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MANAGEMENT OF DIGITAL INNOVATIONS IN TRANSPORTATION SYSTEMS

The relevance of the research is driven by the necessity for transportation systems to adapt to the contemporary challenges of globalization, digitalization, and sustainable development. The utilization of digital innovations such as IoT, blockchain, digital twins, and 5G opens new opportunities for enhancing the efficiency of logistics processes, reducing costs, and improving coordination among supply chain participants. At the same time, transportation systems face environmental, economic, and social challenges that require integrated and strategic solutions.

The management of digital innovations becomes a key tool in ensuring competitiveness, reducing environmental impact, and creating a more sustainable infrastructure. This topic is relevant due to its importance in economic development, improving the quality of transportation services, and integrating innovations into the transportation industry.

In today's world, the development of high-tech innovations opens vast opportunities for improving quality of life, advancing artificial intelligence, creating innovative materials and energy sources, and strengthening the global strategic position of nations and economies. These technologies introduce new approaches to business, described by concepts such as „Industry 4.0", „Smart cities", „Green economy", „Innovation economy" and „Sharing economy".

New requirements for business management systems are being shaped by digital innovations in transport systems. Technologies such as artificial intelligence, the Internet of Things (IoT), big data and blockchain are becoming key tools for optimizing logistics processes, managing vehicle flows and improving supply chain efficiency.

Digital innovations enable the creation of smart transport systems that automate processes, reduce delivery times and lower operating costs. In addition, they improve the interaction between the various actors in the transport infrastructure, increasing the transparency and accuracy of operations.

The management of digital innovation in this area requires the implementation of strategic approaches to change management, staff training in new technologies and the integration of digital solutions into existing business models. Thus, successful transformation of transport systems becomes a key factor for increasing business competitiveness and sustainable development.

Review of scientific sources. An analysis of the literature on the management of digital innovations in transport systems shows the growing importance of introducing modern technologies in the transport industry. A study by T.V. Gaikova, V.G. Zagoriansky and A.O. Leontovych demonstrates the importance of digitalisation in supply chain management, in particular through the use of IoT, automation, and big data, which increases efficiency and reduces costs[1].

O. Dmitrieva and K. Stogul focus on the blockchain's capabilities to ensure transparency of transport operations, reduce risks and optimise documentary support[2]. M.D. Zayachuk and D.V. Zolotunets point out the key role of digital technologies in increasing the competitiveness of the transport sector, especially through process automation and the use of innovations[3].

I. Kryvoviaziuk analyses the effectiveness of management decisions aimed at introducing digitalisation in logistics and shows how such decisions affect productivity and reduce costs[4]. In turn, M.O. Skoryk and O.I. Marchenko focus on the role of „Smart Cities and Urban-Tech" in the development of urban transport infrastructure, which contributes to increased mobility and environmental sustainability[5].

Innovative approaches to transportation in multimodal systems are analysed in the works of V.A. Falovych and co-authors, who emphasise the importance of integrating digital solutions for convenience and reducing delivery time[6].

1 Гайкова Т. В., Загорянський В.Г., Леонтович А.О. (2023). Впровадження цифрових технологій в управління ланцюгами постачань. Центральноукраїнський науковий вісник. Технічні науки. 2023. Вип. 7(38), ч. І. С. 222-228. URL: https://mapiea.kntu.kr.ua/pdf/7(38)_I/27.pdf (05.01.25)

2 Дмитрієва, О., & Стогул, К. (2024). Особливості застосування блокчейну з акцентом на транспортну інфраструктуру. Проблеми і перспективи розвитку підприємництва, (32), 119-135. URL: https://doi.org/10.30977/PPB.2226-8820.2024.32.119 (30.12.24)

3 Заячук, М. Д., & Золотунець, Д. В. (2024). Використання цифрових технологій у транспортному секторі як фактор підвищення конкурентоспроможності. Науковий вісник Херсонського державного університету. Серія «Географічні науки», (20), 22-27. URL: https://doi.org/10.32999/ksu2413-7391/2024-20-3 (02.01.25)

4 Кривов'язюк, І. (2023). Управлінські рішення та їх ефективність щодо впровадження цифрових технологій в логістиці. Collection of scientific papers «SCIENTIA», (October 20, 2023; Sofia, Bulgaria), 34-36. URL: https://previous.scientia.report/index.php/archive/article/view/1253 (25.12.24)

5 Скорик, М. О., & Марченко, О. І. (2024). «Smart Cities» та «Urban-Tech» екосистеми як драйвери сталого розвитку міст і територій. Цифрова економіка та економічна безпека, (5 (14)), 91-98. URL: https://doi.org/10.32782/dees.14-14 (24.12.24)

6 Фалович, В. А., Фалович, Н., & Шевчук, О. С. (2024). Інноваційні підходи до транспортування в мультимодальних системах. Матеріали III всеукраїнської науково-практичної інтернет-конференції „Маркетингові технології підприємств в сучасному науково-технічному середовищі ", 151-152.

