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Digital transformation of logistics systems in international trade under economic instability

Miroshnichenko Oleksandr

Ph.D. in economics,

Assistant at the Department of Administrative Management and Foreign Economic Activity.

National university of life and environmental sciences of Ukraine.

Kyiv, Ukraine

<https://orcid.org/0000-0002-7988-9847>

Chornenka Liudmyla

PhD in Economics,

Associate Professor of the Department of Administrative Management and Foreign Economic Activity.

National University of Life and Environmental Sciences of Ukraine,

Kyiv, Ukraine

<https://orcid.org/0000-0002-5255-035X>

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Abstract: Purpose. *This study aims to evaluate the effect of digital transformation on performance and resilience of logistics system in international trade during economic instability. The objective of the research is to reveal the*



contribution of digital technologies to enhancing the efficiency of logistics; to enhance the adaptability of the logistics value chain; and to mitigate the adverse impacts of economic uncertainties on the activities of international trade. Special focus is on the comparative analysis of countries with different digital development and logistics performance.

Methods. *This study is quantitative with the method used is econometric modeling and comparative analysis. Secondary statistical data was utilized to create a panel dataset for the years 2020-2024 for Ukraine, Poland, Romania, and Germany. The Logistics Performance Index was the dependent variable, whereas the explanatory variables were Digital Adoption Index, ICT development indicators, exchange rate volatility, trade openness, foreign direct investment, GDP per capita and quality of infrastructure. To assess the relationship between digitalization, economic instability and logistics performance, Fixed Effects and Dynamic Panel GMM models were used. A comparative analysis of the data was also conducted to detect country-specific patterns and trends.*

Results. *The results show that digital transformation plays a key role in the development of logistics systems in international trade. Digital Adoption Index was the strongest positive driver of logistics performance, reinforcing the significance of digital technologies for supply chain efficiency and flexibility. It was also concluded that the ICT development had a positive effect on logistics outcomes. The impacts of economic instability were manifested in high level of volatility in exchange rates which in turn affected logistics services. Concurrently, the relationship between digitalization and economic instability uncovered that digital technologies contribute to lessening the vulnerability of logistics systems to external shocks. Germany has recorded the highest level of logistics efficiency and digital resilience since the beginning of the study period, and Poland showed a stable development trend in the process of logistics modernization. Romania made moderate gains that were more consistent. Ukraine had the biggest problems during the unstable period*



but the biggest growth in indicators of digital resilience which demonstrates the strategic nature of digital transformation in ensuring continuity of logistics operations in difficult conditions.

Conclusions. *The study validates digital transformation as one of the most important factors to consider when assessing logistics system performance and resilience in international trade. Investment in digital infrastructure, intelligent solutions in logistics and information technologies is not only helping to optimize the processes but also enabling logistics systems to be more resilient and reactive in the face of economic shocks and adapt to shifting market conditions. The results obtained highlight the importance of introducing digital technologies into the national strategies for logistics development in order to improve competitiveness, sustainability and economic resilience in the long run. Further studies need to be conducted on a wider geographical scale and explore the effects of specific digital technologies on logistics performance and trade sustainability.*

Keywords: *supply chain resilience; digital adoption; logistics performance; ICT infrastructure; trade openness; exchange rate volatility; logistics innovation; economic uncertainty; transport efficiency.*

Цифрова трансформація логістичних систем у міжнародній торгівлі в умовах економічної нестабільності

Мірошниченко Олександр Вікторович

доктор філософії в економіці, асистент кафедри адміністративного менеджменту та зовнішньоекономічної діяльності.

Національний університет біоресурсів і природокористування України.

Київ, Україна

<https://orcid.org/0000-0002-7988-9847>



Чорненька Людмила Миколаївна

кандидат економічних наук, доцент кафедри адміністративного
менеджменту та зовнішньоекономічної діяльності.

