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LOGISTICS IN THE MEDICAL INDUSTRY IN CROATIA: SUPPLY CHAIN OPTIMIZATION FOR SAFER AND MORE EFFICIENT HEALTHCARE DELIVERY

Abstract: *Healthcare systems are increasingly facing challenges in the supply of medicines, medical equipment, and consumables, making logistics a key element in the efficient functioning of the healthcare industry. This paper analyzes the role of logistics in optimizing the healthcare supply chain and its impact on the quality and safety of healthcare delivery. Special emphasis is placed on inventory management, procurement and distribution organization, and the maintenance of the cold chain for sensitive products. The advantages of implementing modern technologies such as ERP and WMS systems, RFID tags, IoT sensors, artificial intelligence, and blockchain are presented, as they enable digital traceability and error reduction. The paper also highlights major challenges such as global supply chain disruptions, regulatory requirements, and the need for sustainability. It concludes that healthcare logistics is not merely a supporting function but a strategic factor that enhances system efficiency and patient safety.*

Keywords: *logistics; healthcare system; medical equipment; technology; supply chain; efficiency*

1. Introduction

Logistics in the healthcare sector represents one of the key factors in the successful functioning of modern health systems. In the context of continuously increasing demand for healthcare services, limited resources, and a high level of regulatory requirements, efficient logistics has become the foundation for ensuring timely, safe, and high-quality healthcare delivery. Unlike general logistics, healthcare logistics has an exceptionally sensitive and responsible role, as any error in the supply chain can have direct consequences on patient health and life. Therefore, the planning, organization, storage, and distribution of medicines, medical equipment, and consumables must be carried out with the highest possible level of precision, safety, and transparency.

The COVID-19 pandemic further emphasized the importance of logistics in healthcare while simultaneously revealing the vulnerability of global and national supply chains. During the pandemic, significant disruptions occurred in the procurement and distribution of essential medical products, such as personal protective equipment, ventila-

tors, vaccines, and medicines. These disturbances exposed a lack of coordination among suppliers, dependence on foreign manufacturers, and insufficient digital connectivity within healthcare systems. The crisis demonstrated that the resilience and flexibility of the logistics system directly influence the ability of healthcare institutions to respond to emergencies effectively. The aim of this paper is to analyze the role and significance of logistics in the medical industry, with a focus on optimizing the supply chain for medicines, medical devices, and auxiliary materials. Particular attention is given to modern logistics models and technologies that enable greater efficiency, cost reduction, and enhanced patient safety. The paper examines current challenges in healthcare logistics, including maintaining supply continuity, process digitalization, and the application of innovative solutions such as RFID systems, the Internet of Things (IoT), ERP, and blockchain technologies. The contribution of this study lies in highlighting the need for integrating logistical and technological approaches that can significantly improve the resilience and efficiency of healthcare systems in the Republic of Croatia and beyond.

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2. Theoretical framework and literature review

Logistics, in its broadest sense, is defined as the process of planning, implementing, and controlling the efficient and cost-effective flow of goods, information, and services from the point of origin to the final user (Ballou, 2007). In an industrial context, logistics ensures optimal resource utilization, cost reduction, and increased customer satisfaction. However, within the healthcare system, its role is considerably more complex, as it directly affects patient safety and the continuity of healthcare delivery (Kumar & Goswami, 2021).

Healthcare logistics encompasses the planning, procurement, storage, distribution, and control of medical products, pharmaceuticals, and equipment in compliance with strict regulatory requirements. The World Health Organization (WHO, 2020) emphasizes that logistics in healthcare plays a crucial role in ensuring the availability of essential medicines and equipment, which is a prerequisite for the effective functioning of health systems. In this sense, logistics is not merely a supporting function but a strategic element that connects medical, administrative, and technical processes into a unified operational system (Van de Velde & Degoulet, 2003).

2.1. Supply Chain Management in Healthcare

Supply Chain Management (SCM) encompasses the coordination of all activities involved in the procurement, production, storage, and distribution of products to the end user (Christopher, 2016). In the healthcare context, SCM refers to the management of complex networks of suppliers, manufacturers, regulatory bodies, and healthcare institutions with the goal of achieving reliability, efficiency, and safety. A distinctive feature of the healthcare supply chain is the need for absolute product traceability, as even the smallest error can jeopardize patient health or result in serious regulatory consequences (Rushton, Croucher, & Baker, 2017).

