International Journal of
Health Sciences
(IJHS)

# The Future of Healthcare Supply Chains Post-Pandemic

International Journal of Health Sciences
ISSN: 2710-2564 (Online)
Vol. 8, Issue No. 4, pp. 1 - 13, 2025
www.carijournal.org

# The Future of Healthcare Supply Chains Post-Pandemic

**Vijitha Uppuluri**
CVS Health, United States
https://orcid.org/0009-0000-8695-649X

*Accepted: 29th Aug, 2025, Received in Revised Form: 15th Sep, 2025, Published: 23rd Sept, 2025*

## Abstract

**Purpose:** This study investigates the impact of the COVID-19 pandemic on healthcare supply chains and emphasizes the need for sustainable, flexible, and resilient systems prepared for future crises.

**Methodology:** A review of emerging trends and technologies was conducted, focusing on localized production, strategic inventory management, digitalization, and real-time data deployment. The analysis also covers Blockchain, AI/ML-based forecasting, IoT applications, supplier diversification, regulatory aspects, and ethical issues.

**Findings:** The study highlights that collaboration among public health systems, private providers, and governments is vital to developing advanced supply networks. It finds that integrating digital technologies with strategic inventory and supplier diversification strengthens resilience while balancing cost considerations.

**Unique Contribution to Theory, Practice, and Policy:** The paper contributes a forward-looking framework for healthcare supply chain resilience. It offers theoretical insights into digital transformation, practical guidance on building collaborative networks, and policy recommendations for regulation and preparedness against future health crises.

**Keywords:** *Healthcare supply chains, Digital transformation, Blockchain, Logistics, Personal protective equipment.*

## 1. Introduction

The COVID-19 pandemic unveiled a number of weaknesses in the healthcare logistics networks, the supply chains being one of the most affected parts. With essential commodities such as Personal Protective Equipment (PPE), ventilators, vaccines and even pharmaceuticals taking centre stage, existing supply chain processes could not handle the degrees of pressure that the COVID-19 pandemic brought about. As the following approaches served to minimize waste and contain costs normally, they also led to the development of brittle systems and weak adaptability. [1-3] Even more concern, at the beginning of Covid 19, the developed nations' health systems were competing for the limited available resources on the moral and functional pretext in the global market for health care. Pre-COVID-19, the supply chain processes in health care sectors were mainly focused on manufacturing logistical perspectives, with the major focus given to cost, the supply of spare parts and future globalization. While these formal structures effectively managed waste and control costs during Downturn scenarios, these processes streamlined organizations. They made them fragile and incapable of responding to Urgent circumstances of change. Consequently, these models proved weak when borders were shut and exportation prohibited. Most organizations did not have real-time data and appropriate digital tools for making decisions; procurement and logistics platforms were not as fast as the calamities. As a result of the aforementioned challenges, supply chains in healthcare care settings worldwide have started to redesign with a focus on managing risk, leveraging the use of technology and sustainability. AI, block chain and predictive analytics are being adopted in order to improve the levels of visibility and flexibility. At the same time, the globalization versus localization debate has intensified, with supply chain integration as the probable means of handling both extremes.

Furthermore, in order to support these they are adopting the policy of partnership improvement along with procurement, management of stocks and provision of data. The authors of the paper focus on the main trends and changes in healthcare supply chains in the post-pandemic period and future developments. This discussion aims to provide a clear understanding of healthcare logistics as contained in case studies from different parts of the world as well as new knowledge in the various ways through which the healthcare departments and organizations can adjust the different approaches to logistics as they try to deliver equal healthcare services amidst shocks or crises encouraging them.

## 2. Related Work

### 2.1. Pre-Pandemic Healthcare Supply Chain Models

Traditionally, the healthcare supply chain was primarily focused on costs and efficiency goals. Optimally implemented policies used management of lean inventories and inventory centralization as well as Just-In-Time (JIT) purchasing. [4-6] Though these systems were fine for routine operations, they were not able to handle grand shifts. High reliance on foreign imports, especially from Asian countries, which held about 80% market share in PPE production, left the healthcare facilities exposed to disruptions of international markets. Some of the pre-2020 research

highlighted some significant systematic vulnerabilities, some of which include ineffective governance of procurement agencies, inadequate physical infrastructure in the supply chain, and ineffective seaports. Also, the lack of integration between the different links at the supply chain level hindered efficient decision-making concerning demand and its volatility during force majeure.