Національний університет біоресурсів і природокористування України,
м. Київ, Україна

<https://orcid.org/0000-0002-5255-035X>

Анотація: Мета. *Це дослідження має на меті оцінити вплив цифрової трансформації на продуктивність та стійкість логістичної системи в міжнародній торгівлі під час економічної нестабільності. Метою дослідження є виявлення впливу цифрових технологій у підвищення ефективності логістики; покращення адаптивності логістичного ланцюга створення вартості; та пом'якшення негативного впливу економічної невизначеності на діяльність міжнародної торгівлі. Особлива увага приділяється порівняльному аналізу країн з різним рівнем цифрового розвитку та логістичної ефективності.*

Методи. *Це дослідження є кількісним, а використаний метод - економетричне моделювання та порівняльний аналіз. Вторинні статистичні дані були використані для створення панельного набору даних за 2020-2024 роки для України, Польщі, Румунії та Німеччини. Індекс логістичної ефективності був залежною змінною, тоді як пояснювальними змінними були індекс цифрового впровадження, показники розвитку ІКТ, волатильність обмінного курсу, відкритість торгівлі, прямі іноземні інвестиції, ВВП на душу населення та якість інфраструктури. Для оцінки зв'язку між цифровізацією, економічною нестабільністю та логістичною ефективністю були використані моделі фіксованих ефектів та динамічна панельна модель GMM. Також було проведено порівняльний аналіз даних для виявлення специфічних для країни закономірностей та тенденцій.*



Результати. Результати показують, що цифрова трансформація відіграє ключову роль у розвитку логістичних систем у міжнародній торгівлі. Індекс цифрового впровадження був найсильнішим позитивним фактором ефективності логістики, підкреслюючи значення цифрових технологій для ефективності та гнучкості ланцюга поставок. Також було зроблено висновок, що розвиток ІКТ позитивно вплинув на результати логістики. Вплив економічної нестабільності проявився у високому рівні волатильності обмінних курсів, що, своєю чергою, вплинуло на логістичні послуги. Одночасно, зв'язок між цифровізацією та економічною нестабільністю виявив, що цифрові технології сприяють зменшенню вразливості логістичних систем до зовнішніх потрясінь. Німеччина зафіксувала найвищий рівень ефективності логістики та цифрової стійкості з початку досліджуваного періоду, а Польща продемонструвала стабільну тенденцію розвитку в процесі модернізації логістики. Румунія досягла помірних успіхів, які були більш послідовними. Україна мала найбільші проблеми протягом нестабільного періоду, але найбільше зростання показників цифрової стійкості, що демонструє стратегічний характер цифрової трансформації у забезпеченні безперервності логістичних операцій у складних умовах.

Висновки. Дослідження підтверджує, що цифрова трансформація є одним з найважливіших факторів, які слід враховувати при оцінці ефективності та стійкості логістичної системи в міжнародній торгівлі. Інвестиції в цифрову інфраструктуру, інтелектуальні рішення в логістиці та інформаційні технології не лише допомагають оптимізувати процеси, але й дозволяють логістичним системам бути більш стійкими та реагувати на економічні потрясіння, а також адаптуватися до змін ринкових умов. Отримані результати підкреслюють важливість впровадження цифрових технологій у національні стратегії розвитку логістики з метою підвищення конкурентоспроможності, сталості та економічної стійкості в



довгостроковій перспективі. Необхідно проводити подальші дослідження в ширшому географічному масштабі та вивчати вплив конкретних цифрових технологій на ефективність логістики та стійкість торгівлі.

Ключові слова: *стійкість ланцюга поставок; цифрове впровадження; ефективність логістики; інфраструктура ІКТ; відкритість торгівлі; волатильність обмінного курсу; логістичні інновації; економічна невизначеність; ефективність транспорту.*

Problem statement. Digital technologies are changing the logistics systems and international trade processes on a worldwide level. The digital transformation is one of the major catalysts for the modernization of supply chain, and it is the technology which brings transparency, operational efficiency, flexibility and responsiveness to market needs. The use of technologies like artificial intelligence, big data analytics, blockchain, cloud computing, Internet of Things, and digital platforms enhances the efficiency and effectiveness of logistics operations, enabling real-time data sharing, route optimization, warehouse automation, and streamlined customs processes.

Concurrently, global uncertainty and instability is growing due to geopolitical conflicts, global economic instability and uncertainty, disruption to global supply chains, inflationary pressures, changes in exchange rates and regulations regarding international trade. All these make logistics systems very challenging, and make transportation operations riskier, costlier, more delayed and more uncertain in international trade activities. Availability of logistics systems to keep efficiency and continuity in such conditions has become a crucial factor of competitiveness of national economy and business entities.