Key SCM activities include inventory management, demand planning, supplier selection, and quality control. An efficient supply chain enables cost reduction, prevents shortages, and enhances operational flexibility, which is particularly important in crisis situations such as the COVID-19 pandemic (Ivanov & Dolgui, 2020). Integrated supply chain management approaches that incorporate

digital tools such as ERP, WMS, and IoT systems have been proven to improve efficiency and accuracy in tracking medical products (Zhong, Newman, Huang, Lan, & Fang, 2016).

2.2. Review of Recent Research

Research conducted in recent years indicates a growing interest in the application of advanced technologies in healthcare logistics. For example, Al-Qatawneh et al. (2022) emphasize that the implementation of digital traceability through RFID tags and blockchain technology significantly reduces the risks of errors and counterfeit medicines. Furthermore, according to the study by Ivanov and Dolgui (2020), the resilience of the healthcare supply chain depends on the ability to quickly adapt to disruptions through scenario planning and diversification of sourcing.

Numerous studies also confirm the importance of sustainability in healthcare logistics. The optimization of transport routes, rational use of packaging materials, and recycling of medical waste have become key elements of sustainable development in healthcare institutions (Sarkis, 2020). At the same time, the digitalization and automation of logistics processes not only increase efficiency but also contribute to reducing the carbon footprint, aligning with the European Union's goals for a green transition (European Commission, 2021).

Overall, recent literature confirms that the digital transformation of logistics processes in healthcare represents a fundamental prerequisite for a safe, efficient, and resilient healthcare infrastructure of the future.

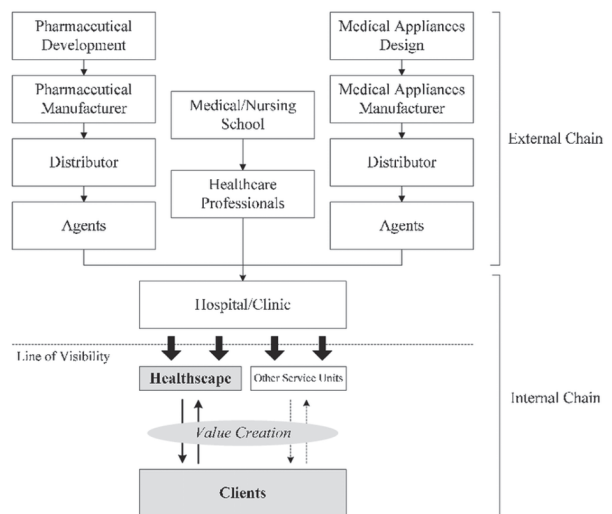


Figure 1. Structure and flows of the healthcare supply chain Source: Paul, S., & Sarker, A. (2019).



3. Logistics processes in the healthcare system

Effective management of logistics processes is the foundation of a stable and reliable healthcare system. These processes encompass all stages—from the planning and procurement of medical products to their storage, distribution, and utilization control within healthcare institutions. Each segment of the logistics chain must be precisely coordinated to ensure the timely availability of medicines, equipment, and materials, thereby preventing disruptions in the provision of healthcare services. The implementation of modern logistics models and digital technologies further enhances efficiency and safety, making healthcare logistics a key factor in the successful functioning of the entire system.

3.1. Inventory Management

Inventory management in the healthcare system represents one of the most critical elements of the logistics process, as it directly affects the availability of medicines, medical equipment, and consumables. Healthcare inventories consist of high-value products with limited shelf lives; therefore, efficient planning and monitoring are essential to ensure the continuity of healthcare delivery (Van de Velde & Degoulet, 2003). Inadequate inventory management can lead to shortages that endanger patients, as well as excessive stock that generates high costs and increases the risk of product expiration (Rushton, Croucher, & Baker, 2017).

Commonly applied methods include the FIFO (first in, first out) and FEFO (first expired, first out) principles, which ensure that products are used according to their order of receipt or expiration date. Additionally, the JIT (just in time) model enables stock optimization by reducing inventory levels and delivering products according to actual needs (Christopher, 2016). Another useful analytical tool is the ABC analysis, which categorizes items according to their value and frequency of use—Category A includes the most valuable items that constitute a small portion of total quantity but the largest share of total value (Ballou, 2007). Digital systems such as ERP (Enterprise Resource Planning) and WMS (Warehouse Management System) allow real-time tracking of stock, automatic order generation, and consumption analysis by department and time period. The use of these tools has been proven to reduce procurement and storage costs while improving patient service levels (Kumar & Goswami, 2021).

