Management (Montevideo). 2025; 3:257
doi: 10.62486/agma2025257
ISSN: 3046-4048

ORIGINAL

The Metamorphosis of Global Trade Routes: Immediate Challenges and Advanced Logistics Techniques

La metamorfosis de las rutas comerciales mundiales: Retos inmediatos y técnicas logísticas avanzadas

Mykyta Hordieiev[1], Nataliia Nalyvaiko[2], Oksana Parkhomenko-Kutsevil[3], Ruslan Molyboha[4], Andriy Chabanov[5]

[1]Danube Institute of Water Transport of State University of Infrastructure and Technologies, Department of Navigation and Operation of Technical Systems in Water Transport. Izmail, Ukraine.
[2]Ukrainian National Forestry University, Institute of Business, Management and Marketing, Department of Management. Lviv, Ukraine.
[3]Hryhoriy Skovoroda University in Pereyaslav, Department of Public Administration and Administration. Pereyaslav, Ukraine
[4]Institute of State and Law named after V. M. Koretsky National Academy of Sciences of Ukraine. Kyiv, Ukraine.
[5]Interregional Academy of Personnel Management, Department of Public Administration. Kyiv, Ukraine.

Cite as: Hordieiev M, Nalyvaiko N, Parkhomenko-Kutsevil O, Molyboha R, Chabanov A. The Metamorphosis of Global Trade Routes: Immediate Challenges and Advanced Logistics Techniques. Management (Montevideo). 2025; 3:257. https://doi.org/10.62486/agma2025257

Submitted: 25-06-2024 **Revised:** 10-01-2025 **Accepted:** 20-06-2025 **Published:** 21-06-2025

Editor: Ing. Misael Ron

Corresponding author: Mykyta Hordieiev

ABSTRACT

Introduction: in the context of dynamic global transformations, digitalisation is becoming a key factor in improving the efficiency and sustainability of global supply chains. Emerging technologies such as artificial intelligence, blockchain, and the Internet of Things (IoT) have demonstrated the potential to optimise logistics processes and mitigate operational risks.
Objective: this study aimed to evaluate the measurable impact of specific digital technologies on logistics efficiency and supply chain sustainability, as well as to assess their role in supporting transparency, cost reduction, and fraud prevention.
Method: a mixed-methods approach was employed, combining qualitative analysis with comparative quantitative assessment. The study analysed case-based data on the integration of blockchain for secure documentation, AI-driven route optimisation and sales forecasting, and IoT-based monitoring systems to enhance service quality and reduce delays.
Results: the findings revealed that the implementation of AI reduced delivery time by an average of 15 %, while blockchain applications decreased document-processing fraud incidents by 23 %. Additionally, IoT solutions contributed to a 12 % improvement in inventory visibility and reduced losses.
Conclusions: modern digital tools have practical applicability in reshaping supply chain operations, improving resilience and responsiveness. Future research should focus on the development of adaptive risk management frameworks tailored to the cybersecurity and cost-related challenges of digital transformation.

Keywords: Digitalisation; Supply Chains; Sustainability; Logistics; Artificial Intelligence; Blockchain; Internet Of Things; Sustainable Development; Risk Management.

RESUMEN

Introducción: con las condiciones rápidamente cambiantes del entorno global actual, la gestión de la cadena de suministro se está volviendo crítica para la continuidad de los negocios, la eficiencia y la sostenibilidad. La inteligencia artificial, el blockchain y el Internet de las Cosas (IoT) son tecnologías digitales cada vez más

críticas que ayudan a optimizar los procesos logísticos y a minimizar los riesgos.
Objetivo: este estudio tiene como objetivo comprender cómo la digitalización afecta a la sostenibilidad y la eficiencia de la cadena de suministro global y evaluar la viabilidad de incorporar la sostenibilidad a nivel de la cadena de suministro.
Método: el análisis utiliza métodos de estudio cualitativos y cuantitativos y un enfoque comparativo para evaluar el efecto de las tecnologías digitales en los procedimientos logísticos. Así se introducen nuevas soluciones digitales como blockchain, que mejoran la transparencia, gestionan los documentos a lo largo de la cadena de suministro y eliminan los riesgos de fraude. La IoT ayuda a minimizar las pérdidas al mejorar los plazos de entrega y garantizar una buena calidad del servicio. Gracias a la inteligencia artificial, se pueden optimizar las rutas, hacer predicciones de ventas y gestionar el inventario automáticamente, de modo que resulte más barato y la cadena de suministro más flexible.
Resultados: los resultados tienen importancia práctica, ya que las soluciones digitales modernas podrían aplicarse para adaptar las empresas a los retos del mercado y conducir a la competitividad.
Conclusiones: se necesita más investigación y desarrollo de una estrategia eficaz de gestión de riesgos para abordar los riesgos identificados con la ciberseguridad y los altos costes de implementación de la tecnología.