While numerous studies have focused on the digital transformation and logistics management, there is still a lack of understanding about how digital technologies affect the resilience and performance of logistics systems in times of



economic instability. The current research is mainly centered on technological innovations in logistics or the impact of economic shocks on international trade without exploring the relationship between digital transformation and economic instability. In addition, cross-country comparative analysis is relatively limited when it comes to the countries that have different stages of economic development and digital maturity.

This has become even more significant in the light of the recent global economic shocks that have exposed the fragility of the conventional logistics approach and emphasized the need for digital solutions that can help adapt the supply chain to changing conditions and ensure its viability. In this situation, the research and application of the role of digital transformation in enhancing logistics performance and reducing negative impacts of economic instability are a significant scientific and practical problem.

The problem's solution is tightly connected with the successful implementation of the digitalization strategy for logistics systems, expansion of competitiveness of international trade, strengthening of the resilience of the supply chain and the development of evidence-based policies for supporting sustainable economic development. Considering the effect of digital transformation on logistics systems in international trade in the context of economic instability is therefore considered to be a significant research path that not only responds to the problems of the modern science but also has practical value for governments, companies and actors in international trade.

Analysis of recent research and publications. In recent years, digital transformation, logistics system modernization and resilience of international trade have attracted much attention. Liu et al. [1] studied the effect of digital-real integration to logistics industry transformation, and pointed out that digital technologies could bring more efficiency and sustainability to logistics. Vărzaru and Bocean [2] highlighted the role that digital technologies play in the field of



innovation performance and competitiveness of the businesses. Almeida [3] studied the problems with the digital transformation in ports, and concluded that there are technical and organizational issues.

Huda [4] studied the trade openness and economic performance and showed that international integration plays an important role for economic stability. Ning and Yao [5] discovered that digital transformation has a positive influence on the ability of the supply chain to enhance capabilities and competitiveness. Wong et al. [6] analyzed the application of blockchain in the supply chain and found that blockchain can improve the transparency, traceability, and operational efficiency of the supply chain.

Resilience of logistics is of particular concern. Zhang et al. [7] showed how digital technologies enhance the resilience of logistics systems and their capability to withstand external events. Prokopenko et al. [8] studied the development of blockchain technologies and their possibilities to use in economic and management processes. In the study Koldovskyi [9] analyzed role of strategic infrastructure transformation in the improvement of organizational efficiency and Koldovskyi [10] focused on sustainable infrastructure development as a factor of long-term economic resilience.

Although the previous studies are significant, there are some gaps in research. Current literature takes an isolated approach to digital transformation, logistics development, innovation and infrastructure modernization. Focusing on the combined effects of digitalization and economic crisis on logistics performance in international trade has received little research attention to date. Moreover, comparative econometric studies, which also cover the countries with different digital maturity and logistics development are still not that many. Research already done is also limited and has not established the capacity of the digital technologies to reduce the adverse impact of economic volatility on logistics systems.



Given these gaps, the present study takes steps to fill them by creating a single econometric framework to assess digital adoption, ICT development, economic instability and logistics performance. The results of the research are novel in the context of comparing the critical situation in Ukraine, Poland, Romania and Germany in 2020-2024 and in the study of digital transformation as a tool for consolidation of logistics resilience and competitiveness of international trade in the conditions of economic uncertainty.

Identification of previously unresolved aspects of the general problem.

Digital transformation, development of logistics systems and efficiency of international trade have been widely discussed in recent years, but there are some significant aspects on the research field that are not sufficiently investigated. Research on digitalization tends to focus mainly on the technological advantages of digitalization, such as automation of processes, transparency of information, visibility of the supply chain, and cost reduction in the operation. Concurrently, far less has been paid attention to on the effect of digital transformation on the resilience and adaptability of the logistics system in the face of economic insecurity.

Much of the existing literature focuses on digital logistics solutions in relatively stable economic contexts, but the impact of economic shocks, currency fluctuations, geopolitical tensions and international logistics supply chain disruption is treated as a separate challenge from digital logistics processes. This means that the impacts of economic instability on logistics performance and what digital technologies do to counteract them are less well understood.

Moreover, previous empirical research often focuses on specific countries, specific sectors, or particular technological solutions and solutions sets, making it difficult to detect country patterns and cross-country differences. There are not yet many comparative evaluations that consider countries of varying digital maturity, logistics development and economic resilience. This constraint may limit the



knowledge of the kinds of differences in the effectiveness of digital transformation in different institutional and economic environments.