3.2. Procurement Organization: Centralized and Decentralized Approaches

Procurement models for medical equipment and pharmaceuticals may be centralized or decentralized, depending on the organizational structure of the healthcare system. Centralized procurement means that all purchasing decisions, supplier selection, and delivery terms are made by a single central authority—such as a Ministry of Health or central procurement agency. The advantage of this approach lies in cost reduction through joint tenders, product standardization, and stronger negotiating power (Ivanov & Dolgui, 2020).

However, centralization may slow down procurement processes and reduce flexibility in emergencies requiring rapid delivery. Conversely, decentralized procurement grants greater autonomy to individual hospitals or departments to acquire supplies according to their specific needs. While this approach enhances flexibility, it may also lead to variations in product quality and price and create additional administrative burdens (Christopher, 2016).

In practice, a hybrid model is increasingly used, combining the benefits of both systems: strategic procurement is conducted centrally, while consumables and low-value items are acquired locally. This mixed approach has proven to enhance efficiency and balance between cost control and product availability (Rushton et al., 2017).

3.3. Distribution Centers and Warehouse Systems

Distribution centers and warehouse systems represent the central hubs of the healthcare supply chain, ensuring the storage, control, and distribution of medical products to end users. Their organization must comply with international standards such as GMP (Good Manufacturing Practice) and GDP (Good Distribution Practice), which define the conditions for storage, transport, and batch traceability (World Health Organization [WHO], 2020).

Successful distribution systems use automated warehouse management systems (WMS) that monitor the entry, exit, and serial numbers of each product. These warehouses are typically organized into standardized zones for different product types: cold chain items, sterile materials, high-value equipment, and consumables (Sarkis, 2020). Additionally, the use of temperature and humidity sensors ensures optimal environmental

conditions and prevents the degradation of medicine quality (Zhong, Newman, Huang, Lan, & Fang, 2016).

Modern distribution centers in advanced healthcare systems increasingly rely on robotic inventory management systems, which accelerate order processing and reduce manual labor requirements. This increases accuracy, minimizes the risk of errors, and speeds up the overall distribution process (Al-Qatawneh, Alrawashdeh, & Alshraideh, 2022). Ultimately, efficient distribution and warehouse systems form the foundation of a stable and resilient healthcare supply chain.

3.4. Cold Chain and the Management of Temperature-Sensitive Products

One of the most critical segments of healthcare logistics is the cold chain, which encompasses the transport, storage, and handling of medicines and biological products under strictly controlled temperature conditions. Maintaining an uninterrupted temperature range—typically between +2°C and +8°C—is crucial for preserving the efficacy of vaccines, insulin, blood products, and other sensitive materials (WHO, 2020).

An effective cold chain requires the use of equipment such as refrigerated chambers, thermal boxes, vehicles with active cooling systems, and IoT sensors for real-time temperature monitoring (Kumar & Goswami, 2021). Improper storage or temperature deviations can cause irreversible product damage, financial losses, and serious risks to patient health (Christopher, 2016).

The integration of digital technologies allows better control over transport and storage processes. For example, linking RFID tags with IoT sensors and blockchain enables complete product traceability from manufacturer to patient,

thereby enhancing system safety and transparency (Al-Qatawneh et al., 2022). This creates a new paradigm of data-driven healthcare logistics based on predictive analytics and real-time monitoring.

4. The role of technology in healthcare logistics

The development of modern technologies has significantly transformed the way logistics processes in the healthcare sector are planned, executed, and monitored. Digital transformation has enabled greater transparency, accuracy, and speed across all stages of the supply chain—from ordering to final delivery to the patient. Technological tools such as Enterprise Resource Planning (ERP) systems, Warehouse Management Systems (WMS), the Internet of Things (IoT), Radio Frequency Identification (RFID) tags, and blockchain technology allow for real-time tracking and control of goods. The implementation of these solutions contributes to more efficient planning, reduced errors and costs, and enhanced patient safety and healthcare system resilience.

4.1. Digital Transformation of Healthcare Logistics

Advances in ICT have reshaped healthcare logistics by integrating all supply chain participants into a transparent, data-driven network (Christopher, 2016). This integration improves demand forecasting, inventory accuracy, and decision-making (Ivanov & Dolgui, 2020). Technologies such as ERP, IoT, RFID, AI, and blockchain enhance efficiency and patient safety, forming smart logistics systems capable of real-time data collection and coordination (Kumar & Goswami, 2021).