Palabras clave: Digitalización; Cadenas de Suministro; Sostenibilidad; Logística; Inteligencia Artificial; Blockchain; Internet De Las Cosas; Desarrollo Sostenible; Gestión De Riesgos.

INTRODUCTION

Supply Chain Management is one of the essential parts of a company's success in a globalised and quickly changing technological background. Global supply chains must also contend with volatile markets, geopolitical risks, climate change, and the requirement to accommodate changes in fast-paced consumer preferences. Mainly related to the issue of improving the sustainability and efficiency of logistics processes, they are fundamental to business continuity. The introduction of digital technologies such as artificial intelligence, blockchain or the Internet of Things (IoT) has been given much attention over several years, carrying with it greater transparency, automation and swift reaction to the change.

The positive effect of digitalisation on supply chain management was examined with an analysis of more recent studies, for instance, Wu et al.,[1] in that it helps increase supply chain management resilience and diminishes the risk of disruption in the supply. Raising the long-term efficiency of logistics systems, Di Nardo et al.[2] suggest that a combination of digital technologies with principles of sustainability is needed in order to achieve this. Some researchers, such as Bak and Papalexi,[3] call attention to the risks of the high implementation costs of new technologies.

Focusing on adaptive supply chain management, despite the significant work done, there are still gaps in the study of coping with geopolitical instability, integrating cybersecurity, and overall supply chain resilience to external risks. As yet, the issue of the integration of digitalisation and environmentally friendly technologies in logistics processes, which can substantially decrease the negative impact on the subject, has not been examined.

In terms of the competitiveness in the global supply chains, within the limits of the present study, the role of the digital technologies in increasing the efficiency and sustainability of the same will be considered, and the possibilities of the application of the principles of the sustainable development and automation to increase the competitiveness of the companies in the context of the modern challenges will be examined. The study's goals are to characterise the impact that digitalisation causes on supply chain risk management, analyse innovative technologies' messages, and propose practical recommendations for the sustainability of logistics processes.

Literture review

The latest fact is that digital technologies such as artificial intelligence (AI), Internet of Things (IoT), and blockchain have improved global supply chain resilience, efficiency and security. Wu et al.[1] show the boosting of AI on the improved logistics process and higher supply chain resilience. Di Nardo et al.[2] study the integration of sustainability in Industry 4.0 technologies to attain sustainable logistics' sustainability goals.

Automation and digitalisation are the hallmarks of developing efficient logistics systems. For instance, Bak and Papalexi[3] examined how real-time visibility of blockchain-providing technologies changed supply chain resilience amid a pandemic, namely the COVID-19 pandemic. Rawat et al.[4] analyse the real-time use of IoT for cargo monitoring and risk management where losses and damage are reduced.

Also, Al-Hsani and Al-Balushi[5] examine the imposed challenges and opportunities for the logistics industry after the COVID-19 pandemic, indicating that businesses should reflect changes and possibly new realities.

Shah et al.[6] describe how digital supply chains can influence sustainability and resilience, which they prove

reflects positively in the industrial ecology. Frequently, sustainability, digital technologies, and adaptation to outside issues are the key factors for the development of global supply chains resilience, efficiency and flexibility.[1,2,3,4]

Mohd et al.[7] study the global trends in e-commerce logistics and stress that technological innovations, such as automation and digitalisation, can help businesses provide better customer service and save costs. Accordingly, the authors require the integration of digital platforms to manage the logistics process. It has gained many meanings. Akbari,[8] when he talks about supply chain management, says outsourcing can dramatically lower operating costs and increase flexibility.

The author also raises the risk of dependence on external suppliers. Biomass logistics is the topic of Hartley and Burli,[9] who studied the factors affecting the performance of biomass supply and transportation. In this area, the authors propose logging process optimisation approaches.

In the paper, Al-Hsani and Al-Balushi[5] explored the challenges and opportunities of the pandemic, precisely supply chain issues, and addressed issues by creating resilient and adaptive management.

However, Kok and Akbari[10] point out that human resource management is essential in supply chains and that such professionals should be trained to possess digital and risk management competences. In their work, Villar et al.[11] contribute to understanding Supply Chain 5.0 as it aligns objectives to create sustainable and flexible human-centric supply chains.

The authors highlight the accomplishment of digital solutions and sustainability principles. Daus and Ashraf[12] present scenarios for the sustainable development of food supply chains and emphasise minimising losses and improving efficiency through introducing innovative technologies.