According to A. Gohar and G. Nencioni, 5G technologies are critical for the development of intelligent transport systems, as they provide fast IoT data processing and traffic optimisation[7]. The concept of digital twins, as shown in the works of M. Jafari and A. Rudskoy, is another promising area that allows modelling and optimising transport processes to achieve greater efficiency[8]. The research of V.Y. Khaustova and co-authors focus on the innovation and investment attractiveness of Ukraine's transport and logistics infrastructure, which emphasises the importance of digital solutions for integration into global markets[9].

Thus, the studies reviewed confirm that digital innovations, such as IoT, blockchain, 5G and digital twins, play a key role in improving the efficiency of transport systems, promoting sustainable development, reducing costs and strengthening the competitive position of enterprises in the global environment. The integration of digital solutions is an important factor in the transformation of the transport industry, which meets modern challenges and trends.

The purpose of the research is to analyze the role and impact of management on the implementation of digital innovations in transport systems and logistics. Particular attention is paid to the study of key aspects of the integration of modern technologies, such as IoT, blockchain, digital twins, 5G and 6G, as well as to the definition of strategic and operational roles of management in this process.

A previously unresolved research problem in the management of digital innovations in transport systems is the lack of a comprehensive approach to their integration that would take into account the specifics of different modes of transport, global challenges and the capabilities of modern technologies. There is a lack of effective coordination between participants in transport and logistics systems, which creates information barriers and reduces the efficiency of innovation. In addition, the lack of standards and models for assessing the impact of digital technologies makes it difficult to develop sustainable development strategies. This problem requires an interdisciplinary approach and new management solutions to ensure the efficiency and competitiveness of transport systems.

7 Gohar, A., & Nencioni, G. (2021). The role of 5G technologies in a smart city: The case for intelligent transportation system. Sustainability, 13(9), 5188. URL: https://doi.org/10.3390/su13095188 (02.01.25)

8 Jafari, M., Kavousi-Fard, A., Chen, T., & Karimi, M. (2023). A review on digital twin technology in smart grid, transportation system and smart city: Challenges and future. IEEE Access, 11, 17471-17484; Rudskoy, A., Ilin, I., & Prokhorov, A. (2021). Digital twins in the intelligent transport systems. Transportation Research Procedia, 54, 927-935. URL: https://doi.org/10.1016/j.trpro.2021.02.152 (30.12.24)

9 Khaustova, V. Y., Boiko, O. V., & Trushkina, N. V. (2022). Vectors of increasing the level of innovation and investment attractiv eness of the transport and logistics infrastructure of the national economy of Ukraine. Problemy Ekonomiky, (3), 84-97. URL: https://ndc-ipr.org/media/publications/files/PE_03_2022-84-97.pdf (03.01.25)

Discussion and Analysis. The implementation of digital innovations in transport systems is becoming a key factor in their development and efficiency in the context of globalisation and digitalisation[10]. The main focus is on the use of technologies such as the Internet of Things (IoT), blockchain, digital twins, 5G and artificial intelligence, which allow optimising logistics processes, reducing costs, improving security and ensuring transparency in supply chains[11].

The integration of digital solutions allows for the creation of smart transport systems, including the automation of transport management processes, demand forecasting, and real-time monitoring of transport infrastructure. The use of IoT facilitates accurate tracking of cargo and vehicles, while blockchain increases transparency and data protection, reducing the risk of fraud[12]. The use of 5G provides high data transmission speeds, which is critical for the integration of IoT equipment and other control systems[13].

Digital twins allow modelling and testing transport processes, increasing the efficiency of resource use and planning operations[14]. They become a key tool for ensuring system flexibility in the event of unforeseen changes or risks. In turn, the concept of „Smart cities" integrates transport systems with other elements of urban infrastructure, ensuring sustainable development and increased mobility[15].

However, the introduction of digital innovations faces a number of challenges, including the high cost of technology, insufficient integration between supply chain participants, and the need for standardisation and regulation[16]. To overcome

10 Гайкова Т.В., Загорянський В.Г., Леонтович А.О. (2023). Впровадження цифрових технологій в управління ланцюгами постачань. Центральноукраїнський науковий вісник. Технічні науки. 2023. Вип. 7(38), ч. І. С. 222-228. URL: https://mapiea.kntu.kr.ua/pdf/7(38)_I/27.pdf (05.01.25); Заячук, М. Д., & Золотунець, Д. В. (2024). Використання цифрових технологій у транспортному секторі як фактор підвищення конкурентоспроможності. Науковий вісник Херсонського державного університету. Серія «Географічні науки», (20), 22-27. URL: https://doi.org/10.32999/ksu2413-7391/2024-20-3 (02.01.25)

11 Дмитрієва, О., & Стогул, К. (2024). Особливості застосування блокчейну з акцентом на транспортну інфраструктуру. Проблеми і перспективи розвитку підприємництва, (32), 119-135. URL: https://doi.org/10.30977/PPB.2226-8820.2024.32.119 (30.12.24); Gohar, A., & Nencioni, G. (2021). The role of 5G technologies in a smart city: The case for intelligent transportation system. Sustainability, 13(9), 5188. URL: https://doi.org/10.3390/su13095188 (02.01.25)