4.2. ERP and WMS Systems in the Healthcare Supply Chain

ERP systems unify procurement, finance, HR, and logistics processes within a single digital platform, reducing errors and increasing process visibility (Zhong et al., 2016). WMS solutions complement ERP by optimizing warehouse operations and enabling real-time tracking of stock, expiry dates, and locations (Rushton et al., 2017). Together, ERP and WMS create a flexible and cost-efficient supply chain able to adapt quickly to fluctuations or crises (Ballou, 2007).

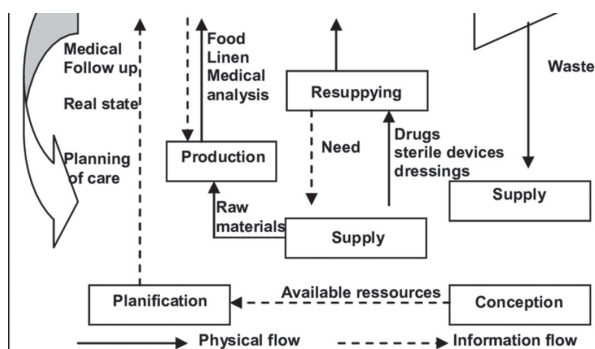


Figure 2. Logistics processes and flows within the hospital system, Source: Volland, J., Fügenger, A., Schoenfelder, J., & Brunner, J. O. (2017).



4.3. RFID and IoT Technologies: Traceability and Safety

RFID ensures automated tracking of pharmaceuticals and medical devices throughout their entire life cycle, reducing errors and counterfeiting risks (Al-Qatawneh et al., 2022). IoT sensors monitor temperature, humidity, and movement in real time, securing the integrity of sensitive products such as vaccines and insulin (Kumar & Goswami, 2021). These technologies significantly enhance traceability and product safety across the supply chain.

4.4. Application of Artificial Intelligence and Blockchain

AI supports predictive planning by analyzing historical and epidemiological data, improving procurement accuracy and reducing shortages (Sarkis, 2020). Blockchain provides immutable, shared records of product movement and conditions, strengthening transparency and preventing manipulation (Al-Qatawneh et al., 2022). Combined with IoT, blockchain enables complete real-time traceability from production to patient use (European Commission, 2021)..

4.5. Benefits of Digitalization in Healthcare Logistics

Digital technologies enhance data accuracy, reduce operational costs, accelerate information flow, improve risk management, and support sustainability through optimized transport and reduced waste. Digitalization represents a strategic shift toward a more efficient, transparent, and resilient healthcare supply chain (Ivanov & Dolgui, 2020).

The listed technologies are presented in the table compiled by the authors.

Table 1. Digital Technologies in Healthcare Logistics
Source: Prepared by the authors

Technology / System	Role in Healthcare Logistics	Key Benefits
ICT / Digital Transformation	Connects all supply chain stakeholders into a unified digital system	More accurate planning, improved inventory control, faster decision-making
ERP Systems	Integrate procurement, finance, HR, and logistics	Greater transparency, fewer errors, more efficient process management
WMS Systems	Optimize warehouse operations and product tracking	More accurate inventory levels, lower costs, improved warehouse organization
RFID Technology	Automatically identifies and tracks medicines and equipment	Full traceability, reduced risk of errors and theft
IoT Sensors	Monitor temperature, humidity, and transport conditions in real time	Increased safety of temperature-sensitive products
Artificial Intelligence (AI)	Predicts demand and optimizes procurement	Fewer shortages, reduced costs, improved analytics
Blockchain	Provides immutable records of product movement	High transparency, reduced risk of manipulation and counterfeiting

5. Challenges and risks in the healthcare supply chain

The healthcare supply chain faces numerous challenges arising from its complexity, global interdependence, and high level of regulation. As it supports systems that are essential for safeguarding human health, any irregularity or disruption can have far-reaching consequences. Disruptions caused by global crises, regulatory requirements, dependence on external suppliers, and limited logistical capacities highlight the need for more resilient and agile management models. In this context, identifying and managing risks become key factors in maintaining the continuity and safety of healthcare supply operations.