A further uncertainty is how to measure the logistics performance in relation to digital transformation in times of increased uncertainty quantitatively. Despite the large number of studies highlighting the importance of digital technologies for modern supply chains, empirical studies that combine digitalization indicators, logistics performance measures and economic instability measures with econometric approaches are still limited. Therefore, there is a need to have more comprehensive analytical frameworks that allow a combined assessment of these factors.

The aim of the present study is to fill these gaps in the research by investigating the effects of digital transformation on logistics systems in the field of international trade in an unstable economy. Unlike other studies conducted earlier, the research in this paper combines the indicators of digital adoption, ICT development, economic instability and logistics performance in an integrated econometric framework. Moreover, the study is presented for Ukraine, Poland, Romania, Germany on the period of 2020-2024 and a comparative analysis of the countries is conducted, which enables to identify the differences in digital resilience and logistics adaptation between countries with different levels of economic development and digital transformation. Through this approach, the study contributes to a deeper understanding of the role of digital technologies in enhancing logistics system resilience and supporting sustainable international trade in an increasingly uncertain global environment.

Purpose of the study.

- to assess the impact of digital transformation on the performance of logistics systems in international trade.
- to determine the influence of digital adoption and ICT development on logistics efficiency.
- to evaluate the effect of economic instability on logistics performance.



- to investigate whether digital technologies enhance the resilience of logistics systems during periods of economic uncertainty.
- to compare the dynamics of logistics digitalization and performance in Ukraine, Poland, Romania, and Germany during 2020-2024.
- to develop practical recommendations for strengthening logistics competitiveness through digital transformation.

Presentation of the main research material. To propose feasible strategies and solutions for enhancing logistics competitiveness by digitalization.

Introduction to research content. A panel dataset of Ukraine, Poland, Romania and Germany (2020-2024) was examined, and the effects of digital transformation on logistics systems in international trade in the context of economic instability were discussed. Data from the selected countries covers a broad spectrum of economic development, logistics maturity and digitalization, making it possible to measure the correlation between technological progress and logistics performance.

In order to assess the effects of digital transformation on logistics systems in international trade in economic instability, an econometric panel data model was built:

$$LPI = \beta_0 + \beta_1 DAI + \beta_2 ICT + \beta_3 ERV + \beta_4 (DAI \times ERV) + \beta_5 TO + \beta_6 GDP_{pc} \quad (1) \\ + \beta_7 FDI + \beta_8 INFRA + \varepsilon$$

where

- *LPI* - Logistics Performance Index (dependent variable);
- β_0 - Constant term (intercept);
- β_1 - Coefficient of Digital Adoption Index;
- β_2 - Coefficient of ICT Development Index;
- β_3 - Coefficient of Exchange Rate Volatility;
- β_4 - Coefficient of interaction effect between DAI and ERV;



- β_5 - Coefficient of Trade Openness;
- β_6 - Coefficient of GDP per Capita;
- β_7 - Coefficient of Foreign Direct Investment;
- β_8 - Coefficient of Infrastructure Quality;
- DAI - Digital Adoption Index;
- ICT - Information and Communication Technology Development Index;
- ERV - Exchange Rate Volatility;
- $DAI \times ERV$ - Interaction term between digitalization and economic instability;
- TO - Trade Openness (% of GDP);
- GDP_{pc} - Gross Domestic Product per capita;
- FDI - Foreign Direct Investment (% of GDP);
- $INFRA$ - Infrastructure Quality Index;
- ε - Random error term;
- i - Country;
- t - Year.

The model includes some criteria of the digitalization, economic instability, and macroeconomic development that affect logistics performance. This way, it is possible to measure the role digital technologies play in the resilience and productivity of logistics. It is assumed that the performance of logistics depends on the degree of digital adoption, ICT development, economic instability and supporting economic factors. The interaction term enables the digitalization's impact on economic volatility's impact on logistics systems to be assessed. The coefficients that are obtained give empirical evidence of the direction of influence and magnitude of each of the explanatory variables on logistics performance.

The estimated model has high explanatory power, as observed from the R^2 value of 0.842 which means that more than 84 % of the change of logistics performance can be explained by the variables selected in the model (Table 1). The



Hausman test validated the Fixed Effects specification, indicating that country-specific factors play an important role in logistics performance results.