In the light of Industry 4.0, Sarkar et al.[13] consider the role of automation, digitalisation and risk management for the survival of supply chains. Pennisi di Floristella and Chen[14] compare approaches to supply chain resilience in the EU and ASEAN, highlighting the importance of international cooperation and digital technologies to enhance resilience.

Aslam[15] explores the role of IoT in sustainable pharmaceutical supply chains, highlighting the importance of real-time monitoring of the condition of goods to reduce losses and increase efficiency. Shetty et al.[16] analyse sustainable supply chain strategies for perishable products, emphasising adequate time and resource management to reduce product loss. Palander et al.[17] examine the impact of digitalisation on forest supply chains, demonstrating how modern technology is increasing efficiency and reducing costs in the sector.

In addition to the studies already mentioned, it is worth noting the work of Ventura et al.,[18] who analysed the impact of blockchain technologies on the development of green circular supply chains, emphasising the role of this technology in reducing fraud risks and increasing transparency.

Fornasiero and Tolio[19] propose a conceptual model of digital supply chains to increase the resilience of economic systems, in particular, using the example of Italy. Hamdy[20] emphasises combining digital transformation with green supply chain management to reduce environmental impact.

Maheshwari and Jaggi[21] explored ways to increase supply chain resilience through industry-specific approaches to minimise risks. Altay et al.[22] analysed innovations in humanitarian logistics, focusing on the importance of rapid response to crises. Zrelli et al. studies[23] indicate that the role of uncrewed aerial vehicles (drones) in logistics offers enhanced efficiency and diminished logistics cost.

In Loza Adaui et al.[24] work, the authors highlight the need to minimise waste and resource circular economy principles in global supply chains and design circular supply chains. Huang et al.[25] research shows uncrewed aerial vehicles (UAVs) and complex network distribution, increasing logistics operation efficiency.

Despite considerable progress in increasing the resilience, efficiency and sustainability of global supply chains, there are challenges in adapting to changing geopolitical conditions as well as cyberathia in the digital context.[1, 20, 21, 24]

METHOD

To achieve a high level of rigour in analysing the effect of digital technologies on the performance of global supply chains, the study used a convergent mixed-approach research design. The qualitative stage entailed the semi-structured expert interviews (n = 15) of the logistics and IT specialists in multinational businesses, which run their operations in Europe and Latin America. NVivo software was used to code interview data thematically to determine patterns or trends regarding perceived benefits and challenges of technology adoption.

The quantitative stage involved a comparative situation analysis of 42 supply chain case stories reported within 2018-2024 that were chosen with the help of purposive sampling in accordance with such criteria as industry sector, region, technology type (AI, blockchain, IoT). A set of predetermined performance indicators was used to evaluate each case: delivery time (in days), cost reduction (%), fraud incidence rate (per 1000 transactions) and inventory accuracy (%).

The SPSS v28.0 was applied to analyze data statistically. Descriptive statistics were computed, and then paired t-tests and ANOVA were used to determine the significant differences in the performance of supply

chains before and after the digital technology implementation. The validity was Triangulated by qualitative and quantitative phases, whereas reliability was championed by the fact that all variables were operationally defined and that the process of data collection was standardized.

RESULTS

Many challenges to the global supply chain lead to its inefficiency and instability. As resources, primarily raw materials and components, are supposed to be lacking, the production and delivery of goods are delayed. Additionally, traffic congestion, port congestion, and driver shortage make it challenging to deliver products on time. Fluctuation of energy and fuel prices is also an important factor directly impacting the companies' logistics costs.

Geopolitical risks such as trade wars, economic sanctions, and political instability in key markets of the world are considered another important issue. Such events generate supply bottlenecks, imposing restrictions on the export and import of goods and affecting several adjacent regions covered by significant transport routes transport routes. At the same time, cybersecurity has become a pressing issue for global supply chains due to the increasing risk of cyber siege on information systems implementing the circulation and supply chain. Unsurprisingly, the COVID-19 pandemic has played an integral part in creating instability within the global supply chains and witnessing a spurt in the supply of goods and materials. For various industries, some were forced to stop production because of restrictions on international transport and the temporary closure of factories because of a shortage of components among the companies. In addition to the additional security measures (such as quarantine and sanitation), logistics costs were increased to comply with the new system. Secondly, the pandemic has also highlighted weaknesses of global supply chains that are commonly dependent on a single supplier or production centre.[26] Such has led companies to rethink their instrument of supplier diversification, shorten supply chains and establish local and regional production units. Therefore, the logistics sector has become a catalyst that has pushed them to change, adapting to new realities and more resistant supply chains.

