport Network (TEN-T) standards and wartime safety protocols.
Structural Reform in Transport	Liberalization of rail markets and digitalization of municipal public transit.	Privatization of port authorities and development of multimodal logistics hubs.	Decentralization of road management and public-private partnerships (PPP) for recovery.
Resilience & Sustainability	Sustainability as a "Green Deal" mandate; focus on carbon neutrality.	Growth-oriented sustainability; balancing energy consumption with massive volume demands.	Resilience-oriented; digital tools used to maintain supply chain continuity during disruptions.

Source: Authors' conceptual framework

Integration notes for the transport study (Table 2):

- Germany represents the "Efficiency Frontier" where digitalization is used to optimize already mature systems.
- BRICS highlights the "Investment Volume" where digital tools enable the management of massive geographic and population scales.
- Ukraine serves as the "Agility Benchmark," demonstrating how digital transformation can ensure the survival and functioning of transport systems in high-risk environments.

To move from descriptive digitalization trends to quantitative analysis, this study explicitly operationalizes investment activity within the transport sector. Investment activity is defined as capital expenditures directed toward both physical transport assets and digital-enabling infrastructure supporting operational efficiency. This includes CAPEX on transport equipment, digital systems integration, and complementary investments that enhance returns on existing

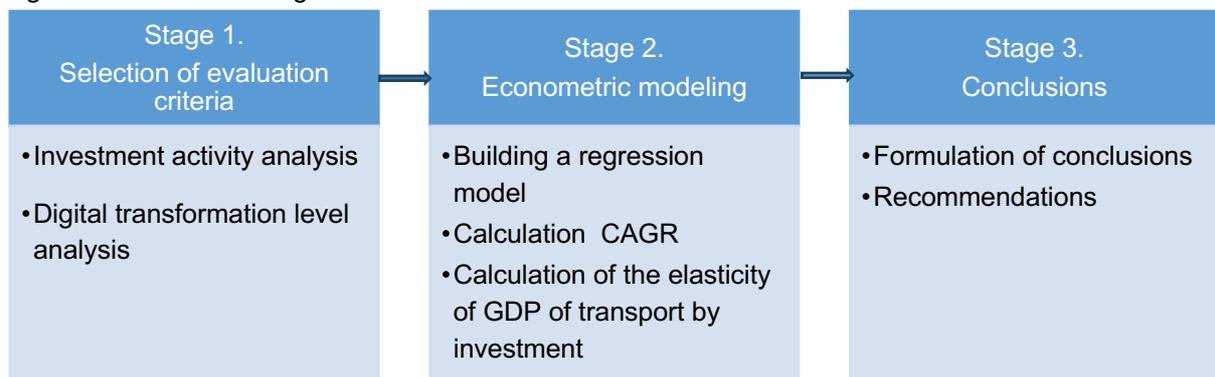
physical assets. Digital investments are captured indirectly through their effect on capital productivity rather than isolated IT spending or R&D accounting items. Accordingly, investment activity reflects the realized economic impact of combined physical and digital capital on transport sector GDP.

2. Research Methodology

Research Design

The impact of digital transformation on investment activity in the transport industry was comprehensively assessed through a phased approach. It includes both quantitative analysis methods and the construction of a special digital impact index. The Figure 1 shows 3 key stages of studying this process.

Figure 2. Research Design



Source: Authors' conceptual framework

So, the research procedure was the following:

1) The first stage provided for the identification of the relevant indicators that reflect the investment activity and the level of digitalization of transport enterprises. This included the collection of statistics on the volume of investments, types of digital technologies.

2) At the second stage, an econometric model was built for assessing the relationship between digital transformation and the investment volume.

3) The final stage was drawing conclusions on the impact of digital changes on investment dynamics and providing practical recommendations for improving the effectiveness of the digital strategy in the transport industry. To compare the dynamics of investment and economic growth in the transport sector between countries with different starting points, the CAGR (Compound Annual Growth Rate) indicator was used. Calculating the elasticity of transport GDP by investment allows us to estimate the sustainable average annual growth over a ten-year period and draw conclusions about the effectiveness of government policy in the field of digital transformation of transport. The elasticity of transport GDP by investment allows us to assess the effectiveness of converting capital investments into sectoral growth. This is important for identifying countries where investments generate economic returns and where growth is driven by other factors, such as external demand or government regulation.

Sampling

The sample of data on capital investments in the transport sector covers four countries: Ukraine, Germany, India, and Brazil for 2015–2024. This composition of the sample is justified by the objectives of the study, which involve studying the impact of digital transformation on investment activity in countries with different models of economic development, level of digital

maturity, institutional conditions, and geographical location. The main criteria for selecting countries were: the level of digital development (according to the EGDI), which allows comparing the impact of digital maturity on investment processes; economic model, from developed social and market economy (Germany) to transition (Ukraine) and large developing countries (India, Brazil); availability and comparability of official statistics; as well as the significance of the transport sector in the national economy of each country.