5.1. Global Disruptions and Supply Chain Vulnerability

The healthcare supply chain is extremely complex and globally interconnected, making it highly sensitive to various external disruptions such as natural disasters, geopolitical conflicts, economic crises, and pandemics. The COVID-19 pandemic was a precedent that exposed the vulnerability and dependency of healthcare systems on global suppliers (Ivanov & Dolgui, 2020). During the pandemic, shortages of essential medical equipment, protective masks, test kits, and ventilators revealed how difficult it is to maintain supply chain continuity when global demand surges dramatically.

Similar challenges have arisen during geopolitical conflicts, such as the war in Ukraine, when the transport of certain pharmaceutical raw materials and medical equipment from Eastern Europe and Asia was disrupted. These events demonstrated the necessity of developing more resilient and regionally diversified supply chains to reduce dependence on a limited number of suppliers and geographic markets (Christopher, 2016).

5.2. Regulatory Requirements and Complexity of Standards

Healthcare products are subject to stringent regulations and standards that vary depending on product type and market. In the European Union, Regulation (EU) 2017/745 on medical devices plays a crucial role in ensuring product safety, traceability, and market surveillance. Similarly, pharmaceutical products must comply with the principles of Good Manufacturing Practice (GMP) and Good Distribution Practice (GDP), which define quality

control procedures across all stages of production and distribution (World Health Organization [WHO], 2020).

For manufacturers, distributors, and healthcare institutions, this means continuous monitoring of regulatory updates, conducting audits, and maintaining certification in accordance with international standards. Although these requirements increase patient safety, they also pose administrative and financial burdens, particularly for smaller suppliers and hospitals with limited resources (Rushton, Croucher, & Baker, 2017).

5.3. Dependence on External Suppliers and Limited Capacities

A large portion of medical products and pharmaceutical raw materials is imported from outside the European Union, especially from China and India, which are the world's leading producers of active pharmaceutical ingredients (Kumar & Goswami, 2021). Dependence on external suppliers increases the risk of delivery delays, price fluctuations, and supply interruptions. In Croatia, this problem is further reflected in limited storage and logistics capacities, insufficient specialized refrigeration infrastructure, and a shortage of qualified logistics personnel.

To mitigate these risks, the development of multi-sourcing strategies and the establishment of regional distribution centers are recommended to ensure faster and safer delivery during crisis situations (Ivanov & Dolgui, 2020). These measures increase the resilience of the supply chain and reduce dependence on global markets.

5.4. Sustainability and Medical Waste Management

Healthcare systems generate significant amounts of waste, including packaging, consumables, and expired medical products. According to WHO (2020), hospitals and laboratories produce between 0.5 and 2.5 kilograms of waste per patient per day, a considerable portion of which is hazardous and requires special disposal procedures. Improper management of such waste can have severe environmental and public health consequences.

In the context of sustainability, increasing attention is being given to green logistics and the circular economy, which include optimizing transport routes, recycling packaging materials, reusing resources, and reducing CO₂ emissions (Sarkis,

2020). The European Commission (2021) encourages healthcare institutions to adopt sustainable logistics practices through digitalization, energy-efficient systems, and staff education. These approaches not only reduce costs and environmental impact but also enhance the long-term efficiency and reputation of healthcare organizations.

5.5. Risk Management and the Need for Resilient Systems

Risk management in healthcare logistics involves identifying, assessing, and mitigating potential threats that may compromise supply chain safety and continuity. According to Christopher (2016), a successful risk management framework is based on a proactive approach that includes crisis preparedness plans, the maintenance of safety stock, and the development of alternative transport and sourcing channels.

Digital tools such as predictive analytics, artificial intelligence, and blockchain can significantly enhance real-time risk monitoring and assessment (Kumar & Goswami, 2021). By combining technological and organizational solutions, healthcare systems can strengthen their resilience and responsiveness to emergencies, which is essential for safeguarding patient health and safety.

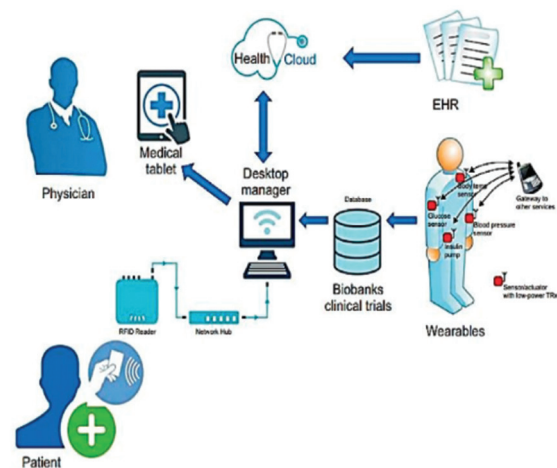


Figure 3. Digital technologies in the healthcare supply chain Source: Hussain, M., Ahmad, N., & Ullah, R. (2023).

