



## Enhancing Healthcare Logistics Through a Blockchain-Iot Framework: A Study on Pharmaceutical Supply Chain Optimization

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## ABSTRACT

Healthcare logistics faced unique challenges that required innovative solutions to enhance transparency, data integrity, and operational efficiency. This study addressed these challenges by developing a Blockchain-Internet of Things (B-IoT) framework for healthcare logistics, with a focus on drug and medical supply management. The integration of a decentralized, tamper-proof ledger with real-time IoT monitoring improved traceability, security, and automation in



pharmaceutical supply chains. To evaluate the impact of this framework, the research employed a mixed-methods approach, combining a literature review with expert interviews involving healthcare logistics managers, technology developers, and regulatory consultants. The proposed framework assessed critical factors such as technological infrastructure, data governance, interoperability, regulatory compliance, and cost-effectiveness. Following B-IoT implementation, significant improvements were observed. Order processing time decreased by 75%, from 48 hours to just 12 hours. Supply chain visibility increased by 137.5%, while shipment errors dropped by 88%, and inventory mismanagement incidents were reduced by 86.7%. Additionally, overall logistics costs fell by 25%, though cybersecurity expenses rose by 20% and training costs increased by 200% due to the need for specialized workforce training. Notably, data breaches and patient privacy violations were completely eliminated, demonstrating the framework's effectiveness in enhancing security. Despite these benefits, several challenges emerged, including high integration costs, a shortage of technical expertise, and regulatory hurdles. To address these barriers, the study recommended phased implementation strategies, including pilot programs and structured training initiatives. The findings suggested that B-IoT technologies could significantly improve healthcare logistics in terms of efficiency, security, and compliance, though further research was needed to optimize scalability and cost-effectiveness.

**Keywords:** Blockchain, Healthcare Logistics, Internet of Things (IoT), Supply Chain Management, Traceability

## INTRODUCTION

The transformations observed within the healthcare sector were particularly significant in the domains of logistics and supply chain management. As healthcare logistics grew increasingly complex, stakeholders emphasized the necessity for enhanced transparency and secure data management, leading to a heightened demand for more advanced, efficient, and agile supply chain systems (Avinash & Joseph, 2024; Chen & Ruan, 2024). Traditional systems faced substantial challenges in the distribution of pharmaceutical products and medical devices, as well as in maintaining optimal inventory levels. These limitations prompted the exploration of innovative solutions to improve the efficiency, security, and traceability of healthcare logistics operations (Lakhwani et al., 2025). Healthcare logistics involved the coordination, procurement, and oversight of activities essential for the timely and effective delivery of medical products, including medications, medical equipment, and healthcare supplies (Özdoğan & Mulgan, 2024). The stakes in this field were exceptionally high, as delays, mismanagement, or a lack of transparency in the supply chain could compromise patient care and result in significant financial



losses for healthcare providers. Furthermore, the COVID-19 pandemic exposed critical vulnerabilities in healthcare supply chains, underscoring the need for more resilient and adaptable systems (McBride, 2024).

Over the past decade, substantial progress occurred in data management across multiple industries due to the emergence of blockchain technology, which offered decentralized, secure, and transparent transaction capabilities (Deepa et al., 2022). Within healthcare, blockchain demonstrated significant potential in areas such as drug traceability, prevention of data breaches, and compliance with regulatory frameworks like the Health Insurance Portability and Accountability Act (HIPAA) and the General Data Protection Regulation (GDPR) (Isibor, 2024). Several studies investigated the prospective applications of blockchain in healthcare. For example, Berdik et al. (2021) highlighted how blockchain implementation addressed challenges related to the fragmented integration of health information systems and data security concerns. Simultaneously, supply chain management exhibited a growing reliance on Internet of Things (IoT) technology, particularly for real-time monitoring and data collection (Khan et al., 2022). IoT-based devices facilitated asset tracking, environmental monitoring (such as temperature control for sensitive pharmaceuticals), and automated inventory management (Sallam, 2023). However, concerns persisted regarding the susceptibility of IoT systems to privacy breaches, data integrity issues, and cybersecurity threats, primarily due to their reliance on centralized data management. Blockchain technology complemented IoT by enhancing data security through encryption, decentralization, and immutable record-keeping (Hossain et al., 2024).