12 Дмитрієва, О., & Стогул, К. (2024). Особливості застосування блокчейну з акцентом на транспортну інфраструктуру. Проблеми і перспективи розвитку підприємництва, (32), 119-135. URL: https://doi.org/10.30977/PPB.2226-8820.2024.32.119 (30.12.24)

13 Gohar, A., & Nencioni, G. (2021). The role of 5G technologies in a smart city: The case for intelligent transportation system. Sustainability, 13(9), 5188. URL: https://doi.org/10.3390/su13095188 (02.01.25)

14 Jafari, M., Kavousi-Fard, A., Chen, T., & Karimi, M. (2023). A review on digital twin technology in smart grid, transportation system and smart city: Challenges and future. IEEE Access, 11, 17471-17484; Rudskoy, A., Ilin, I., & Prokhorov, A. (2021). Digital twins in the intelligent transport systems. Transportation Research Procedia, 54, 927-935. URL: https://doi.org/10.1016/j.trpro.2021.02.152 (30.12.24)

15 Скорик, М. О., & Марченко, О. І. (2024). «Smart Cities» та «Urban-Tech» екосистеми як драйвери сталого розвитку міст і територій. Цифрова економіка та економічна безпека, (5 (14)), 91-98. URL: https://doi.org/10.32782/dees.14-14 (24.12.24)

16 Томочко, В., & Цибульський, І. (2024). Удосконалення організаційно-економічних підходів до управління логістичними системами експортоорієнтованих підприємств. Дослідження та інновації, 1(2 (2)), 30-37. URL: https://rni.com.ua/index.php/ri/article/view/20/18 (27.12.24)

these barriers, it is important to develop comprehensive strategies that combine technical, organisational and economic aspects, as well as to improve the skills of personnel to work with new technologies[17].

Thus, digital innovations are not only changing the nature of transport systems but are also becoming an important tool for ensuring their competitiveness and sustainable development. Their effective implementation requires coordinated management, an interdisciplinary approach and the integration of modern technologies into all stages of transport and logistics processes.

It should be noted that digital innovations in transport systems are being actively implemented in different countries, demonstrating their effectiveness and importance for improving the quality of transport services. For example, in Singapore, intelligent transport systems use artificial intelligence to optimise traffic, adjust traffic lights in real time, and provide drivers with information on the best routes. Such solutions help reduce congestion and improve mobility in urban areas. Companies such as Maersk are using blockchain technologies in their supply chains to track cargo and documents. This increases the transparency of operations, reduces the risk of fraud, and allows for effective coordination of processes between different participants in the supply chain. In turn, the introduction of digital twins is becoming a common practice at airports and ports. These technologies allow creating digital copies of objects that are used to model operations, optimise resources, and predict potential problems[18].

In Germany, autonomous trucks with 5G network support are being successfully tested for the transport of goods. The use of high-speed communication allows vehicles to interact with the infrastructure and ensures safe transportation. IoT sensors are also actively used to monitor the condition of infrastructure, such as bridges and roads. This allows for timely repairs and avoidance of accidents.

Thus, digital innovations not only increase the efficiency of transport systems, but also contribute to the safety, environmental friendliness and transparency of operations, ensuring the sustainable development and competitiveness of the transport industry.

In the context of globalisation and digitalisation, transport logistics is undergoing significant transformations due to the introduction of modern digital innovations.

17 Кривов'язюк, І. (2023). Управлінські рішення та їх ефективність щодо впровадження цифрових технологій в логістиці. Collection of scientific papers «SCIENTIA», (October 20, 2023; Sofia, Bulgaria), 34-36. URL: https://previous.scientia.report/index.php/archive/article/view/1253 (25.12.24)

18 Український технологічний портал iTechua // Скарбик П. Інновації в автоматизації транспортної логістики: приклади успішних кейсів. 19.06.2024. https://itechua.com/other/260885 (04.01.25)

The integration of technologies such as the Internet of Things (IoT), artificial intelligence (AI), blockchain, digital twins and 5G allows us to optimise logistics processes, increase their efficiency, ensure transparency of operations and reduce costs. Such innovations are key to creating a competitive and sustainable logistics system. The above studies allow us to present the results in the form of Table 1.

Table 1

Innovations in the automation of transport logistics

Innovations	Description	An example of a successful case
1	2	3
Artificial Intelligence (AI)	Using AI to analyse large amounts of data to optimise routes, forecast demand and manage inventory.	Amazon: AI is used to forecast demand and optimize inventory, ensuring the availability of goods in warehouses.
Internet of Things (IoT)	Provides continuous communication between vehicles, cargo and control centers through sensors that provide data on location, cargo status and environmental conditions.	DHL: IoT sensors are installed on vehicles and containers, allowing the location and status of cargo to be tracked in real time.
Robotics	Using autonomous robots and automated vehicles to move goods, which reduces the need for human labor, increases accuracy, and reduces the risk of human error.	Amazon: Kiva robots are used in warehouses to move goods, significantly reducing order processing times and reducing the need for human labor.
Autonomous Vehicles	The use of unmanned trucks and drones to deliver goods, which increases the efficiency and speed of logistics operations.	Amazon: Testing delivery of orders using drones, which can reduce delivery times to a few hours.
Software	Integration of various systems and tools to automate planning, monitoring and management of transport operations, providing a single source of truthful information for all participants in the logistics chain.	UPS: Introducing the ORION system for optimizing delivery routes, which uses sophisticated algorithms to determine the most efficient routes taking into account traffic, weather conditions, and delivery schedule.
Blockchain	Technology that ensures transparency and data security in logistics processes, reducing fraud risks and improving coordination between supply chain participants.	Maersk: Using blockchain technology in supply chains to track cargo and documents, which increases transparency of operations and reduces fraud risks.
Digital Twins	Creating digital copies of objects to model operations, optimize resources, and predict potential problems in transportation processes.	Airports and Ports: Implementing digital twins to model and test transportation processes, increasing resource efficiency and operations planning.