### 2.2. Challenges Exposed During the Pandemic

These vulnerabilities have been manifested most prominently in the early months of 2020 with the emergence of COVID-19. This probably explains why healthcare systems globally were stretched to their limits to provide necessities, which were scarce and expensive. For instance, basic N95 masks tripled in price by 6,136% in the initial months of the pandemic, and based on a survey, more than 70% of healthcare facilities reported severe PPE shortages. Such shortfalls, combined with export bans and coordination problems, affected about 85 percent of medical supply movements. Some had pressured and time-bound procurement management systems, which were, to some extent outdated or bulky to handle the VUCA environment. Stagnant and disparate systems and business data were another obstacle that prevented effective real-time communication and collaboration. These resulted in ethically questionable approaches towards sourcing resources; questioning revealed that 98% of healthcare organizations suffered major supply chain risks, demanding change.

**Table 1: Impact of COVID-19 on Healthcare Supply Chains**

| Indicator | Pre-COVID Level | During COVID-19 Peak | Change (%) |
|---|---|---|---|
| N95 Mask Price (per unit) | $0.38 | $24.00 | 6,136% |
| PPE Shortage Reports (Global) | Low | 70% of facilities | Severe Increase |
| Supplier Disruption (Global flows) | Minimal | 85% disrupted | Major |
| Vaccine Cold Chain Capacity (Global) | Limited in LMICs | Inadequate for mRNA | Critical Gap |

### 2.3. Emerging Research and Trends Post-2020

This has occurred especially due to the COVID-19 pandemic, which exposed the vulnerability of existing healthcare supply chain systems models. These are using multiple sources of supply, decentralization of production, and purchasing inventory hedge arrangements. Some technologies

companies are looking at to optimize inventory are blockchain to give a real-time record of the medical supplies that are difficult to tamper with, and artificial intelligence to enhance the accuracy of the forecasts and demand plans. Another change that has also taken place is concentrated procurement systems; for instance, the Nova Scotia province in Canada now has a policy for establishing a central stockpile and crisis. Works published from 2023 and beyond aim to develop the 'buffering-bridging' approach paradigms of the flexibility of operation and reserve. These include supporting the principles of Flexible Sourcing and mapping multiple Suppliers together with embraced technologies for enhanced transparency and performance. The developing literature suggests that robust healthcare supply chains are no longer viewed as an optional nicety to support the operation but as foundational elements of health systems.

## 3. Key Post-Pandemic Changes and Innovations

Future of Health care SC & changes in the stem caused by COVID-19. [7-10] It is implemented in each of the operations and levels of manufacturing and inpatient individuals and uses AI, blockchain, IoT and cybersecurity. It shifts from a rational, sequential model of supply chains to network-based designs that exhibit flexibility, collaboration, adaptability, and visibility. Another element of the proposed system is a real-time inventory replenishment prediction system connected to Electronic Health Record analysis results and implemented on a Centralized Digital Platform. This central node can be considered a control and a central nerve of information gathered from manufacturers, hospitals, logistics organizations, and emergency systems. AI/ML assists the firm in demand forecasting with specific predictions of demand for its products and services and blockchain assists in tracking the firm supply chains through its chain of immutable supplies. Furthermore, in technological and physical security, the organisation's information and business are safeguarded against any interference.