Extensive research has been conducted on blockchain and the Internet of Things (IoT) as independent technologies; however, their combined application in healthcare logistics remained significantly underexplored in prior literature (Rattanawiboomsom et al., 2023). The integration of these technologies presented a viable solution to the persistent logistical challenges within the healthcare industry. Many healthcare supply chains relied on outdated tracking mechanisms that failed to provide real-time visibility into the location and status of critical items, including pharmaceuticals and medical equipment (Kasula et al., 2023). Consequently, inefficiencies such as delays, stockouts, and spoilage of temperature-sensitive products (e.g., vaccines) were prevalent. Additionally, healthcare logistics involved the handling of sensitive data, including patient records and shipment details, which were susceptible to security breaches, unauthorized alterations, and fraudulent activities (Wright, 2023). These vulnerabilities exposed healthcare organizations to substantial financial and reputational risks.



The inefficiencies in healthcare logistics, characterized by excessive costs and delays in delivering urgent medical supplies, were primarily attributed to manual processes, fragmented data systems, and a lack of advanced technological integration (Dasaklis et al., 2024). While prior studies extensively examined blockchain and IoT as standalone technologies, few investigations explored their synergistic potential in optimizing healthcare logistics. This study addressed this research gap by proposing a novel Blockchain-IoT (B-IoT) framework specifically designed to enhance healthcare supply chain operations (Zuo, 2024). Unlike existing models, this framework incorporated the unique requirements of the healthcare sector by leveraging the combined strengths of blockchain and IoT technologies.

The primary objective of this research was to design and propose an integrated technological framework for healthcare logistics supply chains, incorporating blockchain and IoT functionalities. The framework aimed to achieve real-time tracking and monitoring of medical products and equipment throughout the supply chain. By utilizing blockchain's decentralized architecture, sensitive logistics data were securely recorded, mitigating risks associated with data tampering and unauthorized access. Simultaneously, IoT devices facilitated enhanced monitoring and automation of logistics processes, such as temperature control for perishable medical supplies. Additionally, smart contracts on the blockchain streamlined cross-border transactions, reducing administrative delays and human errors.

The findings suggested that the convergence of blockchain and IoT technologies had the potential to revolutionize healthcare logistics by addressing critical issues related to transparency, security, and operational efficiency (Ugochukwu et al., 2022). This study contributed a practical solution tailored to the evolving needs of healthcare providers, offering a structured approach to modernizing logistics management. The proposed framework alleviated existing supply chain inefficiencies by aligning consumer demands with advanced digital communication technologies. Furthermore, the framework was both innovative and feasible, providing healthcare stakeholders with a scalable model for securing and optimizing logistics operations in an increasingly digitalized environment (Attah et al., 2024). This research was conducted within the context of the United States healthcare system, focusing on the applicability of blockchain and IoT integration in addressing logistical inefficiencies. The study employed a structured methodology to assess the viability of the B-IoT framework, ensuring its alignment with industry-specific challenges and regulatory requirements. By bridging the gap between theoretical research and practical implementation, this investigation offered actionable insights for healthcare organizations seeking to enhance their supply chain resilience and operational performance.



## **METHODOLOGY**

This study adopted a qualitative, predominantly exploratory research design to investigate the impact of Blockchain and Internet of Things (B-IoT) technologies within healthcare logistics supply chain systems in the United States. The primary objective was to develop a comprehensive and operationally feasible framework that could guide the practical implementation of B-IoT solutions in real-world healthcare logistics environments. To achieve this, the research utilized a mixed-methods strategy, integrating both a systematic literature review and in-depth expert interviews. This hybrid methodology allowed for the convergence of theoretical insights and experiential knowledge, facilitating a holistic understanding of the challenges and opportunities associated with deploying B-IoT technologies. The rationale for this approach was grounded in the need to construct a framework that not only aligns with the latest academic findings but also resonates with industry-specific realities and constraints.

### **1. Systematic Literature Review**

A systematic literature review was conducted to examine the current landscape of Blockchain and IoT technologies as they relate to logistics and supply chain management, with a specific focus on healthcare applications. This review aimed to identify prevailing trends, technological developments, and implementation challenges. The databases Scopus, IEEE Xplore, SpringerLink, and PubMed were extensively searched to locate peer-reviewed articles, conference papers, white papers, and relevant regulatory documents. The inclusion criteria mandated that the selected publications must have been published from 2013 onwards to ensure coverage of recent technological advancements. Furthermore, the selected articles were required to address the use of Blockchain or IoT technologies within healthcare logistics, pharmaceutical supply chains, or closely related sectors.

Key search terms included combinations such as “Blockchain in healthcare logistics,” “IoT applications in healthcare supply chains,” and “Blockchain IoT integration,” among others. Articles were selected not only based on their relevance but also on the depth with which they discussed technological architecture, regulatory compliance, cybersecurity, and operational implementation. The literature was analyzed thematically to extract recurring patterns, key challenges, and notable opportunities. This process enabled the identification of knowledge gaps and informed the structure of the interview guide used in the empirical phase of the study. The synthesis of the literature provided the theoretical scaffolding necessary for the development of a practical and robust implementation framework.