Continuation of table 1

1	2	3
5G Technologies	They provide high data transfer speeds, which is critical for integrating IoT equipment and other real-time control systems.	Autonomous trucks: Testing autonomous trucks with support for 5G networks for transporting goods, allowing transport to interact with infrastructure and ensuring safe transportation.
6G Technologies	Offers extreme data speeds, near-zero latency, and advanced AI integration, supporting next-generation IoT devices, smart logistics, and real-time automation in complex supply chains.	Huawei: Investing in 6G networks to enable seamless communication in transport logistics and improve operational efficiency.

Source: Author's research

The conclusions drawn from Table 1 demonstrate that digital innovation is driving the transformation of transport logistics. The integration of technologies such as artificial intelligence, the Internet of Things, blockchain, digital twins and 5G is providing a significant increase in the efficiency, transparency and flexibility of logistics operations. For example, the use of AI can optimise planning and inventory management processes, while IoT enables accurate real-time monitoring of cargo.

Robotisation and the use of autonomous vehicles reduce dependence on human labour, speed up operations and reduce the risk of errors. Blockchain helps to improve data security and transparency, which is critical in today's global supply chains. Innovations such as digital twins allow for the modelling and testing of processes to improve the reliability and efficiency of transport infrastructure.

The cases presented here show that these technologies not only increase productivity and reduce costs, but also contribute to the sustainable development of transport logistics. However, their implementation requires significant investments, adaptation of organisational processes and training of qualified personnel. Thus, innovations in transport logistics open up new opportunities for businesses, providing competitive advantages in a rapidly changing global environment.

Research has shown that the implementation of modern technologies to optimize and enhance the efficiency of business processes, particularly in transportation systems, is highly relevant today.

Augmented Reality (AR) and Virtual Reality (VR) are pivotal technologies in the digital transformation of businesses, particularly within transportation

systems. AR enhances the real world by overlaying digital elements such as graphics, text, audio, or video through devices like AR glasses, smartphones, or tablets. It provides an interactive experience in real-time, merging physical and digital realms. Examples of AR applications include interactive navigation systems, optimization of logistics processes such as sorting goods, and assistance in equipment repair or configuration.

In contrast, VR creates a fully digital environment that isolates users from the real world, offering total immersion in a simulated or entirely imagined space. VR is utilized for training personnel, simulating logistics processes, and testing complex operations in transportation systems. Key features of VR include complete detachment from the physical world and interactive engagement with virtual objects, achieved through devices like VR headsets and controllers.

While AR supplements the real world, VR replaces it entirely. AR is commonly used for logistics, navigation, and on-site support, whereas VR excels in training, simulations, and virtual modeling. Together, these technologies significantly enhance operational efficiency, process optimization, and innovative solutions in transportation systems.

This timeline below illustrates the progression and milestones of AR and VR innovations in transportation systems, reflecting their growing influence and practical applications over the years.

The trend of using augmented and virtual reality (AR/VR) in transport systems and logistics is extremely relevant in today's environment, when globalisation, digitalisation and rapid technological development have a significant impact on business processes. The growing complexity of supply chains, the need to ensure transparency of operations, and the demand for rapid adaptation to market changes require the introduction of the latest technological solutions. AR/VR offer unique opportunities for automation, optimisation and an innovative approach to transport process management.

The effectiveness of these technologies is becoming even more important in the face of ever-increasing demands on the accuracy, speed and security of logistics operations. In particular, the COVID-19 pandemic has demonstrated the importance of contactless technologies and the ability to respond quickly to changes in global supply chains. AR/VR has become a powerful tool for improving staff training, optimising warehouse operations and increasing productivity without significant risks.

Additionally, the development of the smart cities concept and the integration of transport systems into urban infrastructure are increasing the demand for technologies that provide effective management of mobility, traffic flows and demand forecasting. AR/VR technologies allow companies not only to solve current problems but also to develop long-term development strategies adapted to the rapidly changing global environment. As a result, these technologies are an important element of the modern digital transformation of the transport industry.

The timeline below illustrates the key milestones in the evolution of digital innovations within transportation systems, showcasing the integration of advanced technologies such as IoT, blockchain, AR/VR, digital twins, and 5G (fig. 1). These innovations have progressively transformed logistics and transportation processes, enhancing efficiency, transparency, and sustainability while addressing the challenges of globalization and digitalization.