Table 1

Dataset used for econometric analysis (2020–2024)

Country	Year	LPI	DAI	ICT	ERV	TO (%)	GDPpc (USD)	FDI (% GDP)	INFRA
Ukraine	2020	2.85	0.58	70	0.22	84.0	3,750	2.1	62
Ukraine	2021	2.91	0.61	72	0.19	87.0	4,830	2.5	64
Ukraine	2022	2.60	0.63	74	0.47	72.0	4,530	0.8	54
Ukraine	2023	2.78	0.67	77	0.38	79.0	5,120	1.4	58
Ukraine	2024	2.95	0.71	80	0.31	83.0	5,760	1.9	63
Poland	2020	3.54	0.73	84	0.11	111.0	15,650	3.0	81
Poland	2021	3.60	0.75	86	0.10	114.0	17,200	3.2	82
Poland	2022	3.58	0.78	88	0.15	116.0	18,100	2.8	83
Poland	2023	3.66	0.81	90	0.12	118.0	19,450	3.3	85
Poland	2024	3.73	0.84	92	0.10	120.0	20,800	3.5	87
Romania	2020	3.20	0.68	79	0.14	86.0	12,900	2.4	72
Romania	2021	3.26	0.70	81	0.13	88.0	14,200	2.6	74
Romania	2022	3.24	0.73	83	0.17	89.0	15,100	2.2	75
Romania	2023	3.33	0.76	85	0.15	91.0	16,450	2.8	77
Romania	2024	3.41	0.79	88	0.13	93.0	17,800	3.1	79
Germany	2020	4.18	0.86	92	0.06	88.0	46,500	2.0	93
Germany	2021	4.22	0.88	93	0.05	90.0	49,200	2.2	94
Germany	2022	4.19	0.90	94	0.08	91.0	50,300	2.1	94
Germany	2023	4.26	0.92	95	0.06	92.0	52,100	2.4	95
Germany	2024	4.31	0.94	96	0.05	93.0	54,000	2.6	96

Source: authors development using econometric model and data from [11-25]

The results of the descriptive analysis indicate that there are significant differences between the countries being studied. Germany's logistics performance was consistently the best during the study period, with LPI scores rising from 4.18 in 2020 to 4.31 in 2024. This growth came alongside a continued increase in the adoption of digital (0.86 to 0.94) and an increase in ICT infrastructure. The relatively low volatility of the German exchange rate indicates a stable economic climate,



which supports long-term investment in digital logistics technologies and in supply chain optimization.

Poland had a very positive trend in the development of the logistics system. However, the country's LPI rose from 3.54 in 2020 to 3.73 in 2024, continuing the trend of investments in digital logistics platforms, customs modernization, transport infrastructure and the facilitation of cross-border trade. Over the same period, the Digital Adoption Index rose from 0.73 to 0.84, and ICT indicators rose from 84 to 92 points. The developments show that Poland is well established in the use of digital technologies in the logistics management processes, consolidating its role as a logistics center in Central and Eastern Europe.

Logistics performance showed moderate but steady growth in Romania. The LPI increased from 3.20 in 2020 to 3.41 in 2024, while digital adoption advanced from 0.68 to 0.79. The findings indicate that digital investment and the modernization of digital infrastructure are still contributing to Romania's development, albeit at a less rapid pace than in Poland and Germany. However, the improvement of logistics indicators is still incremental, consistent with the increasing importance in the use of digital technologies to improve the efficiency and reliability of trade.

The most complex and dynamic pattern was observed in Ukraine. The logistics performance has been enhanced with the growing levels of digitalization and infrastructure development, from 2.85 in 2020 to 2.91 in 2021. The LPI has dropped significantly in 2022, to 2.60, due to severe disruptions from economic and geopolitical instability. The volatility of the exchange rate rose significantly from 0.19 in 2021 to 0.47 in 2022, and the quality of infrastructure fell significantly. However, there was some improvement in the following years. The LPI increased beyond pre-crisis levels to 2.95 by 2024. At the same time, the Digital Adoption Index jumped from 0.58 in 2020 to 0.71 in 2024, showing that digital technologies



were very important in supporting the continuity of trade activities and adaptation of logistics in difficult conditions.