The involvement of countries with different levels of digital integration provides a comparative context for analysis. Germany demonstrates consistently high positions in the EGDI rating and a developed digital infrastructure; Ukraine, the dynamics of the growth of digital services in the face of external challenges; India, rapid urbanization and growth of transport investments against the background of a low digital rating; Brazil, a regional approach to digitalization with limited resources. The period 2015–2024 was chosen as representative to reflect the main stages of digital transformation, including the launch of key electronic services, the development of transport management technologies, as well as crisis phenomena (COVID-19 pandemic, military operations), in order to study the impact of digital solutions under different economic and political conditions. These countries represent different economic development models (Table 3.).

Table 3: Volume of Capital Investments in Transport, Million USD

Year	Ukraine	Germany	India	Brazil
2015	594.0	10,805	1,341	4.7
2016	781.3	12,331	5,519	5.8
2017	975.4	13,753	2,377	5.7
2018	1,258.7	14,178	10,273	5.8
2019	1,357.2	15,652	17,754	4.9
2020	1,105.4	16,806	25,620	3.9
2021	594.0	17,960	36,094	5.9
2022	781.3	28,138	40,582	5.7
2023	975.4	28,000	56,058	5.8
2024	1,162.3	28,229	58,249	6.7

Sources: Developed by the authors based on OECD (2025), State Statistics Service of Ukraine (2025), World Bank Group (2025).

Ukraine is in the course of economic transformation, and recent years have been marked by external challenges, including war. Germany demonstrates a stable policy of modernization of transport infrastructure with reliance on digital technologies. India is actively developing digital services in transport against the backdrop of rapid economic growth. In Brazil, despite limited resources, digital solutions are being integrated at the level of regional initiatives.

The EGDI was chosen because it reflects the level of digital interaction of the state with citizens and business (Table 4) (United Nations, 2025).

Table 4. E-government Indicators (UN E-Government Development Index), Ranking Number

Year	Ukraine	Germany	India	Brazil
2015	87	13	118	57
2016	62	13	107	51
2017	62	13	107	51
2018	82	13	107	44
2019	82	13	107	44
2020	69	25	100	54
2021	69	22	100	54
2022	46	22	105	49
2023	46	12	105	49
2024	30	12	97	50

Sources: Developed by the authors based on (United Nations, 2025).

This index is important for the investment environment, in particular in the transport sector, because it illustrates the level of administrative barriers for investors. It also simplifies access to public information and digital services. This increases the transparency of procedures, in particular tender procurement in transport. Besides, a high EGD I stimulates business to implement digital solutions. This increases the efficiency of transport enterprises. As a result, the industry becomes more attractive to investors.

The GDP of the transport sector was chosen as a key variable because of its complexity and ability to reflect the economic contribution of the sector to the national economy. The GDP of the transport sector indicates the total value of goods and services created in the sector, which makes it possible to assess the scale and dynamics of the development of this sector over time (Table 5).

Table 5: The Transport Sector GDP Volume of the, Milliard USD

Year	Ukraine	Germany	India	Brazil
2015	2,85	145	90,36	2,5
2016	2,94	157,7	98,38	2,25
2017	2,7	167,8	110,18	2,16
2018	2,63	175,7	115,93	2
2019	4,36	184,3	122,02	2,02
2020	4,78	159,9	111,32	1,46
2021	4,57	182,4	115,93	1,35
2022	6,13	195	139,52	1,58
2023	7,14	196	135,65	1,48
2024	9,05	200,9	138,18	1,57

Sources: Developed by the authors based on (OECD, 2025; State Statistics Service of Ukraine, 2025; World Bank Group, 2025).

The period 2015–2024 covers key stages of digital transformation in the transport sector. At this time, many countries began to implement automated transportation management systems, data analysis in logistics, etc. These data show the connection between digital transformation and investment volumes, compare the effectiveness of different strategies, and draw practical conclusions for countries with different levels of digital maturity.

Methods

The study uses a combination of quantitative and qualitative approaches, which provides a comprehensive assessment of the impact of digital transformation on investment activity in the transport sector. One of the key approaches was a comparative analysis, which involved cross-country comparison of data on the volume of capital investments in transport, the level of digital transformation, and the dynamics of GDP in the transport sector. This made it possible to identify similarities and differences in the impact of digitalization on investment processes under different models of economic development and specific national contexts (Zhang & Wang, 2024).

Statistical generalization methods were also applied. The analysis covered multi-year statistics for 2015–2024. The generalization included the calculation of average annual growth rates, moving averages, as well as the correlation between the digitalization index and indicators of investment activity and GDP in the transport industry. This made it possible to identify trends and assess the long-term dynamics of changes under the influence of digital transformation (Niranga et al., 2022).

An index assessment occupied a separate place in the study, within which digital maturity was measured using a generalized indicator, the EGDI. It served as an integrated indicator reflecting the level of digital interaction between the state, business, and citizens. Its inclusion in the model made it possible to quantitatively assess the impact of digital factors on the investment attractiveness of the transport industry (Straccamore et al., 2025).