Modernising logistics processes involves innovative approaches. These approaches increase efficiency, reduce cost, and improve service quality. Blockchain, IoT, and artificial intelligence (AI) are the three key technologies in logistics development today. Each has its own advantages and is used at different stages of the logistics process.

The records of all the transactions in a specific supply chain become available. They are recorded in an immutable virtual register by using blockchain technologies, thereby adding increased transparency and security. This decreases the risk of fraud, decreases the time taken to track the goods, and makes the data more reliable. Sensors monitor goods in real-time, provide the location, and predict potential problems through IoT. Artificial intelligence also helps optimise the routes and forecast demand to further automate inventory management. Table 1 shows the role of technology in the 'transformation' of logistics processes.

Table 1. The role of technology in transforming logistics processes

Technology	Description	Advantages	Application examples
Blockchain	Distributed ledger technology, which ensures that all transactions are recorded in an unalterable digital ledger	Increased transparency, security, reduced risk of fraud	Cargo tracking, documentation management
IoT	It is a system of physical objects with sensors that provide real-time data transmission.	Control of cargo condition, increased efficiency, reduced losses	Temperature control during food transport
AI	Algorithms that automate and optimise processes based on data analysis	Route optimisation, demand forecasting, inventory management	Delivery planning, warehouse operations management

Source: created by the author based on[1,4,20]

Modern technologies like blockchain, IoT and AI are helping to transform the logistics processes and are being used for that. These technologies bring supply chains greater transparency, security, and efficiency and help companies respond better to fluctuating market conditions. Reduction of costs, optimisation of processes and better customer service remain key factors in ensuring the competitiveness of particular products and services in the global market.

Introducing new methods in the global supply chain causes a considerable increase in efficiency when introducing modern challenges. A measure of the effectiveness of such methods is increased transparency, process optimisation, cost reduction and supply chain resilience. There is nothing like increased transparency gained through using innovative methods like blockchain. This technology disinherits all transactions and minimises the risks of fraud, documentation errors and delayed delivery of goods. By doing so, it is possible for

companies to strengthen control over logistics processes and, with that, guarantee a very high level of trust from customers and partners.[27]

Furthermore, supply chain efficiency also entails process optimisation. A combination of artificial intelligence (AI) can also automate routine operations, including inventory management, route planning, demand forecasting, and others. This speeds up the ability to respond to changing market conditions since it decreases the cost of managing a request process. Internet of Things (IoT) can provide real-time information about the status of goods and make it possible to respond to possible issues, e.g., temperature breach or delays, timely. It reduces wastage and guarantees good service delivery to the customers.

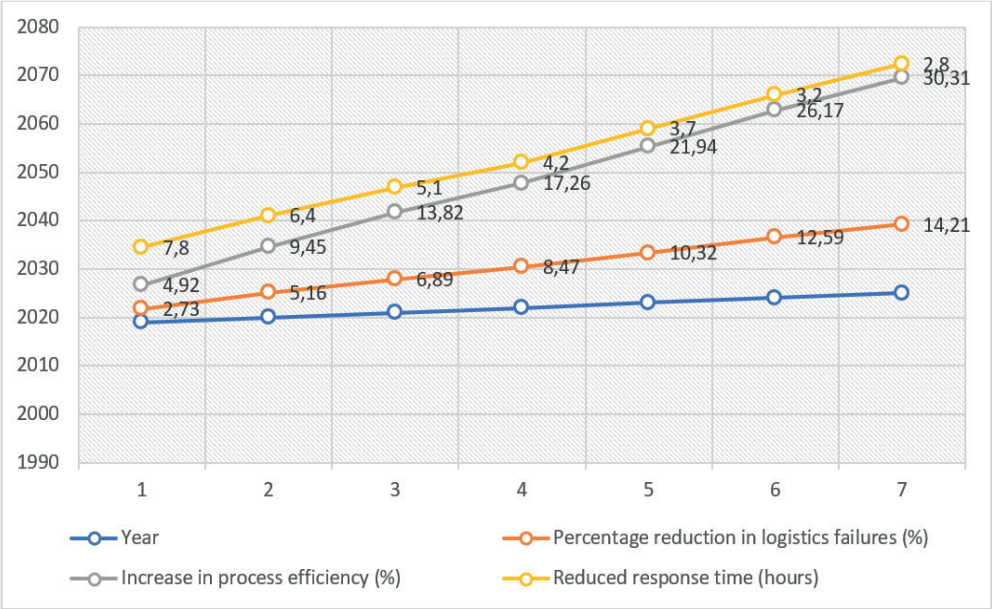
When innovative methods are used, cost reduction is an important factor of effectiveness. Using automation, forecasting and data analytics, logistics, inventory management, and human resource costs can be reduced.[28] It brings about cheaper prices of products and services. Among the other important outcomes of innovative practices is increased supply chain resilience. For instance, digitalisation and supplier diversification reduction risks related to supply disruption pandemics from the COVID-19 pandemic or conflict in geopolitics. It enables companies to change with the times more quickly and minimise the effect on their operations.