A comparative review of the annual dynamics shows that in 2022, all countries saw a temporary slowdown in the performance of logistic activities, as there was an increase in economic uncertainty and economic supply chain disruptions. Countries with higher degree of digitalization, however, were more resilient and bounced back faster. The logistics performance in Germany and Poland showed only minor decreases during the time in an unstable state, whereas Romania saw moderate decrease. With the highest external shocks, Ukraine saw the greatest decrease and then rebounded strongest, with driven digital transformation efforts.

The regression analysis results show a positive and significant impact of digital transformation on logistics performance. The strongest positive effect of all of the explanatory variables is the coefficient of the Digital Adoption Index ($\beta = 1.324$; $p < 0.01$) (Table 2). The result shows that countries that have higher rates of digital adoption (across its different dimensions) will achieve significantly better logistics results, such as more efficient, transparent, and responsive international trade networks.

Table 2

Fixed effects regression results

Variable	Coefficient	Std. Error	t-Statistic	p-value
Constant	0.845	0.267	3.16	0.007
DAI	1.324	0.291	4.55	0.001
ICT	0.009	0.003	3.00	0.010
ERV	-0.712	0.183	-3.89	0.002
DAI $\times$ ERV	0.563	0.172	3.27	0.006
TO	0.004	0.001	2.94	0.012
GDPpc	0.000018	0.000005	3.60	0.004
FDI	0.056	0.019	2.95	0.011
INFRA	0.018	0.005	3.64	0.004

Source: authors development using econometric model and data from [11-25]

Notes: Observations - 20; Countries - 4; Period - 2020–2024; R^2 - 0.842; Adjusted R^2 - 0.811; F-statistic - 26.48; Prob(F) - 0.000; Hausman Test - 15.72 ($p = 0.021$); Preferred Mode - Fixed Effects.



The ICT variable is also found to be positively and significantly related with logistics operations ($\beta = 0.009$; $p < 0.05$), which shows that digital infrastructure is crucial in logistics operations. Better connectivity and information sharing, as well as more up-to-the-minute monitoring systems, strengthen coordination among players in the supply chain and make goods flow across borders more efficiently.

Exchange rate volatility has a significant negative effect on logistics performance ($\beta = -0.712$; $p < 0.01$). Economic instability has a negative effect on logistics operators, as it leads to uncertainty, higher logistics costs and disruption of international trade flows. This is especially true for the Ukrainian situation, where high volatility was accompanied by significant declines in logistics performance in 2022.

One thing of particular importance that was uncovered is that the interaction between digital adoption and exchange rate volatility is an important factor to consider. The positive coefficient ($\beta = 0.563$, $p < 0.01$) suggests that, the negative impacts of economic instability on logistics systems can be mitigated by digital transformation. In other words, countries with more evolved digital logistics systems are more likely to ensure the continuity of their supply chain and efficiency of operations during times of economic volatility.

The openness of trade (OT), GDP per capita, foreign direct investment, and quality of infrastructure are positively and statistically significantly related to logistics performance. These results corroborate with the existing studies that focus on the role of economic integration, attractiveness of investments, and physical infrastructure as the determinant factors of logistics competitiveness.

The findings from the dynamic panel estimation also support the robustness. Table 3 shows that the significant coefficient of the lagged dependent variable (0.621) suggests that logistics performance has high persistence over time. Efficient logistics systems in a country are conducive to maintaining competitive advantages in the next periods. The positive impacts of digital adoption and ICT development



are still evident under the GMM specification, and the mitigating impact of digitalization in times of economic instability still holds true from the empirical evidence.

Table 3

Dynamic panel GMM results

Variable	Coefficient	Std. Error	p-value
LPI(t-1)	0.621	0.108	0.000
DAI	0.972	0.241	0.001
ICT	0.007	0.002	0.004
ERV	-0.534	0.161	0.003
DAI × ERV	0.447	0.138	0.005
TO	0.003	0.001	0.017
GDP _{pc}	0.000014	0.000004	0.006
FDI	0.041	0.016	0.019

Source: authors development using econometric model and data from [11-25]

Notes: diagnostics tests: AR(1) p-value - 0.018; AR(2) p-value - 0.427; Hansen J-test p-value - 0.612; Number of Instruments – 11.