A linear regression model of the type is used to analyse the impact of digitalization, economic development and exports on the volume of investment in the transport industry:

$$GDP = \alpha + \beta_1 \times DigitalIndex_t + \beta_2 \times Investment_t + \varepsilon_t, \quad (1)$$

where: $Investment_t$ (X1) - volume of investments in the transport sector in period t ; $DigitalIndex_t$ (X2) - a digital index reflecting the level of digitalization (EGDI); GDP_t (Y) - GDP of transport sector for period t ; α - a constant (free term of the model); β_1 , β_2 - model parameters characterizing the impact of the corresponding variables on the investment volume; ε_t - a random error reflecting the impact of other unaccounted factors.

This model is a linear regression model that quantitatively assesses how changes in digitalization and investments affect the level of GDP. The least squares method (LSM) is used to estimate the parameters α , β_1 , β_2 (Baltagi, 2021).

Calculating elasticity coefficients will show how much percent transport GDP changes when the digital index or investment changes by 1% (Pechdin & Swangsilp, 2024):

$$E = \frac{\partial Y}{\partial X} \cdot \frac{X}{Y}, \quad (2)$$

where: $\frac{\partial Y}{\partial X}$ - the marginal change in Y when X changes - that is, the derivative (how quickly Y changes depending on X); X - current value of the independent variable, that is, the

influencing factor (for example, the amount of investment); Y - current value of the dependent variable, that is, the result (for example, the GDP of the transport industry).

The calculation of CAGR allows us to identify differences in the growth rates of investments and economic results of the transport industry in Ukraine and the compared countries. This creates a basis for further analysis of the efficiency of capital investments (How to Calculate CAGR):

$$CAGR(t_0, t_n) = \left(\frac{V(t_n)}{V(t_0)} \right)^{\frac{1}{t_n - t_0}} - 1, \quad (3)$$

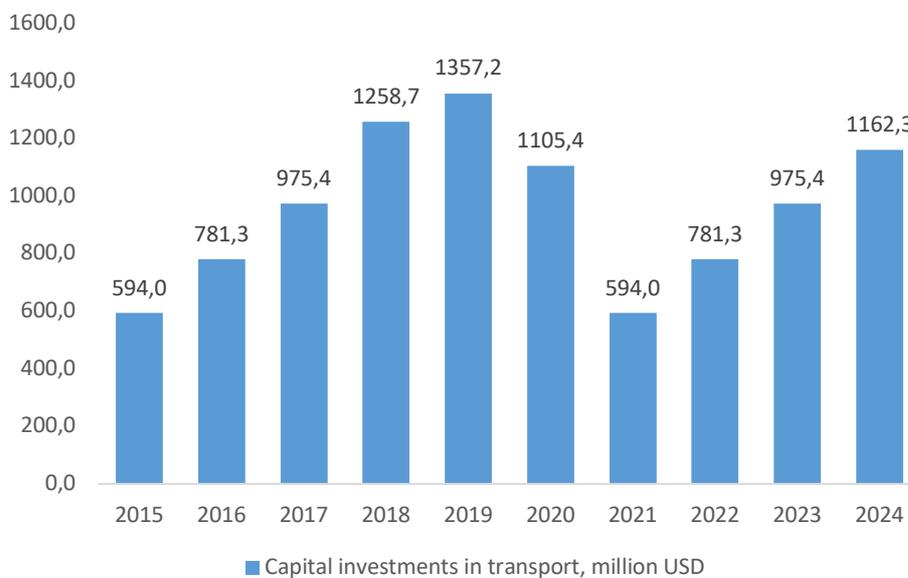
where: $V(t_0)$ – is the initial value, $V(t_n)$ – is the final value, $t_n - t_0$ – is the number of years.

This formula geometrically averages the change in the indicator per year, taking into account compounding, which is extremely relevant for analysing the growth rates of investments and transport GDP.

3. Research Results

During 2015 – 2024, capital investments in the transport sector of Ukraine, Germany, India and Brazil demonstrate mixed dynamics, which is due to internal socio-economic factors and external challenges. In Ukraine, a gradual increase in capital investments was recorded, from \$594 million in 2015 to \$1,162.3 million in 2024 (Figure 2).