The Logistics and Distribution Section involves automation and fleet coordination, which are inventions. Automated warehouses, IOT, cold chain monitoring suppliers, 3PL / 4PL directly linked into fleets and drones. This has a network for the last mile delivery and emergency service to areas that may be hard to reach. Integrating the dispatch interface of the drones with hospital-ERP systems introduces the needed, less challenging deliveries with live monitoring of the whole delivery process. It enhances the effectiveness and efficiency of the delivery systems. On the clinical side, demand signals are dynamic based on the needs of patients at the healthcare endpoints, such as hospitals. These are managed through inventories and procurement checkpoints linked to the central system. Real-time inventory tracking is very effective in helping minimize the occurrences of hoarding or wastage of inventory significantly. Further, compliance engines assist in monitoring and reporting any usage instances outside compliance with the permitted standard set by the public health regulations. The structure also consists of layers related to emergencies and regulatory authorities. These accumulate and strengthen the health supply chain to become more flexible during normal and abnormal conditions that improve the patients' lives. The regulatory tools assist with identifying risk in the Supply chain and comparing legal

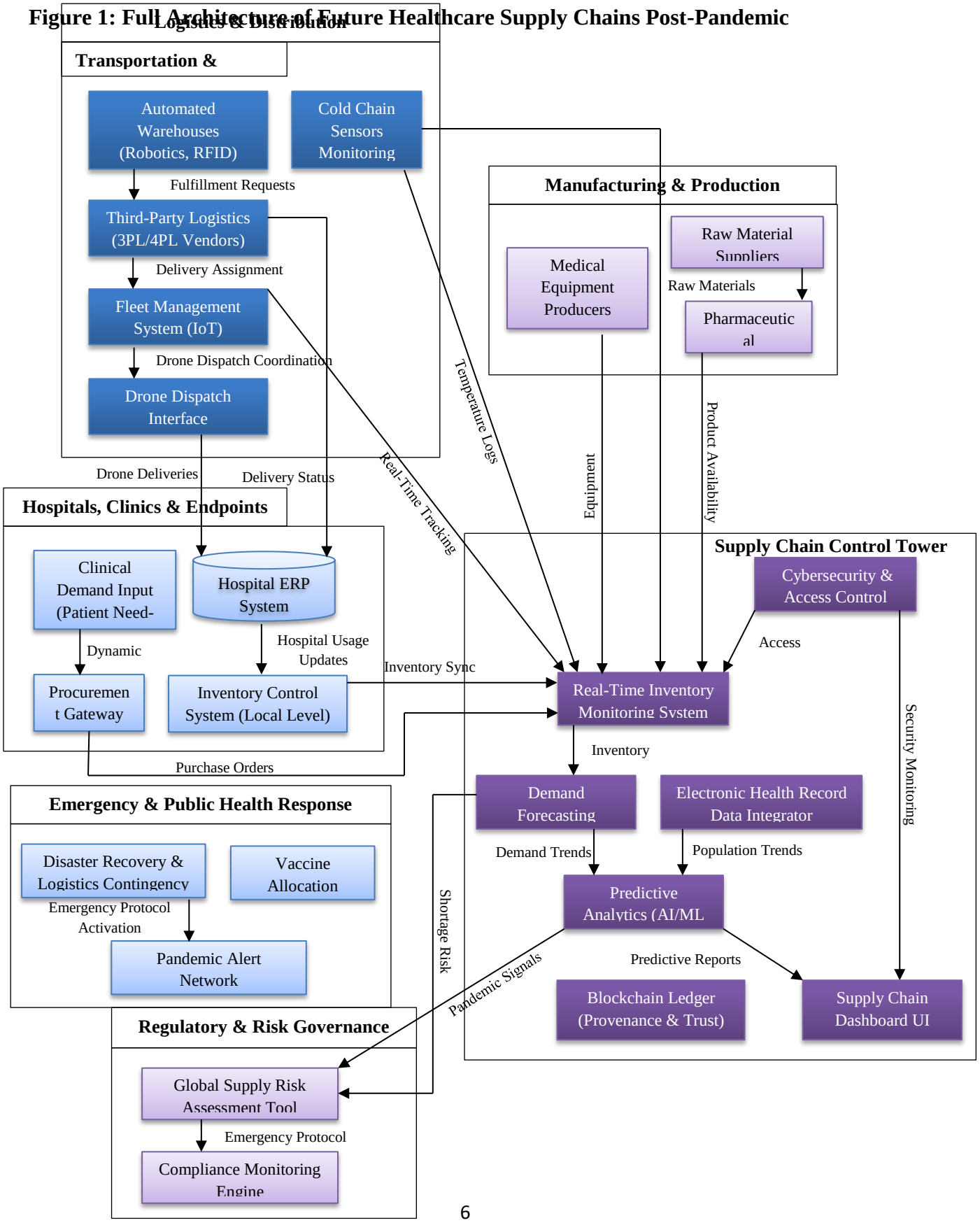
requirements in several geographical regions. All these layers can contribute to creating a single-sided solution to the organization of future-proof solutions related to the healthcare supply chain that can ideally function not merely during normal conditions but also during emergencies.