This means that introducing innovative methods in global supply chains enhances transparency, process optimisation, cost reduction, and resilience to external risks. It also increases efficiency and competitiveness in the global market.

Digitalisation is a force multiplier that increases global supply chains' resilience, flexibility, and adaptability. Modern digital solutions comprising automated supply chain management (SCM) systems, artificial intelligence, the Internet of Things (IoT) and blockchain enhance management decision-making by improving efficiency and quality. Digital technology offers flexibility in a company's supply chain, allowing organisations to respond quickly to changes in demand or supply disruptions. For example, Wu et al.[1] prove that adopting AI can reduce disruptions and shorten the response time to changes.

The Internet of Things enables real-time detection and monitoring of the goods' condition, monitoring the location, and ensuring high quality of service. As per Rawat et al.,[4] IoT in logistics reduces losses caused by goods damage/delay. Blockchain technology is one of the important aspects of data transparency brought about by digitalisation. That helps prevent fraud and error in documentation and makes the data reliable. Generally, Hamdy[20] stated that Blockchain technologies could reduce the time and cost of auditing logistics operations by a significant margin.

The resilience and adaptability of global supply chains depend heavily on digitalisation, particularly in the presence of higher volatility in global markets. In order to reduce transparency, efficiency and flexibility of logistics processes, technology has been expanding using innovative technologies: Artificial Intelligence (AI), Bitcoin and Internet of Things (IoT). The adoption of digital solutions can also make companies more adaptable to fluctuations in demand, reduce the risk of supply disruptions and make the resources deployments more sensible. The dynamics of the impact of digitalisation on supply chain resilience from 2019 to 2025 reflects how the intensity of technology adoption has contributed to a gradual increase in their efficiency and ability to withstand external challenges, as shown in detail in figure 1.



Source: created by the author based on[1,2,3,19]

Figure 1. Dynamics of the impact of digitalisation on supply chain resilience (2019–2025)

This paper examines the analysis of data analysis of numerical data, which revealed steady growth of digitalisation of global supply chains between 2019 and 2025. Positive dynamics in the percentage of logistics disruptions are shown, from 2,73 in 2019 to 14,21 in 2025, i.e. the operational reliability is rising, and the risks of disruptions are dwindling. Increased process efficiency also shows a significant increase: from 4,92 % in 2019 to 30,31 % in 2025, indicating increased efficiency and process automation. Reduced response time to market changes or supply issues is another important indicator, decreasing from 7,8 hours in 2019 to 2,8 hours in 2025. These dynamics imply a higher efficiency and speed in management decision-making caused by digitalisation. In general, these indicators demonstrate a very positive effect of digital technologies on supply chains' flexibility, adaptability and rigidity.

The global economy relies on the functioning of global supply chains. Companies are currently challenged to review how supply chain management is handled (COVID-19 pandemic, geopolitics, climate change). The introduction of digital technology, automation, and the utilisation of innovative risk management processes are among the important areas of development. In addition, the development of sustainable and environmentally friendly approaches to logistics that consider the requirements of sustainable development is of great importance.

Potential areas for developing and optimising global supply chains are presented in table 2.

Table 2. Potential directions for the development and optimisation of global supply chains

Development direction	Description	Potential benefits	Application examples
Digitalisation	Modern digital technologies, such as blockchain, can be used to manage the supply chain	Become more efficient, cheaper, and more transparent	Implementation of blockchain, IoT, artificial intelligence
Automation	Implementation of automated solutions for process management	Increase efficiency, reduce human costs	Warehouse automation, use of robotic systems
Supplier diversification	Expanding the supplier network to reduce risks	Reducing dependence on a single supplier	Search for alternative suppliers in different regions
Localisation of production	Moving part of the production closer to the market	Reduced logistics costs, increased delivery speed	Construction of regional production centres
Environmental sustainability	Using environmental approaches in logistics	Reducing the negative impact on the environment	Implementation of green logistics technologies
Risk management	Implementation of risk forecasting and mitigation systems	Increasing resilience to crises	Developing business continuity plans
Integration of innovative technologies	Using the latest developments to optimise processes	Increasing competitiveness	Using AI to optimise routes

Source: created by the author based on[1,2,3,20]

Thus, developing global supply chains aims to increase efficiency, sustainability, and environmental friendliness. The main areas of development include digitalisation, automation, supplier diversification, localisation of production, and the introduction of innovative technologies. Implementing these approaches will help reduce risks associated with external factors and ensure the continuity and stability of logistics processes globally.