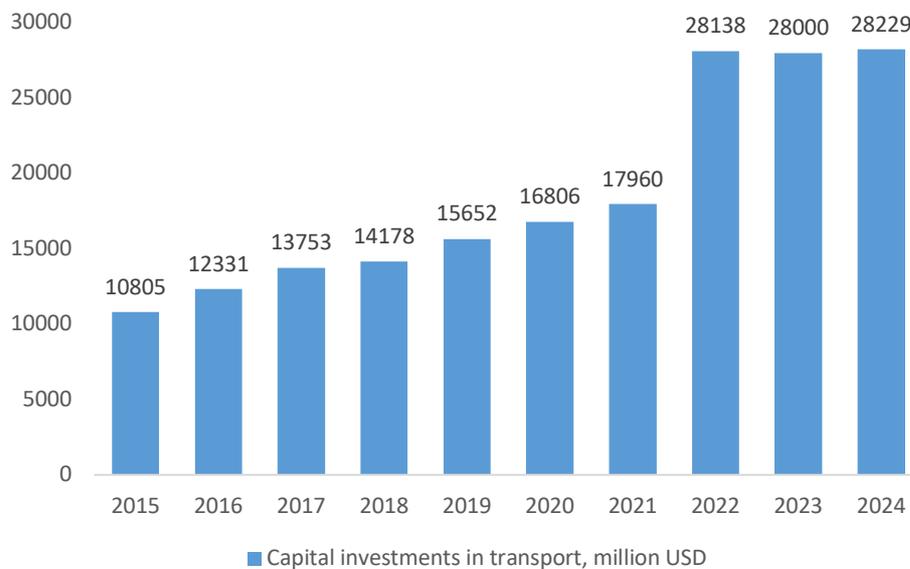
Figure 2: Capital Investments in Transport in Ukraine for 2015-2024



Sources: Developed by the authors based on (OECD, 2025; State Statistics Service of Ukraine, 2025; World Bank Group, 2025).

The highest growth rates were observed in 2017–2018. However, there was a significant decrease in investment volumes in 2020–2021 because of the COVID-19 pandemic and the start of a full-scale war. Starting in 2022, investments show signs of stabilization and growth. Germany is characterized by stable positive dynamics, from \$10.8 milliard in 2015 to over \$28.2 milliard in 2024 (Figure 3).

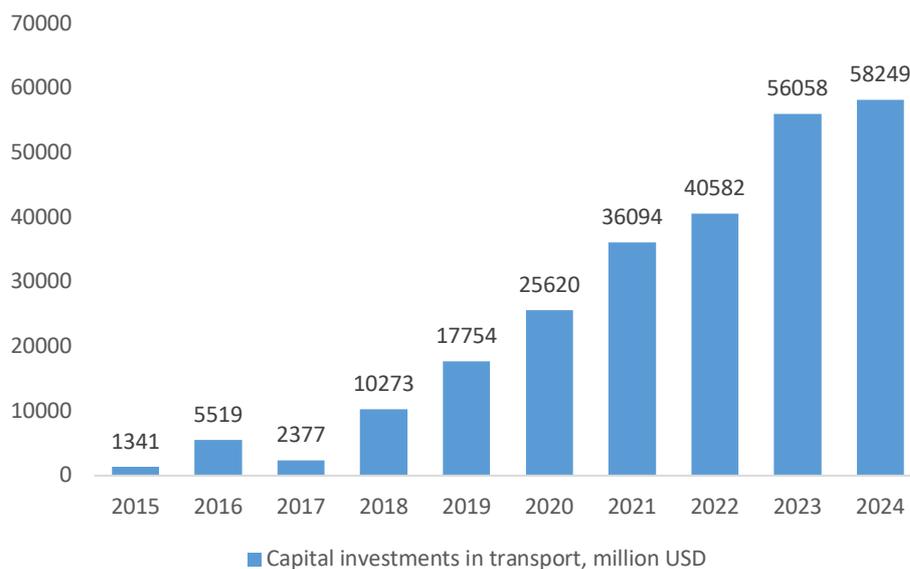
Figure 3: Capital Investments in Transport in Germany for 2015-2024



Sources: Developed by the authors based on (OECD, 2025; State Statistics Service of Ukraine, 2025; World Bank Group, 2025).

A particularly notable growth in investment occurred in 2022. This indicates consistent government policies in the field of transport infrastructure, including railway renewal, development of electric transport and digital solutions in logistics. India demonstrated the highest growth rates during this period: from \$1.34 milliard in 2015 to \$58.2 milliard in 2024 (Figure 4).

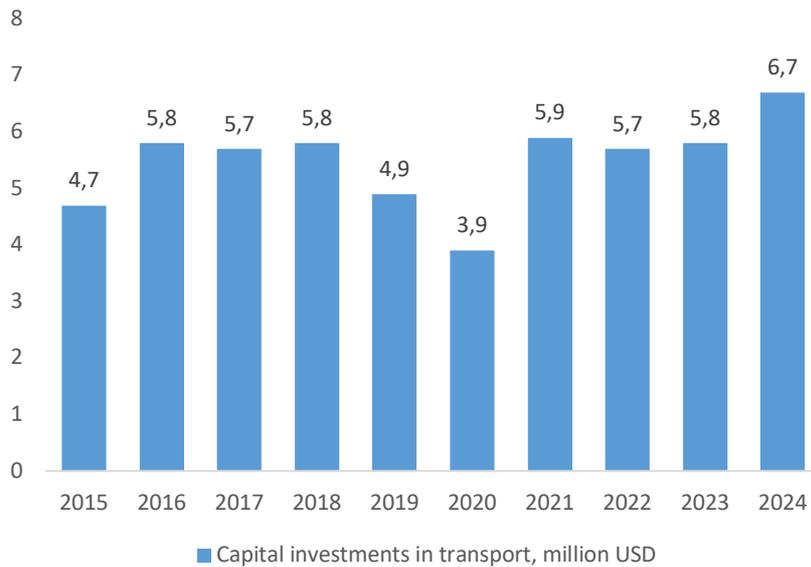
Figure 4. Capital Investments in Transport in India for 2015-2024



Sources: Developed by the authors based on (OECD, 2025; State Statistics Service of Ukraine, 2025; World Bank Group, 2025).

