

The benefits of integrating AI, IoT, and Blockchain in healthcare supply chain management: A multi-dimensional analysis with case study

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Abstract— As time goes on, rapid development happens in the healthcare industry, and most of the significant challenges healthcare professionals and stakeholders face is supply chain management. With an excessive increase in demand for healthcare services and the need for efficient, cost-effective, and high-quality healthcare delivery, healthcare supply chain management has become a crucial factor in considering success in healthcare structures. Recently, Artificial Intelligence (AI), the Internet of Things (IoT), and blockchain have shown some potential to revolutionize healthcare supply chain management. In this research, we explore the benefits associated with integrating the abovementioned technologies in healthcare for more effective and efficient supply chain management in this industry. By leveraging these technologies, we explore the potential benefits of their integration into the healthcare supply chain using the eventual existing challenges. In this paper, we highlight the problems faced by conventional supply chain management and show how integrating AI, IoT, and BC can serve as a powerful tool to overcome these challenges. To achieve our goal, we carried out a multi-dimensional analysis with case studies that considered crucial aspects such as visibility, efficiency, data-driven decision-making, security, and trust in the supply chain. We proposed a healthcare supply chain management system that incorporates AI, IoT, and blockchain to raise awareness among healthcare providers about the benefits of an intelligent supply chain management system.

Keywords— Artificial intelligence, Blockchain, Healthcare supply chain management, Internet of Things

I. INTRODUCTION

As in many other industries, the logistics of goods and services are a necessity of the first order. The Healthcare Supply Chain Management (HCSM) monitors and manages the flow of healthcare products and services from the manufacturing plant to the end user. It is a critical aspect of the healthcare industry that involves planning, procuring, storing, and distributing medical supplies, drugs, and equipment [1]. An effective healthcare supply chain system can deliver medications and treatment protocols to patients at any time that suits their needs. From the onset, the supply chain management system in healthcare involves getting the best suppliers with the

best deals for healthcare-related products, managing stock at all levels of the delivery process, including the tracking of expiration dates, ensuring efficient movement of products and their effective delivery, ensuring the quality of the products in compliance with the industrial regulations while maintaining cost control and supplier relationship [2].

Effective supply chain management ensures patients receive timely, high-quality care while reducing costs and waste [3]. However, healthcare supply chain management faces several challenges that hinder its efficiency and effectiveness [2, 4]. These challenges include the lack of transparency and visibility, fragmented systems and processes, limited interoperability between stakeholders, inefficient inventory management, and inadequate data management and analytics. Given the challenges faced in healthcare supply chain management, there is a need for innovation that will help to improve efficiency and effectiveness in processes [5].

Addressing these challenges calls for innovation in the supply chain management system. A significant improvement can be noticed in HCSM over the years due to the integration of digital technologies and data analytic techniques driving toward patient-centred and value-based care. Emerging technologies such as Artificial Intelligence (AI), Internet of Things (IoT), and Blockchain have the potential to revolutionize healthcare supply chain management by addressing some of the challenges mentioned above [6- 9]. An example of using AI can be the improvement of demand forecasting. At the same time, IoT is the backbone for tracking deliveries, and blockchain provides a transparent platform for stakeholder operations. By leveraging these technologies, healthcare supply chain management can become more efficient, cost-effective, and patient-centric.

This study highlights the benefits of integrating emerging technologies (AI, IoT, and blockchain) into the HSCM for more effectiveness. Current challenges of HCSM are discussed; the integration of emerging technologies demonstrated a promising way to address these challenges. We adopted a multi-dimensional analysis of vital and critical aspects of the supply chain that are fundamental for its optimal operation. As

depicted in Figure 1, these key aspects include visibility, efficiency, data-driven decision-making, security, and trust in the supply chain. By analyzing the challenges and solutions of the HSCM based on these aspects, we demonstrate the potential of AI, IoT, and blockchain to improve HSCM and enhance patient outcomes.