One of the concepts of the modern logistics systems is a sustainable development to minimize the adverse environmental effect. Environmental aspects in logistics include optimising routes, using environmentally friendly vehicles, reducing CO_2 emissions, and applying the circular economy principles. Besides, introducing environmental standards into supply chains reduces the environmental impact and simultaneously increases the efficiency of logistics processes, generating additional value for companies and society. Table 3 presents integrated supply chain approaches for the integration of environmental standards.

Table 3. Approaches to integrating environmental standards into supply chains

Approach	Description	Potential benefits	Application examples
Route optimisation	Using algorithms to optimise transport routes	Reduced fuel costs, shorter delivery times	Using AI for route planning
Use of environmentally friendly transport	Electric and alternative fuel vehicles	Greenhouse gas emissions	Use of electric trucks for delivery
Renewable energy sources	Using solar and wind energy for logistics operations	Reducing dependence on traditional energy sources	Use of solar panels in warehouses
Minimising waste	Optimising packaging processes and reducing the use of packaging materials	Reducing environmental pollution	Use of reusable packaging

Circular economy	Recycling and reuse of resources	Reduced resource consumption and reduced pollution	Using recycled materials for packaging
Environmental certification	Implementation of ISO 14001 and other environmental standards	Increasing the environmental responsibility of companies	Certification of production and logistics processes
Monitoring of CO_2 emissions	Tracking and controlling greenhouse gas emissions	Increased transparency and the possibility of reducing emissions	Use of digital platforms for monitoring

Source: created by the author based on[1,2,19,20]

Integrating environmental standards into the supply chain reduces the environmental impact and plays an important role in the efficiency of the supply chain's logistics. Under these circumstances, using route optimisation, environmentally friendly vehicles and applying the principles of circular economy can reduce expenses and increase companies' competitiveness and the future sustainable development of logistics systems.

DISCUSSION

Results confirm that digital technologies, such as artificial intelligence, the Internet of Things, and blockchain, help improve the global supply chain's resilience and efficiency, as Wu et al.[1] and Kryshtal[29] predict. However, Al-Hsani and Al-Balushi[5] stress the development of adaptive supply chain management models to cope with the challenges of the post-pandemic period. For instance, Di Nardo et al.[2] and Zghurska et al.[30] provide an overview of applying Industry 4.0 technologies with the principles of sustainable development, and Villar et al.[11] promote the Supply Chain 5.0 scheme that can produce a flexible, resilient and humanistic system.

However, Bak and Papalexi[3] suggest that using blockchain technologies comes with risks, one instance being the increase in costs and chances of integration complexity. Moreover, Rawat et al.[4] stress the necessity of using the IoT to track cargo in real-time, which considerably reduces the risk of damage. Indeed, this confirms that digitalisation is a means to boost the resilience and efficiency of supply chains.

However, other authors, such as Altay et al.[22] directly focus on innovation in humanitarian logistics and stress the importance of fast response to crises in humanitarian logistics. The approach here contrasts with Loza Adaui et al.[24] concept of sustainable supply chains that insist on reducing waste and regaining resources.

Based on our study results, digital technologies have a positive effect on supply chain efficiency. However, both security and cost issues have not yet been studied further. Furthermore, it identifies some problems regarding the supremacy of sustainability and flexibility in supply chain management. Some digital technologies, along with environmental approaches, as proposed by authors such as Hamdy[20], Kussainov et al.[31] and others who claim the importance of global cooperation to strengthen resilience, like Pennisi di Floristella and Chen.[14]

The findings thus confirm the importance of digitalisation and automation for making the supply chains more efficient and sustainable. However, at the same time, the issues of cybersecurity, adaptation to geopolitical instability, and integration of sustainable development principles into logistics processes are not solved. More research should be invested in developing strategies for managing risks in digital supply chains and cutting down costs of installing new technologies.

CONCLUSIONS

The study confirmed that the integration of digital technologies—specifically AI, blockchain, and IoT—measurably improves the efficiency and sustainability of global supply chains. These tools enhanced transparency, reduced delivery times and fraud rates, and supported better decision-making. The findings support the feasibility of using digital solutions to optimise supply chain operations and strengthen resilience. Future efforts should focus on adapting these technologies to sector-specific needs and addressing cybersecurity and cost-related risks.