The sharp growth in 2016 (up to \$5.5 milliard) was the result of the implementation of large-scale state infrastructure development programmes. In the following years, the trend continued due to intensive urbanization, increasing needs for population mobility, and modernization of the transport system. Brazil's indicators for this period ranged from \$3.9 to \$6.7 milliard (Figure 5).

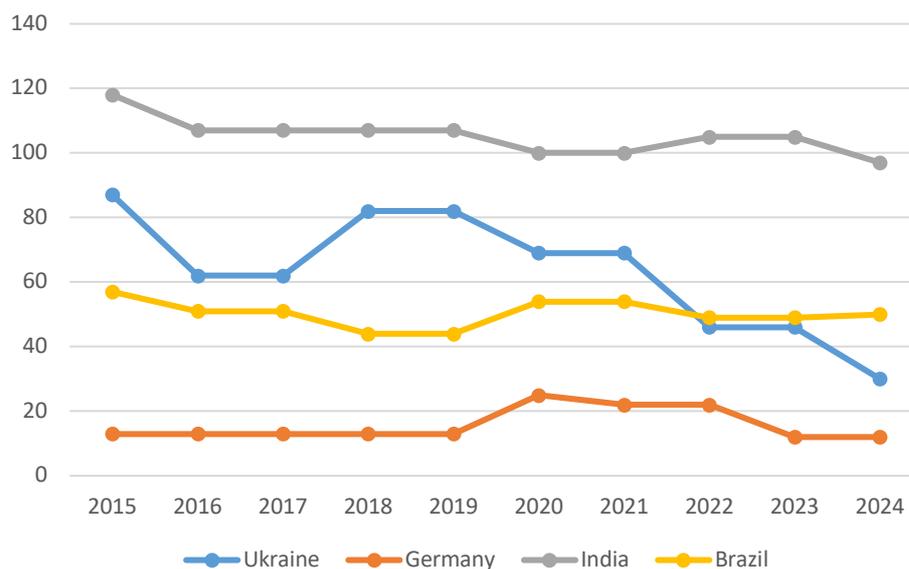
Figure 5. Capital Investments in Transport in Brazil for 2015-2024



Sources: Developed by the authors based on (OECD, 2025; State Statistics Service of Ukraine, 2025; World Bank Group, 2025).

The noticeable decrease in 2020 is explained by the impact of the pandemic, but the highest growth rates were recorded in a decade — in 2024 (Figure 6).

Figure 6. E-Government Indicators (UN E-Government Development Index)



Sources: Developed by the authors based on (OECD, 2025; State Statistics Service of Ukraine, 2025; World Bank Group, 2025).

In general, India stands out for the most active investment dynamics, Germany demonstrates stability and strategic approaches, Ukraine is gradually restoring its positions in the crisis, and Brazil maintains a stable investment volume in the transport sector. The EGDI for 2015–2024 makes it possible to assess the level of digital transformation in selected countries and its possible impact on investment activity in the transport sector. Ukraine demonstrates a clear improvement in its positions: from 87th place in 2015 to 30th in 2024. Particularly noticeable progress after 2020 is associated with the implementation of digital government services, in particular the Diia platform, automation of permitting procedures, and the development of electronic document management. These changes contribute to reducing bureaucratic barriers, increasing the transparency of management processes and creating better conditions for investors in transport infrastructure. Germany has maintained a consistently high position in the EGDI ranking throughout the period (13th place in 2015–2019, 12th place in 2023–2024), which indicates a sustainable digital policy. A developed e-government system ensures transparency of public procurement, effective interaction with business, and favourable conditions for investment in transport.

India is gradually improving its position: from 118th place in 2015 to 97th in 2024. However, the overall level of digitalization remains low, which limits the possibilities of effective interaction of the state with business, in particular in infrastructure projects. Steady but slow progress has been recorded in Brazil: from 57th place in 2015 to 50th in 2024. This indicates limited implementation of digital solutions in public administration, in particular in the transport sector. In general, there is a relationship between the level of digital maturity of the state and institutional attractiveness for investors. High positions in the EGDI rating mean simplification of administrative procedures, accessibility of digital services and openness of data, which is especially important for complex sectors such as transport. For Ukraine, the EGDI growth is a positive signal for potential investors and an indicator of the growing digital capacity of the state.

The next stage of the study is the construction and evaluation of the regression model, the results of the calculation of the regression model are given in Table 6.