6. Discussion

The healthcare supply chain, as one of the most complex and sensitive logistical systems, plays a crucial role in ensuring the efficiency and safety of healthcare delivery. This discussion synthesizes the previously analyzed findings on logistics processes, technologies, and challenges in healthcare



and relates them to current research and practices in Croatia and the European Union. Particular emphasis is placed on digital transformation, system resilience, and the strategic importance of logistics in the medical industry.

6.1. Healthcare Logistics as a Strategic Function

Traditionally, logistics in healthcare was considered a supportive function focused on operational tasks such as procurement, storage, and distribution. However, modern approaches increasingly emphasize its strategic dimension. According to Christopher (2016), an efficient healthcare supply chain can be as critical to treatment outcomes as the medical therapy itself. Timely delivery of medicines, vaccines, and medical devices directly affects the quality of healthcare, whereas any delay can have severe consequences for patients.

In the context of the Republic of Croatia, healthcare logistics has not yet been fully recognized as a strategic instrument. Although the Ministry of Health and the Croatian Health Insurance Fund (HZZO) have initiated efforts toward digitalization and centralized procurement, many hospitals still rely on outdated and non-integrated systems. Consequently, frequent medicine shortages, inconsistent supply quality, and high operational costs persist. The implementation of integrated information systems such as ERP and WMS can significantly improve resource planning and control, as demonstrated by examples from Western European countries (Rushton, Croucher, & Baker, 2017).

6.2. Digitalization and Technological Innovation as a Prerequisite for Resilience

The COVID-19 pandemic accelerated digital transformation in the healthcare sector and emphasized the need for automation and real-time data monitoring. Technologies such as RFID, IoT, and blockchain enable full traceability and transparency across the supply chain (Al-Qatawneh, Alrawashdeh, & Alshraideh, 2022). In practice, this means that each medical product can be tracked from the manufacturer to the end user, reducing the risk of counterfeiting and errors.

Digital solutions represent not only technological advancement but also a transformation of organizational culture. Effective digitalization requires employee training, process adaptation, and standardization of protocols across stakehold-

ers (Kumar & Goswami, 2021). According to the WHO (2020), countries that had previously implemented digital procurement and distribution platforms—such as the Netherlands and Sweden—demonstrated higher resilience during pandemic crises. Digital tools enabled faster resource reallocation, optimized transportation, and precise tracking of temperature-sensitive products such as vaccines and medicines.

In Croatia, however, digital connectivity between suppliers, distributors, and hospitals remains insufficient. Data are often managed manually or within disconnected systems, increasing the risk of errors and slowing decision-making. Implementing integrated ERP and WMS systems across all public hospitals could create a unified platform for consumption tracking, improving transparency and cost-efficiency.

6.3. Sustainability as a Core Element of Logistics Strategy

Recent literature increasingly highlights the concept of sustainable logistics (green logistics), which encompasses transport optimization, energy reduction, and proper medical waste management (Sarkis, 2020). Given that the healthcare sector generates substantial waste, sustainable logistics becomes not only an environmental necessity but also an economic imperative. The application of circular economy principles in the medical industry involves material reuse, packaging recycling, and energy-efficient distribution (European Commission, 2021).

In Croatia, there is significant potential for improvement in this area, particularly in the adoption of green transport and rational delivery planning. Introducing electric vehicles, reducing empty runs, and consolidating hospital orders can substantially reduce CO₂ emissions. It is essential to develop systems for monitoring the environmental footprint of logistics processes to enable data-driven decision-making on resource consumption.

Sarkis (2020) emphasizes that sustainability in logistics is not only a matter of ecological responsibility but also a factor of competitiveness. Hospitals and pharmaceutical companies that invest in sustainable practices often achieve lower operational costs and stronger reputations among patients and investors. The introduction of environmental management systems such as ISO 14001 can further standardize ecological procedures and increase logistical efficiency.



6.4. Risk Management and System Resilience

Resilience in the healthcare supply chain refers to a system's ability to anticipate, absorb, and recover from disruptions (Ivanov & Dolgui, 2020). Risks may be operational (e.g., transport delays), strategic (dependence on a single supplier), or environmental (natural disasters, pandemics). Establishing a risk management framework requires a comprehensive approach that includes vulnerability assessments, business continuity planning, and continuous monitoring of risk indicators (Christopher, 2016).