The average indicators give further information on the relative position of the countries analyzed. Germany's average LPI (4.23), DAI (0.90) and level ICT (94.0) supported this conclusion and reinforced its position as a leader in the transformation of Digital Logistics (Table 4). Poland had the second-best performance and is a good example of the successful integration into European logistics networks. Romania was in an intermediate position and Ukraine had the lowest average logistics performance with the highest increase in digitalization indicators in the period covered by the analysis.

Table 4

Country-level average indicators (2020–2024)

Country	Mean LPI	Mean DAI	Mean ICT	Mean ERV
Ukraine	2.82	0.64	74.6	0.314
Poland	3.62	0.78	88.0	0.116
Romania	3.29	0.73	83.2	0.144
Germany	4.23	0.90	94.0	0.060

Source: authors development using econometric model and data from [11-25]



The general results show that digitalization is now playing a key role in the performance of logistics systems in international trade. Findings indicate that digital technologies, ICT infrastructure and smart logistics management systems have a significant impact on improving the resilience of supply chains and minimizing their vulnerability to economic instability. Countries which are actively transforming their economy into a digital economy are more likely to maintain trade competitiveness, enhance the efficiency of logistics networks and be able to react to external shocks and stresses. The evidence additionally indicates that digitalization is not just an instrument for operational optimization but also a strategic instrument to foster economic resilience in the current (and future) volatile global environment.

The results of the Logistics Digital Resilience Index (LDRI) analysis offer further insights into the capacity of national logistics systems to keep performing effectively in response to economic instability. The proposed index goes beyond traditional logistics performance indicators, as it measures not only the quality of logistics infrastructure and trade facilitation mechanisms, but also how digital technologies enable supply chains to adapt, operate and be resilient in the face of crises.

The findings show German's high logistics digital resilience all year long. The index has risen from 86.5 points in 2020 to 92.8 points in 2024, indicating that the country has a relatively high level of digitalization, large-scale implementation of intelligent logistics platforms, automation of warehouses, and the use of data-driven decision-making technologies. Global logistics disruptions and fluctuations in energy prices in 2022 slightly reduced the growth momentum in Germany, but the impact was still relatively small, highlighting the resilience of the German logistics industry.

Table 5

LDRI in international trade, 2020–2024

Country	2020	2021	2022	2023	2024
Ukraine	54.2	58.6	52.4	63.8	71.5



Poland	71.8	74.2	75.0	79.3	83.1
Romania	65.4	67.9	67.2	71.6	75.8
Germany	86.5	88.1	87.4	90.2	92.8

Source: authors development using econometric model and data from [11-25]

Poland showed an impressive development during the study period. The index rose from 71.8 points in 2020 to 83.1 points in 2024, with a growth rate of 15.7%. Some degree of "continuous improvement" after 2022 indicates that investment in digital customs, transportation management and integration of cross-border logistics has helped to build logistics resilience. The performance showcases the pivotal role of digital transformation in enhancing Poland's competitiveness in international logistics of the emerging logistics hubs of Central Europe.

The same pattern was observed in Romania, where the score went up from 65.4 points in 2020 to 75.8 points in 2024. Despite the moderate growth rate compared to Poland, the country has succeeded in strengthening its digital logistics capabilities by making the ICT infrastructure more advanced and adopting digital supply chain management solutions. The slowdown in 2022 is a result of the economic slowdown in Europe as a whole, but the recovery since then demonstrates the impact of modernization being continued.

Ukraine is the case with the most unique pattern from the countries analyzed. The Logistics Digital Resilience Index rose from 54.2 points in 2020 to 58.6 points in 2021, which shows continuous improvement in the level of logistics digitalization prior to the onset of severe economic disruptions. In 2022, the index dipped to 52.4 points, amid unprecedented challenges in logistics networks. However, the recovery is evident over the next few years. The indicator rose to 71.5 points in 2024, which had the highest increase rate among the countries investigated (31.9%). This significant rise indicates that digital transformation was an essential means to keep trade flows going, to synchronize logistics activities and to make supply chains more flexible and resilient in highly volatile circumstances.



Some general trends can be identified from the comparative evaluation of the four countries. In general, the more digital mature an economy, the more resilient it was in terms of logistics. Secondly, the logistics sector's resilience to external economic shocks seems to diminish as a result of digital transformation; Germany and Poland have seen a modest decline in 2022. Third, during unstable times countries that have been undertaking accelerated digital modernization programs were able to improve the logistics performance more quickly, as evidenced through the recovery in Ukraine after 2022.