Source: Author's research

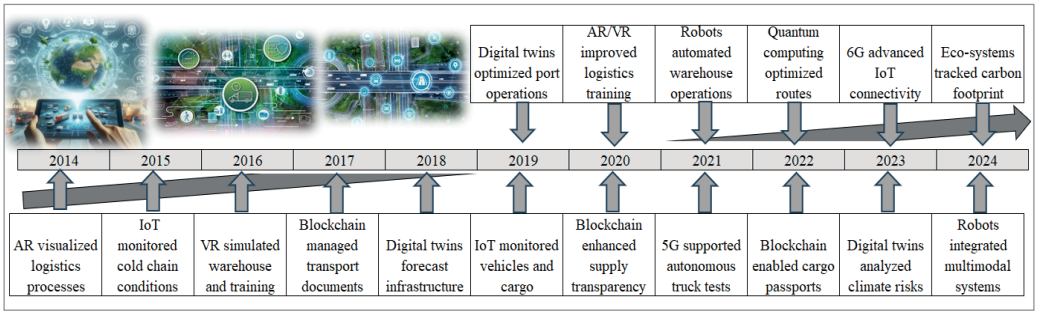

Figure 1. Timeline of Key Digital Innovations in Transportation Systems

The conducted analysis allowed identifying the key milestones in the development of digital innovations in transportation systems. It was revealed that the integration of AR and VR technologies began with experimental applications in 2014, focusing on interactive visualization of logistics processes. By 2015, the introduction of IoT enabled enhanced monitoring of temperature and transportation conditions in cold supply chains.

Further, it was discovered that 2016 marked the beginning of VR usage for warehouse process modeling and staff training. In 2017, the development of blockchain platforms for document management in transportation systems was noted as a significant advancement. By 2018, the analysis highlighted the integration of digital twins for planning and forecasting transport infrastructure as a transformative step.

The study identified 2019 as a pivotal year with the application of digital twins for operational optimization in ports and airports, alongside the growing implementation of IoT for vehicle and cargo monitoring. It was observed that 2020 witnessed the mass adoption of blockchain technologies for enhancing supply chain transparency, as well as the widespread use of AR/VR for personnel training.

The findings show that 2021 brought advancements such as 5G-enabled autonomous truck testing in Germany and the deployment of robots to automate warehouse operations. In 2022, the introduction of quantum computing for route optimization and inventory management was noted, along with the implementation of blockchain-based digital cargo passports.

Moreover, 2023 was marked by the adoption of 6G technologies to support next-generation IoT devices and the extensive application of digital twins for climate risk analysis. Finally, the analysis confirmed that 2024 saw the integration of robots into multimodal transport systems and the implementation of eco-monitoring systems for tracking the carbon footprint in logistics.

This comprehensive analysis has provided valuable insights into the progression of digital technologies and their transformative impact on modern transportation systems.

It is worth noting that the modern world is on the threshold of a new era of digital technologies, which will have a significant impact on the development of transport systems. With the growth of urbanisation, globalisation and the increasing demand for fast and efficient logistics solutions, transport systems need to innovate to adapt to new challenges. One of the key factors in this process is the evolution of wireless technologies, in particular the development of sixth generation (6G) networks.

Studies have shown that 6G is not just the next stage of mobile technology development, but a revolutionary approach to the interaction of devices, people and systems[19]. 6G will provide data transmission speeds hundreds of times faster than 5G, ultra-low signal latency, high energy efficiency and full integration with artificial intelligence. Such capabilities will open up new horizons for the use of the Internet of Things (IoT), automated vehicles, smart infrastructure and digital twins.

In the transport industry, 6G will be the basis for innovative solutions such as autonomous trucks, delivery drones, smart road networks and automated

19 Nguyen, D. C., Ding, M., Pathirana, P. N., Seneviratne, A., Li, J., Niyato, D., ... & Poor, H. V. (2021). 6G Internet of Things: A comprehensive survey. IEEE Internet of Things Journal, 9(1), 359-383.

ports. The ability to integrate large volumes of data from various sources in real time will create opportunities to significantly improve the safety, efficiency and transparency of transport operations. In addition, 6G will help to reduce the carbon footprint of transport by optimising routes and increasing the energy efficiency of systems.

Recently, a number of companies have been actively implementing 6G technologies, which facilitates the development of transport systems and the integration of modern digital innovations. Figure 2 shows examples of successful cases. For example, corporations such as Huawei and Samsung are investing in the development of 6G to provide high-speed data transmission in transport logistics. In Germany, Volkswagen is testing autonomous trucks integrated with 6G for efficient communication between vehicles and infrastructure. Amazon is using 6G-based technologies to optimise the performance of its autonomous delivery drones. In China, logistics company Cainiao is using 6G to track cargo in real time, which significantly increases the efficiency of supply chain management.