### 3.1. Digital Transformation and Automation

The current healthcare sector worldwide has witnessed automation and smart technology implementation which is still progressing even after the pandemic. A prime traditional field, which has been experiencing a lot of delays and employments of numerous human errors, entails the manual decoupling of task workflows and is being substituted by quick digital ones. Automated warehouses order robots and RFID (Radio Frequency Identification) systems in order fulfilment, especially in a crisis. Similarly, IoT has also played a role in managing cold chains so that delicate commodities like vaccines are not affected in transit. Some of these interfaces facilitate influencing central managing of inventories, which enables the anticipation of the logistics and probable response time of products. This is because it also improves the company's efficiency since it is a digital process, implying that it will be faster and more adaptive to shifting circumstances than a traditional, physical process. Another aspect is that it will minimize the system's susceptibility to the negative impacts of certain external factors, such as pandemics and other geopolitical interference.

International Journal of Health Sciences
ISSN: 2710-2564 (Online)
Vol. 8, Issue No. 4, pp. 1 - 13, 2025
www.carijournal.org

**Figure 1: Full Architecture of Future Healthcare Supply Chains Post-Pandemic**



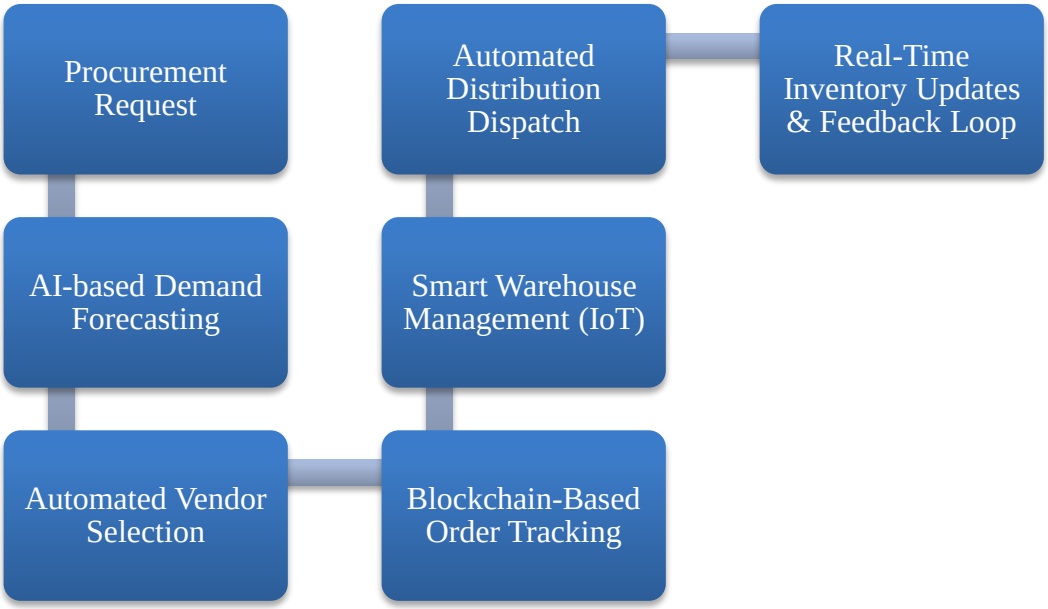



**Figure 2: Digital Transformation in Healthcare Supply Chains**

### 3.2. Localized vs Globalized Supply Models

Before the COVID-19 outbreak, healthcare facilities relied more on outsourcing, where places like Asia provided most PPE and drug precursors. However, this dependence caused critical problems to be developed when the international trade routes were disturbed. [11-14] As a result, more nations and regions are trying to climb the value chain and deal with risks by establishing localized or regional manufacturing hubs. The trend is to have a global service supplier and an additional local capacity for backup purposes. For instance, manufacturing items such as masks and ventilators are being locally boosted while international cooperation is still being strengthened. With this strategy coupled with digital monitoring tools, it is easier to handle emergencies than when one sticks to economies of scale globally.