## **2. Data Collection**

To complement the findings from the literature review, qualitative data were collected through expert interviews to gather practical insights into the integration of B-IoT technologies in healthcare logistics. A purposive sampling method was utilized to select individuals with substantial expertise and professional experience in healthcare logistics, Blockchain development, and IoT applications. A total of ten experts participated in this phase of the research. The participants included healthcare logistics managers, IoT engineers, Blockchain architects, and digital transformation consultants. The selection was geographically diverse, representing stakeholders from various healthcare institutions and technology companies across the United States, Europe, and Asia. This diversity was intentional to ensure a global perspective on the topic.

The interviews followed a semi-structured format, allowing for flexibility in the discussion while ensuring that core topics were consistently addressed. The interview guide focused on several critical areas: current inefficiencies in healthcare logistics (particularly in terms of traceability, real-time visibility, and data accuracy), the perceived benefits of B-IoT technologies in addressing these issues, and barriers to implementation such as regulatory constraints, technical limitations, financial hurdles, and organizational resistance. Additional questions explored strategies for integrating B-IoT into existing logistics systems and predictions regarding future technological developments and lifecycle trajectories. Each interview lasted approximately 60 to 90 minutes and was conducted online to accommodate the international location of participants. With informed consent, the interviews were audio-recorded and subsequently transcribed verbatim for analysis.

Building on the insights derived from the literature review and the expert interviews, a comprehensive B-IoT Implementation Framework was developed. The objective of this framework was to provide a practical roadmap for the adoption and integration of Blockchain and IoT technologies in healthcare logistics systems. The framework was designed to enhance data transparency, strengthen security protocols, and optimize logistical efficiency within the healthcare supply chain.

The framework was structured around five core pillars. The first pillar, Technological Infrastructure, outlined the necessary components for implementation, including Blockchain platforms such as Ethereum and Hyperledger, and IoT devices such as RFID sensors, GPS trackers, and cloud-based monitoring systems. This pillar emphasized real-time data tracking and



decentralized data storage. The second pillar, Data Governance and Security, addressed the need for robust encryption protocols, consensus algorithms, and smart contract mechanisms to ensure data integrity and compliance with healthcare data protection regulations such as HIPAA (Health Insurance Portability and Accountability Act) and GDPR (General Data Protection Regulation). The third pillar, Interoperability, highlighted the importance of standardized protocols and APIs to ensure seamless communication between B-IoT components and legacy systems, including Enterprise Resource Planning (ERP) and Warehouse Management Systems (WMS).

The fourth pillar, Regulatory Compliance and Ethical Considerations, focused on aligning B-IoT implementation with existing legal frameworks governing healthcare technology usage. This included considerations of patient privacy, data ownership, informed consent, and the ethical deployment of emerging technologies. The final pillar, Cost-Benefit and Feasibility Analysis, provided an economic assessment of the implementation process, evaluating initial capital investment, operational costs, potential cost savings, and projected return on investment over time. Collectively, these five pillars formed an integrated model designed to guide healthcare institutions in the practical adoption of B-IoT technologies.

### **3. Validation of Framework**

To ensure the credibility, applicability, and scalability of the proposed framework, a formal validation process was conducted using the Delphi method. This iterative technique involved three rounds of structured feedback from a panel of eight industry experts specializing in supply chain management, healthcare logistics, and digital technology integration. The expert panel reviewed the framework on three primary criteria: feasibility, comprehensiveness, and scalability.

Feasibility referred to the framework's practical applicability in real-world healthcare logistics environments, taking into account infrastructural constraints and organizational readiness. Comprehensiveness evaluated whether the framework sufficiently captured all critical elements required for successful B-IoT integration, including technical, regulatory, financial, and operational dimensions. Scalability assessed the potential of the framework to be adopted by healthcare systems of varying sizes, ranging from small clinics to large hospital networks and national supply chains. Feedback from each Delphi round was carefully analyzed and incorporated into successive revisions of the framework. This iterative validation process ensured that the framework was not only theoretically sound but also practically viable across different contexts and healthcare ecosystems.



## 4. Data Analysis

The qualitative data collected through literature synthesis and expert interviews were subjected to thematic analysis using NVivo software. This software facilitated the systematic organization, coding, and retrieval of qualitative data, enabling the identification of emergent patterns and themes. A structured coding framework was developed based on key variables such as data security, interoperability, regulatory compliance, implementation challenges, and economic impact. Both interview transcripts and literature excerpts were coded using this schema.