Source: Author's research

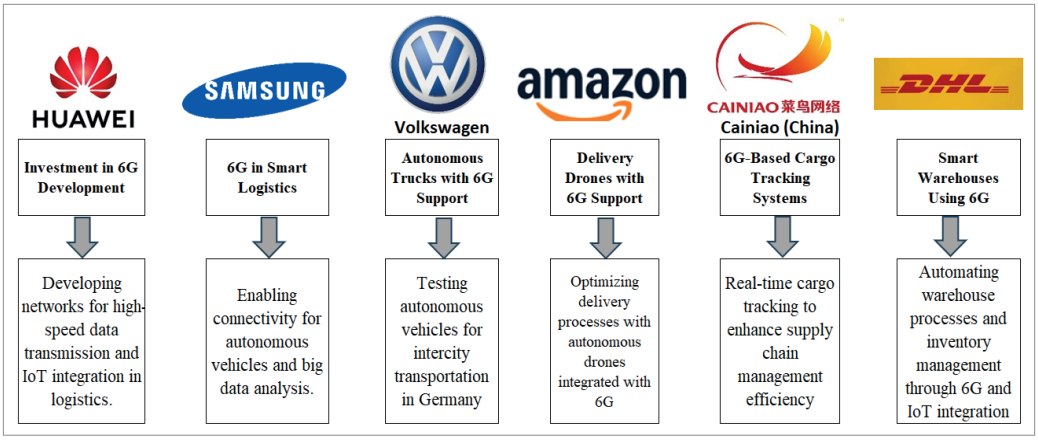

Fig. 2. Implementation of 6G Technologies in Transportation Systems: Examples of Successful Cases

These examples demonstrate the significant potential of 6G in transport systems, especially in automation, increased data transfer speeds and IoT integration for efficient operations management. It is worth noting that the introduction of 6G technologies in logistics opens up new horizons for automation, process optimisation and integration of modern solutions such as the Internet of Things (IoT), blockchain and artificial intelligence. These technologies promise

significant benefits, including increased efficiency, reduced costs and improved customer service.

Scientific research shows that 6G technologies provide ultra-high data transfer speeds, ultra-low latency and the ability to support massive connectivity of IoT devices. In particular, 6G allows for the full integration of IoT into logistics processes, providing continuous real-time monitoring of vehicles, cargo, and warehouse facilities (D.C. Nguyen, et al., 2021)[20]. This helps reduce the risk of loss or damage to goods and ensures accurate inventory management.

Research by S.A.A. Hakeem, H.H. Hussein and H. Kim (2022) show that autonomous vehicles and delivery drones are another key area for 6G implementation in logistics[21]. Thanks to its low latency and stable connectivity, 6G allows autonomous trucks and drones to seamlessly interact with infrastructure, increasing the speed and safety of deliveries. Volkswagen and Amazon, for example, are actively testing autonomous vehicles integrated with 6G for long-distance transport and order delivery.

The use of 6G also opens up opportunities to improve transparency in supply chains through integration with blockchain technologies. As noted by K.M.B. Hasan, M. Sajid, M. A. Lapina, M. Shahid and K. Kotecha (2024) note in their publication that such solutions allow for the creation of digital cargo passports and real-time tracking, which significantly increases trust between supply chain participants[22].

Additionally, the introduction of 6G in smart warehouses allows for automated order processing, optimised inventory management, and reduced manual labour requirements. Authors D.C. Nguyen, M. Ding, P.N. Pathirana, A. Seneviratne, J. Li, D. Niyato, H.V. Poor (2021) note that DHL uses 6G to integrate IoT devices that automate warehousing processes and provide continuous monitoring of inventory[23].

Despite the significant potential, the introduction of 6G in logistics faces challenges such as high infrastructure costs, the need for standardisation and training. However, the benefits that 6G brings to the logistics industry, including

20 Nguyen, D. C., Ding, M., Pathirana, P. N., Seneviratne, A., Li, J., Niyato, D., ... & Poor, H. V. (2021). 6G Internet of Things: A comprehensive survey. IEEE Internet of Things Journal, 9(1), 359-383.

21 Hakeem, S. A. A., Hussein, H. H., & Kim, H. (2022). Vision and research directions of 6G technologies and applications. Journal of King Saud University-Computer and Information Sciences, 34(6), 2419-2442.

22 Hasan, K. M. B., Sajid, M., Lapina, M. A., Shahid, M., & Kotecha, K. (2024). Blockchain technology meets 6 G wireless networks: A systematic survey. Alexandria Engineering Journal, 92, 199-220.

23 Nguyen, D. C., Ding, M., Pathirana, P. N., Seneviratne, A., Li, J., Niyato, D., ... & Poor, H. V. (2021). 6G Internet of Things: A comprehensive survey. IEEE Internet of Things Journal, 9(1), 359-383.

increased efficiency, transparency and environmental friendliness, make it a key enabler for global competitiveness.

Companies implementing 6G technologies in logistics face a number of challenges that slow down the integration of new solutions and require additional resources to overcome. One of the main problems is the high cost of infrastructure, including the construction of new base stations, the purchase of modern equipment and the modernisation of existing systems. For small and medium-sized companies, this can be a serious financial obstacle. Another significant problem is the lack of qualified personnel capable of working with advanced technologies. The demand for specialists in telecommunications, logistics, and digital innovation far exceeds the supply, making it difficult to implement projects.