### 3.3. AI and Predictive Analytics in Inventory Management

Artificial Intelligence (AI) and its subset, predictive analytics, are important in inventory and demand avowal. These technologies consider past usage of the products and the population's health status, as well as real-time data feed from Electronic Health Record systems, to accurately predict the future demand for medical supplies. This predictive capability does not make supply chains just respond to the changes that happen at a tremendous rate but makes the chains able to predict the cases that are likely to occur in advance. It also enables the stylization of different emergency conditions to make it easier for the speculative stakeholder to have contingencies, budgets and inventories in place. Such tools as digital stock tracking systems help minimise the exposure to wastage and the risk of product depletion and maximise the available resources' utilisation. As it

turned out, they proved valuable, especially when vaccines were being administered because distribution was proportional to the population size and the needs of a certain area.

### 3.4. Blockchain and Supply Chain Transparency

Blockchain technology is the most crucial technology that has gained importance in supply chain management since the pandemic. Blockchain ensures that all transactions are documented and recorded in multiple copies, and through tracking codes, the status of the medical supplies is recorded in real time. This helps prevent fake goods and ensure they conform to the right standards. For instance, while managing the distribution of vaccines, the hospitals and the regulatory bodies can inspect the block chain records of temperature readings to see if the particular lot of vaccines was appropriately stored and conveyed at a convenient temperature. It also has the added benefit of providing a secure platform to share data between suppliers, logistics companies, and healthcare facilities to help hold each other accountable. However, what has made blockchain more profound in managing the health supply network or chain is the integration of blockchain with other systems like an intelligence-based dashboard or a compliance engine that provides total open visibility for effective and efficient handling of a multi-layered health care supply chain.

## 4. Challenges and Limitations

### 4.1. Data Availability and Integration

Therefore, elements that have formed the basis of the modernization of healthcare supply chains include availability, quality and integration of data systems. Many healthcare facilities involve multi-tier separated databases that include inventory-keeping records, procurement records, EHRs and supplier networks. [15-18] No structures would enable the real-time analysis and predictive modeling necessary for sustaining strong markets within the supply chain. The problem arises even when the data is available its quality can be influenced by the possibility of errors made while entering data or outdated systems. Furthermore, supply chain platforms are required to integrate structured forms of data, such as SKUs or delivery schedules, with unstructured data forms, including physician notes or regulatory updates, making integration difficult. This paper has identified that data sharing, especially between public and private organizations and agencies during emergencies, remains a technical and organizational issue in terms of interoperability that needs to be resolved.

### 4.2. Policy and Regulatory Barriers

Policies and compliance regimes remain important to prevent risks but generally stifle flexibility and change in healthcare supply chains. Various regulations that a country or a region has in place offer a rationale for the kind of data released, the supply cleared to be made available to the market, and the methods of international transportation. For instance, dissimilarities in labeling for medical devices or pharmaceutical affects the time taken to obtain them and hampers their transit in case of an emergency. First, legal aspects, such as GDPR or HIPAA, set some limitations for sharing patient-related or operational data, which limits the utilization of central digital suites. All these

are important ingredients, but lacking is the elastic legislation that would enable the protection of the public through the progressive and openness of novel structures. Integrating policies, developing efficient regulatory systems, and searching for ways to overcome the pandemic's lessons are vital for supply chain development post-crisis.