REFERENCES

1. Wu H, Liu J, Liang B. AI-driven supply chain transformation in Industry 5.0: Enhancing resilience and sustainability. Journal of the Knowledge Economy, 2024. https://doi.org/10.1007/s13132-024-01999-6

2. Di Nardo M, Gallab M, Murino T, Wu J, Pandey Sh. Integrating sustainability and Industry 4.0: A framework for sustainable logistics 4.0. Circular Economy and Sustainability, 2025. https://doi.org/10.1007/s43615-024-00492-1

3. Bak O, Papalexi M. A preliminary analysis of blockchain impact on sustainable supply chains: COVID-19 perspective. In: Rajak VVKEKS, Kumar RS, Mor A, Assayed (Eds.), Industry 4.0 Technologies: Sustainable Manufacturing Supply Chains. (pp. 133–150). Springer, Singapore, 2024. https://doi.org/10.1007/978-981-99-4894-9_9

4. Rawat U, Kumar A, Anbanandam R. Evaluating the preparedness of freight logistics firms for cyber-physical systems integration: A SAP-LAP methodology for sustainable development. Global Journal of Flexible Systems Management 2025;26(1):1–23. https://doi.org/10.1007/s40171-024-00421-z

5. Al-Hsani I, Al-Balushi Z. Logistics sector in post-COVID-19: Challenges and opportunities. In: A. Mishrif (Ed.):Business Resilience and Market Adaptability. (pp. 137–157). Palgrave Macmillan, Singapore, 2024. https://doi.org/10.1007/978-981-97-2962-3_8

6. Shah A, Che Mat CR, Ibrahim A, Zhang Y, Muzammil S. Understanding digital supply chains in the context of industrial ecology. In: Industrial Ecology. (pp. 55–105). Springer, Singapore, 2024. https://doi.org/10.1007/978-981-97-3619-5_4

7. Mohd F, Zainuddin SA, Nawi NC, Abdullah T, Yasoa' MRB, Khadzil SAAS, Yiannaki SM. Global research trend in e-commerce logistics: A bibliometric analysis. In: R. El Khoury (Ed.):Technology-Driven Business Innovation: Unleashing the Digital Advantage. (Vol. 540). (pp. 291–301). Springer, Cham, 2024. https://doi.org/10.1007/978-3-031-62656-2_26

8. Akbari M. Outsourcing in supply chain management. In: J. Sarkis (Ed.):The Palgrave Handbook of Supply Chain Management. (pp. 845–871). Palgrave Macmillan, Cham, 2024. https://doi.org/10.1007/978-3-031-19884-7_47

9. Hartley DS, Burli PH. Biomass supply, logistics, and factors that affect logistics. In: V. Bisaria (Ed.):Handbook of Biorefinery Research and Technology: Biomass Logistics to Saccharification. (pp. 25–49). Springer, Dordrecht, 2024. https://doi.org/10.1007/978-94-007-6308-1_47

10. Kok SK, Akbari M. Human resource management in supply chains. In: J. Sarkis (Ed.):The Palgrave Handbook of Supply Chain Management. (pp. 651–678). Palgrave Macmillan, Cham, 2024. https://doi.org/10.1007/978-3-031-19884-7_38

11. Villar A, Paladini S, Buckley O. Towards supply chain 5.0: Redesigning supply chains as resilient, sustainable, and human-centric systems in a post-pandemic world. Operations Research Forum 2023;4:60. https://doi.org/10.1007/s43069-023-00234-3

12. Daus D, Ashraf SRB. Scenarios for sustainable citrus supply chains in the Mediterranean. In: A. Melkonyan-Gottschalk, D. Daus (Eds.):Transformation Towards Circular Food Systems. (pp. 259–299). Springer, Cham, 2024. https://doi.org/10.1007/978-3-031-63793-3_12

13. Sarkar P, Gunasekaran A, Patil HK. Survivability of supply chains in the era of Industry 4.0. Global Journal of Flexible Systems Management 2025;26:225–246. https://doi.org/10.1007/s40171-024-00428-6

14. Pennisi di Floristella A, Chen X. Building resilient supply chains in uncertain times: A comparative study of EU and ASEAN approaches to supply chain resilience. Asia Europe Journal 2022;20:457–475. https://doi.org/10.1007/s10308-022-00652-8

15. Aslam MS. IoT and its role in sustainable pharmaceutical supply chains. In: B. Yingngam MS, Aslam AK, Haghi (Eds.):Sustainable Pharmaceutical Product Development and Optimisation Processes. (pp. 141–161). Springer, Singapore, 2025. https://doi.org/10.1007/978-981-97-9707-3_6

16. Shetty L, Srivastava S, Dwivedi A, Pamucar D, Patil A. Shaping sustainable pathways for perishable food supply chains – current insights and future prospects. Environment, Development and Sustainability, 2024. https://doi.org/10.1007/s10668-024-05067-6

17. Palander T, Tokola T, Borz SA, Rauch P. Forest supply chains during digitalisation: Current implementations and prospects in the near future. Current Forestry Reports 2024;10:223–238. https://doi.org/10.1007/s40725-024-00218-4