In addition, the lack of clear standards and regulations for 6G technologies creates difficulties in developing common protocols for interoperability between systems and devices, as well as in cooperation between companies within supply chains. The integration of 6G with existing technologies such as IoT, blockchain or AR/VR is also technically challenging, requiring significant time and resources. At the same time, companies are facing cybersecurity challenges, as the increase in data transmitted and the widespread use of IoT devices increase the risk of cyberattacks and require comprehensive solutions to protect data privacy.

Implementation of 6G is a long-term process that requires testing, scaling of technologies and adaptation of companies to new working conditions. This can cause delays in implementation, which affects business competitiveness. In addition, in the early stages of integration, it is difficult to measure the profitability of new technologies and assess their real impact on business processes, which can deter management from further investment. Overcoming these challenges requires cross-industry cooperation, the development of international standards and development strategies, and the creation of training programmes. Successfully addressing these issues will provide companies with a significant competitive advantage by increasing the efficiency and innovation of their logistics processes.

6G technologies, which are currently under active development, promise to significantly change the way we manage logistics. With its high data transfer speeds, reduced delays and improved connectivity, 6G has the potential to revolutionise logistics processes. At the same time, the implementation of

this technology is accompanied by numerous challenges that require detailed analysis and a strategic approach. Table 2 shows the main advantages and disadvantages of implementing 6G technologies in logistics, which allows us to assess their impact on the efficiency and sustainability of transport systems.

Table 2

Benefits and shortcomings of implementing 6G technologies in logistics

Benefits	Shortcomings
1. Increased data transfer speed. 6G technologies provide extremely high data transfer speed, which allows real-time processing of large amounts of information.	1. High infrastructure costs. Building 6G base stations, upgrading equipment, and integrating with existing systems require significant financial investments.
2. Improved accuracy and efficiency. The implementation of 6G contributes to accurate monitoring of cargo, demand forecasting and optimization of transportation routes.	2. Lack of qualified personnel. The implementation of new technologies requires the involvement of specialists with deep knowledge in the field of 6G, IoT, blockchain, and logistics.
3. Support for autonomous vehicles. 6G provides real-time communication necessary for the safe operation of autonomous trucks and drones.	3. Lack of standards. The technology is at the development stage, so the lack of international standards creates problems with the integration of systems between different companies.
4. Increased transparency of processes. The use of 6G together with blockchain technologies allows for the creation of transparent and reliable logistics chains, reducing the risk of fraud.	4. Cybersecurity challenges. Increasing data volumes and the number of IoT devices increases the risks of cyberattacks and requires complex solutions for information protection.
5. Reduced data transfer delays. 6G technologies allow for the minimization of delays, which is critical for real-time operations.	5. Long implementation process. The technology requires a long period of testing and scaling, which can hinder the competitiveness of companies in the early stages of integration.
6. Support for smart warehouses. The integration of 6G with IoT and robotics improves inventory management, automates processes in warehouses and increases their productivity.	6. Uncertain return on investment. At the initial stages, it is difficult to assess the economic benefit of implementation, which may cause management to doubt the investment.
7. Reducing environmental impact. Through route optimization and carbon footprint monitoring, 6G technologies contribute to the environmental sustainability of logistics processes.	7. Integration complexity. Combining 6G with existing technologies such as AR/VR, blockchain, or IoT can cause technical and organizational difficulties.

Source: Author's research

The presented results of the research on the implementation of 6G technologies in logistics show that this technology has significant potential for

transforming the industry. The key benefits include improved data transfer speeds, enhanced process automation and IoT integration capabilities, and improved monitoring and forecasting accuracy. They help to reduce costs, increase efficiency and make logistics operations more environmentally friendly.

However, disadvantages such as high implementation costs, the need to modernise infrastructure and possible cyber risks pose serious challenges for companies. The issue of adapting existing business models and training staff in new technologies is particularly acute.

In general, the introduction of 6G technologies in logistics requires a comprehensive approach that includes strategic planning, infrastructure investment, cooperation between all supply chain stakeholders and effective risk management. Despite the challenges, these technologies open up new prospects for creating sustainable, innovative and competitive transport systems.

The issue of 6G technologies implementation in logistics deserves special attention among scientists and practitioners, as it is one of the most pressing at the current stage of development of science and technology. This issue is quite timely, as globalisation, digitalisation and growing demands on the efficiency of business processes are forcing companies to look for new technological solutions. It is well known that the development of transport systems largely depends on the introduction of innovative solutions, such as 6G, which provide high-speed communication, IoT integration and process automation.

According to leading researchers in the field, the problem of 6G integration is not only relevant, but also underdeveloped. The existing views on this issue can be classified as optimistic, emphasising the enormous potential of 6G for logistics, and cautious, focusing on challenges and risks. According to D.C. Nguyen et al. (2021), the development of 6G technologies should change the structure of transport systems, contributing to their transparency, efficiency and sustainability[24]. According to S.A.A. Hakeem et al. (2022), the introduction of 6G will be a key factor in the transformation of supply chains, increasing the level of automation and security[25].