### 4.3. Resistance to Change and Adoption Issues

However, for the contemporary technologies, ideas, and management approaches to the healthcare supply chain, the main issue seems to be the resistance to change. Some organisations, especially in the public domain, are tightly framed by outdated structures, procedures, and fear of change. The transition from traditional inventory management, blockchain tracking, or procurement automation also requires a change in the organizational culture and procedures, resulting in extra funding. Employees must learn to use new systems; IT has to manage immensely complex technology. Small centers or low-resource environments may lack the proper personnel to implement these improvisations effectively or may not afford to invest in implementing these changes. Other issues that make people hesitant are doubts, possible inaccuracy of data, hacking cases, and fear of losing control. These problems must be addressed by solving the challenges related to change management, policy incentives, and training to make innovation feasible and containable.

## 5. Case Study

### 5.1. National Health Services (NHS) Response

The COVID-19 shock provides an excellent and real-life illustration of the fluctuation of the dynamics of the healthcare SC in the case of the National Health Services of the United Kingdom. When the pandemic started, the NHS struggled with severe shortages of PPEs, ventilators and important medicines. The situation was not improved by outsourcing procurement and the development of only a few local industries. In response, the NHS streamlined its purchasing functions and collaborated better with suppliers and suppliers, increasing response rates. Real-time inventory management systems helped the organization to enhance the distribution by giving resources per each region's requirement. Moreover, establishing regional distribution centers facilitated the decentralization of inventory, but it maintained control over them to avoid delays at the final stage. A particular focus was made on enhancing donor contributions in supporting investment in the physical frameworks of the public health information infrastructure and network and logistics during the scaled up mass vaccinations. The following examples, starting from the dismissal of Carillion to the more recent strike action taken by the workers, demonstrated the support for digitization, centralised control, and infrastructure to counteract disruptions in the supply chain.

### 5.2. Pharmaceutical Supply Chains in Low-Income Countries

COVID-19 quickly exposed some inherent vulnerabilities of the pharmaceutical supply chain systems in many low-income countries, such as over reliance on imports, poor transportation, and

inconvenient means for maintaining the low temperatures appropriate for the preservation of the drugs. Most nations faced some challenges on the importation of APIs particularly from some of the main suppliers like China and India. For instance, India, where drug manufacturers are famously known as the pharmacy of the world, sources about 60% of APIs from overseas and hence are likely to be affected by disruptions in trade relations. Research conducted on pharmaceutical supply companies in Pune, Hyderabad, and Delhi NCR brought out factors like growing trade costs, supply shock, and technological restrictions. Thus, distribution networks confronted such problems as the lack of personnel, outdated methodologies, and weak digital platforms. The study urged increased funding for localized production of medicines, enhanced partnership between the public and private sectors, and enhanced cold chain infrastructure. These changes are strategic for increasing the preparedness of healthcare supply chain systems for local and regional disruption and shocks in the developing world.

### 5.3. Vaccine Distribution Networks

Several vaccine distribution designs were implemented in Middlesex County, New Jersey, where Minim Michael Porter noted that the hub-and-spoke network implement easy, efficient, and scalable designs. In order to immunize the population quickly and maintain the proper temperature of some vaccines, such as from Pfizer-BioNTech, the county introduced the strategy of a central distribution center and many remote administering sites. This structure facilitated fast distribution in a manner that was governed by demand. The vaccine produced little amount of wastage and also ensured that there was strict compliance with the cold chain requirements. It helped the central hub to have comprehensive information about the inventory and balance to facilitate improved forecasting and integration of redistribution. It also eliminated geographical constraints and assisted in delivering services to the unreached people, especially in increased demand. Since then, the Middlesex model has been used to reference by future mass immunization planning in an indicative manner to elaborate how adaptive networks with high data processing capacity may potentially boost organizational dispatch and equality.

## 6. Future Directions

### 6.1. Building Resilience in Supply Chains

New world: ‘Resilience’ is the new mantra as healthcare supply chains push through the new normal. Future supply networks require a decrease in their susceptibility to volatility and an ability to adapt to such occurrences as pandemics, geopolitical issues, and ‘climate shifts.’ Resilience, therefore, goes a notch higher and rejects JIT-type inventory systems and embraces the viable gps that includes safety stock, local reserve, and multi-sourcing. Digitization is also important; status checks of the livestock, analyzing the trends, and direct procurement order helps to identify the shortage sufficiently before time. Furthermore, the distribution centers and expandable cold storage required to accomplish modular logistics will be easily scalable in response to surge demands. Enhancing the healthcare systems' ability to continue operating in disaster situations is useful in keeping the services going despite adverse occurrences.