Modern risk management is unthinkable without digital tools. Predictive analytics and artificial intelligence enable healthcare systems to identify consumption patterns and forecast potential shortages (Kumar & Goswami, 2021). This approach allows proactive actions such as resource redistribution or earlier replenishment of stock. Combined with blockchain technology, these systems ensure complete transparency of risks throughout the supply chain.

For Croatia, developing a national healthcare logistics resilience strategy is particularly important. This includes establishing emergency medical equipment warehouses, rapid procurement plans, and strategic reserves of essential medicines. Similar models exist in countries such as Germany and Denmark, where government agencies coordinate equipment distribution during crises. Croatia could adopt a comparable approach through stronger public-private collaboration and a national digital platform for information exchange on inventory and needs.

6.5. Human Capital and Organizational Culture

Technological advancement and digitalization can bring significant benefits, but without adequately trained personnel, their potential remains limited. According to Van de Velde and Degoulet (2003), successful implementation of information systems in healthcare requires an interdisciplinary approach involving IT professionals, pharmacists, medical staff, and managers. The lack of logistics education in Croatian healthcare institutions remains a critical issue. Systematic professional training programs in healthcare logistics, SCM, and digital technologies are essential. A culture of continuous learning and openness to innovation is the foundation for building a resilient and efficient logistics system.

6.6. Comparative Analysis: Croatia and the European Union

A comparison of Croatia's healthcare logistics systems with those of EU countries reveals significant room for improvement but also many opportunities for growth. While developed countries such as Germany, Sweden, and the Netherlands already use integrated digital systems and automated warehousing processes, Croatia's system still largely relies on manual operations and fragmented data sources (European Commission, 2021).

Nevertheless, Croatia's smaller system size represents an advantage—fewer hospitals and patients enable faster implementation of digital solutions and process standardization. With support from EU funds and national digital transformation strategies, healthcare logistics can become one of the most dynamic areas of healthcare reform. Achieving such transformation requires coordinated action by the government, academia, and industry.

6.7. Knowledge Integration and Future Directions

The discussion on the future of healthcare logistics demonstrates that integrating different fields—technology, management, economics, and medicine—is essential for developing a resilient system. The healthcare logistics of the future will be smart, predictive, and sustainable. Technologies such as artificial intelligence, robotics, and 5G networks will enable fully automated and interconnected systems where decisions are made based on real-time data analysis (Zhong, Newman, Huang, Lan, & Fang, 2016).

As a member of the European Union, Croatia has the opportunity to leverage EU funds and programs such as *EU4Health* and *Digital Europe* to modernize its healthcare supply chain. It is crucial that digital solutions are not implemented in isolation but through an integrated national strategy that includes data standardization, workforce training, and the promotion of innovation within the private sector.

7. CONCLUSION

Healthcare logistics, as an interdisciplinary field connecting medicine, economics, technology, and management, has become one of the key pillars of modern healthcare systems. This study analyzed its role, structure, and challenges, with particular



emphasis on digital transformation and the application of advanced technologies in supply chain optimization. Based on theoretical and practical analysis, it can be concluded that healthcare logistics is much more than an operational activity—it is a strategic function that directly influences the quality of healthcare delivery, patient safety, and the financial sustainability of healthcare institutions.

Healthcare logistics encompasses a complex system of planning, procurement, storage, distribution, and tracking of medical products. The success of this system depends on its ability to ensure timely product availability at minimal cost and maximum safety. An efficient supply chain can directly impact treatment outcomes by guaranteeing the timely delivery of medicines and medical devices.

The analysis reveals that traditional logistics models, based on manual inventory tracking and fragmented processes, no longer meet the needs of modern healthcare systems. The implementation of integrated systems such as Warehouse Management Systems (WMS) and Enterprise Resource Planning (ERP) solutions provides better control, accuracy, and transparency. This not only increases operational efficiency but also reduces costs and mitigates the risk of shortages—issues that continue to burden many Croatian hospitals.

Within the medical industry, the cold chain and temperature-sensitive product management systems play a particularly important role. It has been observed that losses of medical products in developing countries often occur due to inadequate transport and storage. The implementation of sensors and IoT technologies can almost entirely eliminate such losses while enhancing trust among patients and regulatory bodies regarding product safety.