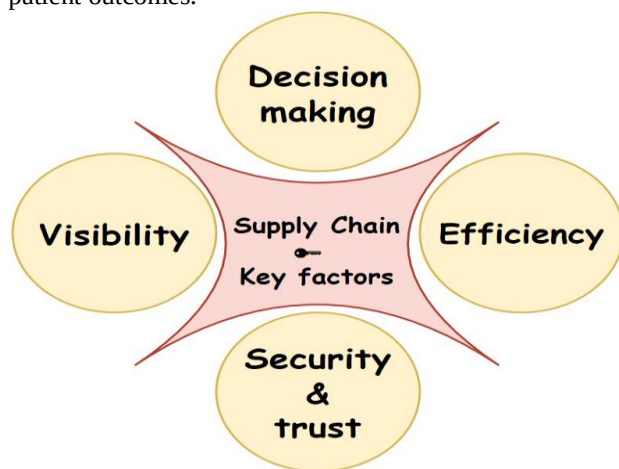


Figure 1. Key aspects considered in supply chain innovation

II. CHALLENGES IN HEALTHCARE SUPPLY CHAIN MANAGEMENT

Several studies have identified the HSCM system's challenges. These challenges are numerous, and a few will be discussed in this section. Figure 2 shows some challenges of conventional HSCM.

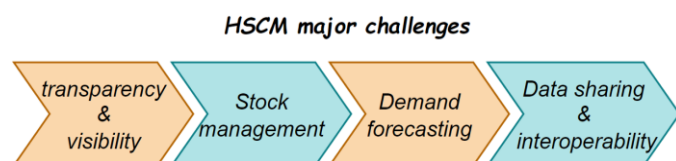


Figure 2. Challenges of the conventional healthcare supply chain management

- **Lack of transparency and visibility:** Tracking and monitoring products as they move on the supply chain system is crucial to give stakeholders insights into their delivery schedules and inventories. In healthcare systems, disruption can be observed in real-time operations, leading to delayed and errored deliveries. A more visible and transparent supply chain system is necessary to boost business effectiveness while optimizing transactions. The lack of visibility in the HSCM can result in inefficient operations, unmitigated supply chain disruptions, increased risk of theft or loss, inaccurate data, and poor relationships between customers and suppliers [4].
- **Stock management challenges:** Maintaining inventory levels to avoid stockouts and overstocking is significant in healthcare supply chain management. The lack of accurate data on the real-time inventory can lead to overstocking or

stockouts with considerable financial implications. The supply and demand should be controlled in the HSCM to avoid unexpected issues such as expiration. Expiration is a waste that causes many businesses to collapse. Inappropriate stock management is caused by poor medicine selection, inaccurate forecasting, missed demand quantification, and poor warehouse management. It can lead to storing more products that can't be consumed before the expiration date, generating waste of storage and financial resources [4, 10].

- **Demand forecasting:** Anticipating the demand for medical supplies, equipment, pharmaceuticals, and services to ensure the availability of resources when needed is a complex and challenging task in HSCM. The variability in patient demand and clinical practices are key factors that make demand forecasting complex. Moreover, lack of real-time quality data on patient demographics and solicited products, regulatory changes, eventual disruptions, and interconnected processes in the supply chain equally contribute to poor demand forecasting that leads to low quality of healthcare services and deliveries with associated high costs [11-12].
- **Data sharing and interoperability:** The ability to exchange data seamlessly and efficiently among various stakeholders is essential for efficient HSCM. It can be noticed that the traditional HSCM is facing a lot of challenges in achieving data sharing and interoperability due to data silos across healthcare organizations, lack of standardization, interoperability gaps, privacy and security concerns, cost and resources constraints, regulatory, cultural, and organizational challenges. These challenges must be addressed to allow stakeholders to seamlessly exchange data over different healthcare platforms for effective and efficient HSCM [13].

The list of challenges can't be exhaustive; some other challenges include temperature control, considering its importance in drug supply, shipment visibility for real-time tracking, data-driven decision-making, trust, and security issues [14-16]. Given the challenges facing healthcare supply chain management, innovation is needed to improve its efficiency and effectiveness [5, 17]. Integrating Artificial Intelligence (AI), Internet of Things (IoT), blockchain, and other emerging technologies in the HSCM can potentially address some of the abovementioned challenges, thus revolutionizing it.

III. INTEGRATION OF AI, IOT, AND BLOCKCHAIN IN HSCM

Globally, Artificial Intelligence (AI) is the simulation of human intelligence processes by computers to perform problem-solving, decision-making, and prediction tasks. On the other hand, The Internet Of Things (IoT) enables the connection between objects (drugs, medical devices, animals, people) and devices over the Internet to facilitate data exchange. Blockchain is a distributed ledger technology that provides secure, transparent, and tamper-proof record-keeping without the need for approval of a central authority. In healthcare, AI predicts a disease based on patient data [18]; IoT sensors help

collect the patient's vital signs [19], while blockchain assures the authenticity and security of healthcare data and transactions [20].