Table 6. Results of the Regression Model for Ukraine

Regression Statistics		$Y = 9,591 + 0,001X1 - 0,097X2$		
Multiple R	0,847390548			
R-squared	0,718070741			
Normalized R-squared	0,637519524			
Standard Error	1,298477455			
Indicator	Coefficient	Standard error	t-statistic	P-value
Y-intercept	9,591461225	2,211103024	4,337862652	0,003404953
Variable X 1	0,001355408	0,001621697	0,835796208	0,430870632
Variable X 2	-0,09725393	0,023566221	-4,126836137	0,004421489

Sources: Developed by the authors based on (OECD, 2025; State Statistics Service of Ukraine, 2025; World Bank Group, 2025).

The results of the regression analysis based on data for Ukraine for 2015–2024 show that the coefficient of determination R^2 is 0.718, i.e., the model explains 71.8% of the variation in the GDP of the transport sector. The adjusted R^2 is 0.638, which takes into account the number of independent variables. The value of the F-statistic is 8.91, and the p-value = 0.0119, which indicates the statistical significance of the model as a whole. The interpretation of the model coefficients showed that capital investments have a positive impact on the GDP of the transport sector.

In contrast, the E-Government Index (UN) demonstrates a negative relationship, which is likely explained not by a decrease in digital efficiency, but by a specific context: the decrease in the index in 2022–2024 coincided with the active growth of logistics activities under martial law. So, transport GDP grew not due to digital tools, but due to high demand for physical mobility of resources. This result is important to consider when shaping public policy in the field of transport and digital transformation.

The results of the regression model calculation for Germany are given in Table 7.

Table 7. Results of the Regression Model for Germany

Regression Statistics		$Y = 139,97 + 0,002X_1 - 0,516X_2$		
Multiple R	0.88408043			
R-squared	0.78159821			
Normalized R-squared	0.71919769			
Standard Error	9.85223447			
Indicator	Coefficient	Standard error	t-statistic	P-value
Y-intercept	139.965493	13.15807	10.637230	1.42E-05
Variable X 1	0.00240353	0.00048	5.002797	0.001560
Variable X 2	-0.51681540	0.655552	-0.78837	0.456346

Sources: Developed by the authors based on (OECD, 2025; State Statistics Service of Ukraine, 2025; World Bank Group, 2025).

In the model for Germany, it was found that the GDP of the transport sector depends to a large extent on capital investment. The coefficient of determination ($R^2 = 0.782$) indicates that about 78% of the variation in GDP is explained by the selected factors. Capital investment (X1) has a positive and statistically significant effect ($p = 0.00156$), while the effect of the digital governance index (X2) was statistically insignificant ($p = 0.456$).

This may be determined by the fact that the level of digitalization in Germany is already stable and changes little, or to the fact that the e-government index does not reflect the specifics of the transport sector. Digital technologies probably have a greater impact on logistics and management than directly on GDP.

The results of the regression model for India are given in Table 8.

Table 8. Results of the Regression Model for India

Regression Statistics		$Y = 118,01 + 0,0006X_1 - 0,155X_2$		
Multiple R	0,858657			
R-squared	0,737293			
Normalized R-squared	0,662233			
Standard Error	9,609737			
Indicator	Coefficient	Standard error	t-statistic	P-value
Y-intercept	118,0704	84,04868	1,404785	0,202872
Variable X 1	0,000632	0,000204	3,089992	0,017567
Variable X 2	-0,15534	0,763137	-0,20356	0,844491

Sources: Developed by the authors based on (OECD, 2025; State Statistics Service of Ukraine, 2025; World Bank Group, 2025).

For India, the regression model showed that the GDP of the transport sector is largely dependent on capital investment. $R^2 = 0.737$ means that more than 73% of the changes in GDP are explained by the model. The coefficient on investment is positive and statistically significant ($p = 0.0176$), therefore, financing transport has a direct economic effect. In contrast, the impact of the e-government index was insignificant ($p = 0.844$), which may be due to the fact that digitalization is not the main driver for the growth of the sectoral GDP. The index may not accurately reflect changes in the transport sector itself.

The results of the calculation of the regression model for Brazil are given in Table 9.

Table 9: Results of the Regression Model for Brazil

Regression Statistics		$Y = 2,42 - 0,089X_1 - 0,002X_2$		
Multiple R	0,170422			
R-squared	0,029044			
Normalized R-squared	-0,24837			
Standard Error	0,443591			
Indicator	Coefficient	Standard error	t-statistic	P-value
Y-intercept	2,422947	2,422409	1,000222	0,350516
Variable X 1	-0,08894	0,19762	-0,45003	0,666294
Variable X 2	-0,00194	0,037125	-0,05231	0,959739

Sources: Developed by the authors based on (OECD, 2025; State Statistics Service of Ukraine, 2025; World Bank Group, 2025).

For Brazil, the model showed a very weak relationship between transport GDP and capital investment and the e-government index. R^2 is only 0.029, meaning the model explains less than 3% of the changes in GDP. The coefficients for both variables are insignificant ($p > 0.6$ and $p > 0.9$). The normalized R^2 is negative, which means poor model quality. This indicates that these factors do not significantly affect transport GDP in Brazil or that other factors are more important. The analysis of digital transformation should include other indicators that are more relevant to the transport sector (Table 10).