Digital transformation in healthcare logistics is no longer a choice but a necessity. The use of ERP, RFID, IoT, blockchain, and AI systems establishes new standards in traceability, planning, and resource management. In a digitally connected supply chain, all stakeholders have access to the same, up-to-date information, reducing the risk of errors and accelerating the flow of goods and data.

In EU countries, these technologies have already become integral to daily logistics operations. For instance, Sweden and the Netherlands have implemented national digital platforms for tracking medical products, which allowed for more efficient procurement management during the

COVID-19 pandemic. Croatia still has significant room for improvement, particularly through hospital digitalization and integration with national procurement platforms.

Technology not only addresses efficiency but also strengthens trust. Blockchain systems enable the creation of immutable records of product movement and condition, reducing the risk of manipulation and counterfeiting. This creates a new level of transparency and accountability among supply chain participants. In the future, artificial intelligence is expected to further improve planning and demand forecasting, minimizing the risks of shortages and overstocking.

The analysis of healthcare supply chain challenges demonstrates that global disruptions such as pandemics and wars pose the greatest risks to system stability. Dependence on global suppliers, particularly Asian manufacturers, increases vulnerability and limits rapid response capabilities in crises. The solution lies in regional diversification of suppliers and developing domestic production capacities for essential medical supplies. In Croatia, this could involve collaboration between public hospitals, pharmaceutical companies, and logistics operators to create regional distribution centers serving as the foundation for a national emergency supply network.

Another key challenge is sustainability. Healthcare systems generate large amounts of waste, and disposal costs continue to rise. Integrating green logistics principles—such as transport optimization, rational resource use, and recycling—can yield long-term savings and reduce environmental impact. The European Commission recognizes sustainable logistics as a priority within the European Green Deal, opening opportunities to utilize EU funds for modernizing Croatia's healthcare sector.

Supply chain resilience represents one of the most important indicators of healthcare system maturity. Resilience means not only surviving crises but also adapting and learning from them. It arises from the combination of three key factors: flexibility, redundancy, and visibility. Flexibility refers to the ability to quickly redirect resources and orders to alternative sources. Redundancy includes maintaining safety stocks and additional capacities for emergencies. Visibility enables real-time monitoring of product flows, now made possible by digital tools and IoT sensors. Risk management should be institutionalized through national policies and standards. In Croatia, establishing a central coordination body for healthcare logistics could enhance inventory monitoring, risk assess-



ment, and decision-making on resource redistribution. Such a structure would allow faster and more effective crisis response while ensuring greater transparency and accountability.

Regardless of technological innovation, human capital remains the most valuable resource in healthcare logistics. The shortage of trained logistics professionals is a significant limitation in many Croatian hospitals and institutions. Successful digital transformation requires interdisciplinary teams capable of understanding both technical and operational system aspects. Investing in education and professional development in supply chain management should become a priority of healthcare policy. Universities, vocational schools, and professional associations should develop specialized programs in healthcare logistics that integrate theoretical knowledge with practical skills, fostering a new generation of professionals equipped to lead the digital and organizational transformation of the healthcare system.

Based on the conducted analysis, the following key recommendations can be made for improving healthcare logistics in Croatia and the EU:

1. **Digital integration** – Implement a national platform connecting all healthcare supply chain participants via ERP and WMS systems.
2. **Resilience and crisis planning** – Develop multi-sourcing strategies and establish regional emergency storage centers for medical products.
3. **Standardization and transparency** – Apply blockchain and RFID technologies to ensure full product traceability and safety.
4. **Sustainable logistics** – Promote green practices in transport and warehousing, with emission tracking and waste recycling.
5. **Education and workforce development** – Introduce specialized programs and certifications in healthcare logistics in cooperation with higher education institutions.
6. **Public–private collaboration** – Foster partnerships among healthcare institutions, the pharmaceutical industry, and logistics providers to drive innovation and efficiency.

In conclusion, healthcare logistics represents a vital element of a resilient, efficient, and sustainable healthcare system. Without effective logistics, no healthcare system can ensure the accessibility and quality of care that citizens expect. Despite existing challenges, Croatia possesses all the prerequisites for progress—educated professionals, technological capabilities, and the support of European programs. The future of healthcare logistics lies in digital integration, sustainability, and knowledge. Systems willing to invest in innovation and workforce competence will become not only more efficient but also more resilient to future challenges. In this sense, healthcare logistics should no longer be seen as a cost, but as a strategic investment in safety and quality of life.

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