The convergence of AI, IoT, and blockchain in healthcare supply chain management is a transformative development. AI processes data to predict demand and optimize inventory, while IoT devices monitor the condition and location of medical supplies. Blockchain provides a secure and transparent ledger to track the flow of medical products. These technologies work together to create a more efficient and safe supply chain.

The benefits of the integration of these technologies in HCSM can be summarized as follows:

- **Improved Visibility:** AI analyzes historical data to predict demand accurately, while IoT sensors provide real-time tracking of product conditions and locations. Blockchain ensures transparency and data integrity throughout the supply chain.
- **Enhanced Efficiency:** Automation through AI and IoT reduces manual intervention, streamlining tasks like order processing and inventory management. Blockchain smart

contracts automate transaction processes, reducing administrative overhead.

- **Data-Driven Decision-Making:** AI analyzes data for informed procurement, distribution, and demand forecasting decisions. IoT-generated data is valuable for monitoring the condition of products, enabling proactive measures. Blockchain provides a trustworthy audit trail for data-driven decisions.
- **Enhanced Security and Trust:** AI can identify anomalies or suspicious activities, reducing the risk of fraud or theft. IoT's real-time monitoring prevents unauthorized access to supplies. Blockchain's immutability ensures the authenticity of products and builds trust among stakeholders.

Figure 3 below describes the potential benefits of integrating AI, IoT and blockchain in conventional HSCM with some applications use cases.

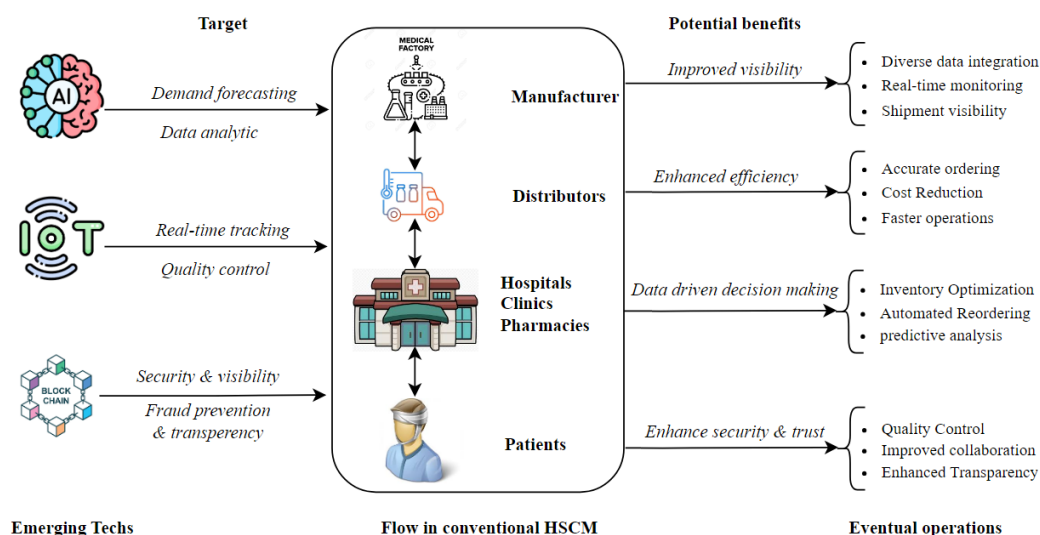


Figure 3. Integration of AI, IoT and blockchain in healthcare supply chain

IV. CASE STUDY OF INTEGRATING AI, IoT, AND BLOCKCHAIN IN HSCM

A. Pharmaceutical Distributor Efficiency

AI in predictive analytics and inventory management can significantly improve pharmaceutical distributor efficiency. By analyzing vast amounts of data, AI-powered predictive analytics can enable proactive identification and mitigation of potential risks in the drug supply chain. This can help distributors optimize inventory levels, reduce waste, and ensure timely delivery of drugs to healthcare providers and patients. With the help of AI, pharmaceutical distributors can achieve greater efficiency and accuracy in their supply chain management, ultimately benefitting patients and healthcare providers alike.