Table 10: Results of Calculation of Average Annual Growth Rates (CAGR) in 2015–2024

Country	Investment CAGR	CAGR GDP for transport
Ukraine	7,74%	13,70%
Germany	11,26%	3,69%
India	52,05%	4,83%
Brazil	4,02%	-5,04%

Source: Authors' calculations.

The highest growth rates of investments in the transport sector in 2015–2024 were recorded in India (over 52% per year), which is due to large-scale government programs. At the same time, the GDP of the transport sector in India grew by only 4.8% annually, which indicates limited capital efficiency. Ukraine, despite external challenges, demonstrates a balance between investment growth (7.7%) and sectoral GDP growth (13.7%) (Table 11).

Table 11: Results of Calculating the Elasticity of GDP of Transport by Investment (2015–2024)

Country	GDP elasticity of investment
Ukraine	1,61
Germany	0,36
India	0,22
Brazil	-1,30

Source: Authors' calculations.

The Marginal Efficiency of Capital (MEC) differs substantially between digital and physical assets in transport enterprises due to distinct cost structures and scalability effects. Physical assets exhibit diminishing MEC as fleet expansion increases fixed costs, maintenance intensity, and underutilization risks, particularly in mature or demand-volatile transport markets. Digital assets, by contrast, raise MEC by improving asset utilization through route optimization, predictive maintenance, and real-time coordination without proportional increases in physical capital. Digital transformation shifts the investment frontier by enabling transport firms to generate higher returns from smaller physical footprints supported by data-driven operational efficiency. This explains why investment elasticity remains moderate in capital-intensive economies, while digital tools primarily enhance capital productivity rather than expanding physical capacity. Thus, digital investment complements physical capital by elevating MEC, not by replacing infrastructure, but by maximizing returns on existing transport assets.

The elasticity of Ukraine's transport GDP to investment is 1.61, indicating a high sensitivity of the sector's economic growth to the volume of financing. In Germany and India, these indicators are moderate (0.36 and 0.22, respectively), while in Brazil the elasticity is negative, indicating the presence of other constraining factors unrelated to the volume of investment.

Research into the relationship between digital transformation and investment activity in the transport sector shows mixed results for Ukraine, Germany, India, and Brazil. This is explained both by the unevenness of digital progress and differences in the economic structures of the countries in question. In the context of Ukraine, there is a positive dynamic of

attracting investment in transport infrastructure, which to some extent correlates with the growth of the digital index. This connection is explained by the active implementation of digital services, which increase the efficiency and attractiveness of the industry. At the same time, this factor loses its importance during the period of hostilities, giving way to factors of operational mobilization of economic and material resources.

The study of the impact of digital transformation on investment activity in the transport sector shows different results for individual countries. This is determined by the uneven development of digital infrastructure and the specifics of national economies. In Ukraine, positive dynamics of investments in transport are observed against the background of an increase in the digital index. This is partly explained by the introduction of digital services that increase the efficiency of the industry. However, this impact decreased during the military conflict. The mobilization of material and human resources was the main factor in the growth of transport GDP.

In Germany, digital development is at a consistently high level. At the same time, its impact on the transport economy turned out to be insignificant. This may indicate the limited effectiveness of further digitalization without technological breakthroughs. In India, investment activity is growing mainly because of large-scale government programmes. At the same time, digital indicators do not have a significant impact on the transport sector. This indicates a weak integration of digital solutions into the industry system. In Brazil, the digital index did not show a significant relationship with the investment volume in transport. It is likely that the digital transformation in the country has not reached the required level. It is also possible that other macroeconomic factors that determine investment processes dominate.

So, countries should not only strengthen general-purpose digital infrastructure. It is also important to implement applied digital solutions adapted to the needs of the transport industry.

The results of the study indicate differences in the impact of digital transformation on investment activity in transport depending on the national context. In Ukraine, a positive relationship between the EGD I and GDP growth in the transport sector is found. This partially confirms the results of Zhong and Ren (2023), who indicate that digital innovations can enhance efficiency under instability.

At the same time, such an effect is either absent or not statistically significant in Germany, India, and Brazil. Similar results are presented in Wang *et al.* (2023), who proved the importance of state support for digitalization in industries with high barriers to entry. In Germany, despite a high level of digital maturity, EGD I does not affect the change in transport GDP. This indicates a saturation effect similar to that described in Pasichnyi *et al.* (2024). In the case of India, investment in transport increases due to government programmes, not digital factors. This is consistent with the findings of Niu *et al.* (2023), who note that in developing countries, digitalization is not the main driver of development. In Brazil, there was no relationship between EGD I and investment, which is consistent with the position of Feliciano-Cestero *et al.* (2023) on the impact of structural barriers in Latin America. The academic novelty of our study is the comprehensive comparative analysis of four countries with different levels of digital development. We are the first to use EGD I as a variable in a quantitative model for the transport sector. Previous works have focused mainly on the micro level (Guo *et al.*, 2023; Li *et al.*, 2023).

