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DIGITAL MANUFACTURING: MODERN TECHNOLOGIES AND APPLICATIONS IN LOGISTICS

Abstract: *Under the influence of digital technologies, modern industrial systems are undergoing profound transformation, leading to the creation of new production models and management of logistics processes. Concepts such as Industry 4.0 and the increasingly prevalent Industry 5.0 introduce advanced solutions such as the Internet of Things (IoT), Artificial Intelligence (AI), digital twins, and smart factories, enabling greater flexibility, efficiency, and adaptability in production processes.*

In such an environment, logistics plays a key role in ensuring the continuous flow of materials, information, and energy throughout all phases of production and distribution. The integration of digital technologies into logistics processes enables better planning, real-time tracking, and resource optimization, which directly impacts the overall competitiveness of production systems.

This paper demonstrates how modern technologies affect logistics processes, with an emphasis on challenges, and development prospects. Special attention is given to the possibilities for improving logistics through the application of digital tools.

Keywords: *digital technologies, logistic, digital manufacturing.*

1. Introduction

With the exponential development of information technologies, an increasing number of manufacturing companies are adopting digital tools within production and logistics processes. Digital technologies are gradually integrating into the entire lifecycle of products and production, replacing traditional approaches with digital and informational solutions. This has led to the emergence of the concept of the digital factory (Gregor et al., 2009), which involves virtual planning, simulation, and optimization of the real production system, while data from physical components is continuously collected, analyzed, and returned to the system for further adaptation (Zuehlke, 2010).

At the same time, modern logistics is becoming increasingly complex due to the need for greater adaptability, responsiveness, and cost optimization. The integration of digital technologies into logistics flows (such as inventory planning, transportation, supply chain management, and distribution) has resulted in so-called digital logistics—where real-time information is used to make quick, accurate, and optimized decisions (Ivanov & Dolgui, 2020). In this context, logistics is

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increasingly becoming an active element of the production system.

The use of digital twins for warehouse modeling, predictive analysis in transportation networks, as well as autonomous vehicles and robots in logistics centers, are just some of the innovations that are reshaping the image of logistics today. Furthermore, synchronization between production and logistics enables cost reduction, shorter delivery times, and increased reliability of delivery to end-users.

The goal of this paper is to analyze the possibilities of applying modern digital technologies in logistics by identifying key technologies, benefits, and challenges of implementation. The paper seeks to demonstrate how technological innovations not only change production methods but also transform entire logistics chains in terms of efficiency, transparency, and adaptability.

2. Technologies of Digital Manufacturing

Modern digital manufacturing (Chryssolouris et al., 2009) represents a set of integrated technological solutions that enable automation, digitization, and intelligent management of the entire production process—from product design, through production planning, to execution and reverse logistics. At the core of this approach lies the application of advanced digital technologies that transform traditional production systems into flexible, adaptable, and highly efficient entities.

Digital manufacturing technologies (Wan et al., 2020) encompass a wide range of tools, platforms, and methods that facilitate the creation, management, and distribution of products and services. Some of the most significant technologies in this area include: Internet of Things (IoT), Artificial Intelligence and Machine Learning (AI/ML), Digital Twins, Additive Manufacturing (3D Printing), Cloud and Edge Computing, Cyber-Physical Systems (CPS), Advanced Analytics and Big Data, VR/AR (Virtual and Augmented Reality), Robotics and Automation, etc. (Strazzullo, 2024; Krstić et al., 2021).

Digital manufacturing (Wu et al., 2015), through the integration of advanced information and communication technologies into all phases of the production process, significantly contributes to improving effectiveness and efficiency, enabling optimal management of production resources, better process control, and enhanced system adaptability (Zhong et al., 2017).

3. Digital Technologies in Modern Logistics

Logistics plays a key role in digital manufacturing, ensuring efficient management of transportation, storage, and distribution of products, services, and information (Vashishth et al., 2025). Within digital manufacturing, logistics is increasingly focused on the application of innovations and new technologies to optimize operations and enhance the entire supply chain. Below is an overview of the most commonly used digital technologies in modern logistics and their applications.

The Internet of Things (IoT) plays a significant role in modernizing and optimizing logistics processes. It enables the connection and communication between various devices, machines, and systems via the Internet, creating opportunities for managing and monitoring production processes and enhancing business operations through real-time data collection and exchange. In logistics, this technology connects physical objects such as vehicles, sensors, pallets, and warehouses into a single network, improving transparency, efficiency, and security across all stages of the logistics process—from warehousing to the last point of delivery (Ben-Daya et al., 2019).

Some of the most commonly used IoT technologies are **RFID** and **NFC**, which enable identification and tracking of packages and automation of receiving and delivering (Angeles, 2005). RFID technologies: Supply-chain applications and implementation issues. *Information Systems Management, 22*(1)]. RFID is utilized when quick and precise tracking, control, and recording of object movement are required (Popova et al., 2021). While RFID enables automated object tracking (packages, pallets, and vehicles) and contactless reading of information from a distance (Dobkin, 2012), NFC has a shorter range and is used for product authentication, delivery confirmation, and retrieving information about shipments (Coskun et al., 2013).

Artificial Intelligence (AI) and **Machine Learning (ML)** are used for analyzing large datasets and making intelligent decisions within manufacturing and logistics processes. They offer numerous opportunities for optimizing production processes, improving product quality, and enhancing efficiency. In logistics, AI and ML are often employed to optimize transportation routes, taking into account a wide range of factors (Becker et al., 2016). These systems can predict the best possible routes, minimizing costs and delivery time.