Implementing blockchain technology can provide secure and transparent transactions, ensuring the integrity and authenticity of the supply chain. Blockchain can enable end-to-end traceability of drugs, allowing for better tracking of products from manufacturers to patients. By leveraging blockchain for transparency and security, pharmaceutical distributors can enhance their supply chain management, reduce the risk of counterfeit products, and ensure the safe and timely delivery of drugs to patients. Blockchain technology can also facilitate data sharing across the supply chain, enabling better stakeholder collaboration and coordination.

Leveraging IoT can provide real-time visibility and monitoring of supply chain processes, enabling pharmaceutical distributors to identify and address any issues that may arise quickly. IoT devices can track the location and condition of drugs during transportation, ensuring that they are stored and

transported under appropriate conditions. IoT can help distributors optimize their operations, reduce waste, and improve overall efficiency by providing real-time visibility into the supply chain. IoT in supply chain management can also enable better communication and collaboration among different stakeholders, improving the overall effectiveness of the supply chain.

B. Hospital Inventory Optimization

Stock management is a challenge that can generate a significant loss of money and resources when attention is not adequately paid. Healthcare institutions such as hospitals, pharmacies, and clinics in charge of patients' care must be cautious when ordering supplies. The traditional HSCM has proven limits in managing accurate orders that suit the population's needs. AI uses data to forecast demand, considering the population's needs accurately. From the manufacturing plant to the complete order delivery, the supplier and the customers can get real-time information during shipping. The IoT sensors can be attached to the parcel to capture real-time and vital information, such as the ambient temperature, and then transmit it to a server for visualization. Getting such data can help confirm the product's quality, a crucial parameter in a drug delivery scenario. While controlling the supplies from natural hazards using IoT sensors, blockchain technology can help secure procurement records. This integration will lead to rational stockouts, improving waste management and ensuring substantial cost savings.

C. Healthcare Network Data-Driven Decisions

Data-driven decision-making is a process that involves using data to inform and guide decision-making processes. In healthcare supply chain management, data-driven decision-making can help to optimize the flow of goods and services, reduce costs, and improve patient outcomes. By leveraging data analytics tools and techniques, healthcare organizations can gain insights into their supply chain operations and make informed inventory management, logistics, and distribution decisions.

AI, IoT, and blockchain can help to automate and streamline supply chain processes, reduce errors and inefficiencies, and improve data security and privacy. For example, AI can analyze large amounts of data and identify patterns and trends. At the same time, blockchain can provide a secure and transparent way to store and share data across different entities. IoT devices can also track and monitor inventory in real-time, providing greater visibility and control over the supply chain. By integrating these technologies into their supply chain operations, healthcare organizations can make more informed and data-driven decisions, improving patient outcomes and increasing efficiency and profitability.

Data-driven decision-making in HSCM leads to more optimized supply chain operations, causing a reduction in costs, improving profitability and patient outcomes/satisfaction, increasing efficiency and productivity, enhancing data security and privacy, and enhancing inventory and logistics management.

V. CHALLENGES AND PROSPECTS

While AI, IoT, and blockchain show the potential to revolutionize healthcare supply chain management, challenges such as data privacy, implementation cost, regulatory compliance, and platform interoperability must be acknowledged. The future of the HSCM is more promising with the integration of more emerging technologies such as Edge computing, 5G, digital twins, and others that can advance the capabilities of AI, IoT, and blockchain and ensure patient outcomes while increasing efficiency and profitability.

VI. CONCLUSION

This paper presents conventional healthcare supply chain management challenges and suggests solutions using AI, IoT, and blockchain technologies. A multi-dimensional analysis approach was adopted for key aspects like visibility, efficiency, data-driven decision-making, security, and trust. The paper discusses three case studies demonstrating the facilities that these technologies can bring into the HSCM. In pharmaceutical distribution, inventory optimization, or data-driven decision-making, AI technology is used for demand forecasting, data analytics, and other predictions. IoT sensors provide real-time information that can inform supplies' condition while blockchain ensures security in automated contracts and verification of pharmaceutical provenance. Though some challenges can be observed in fully implementing these three technologies in the HSCM, the product of this convergence will be helpful for the healthcare industry and is worth implementation to achieve user satisfaction.

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