### 6.2. Role of Public-Private Partnerships

Public-Private Partnerships (PPPs) are set to become the defining features of the future in health supply chain management. The supply demands frequently change and evolve at a fast pace and it can be noted that governments on their own may not have the necessary speedy, innovative management capacities. Other private entities that have helped improve the benefits include the logistics companies, the technology companies, and the manufacturers. For instance; joint ventures may offer support to establish the stocks of bases, supply tracking through artificial intelligence, and strong cold chains. It also allows them to become mechanisms for creating vast bodies of common sense regarding problems so that multiple jurisdictions can react at once. For this reason, PPPs must be equipped with the governance structure, goals, objectives and risk allocation mechanisms. Cooperation during emergencies is one aspect of communicating, but long-term relations involve planning and investing in the system in non-emergency conditions.

### 6.3. Sustainable and Ethical Sourcing

Sustainability and ethical sourcing are the values and directions steadily becoming mandatory in modern healthcare supply chains. COVID uncovered the products that were earlier marketed for emergency needs have an impact on both the environment and people; for example, Personal Protective Equipment (PPE) litter and buy one, get one free offers that promote economies of scale while disregarding workers' rights amid COVID. Sustainability considerations should be a form factor of a Healthcare System and must be integrated into the procurement and logistics activities. Supplier evaluation for eco-friendly material manufacturing, reducing the carbon footprint through local sourcing, and using circular economy concepts such as reusable medical products in order. Information technology, including AI, blockchain, and real-time inventory platforms, has played a big role in this transformation process. The benefits of this technology on the blockchain and AI instruments for tracking the origins and checking compliance with social and environmental requirements are apparent. The humanities can also broaden the evaluation time frame and make sustainability and ethics fundamental elements of supply chain management.

**Recommendations:**

Healthcare supply chains should adopt advanced technologies such as AI, blockchain, and IoT to enhance forecasting, transparency, and real-time decision-making. Second, building regional distribution hubs, diversifying suppliers, and institutionalizing hub-and-spoke models will ensure flexibility and reduce vulnerability to global disruptions. Additionally, strengthening public-private partnerships and establishing robust regulatory frameworks will enable coordinated responses to crises while promoting ethical and equitable practices. Lastly, greater investment in cold chain systems, logistics, and storage capacity is needed, alongside long-term preparedness frameworks to institutionalize crisis readiness and resilience.

## 7. Conclusion

Coronavirus significantly affected the healthcare supply chain/ thus implying operation pressure and challenges such as data integration, operating globalization and flexibility. In reply, the healthcare systems across the globe started reconstructing their supply chain management planning moving from the traditional efficacy-focused to the ones that respect such values as openness and adaptability. Technological factors such as artificial intelligence, blockchain, and the use of real-time inventory have also helped in the change. Concepts of a regional distribution centre and hub-and-spoke model of vaccines have also demonstrated their efficiencies in demand variability due to a crisis. Stressing sustainability and ethical approaches, more investment in infrastructures, and enhancement of Public-Private Partnerships are required to prepare the healthcare supply chain industry for the future. Improving supply systems is useful not only for preparedness in disasters and emergencies but also for general healthcare; it would, for instance, make logical sense to reduce waste and provide equity regarding supplies needed by the patients for their treatment and care. The pandemic must be institutionalized to ensure that such interruptions can never happen again and that healthcare systems are always prepared to combat them.

## References

[1] Singh, A., & Parida, R. (2022). Decision-making models for healthcare supply chain disruptions: review and insights for the post-pandemic era. International Journal of Global Business and Competitiveness, 17(2), 130-141.

[2] Scala, B., & Lindsay, C. F. (2021). Supply chain resilience during pandemic disruption: evidence from healthcare. Supply Chain Management: An International Journal, 26(6), 672-688.