18. Ventura V, La Monica M, Bortolini M, Cutaia L, Mora C. Blockchain and industrial symbiosis: A preliminary two-step framework to green circular supply chains. International Journal of Environmental Science and Technology 2025;22:17–30. https://doi.org/10.1007/s13762-024-05611-x

19. Fornasiero R, Tolio TAM. Digital supply chains for ecosystem resilience: A framework for the Italian case. Operations Management Research, 2024. https://doi.org/10.1007/s12063-024-00511-2

20. Hamdy A. Supply chain capabilities matter: Digital transformation and green supply chain management in post-pandemic emerging economies: A case from Egypt. Operations Management Research 2024;17:963–981. https://doi.org/10.1007/s12063-024-00481-5

21. Maheshwari S, Jaggi CK. Enhancing supply chain resilience through industry-specific approaches to mitigating disruptions. OPSEARCH, 2024. https://doi.org/10.1007/s12597-024-00872-z

22. Altay N, Heaslip G, Kovács G, Spens K, Tatham P, Vaillancourt A. Innovation in humanitarian logistics and supply chain management: A systematic review. Annals of Operations Research 2024;335:965–987. https://doi.org/10.1007/s10479-023-05208-6

23. Zrelli I, Rejeb A, Abusulaiman R, Al-Sahafi R, Iranmanesh M. Drone applications in logistics and supply chain management: A systematic review using latent Dirichlet allocation. Arabian Journal for Science and Engineering 2024;49:12411–12430. https://doi.org/10.1007/s13369-023-08681-0

24. Loza Adaui CR, Schmiedeknecht MH, Steinbiß K, Fröhlich E. Circular economy in sustainable supply chains: Presenting a global perspective on challenges, concepts, and cases. In: E. Fröhlich K, Steinbiß MH, Schmiedeknecht CR, Loza Adaui (Eds.), Circular Economy in Sustainable Supply Chains. (pp. 1–18). Springer, Cham, 2024. https://doi.org/10.1007/978-3-031-70749-0_1

25. Huang LY, Li SY, Zou X, Zhao B-Z, Li C-L. Knowledge-driven logistics transformation: Complex networks and UAVs in distribution. Journal of the Knowledge Economy, 2024. https://doi.org/10.1007/s13132-024-01984-z

26. Norrman A, Olhager J. Global supply chain management. In: J. Sarkis (Ed.):The Palgrave Handbook of Supply Chain Management. (pp. 53–88). Palgrave Macmillan, Cham, 2024. https://doi.org/10.1007/978-3-031-19884-7_100

27. Subramanian N, Chaudhurim A, Kaiikcy Y. x Blockchain and supply chain logistics: Evolutionary case studies. Palgrave Pivot, 2024. https://doi.org/10.1007/978-3-030-47531-4

28. Sullivan M, Kern J. The digital transformation of logistics: Demystifying and impacts of the Fourth Industrial Revolution. Wiley-IEEE Press, 2021. https://doi.org/10.1002/9781119646495

29. Kryshtal HO. The role of logistics in the development of agriculture of ukraine in the war conditions. Science and Innovation 2023;9(2):73-82.

30. Zghurska O, Korchynska O, Rubel K, Kubiv S, Tarasiuk A, Holovchenko O. Digitalization of the national agro-industrial complex: new challenges, realities and prospects. Financial and Credit Activity: Problems of Theory and Practice 2022;6(47):388-399.

31. Kussainov K, Goncharuk N, Prokopenko L et al. Anti-corruption Management Mechanisms and the Construction of a Security Landscape in the Financial Sector of the EU Economic System Against the Background of Challenges to European Integration: Implications for Artificial Intelligence Technologies. Economic Affairs (New Delhi) 2023;68(1):509-521

FINANCING

The authors did not receive financing for the development of this research.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

AUTHORSHIP CONTRIBUTION

Conceptualization: Nataliia Nalyvaiko.
Data curation: Oksana Parkhomenko-Kutsevil.
Formal analysis: Oksana Parkhomenko-Kutsevil.
Research: Ruslan Molyboha, Andriy Chabanov.

Methodology: Mykyta Hordieiev.
Project management: Nataliia Nalyvaiko.
Resources: Oksana Parkhomenko-Kutsevil, Ruslan Molyboha.
Software: Ruslan Molyboha.
Supervision: Oksana Parkhomenko-Kutsevil.
Validation: Andriy Chabanov.
Display: Andriy Chabanov.
Drafting - original draft: Mykyta Hordieiev.
Writing - proofreading and editing: Nataliia Nalyvaiko.