Numerous scholars have studied this problem at different times and put forward hypotheses about its prospects. The trend of studying the impact of 6G on transport logistics was initiated by researchers who drew attention to

24 Nguyen, D. C., Ding, M., Pathirana, P. N., Seneviratne, A., Li, J., Niyato, D., ... & Poor, H. V. (2021). 6G Internet of Things: A comprehensive survey. IEEE Internet of Things Journal, 9(1), 359-383.

25 Hakeem, S. A. A., Hussein, H. H., & Kim, H. (2022). Vision and research directions of 6G technologies and applications. Journal of King Saud University-Computer and Information Sciences, 34(6), 2419-2442.

the importance of integrating this technology with blockchain and IoT (K.M.B. Hasan et al., 2024)[26].

It is widely believed that 6G can significantly improve the efficiency of logistics operations management by enabling the rapid exchange of large amounts of data and supporting high-speed communication. However, the issue of implementing these technologies is not only relevant but also controversial, as it requires significant investments, infrastructure adaptation and overcoming regulatory barriers. This challenges management to develop new approaches to strategic planning, change management, and evaluating the effectiveness of implemented solutions.

Thus, the study of the role of 6G in logistics is important not only for the scientific community but also for practical implementation, which makes this issue a key one in the modern development of transport systems.

Effective management of digital innovation in transport systems and logistics is a key factor in the successful integration of modern technologies. Management plays an important role in aligning innovation strategies with the organisation's goals, facilitating adaptation to innovations, and addressing the challenges associated with technology adoption. In Figure 3 shows the main aspects in which management influences the implementation and optimisation of digital innovations in transport and logistics.

The information presented here demonstrates that the effective implementation of innovations depends on the strategic involvement of management at all stages of the process. Management plays a key role in defining the direction of digital transformation, planning and integrating technologies to ensure that they meet the company's goals.

Moreover, managers play a pivotal role in mitigating risks by analyzing potential challenges and developing adaptive strategies. Through enhancing staff qualifications and fostering an innovative culture, management ensures the resilience of the company in the face of rapid changes within transportation systems and logistics.

Equally important is the role of management in ensuring transparency, improving operational efficiency, and optimizing supply chains by integrating technologies such as IoT, blockchain, digital twins, and 5G.

Thus, the management of digital innovations requires a comprehensive approach that encompasses both strategic decision-making and operational management, enabling companies to enhance their competitiveness and achieve sustainable growth in the modern globalized environment.

26 Hasan, K. M. B., Sajid, M., Lapina, M. A., Shahid, M., & Kotecha, K. (2024). Blockchain technology meets 6 G wireless networks: A systematic survey. Alexandria Engineering Journal, 92, 199-220.

Source: Author's research

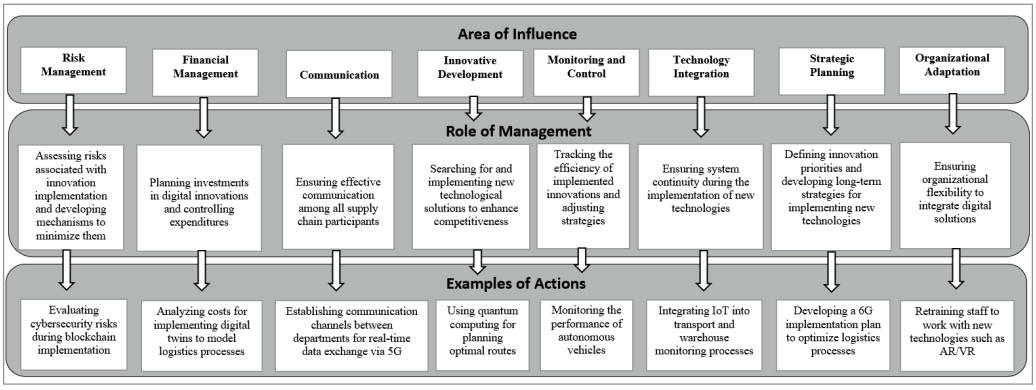

Fig. 3. Operational and Strategic Roles of Management in Digital Logistics

Conclusions. Thus, the conducted research confirms that management plays a key role in the implementation of digital innovations in transportation systems and logistics, ensuring strategic planning, technology integration, and adaptation to modern challenges.

The results of the analysis allow the conclusion that technologies such as IoT, blockchain, digital twins, 5G, and 6G are the primary drivers of digital transformation in the transportation sector. Hence, it can be confidently stated that their integration enhances the efficiency, transparency, sustainability, and competitiveness of transportation systems.

The research allows us to assert that strategic management of digital innovations is critically important for overcoming the technical, organizational, and economic barriers to the implementation of new technologies. The adoption of technologies such as 6G opens new horizons for the development of autonomous transportation, transparent supply chains, and smart warehouses.

The conducted research allowed formulating the following conclusions: the successful implementation of digital innovations in transportation systems requires a comprehensive approach that includes strategic planning, effective risk management, and the development of an innovative culture within organizations. The analysis addressed the set objectives and confirmed the key principles regarding the importance of management in creating a sustainable, efficient, and competitive transportation infrastructure.

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