[3] Healthcare Supply Chain Resilience: Lessons Learned from the Pandemic and Strategies for the Future, online. https://www.news-medical.net/health/Healthcare-Supply-Chain-Resilience-Lessons-Learned-from-the-Pandemic-and-Strategies-for-the-Future.aspx

[4] Ozdemir, D., Sharma, M., Dhir, A., & Daim, T. (2022). Supply chain resilience during the COVID-19 pandemic. Technology in society, 68, 101847.

[5] Da Conceição, J. R. B., Spiegel, T., de Vasconcelos Silva, A. C. P., & da Cunha Reis, A. (2020). Issues in healthcare supply chain management: from literature to practice. International Journal of Supply Chain Management, 9(2), 18-27.

[6] Spieske, A., Gebhardt, M., Kopyto, M., & Birkel, H. (2022). Improving resilience of the healthcare supply chain in a pandemic: Evidence from Europe during the COVID-19 crisis. Journal of Purchasing and Supply Management, 28(5), 100748.

[7] Snowdon, A. W., & Saunders, M. J. (2022, March). Supply chain integration as a strategy to strengthen pandemic responsiveness in Nova Scotia. In Healthcare management forum (Vol. 35, No. 2, pp. 62-70). Sage CA: Los Angeles, CA: SAGE Publications.

[8] We designed the NHS Covid vaccine supply chain, putting patients at its centre, baringa, 2022. online. https://www.baringa.com/en/impact/case-studies/we-designed-the-nhs-covid-vaccine-supply-chain-putting-patients-at-its-centre/

[9] Poursadeqiyan, M., Bazrafshan, E., & Arefi, M. F. (2020). Review of environmental challenges and the pandemic crisis of Covid-19. Journal of education and health promotion, 9(1), 250.

[10] Filip, R., Gheorghita Puscaselu, R., Anchidin-Norocel, L., Dimian, M., & Savage, W. K. (2022). Global challenges to public health care systems during the COVID-19 pandemic: a review of pandemic measures and problems. Journal of personalized medicine, 12(8), 1295.

[11] Sharma, A., Gupta, P., & Jha, R. (2020). COVID-19: Impact on health supply chain and lessons to be learnt. Journal of Health Management, 22(2), 248-261.

[12] Francis, J. R. (2020). COVID-19: implications for supply chain management. Frontiers of health services management, 37(1), 33-38.

[13] Laranja, M., & Pinto, H. (2022). Transformation for a post-pandemic world: Exploring social innovations in six domains. Knowledge, 2(1), 167-184.

[14] Shen, Y., & Guo, H. (2022). Breakthroughs and innovation modes in English education in the post-pandemic era. Frontiers in Psychology, 13, 839440.

[15] Furstenau, L. B., Zani, C., Terra, S. X., Sott, M. K., Choo, K. K. R., & Saurin, T. A. (2022). Resilience capabilities of healthcare supply chain and supportive digital technologies. Technology in Society, 71, 102095.

[16] Dukes, M. N. G., Haaijer-Ruskamp, F. M., de Joncheere, C. P., Rietveld, A. H., & Everard, M. (2002). Access to medicines in low-income countries. International Journal of Risk & Safety in Medicine, 15(1-2), 137-149.

[17] Jbaily, A., Feldhaus, I., Bigelow, B., Kamareddine, L., Tolla, M. T., Bouvier, M., ... & Verguet, S. (2020). Toward health system strengthening in low-and middle-income countries: insights from mathematical modeling of drug supply chains. BMC Health Services Research, 20, 1-12.

[18] Yang, Y., Bidkhori, H., & Rajgopal, J. (2021). Optimizing vaccine distribution networks in low and middle-income countries. Omega, 99, 102197.

[19] Giralt, A. N., Bourasseau, A., White, G., Pouget, C., Tabernero, P., Van Assche, K., & Ravinetto, R. (2020). Quality assurance systems of pharmaceutical distributors in low-income and middle-income countries: weaknesses and ways forward. BMJ Global Health, 5(10), e003147.

[20] Chen, S. I., Norman, B. A., Rajgopal, J., Assi, T. M., Lee, B. Y., & Brown, S. T. (2014). A planning model for the WHO-EPI vaccine distribution network in developing countries. Iie Transactions, 46(8), 853-865.