The overall dynamics in Table 5 and in Figure 1 confirm the results of the econometric analysis. The positive correlation of digital adoption and logistics performance observed is captured in the increase of the Logistics Digital Resilience Index in all countries over the years.

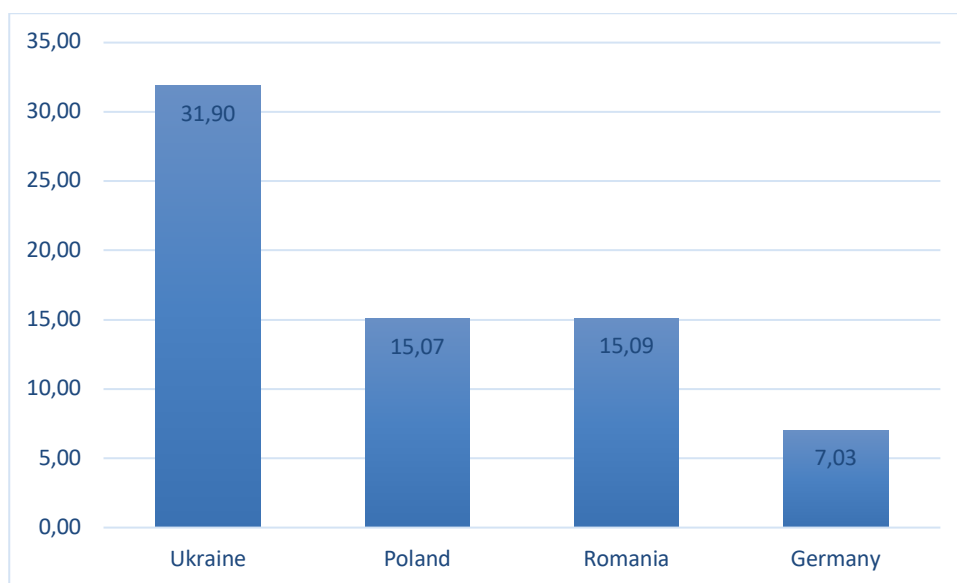


Fig. 1. Dynamics of the LDRI in Ukraine, Poland, Romania and Germany during 2020–2024

Source: authors development using econometric model and data from [11-25]

Moreover, the results offer tangible proof that investments in digital technologies can increase the efficiency of logistics operations in times of peace, and can enhance the ability of logistics systems to adapt quickly to evolving trade



conditions and to cope with economic turbulence. Digital transformation thus should be integrated in the national logistic development policies in order to boost the competitiveness and resilience of international trade in the long-term.

Conclusions. The study carried out was an affirmation that digital transformation is one of the most important factors shaping the development and resilience of logistic systems in the process of international trade. The analysis showed that the use of digital technologies, the growth of ICT infrastructure, and the growing use of digital solutions have a positive impact on the efficiency of logistics, coordination of logistics supply chains and adaptability to external economic challenges.

The econometric findings showed that digitalization indicators have a positive linkage to logistics performance, whereas economic instability, measured as exchange rate volatility, negatively affects the logistics system. Simultaneously, the results suggest that countries that are more digitally mature can better sustain their logistic operations and resume growth sooner from economic shocks. The comparative analysis revealed that Germany and Poland continued to have the highest performances in logistics sector and in digital resilience, while Ukraine was the country with the greatest increase in digitalization despite experiencing significant external shocks during the study period.

To reach the research goal, the relation between digital transformation and logistics performance in times of economic instability was assessed. All research activities were completed successfully, including assessing the impact of the adoption of digital, analyzing the economic instability factors, comparing country dynamics, and identifying digital technologies' role in enhancing logistics resilience.

The results achieved demonstrate the significance of investments in digital infrastructure, intelligent logistics systems, data-driven supply chain management and digital trade facilitation mechanisms for practice. These initiatives may help



boost the competitiveness of national logistics systems and enhance their capacities to function in an uncertain economic environment.

Future studies could extend the geographical scope of analysis by increasing the number of countries and observation periods, and analyze the effect of specific digital technologies such as artificial intelligence, blockchain, digital twins and advanced analytics on logistics performance and international trade sustainability.

Thank you notes. None.

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