Additionally, by analyzing large quantities of data, future demand for products can be forecasted, enabling logistics companies to adjust their inventory in a timely manner (Zhao et al., 2023).

Digital twins are virtual replicas of physical objects and processes that allow for simulation, monitoring, and real-time optimization (Kuo & Choi, 2024; Tao et al., 2018). They enable the simulation of warehouse operations (movement of robots, flow of inventory, goods, and people), which helps optimize space, as well as the processes of receiving and dispatching goods. Using digital twins, logistics managers can simulate in real-time how disruptions (e.g., delivery delays, changes in demand) impact the entire supply chain—an especially vital capability in global and complex systems. Additionally, they can monitor environmental conditions, such as temperature and humidity, which is particularly important in cold chain warehouses (Hu et al., 2023).

Additive Manufacturing (3D Printing) enables rapid and flexible production of prototypes and functional parts without the need for tools. Although it is not primarily focused on logistics activities (such as transportation or storage), its impact on logistics processes is becoming increasingly significant, especially in the context of shortening supply chains, reducing inventory, and quickly producing spare parts, thereby contributing to the overall optimization of the supply chain (Walter et al., 2004).

Cloud computing represents one of the key technologies in the context of digital manufacturing. It refers to accessing computing resources (data, servers, software, etc.) over the internet without the need for these resources to be locally stored on the user's device (Xu, 2012). Cloud-based solutions allow logistics companies to monitor shipment status, inventory availability, and transportation conditions in real time. Their application results in significant cost, time, and effort savings by eliminating the need to build in-house IT infrastructure (Temjanovski et al., 2021).

Robotics is a highly important component of modern digital technologies, playing a significant role in the automation, optimization, and improvement of production and logistics processes (Bogue, 2024). Various types of robots are used in warehouses, including robots for sorting, transport, and packaging. They enable faster distribution processes and reduce errors in sorting (Wilson, 2023).

Virtual and **augmented reality** are two emerging technologies that have become very significant elements in the modernization of various industries in recent years. Virtual reality allows users to fully immerse themselves in a digital world simulated by computer systems (Kuo & Choi, 2024). In logistics, it has numerous applications that assist in training (Ogrizović et al., 2021; Yigitbas et al., 2020), warehouse management, and the simulation of various logistics processes. It can help design and optimize warehouse layouts, as well as analyze safety protocols within warehouses.

Augmented reality combines the virtual world with the real environment. In logistics, AR can assist workers in more easily locating goods in warehouses (through the use of smart glasses), provide support for inventory management (by offering visual information on the quantity, type, and condition of goods), and more (Wang et al., 2020).

Table 1 presents various potential applications of digital technologies in the field of logistics.

Table 1. The applications of digital technologies in logistics

Technology	Applications in logistics	References
Internet of Things (IoT)	Sensors in warehouses, real-time tracking of goods, predictive maintenance of transportation vehicles, automated inventory management, automated tracking of objects, product authentication, delivery confirmation, and retrieving information about shipments	Ben-Daya et al. (2019); Zrelli & Rejeb (2024); Dobkin (2012); Popova et al. (2021); Coskun et al. (2013)
Artificial Intelligence (AI) and Machine Learning	Route optimization, delay prediction, prediction of future inbound logistics processes	Becker et al. (2016); Silva et al. (2021); Knoll et al. (2016).
Digital Twins	Warehouse modeling, simulation of transportation flows, monitoring and supervision, decision-making, supply chain optimization	Hu, et al. (2023); Leng et al. (2021); Jiang et al. (2020)
Cloud Computing	Outsourcing IT services (various software solutions for managing transportation, warehousing, route planning, and tracking), integration, synchronization, and data sharing.	Arnold, et al. (2013)
Robotics	The use of robots for sorting, transporting, and packaging in warehouses	Lin et al. (2021); Wilson (2023); Jin et al. (2016)
Virtual and Augmented Reality	Training, simulation of various logistics processes, designing and optimizing warehouse layouts, support in inventory management, analysis of safety protocols in warehouses	Ogrizović et al. (2021); Yigitbas et al. (2020); Wang et al. (2020)

4. Benefits and Limitations

The introduction of digital technologies into logistics flows brings numerous advantages but also certain challenges that require careful analysis and a strategic approach to their implementation.

Some of the advantages (Popova et al., 2021) of introducing these technologies into the logistics process are:

- More precise management of resources and real-time data
- Improved training and communication among staff

- Reduced operational costs
- Enhanced control over the movement of goods throughout the supply chain
- Reduction of inventory storage time
- Real-time access to information to boost efficiency
- Lower error rates compared to conventional methods
- Effective organization of order preparation and processing
- Reduced time for transmitting information.

Limitations of introducing these technologies into the logistics could be:

- High initial investment costs
- Integration with existing systems
- Training requirements
- Privacy and security concerns
- Technical challenges
- Potential ethical dilemmas with AI usage.

5. Conclusion

The inclusion of digital technologies in production processes is inevitable and represents a key element for successful operations in a modern environment. There is significant potential for innovation and growth through the application of these technologies, and organizations that establish robust digital manufacturing strategies will gain an advantage in the future.

The application of digital technologies in logistics enables better management of the entire supply chain, including tracking and inventory management, route optimization, reducing delivery times, and cost savings.

However, to fully utilize the advantages of these technologies, it is necessary to invest in infrastructure, staff training, the development of new business models, and organizational culture change. Additionally, attention must be paid to issues related to data privacy, information security, and the ethical aspects of using artificial intelligence and other advanced technologies.

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