The relevance of this approach is also confirmed in recent studies on public sector management. In particular, Serhieiev *et al.* (2025) emphasize the need for innovative competencies in public administration to ensure sustainable development and financial

efficiency. Such competencies are critically important for the creation of digital infrastructure in transport. Besides, Pasichnyi *et al.* (2024) emphasize that changing socio-economic conditions, including human migration, affect the ability of countries to implement digital reforms. This is relevant for Ukraine, where digitalization is taking place under the conditions of war and loss of human capital. The limitations of the study are the use of only one digital indicator (EGDI) without taking into account industry specifics (for example, the level of automation of transportation). Another limitation is that the regression model does not cover all relevant factors, such as currency policy, the level of corruption or infrastructure programmes. For further research, it is advisable to use additional digital indices (the Digital Economy and Society Index (DESI), the ICT Development Index (IDI)) and analyse individual transport subsectors.

Micro-level investment decisions of transport firms aggregate into national financial sustainability through their cumulative impact on logistics efficiency and cost structures. In transitional economies, efficient transport networks reduce transaction and logistics costs, directly lowering inflationary pressures across goods markets. Lower logistics costs improve export competitiveness and trade balances, strengthening external financial stability and reducing dependence on fiscal or monetary interventions. Digital-enhanced transport investments amplify this effect by increasing capital productivity, allowing macroeconomic gains without proportionate growth in public infrastructure spending. Thus, micro-level digital and physical investment efficiency functions as an indirect stabilizer of national financial sustainability.

In contrast to the stable level of digital maturity in Germany, Ukraine demonstrates dynamic growth of EGDI in wartime conditions, accompanied by active development of e-services. Compared to Brazil, where digitalization is developing fragmentarily, in Ukraine digital solutions have become one of the tools for resource mobilization. India, although it has the fastest investment rate, still demonstrates weak integration of digital technologies into the transport sector. Thus, Ukrainian companies, although operating in conditions of limited resources, demonstrate high potential for digital adaptation, which favourably distinguishes them in the international context.

Conclusion

The results of the study confirm that digital transformation has a complex and ambiguous impact on the investment activity of transport enterprises. Empirical data indicate significant variability of this impact depending on the country and the level of digital maturity. In Ukraine, positive dynamics of attracting investments in the transport sector have been recorded. This is partly due to the intensification of digital reforms, in particular the implementation of e-government. However, during the military conflict, there is a shift in priorities towards the physical mobilization of resources. Such a context reduces the weight of digital factors in the structure of influence on the sectoral GDP.

Germany demonstrates a consistently high level of digitalization, but no statistically significant impact of the digital index on transport GDP has been identified. This indicates a saturation effect, in which additional digitalization does not provide significant economic growth without innovative breakthroughs. In India, the main driver of investment growth is state infrastructure programmes. At the same time, digital indicators are not decisive for the economic development of the transport industry. In Brazil, a low correlation between digital indicators and investment activity was found, which is caused by structural constraints and low

digital integration. So, digital transformation is not a universal tool for stimulating investment. Its effectiveness can be increased by taking into account industry specifics, institutional conditions, and the level of technical readiness.

According to the author, in times of instability, digital transformation plays the role not only of an efficiency tool, but also of a means of adaptation to new realities. It is in times of crisis that digital services can ensure flexibility, transparency and sustainability of transport enterprises. For countries with high risks (such as Ukraine), digital solutions are often the only way to maintain investment attractiveness. The conditions of change, in particular global crises and military actions, have significantly affected investment processes in transport, changing the priorities of enterprises: from long-term innovative development to ensuring sustainability and mobility.

Credit Authorship Contribution Statement

Sakhno, D. contributed to the conceptualization of the study, validation of the research framework, and overall project administration. Zgalat-Lozynska, L. was responsible for the investigation, development of the research methodology, and writing - review and editing of the manuscript. Rybak, I. provided supervision of the research process and contributed to data visualization. Mukha, T. conducted the formal analysis and was responsible for data curation. Medyna, A. prepared the original draft of the manuscript and developed the software components used in the analysis. All authors reviewed and approved the final version.

Conflict of Interest Statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Data Availability Statement

The data supporting the findings of this study are derived from publicly available sources, including the OECD, World Bank, United Nations E-Government Survey, and the State Statistics Service of Ukraine. The datasets used and analysed during the current study are available from these official databases and from the corresponding author upon reasonable request.

Ethical Approval Statement

This study was conducted in accordance with accepted standards of academic research ethics. The analysis relied exclusively on publicly available secondary data from international and national statistical databases, including the OECD, World Bank, United Nations E-Government Survey, and the State Statistics Service of Ukraine. No human participants or personal data were involved; therefore, formal ethical approval was not required. All data were used in aggregated form and properly cited to ensure transparency and research integrity.

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