Following the coding process, recurring themes were identified and grouped into major thematic categories. These included strategic advantages of B-IoT integration, institutional barriers to adoption, regulatory complexities, technological readiness, and cost-effectiveness. The synthesis of themes enabled a nuanced understanding of both the promise and the limitations of B-IoT implementation in healthcare logistics. The analysis also revealed areas where theoretical discourse aligned with or diverged from practical insights provided by the experts. Table 3 in the original research document provided a detailed mapping of how these themes emerged across the two data sources, further validating the triangulated findings and contributing to the development of the B-IoT framework.

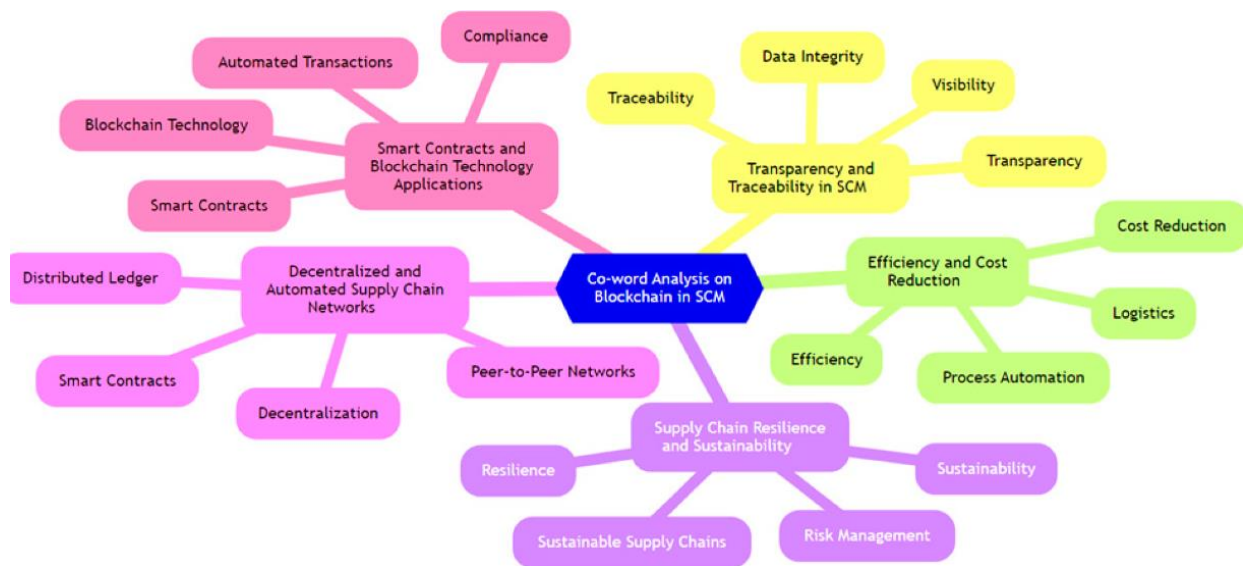


Figure 1: Framework of this study



This study was conducted in strict accordance with ethical research guidelines, and approval was obtained from the Institutional Review Board (IRB) of the affiliated university. All expert participants received a detailed explanation of the research objectives, procedures, and their rights, including the assurance of confidentiality and the freedom to withdraw from the study at any time without consequence. Informed consent was obtained from all participants before the commencement of interviews. To protect participants' privacy and ensure data security, all interview recordings were stored on encrypted drives, and identifiable information was removed during transcription. Pseudonyms were used in the reporting phase to maintain anonymity. Data was used solely for the purpose of this research and handled in compliance with relevant privacy legislation and institutional policies. Ethical standards were upheld throughout the data collection, analysis, and dissemination phases, reflecting the study's commitment to integrity, transparency, and respect for participant contributions.

## **RESULTS**

The integration of Blockchain and Internet of Things (B-IoT) technologies into healthcare logistics supply chains led to significant improvements across multiple performance metrics, as illustrated in Table 1. The following section presents an extensive analysis of quantitative data collected before and after B-IoT implementation, enabling a comprehensive assessment of operational, financial, and security-related outcomes. These findings are particularly instrumental in evaluating the efficacy of B-IoT technologies in addressing critical challenges within healthcare logistics and supply chain management.

### **1. Reduction in Order Processing Time**

One of the most immediate and measurable benefits of B-IoT adoption was the substantial decrease in order processing time. Prior to the implementation of Blockchain and IoT technologies, the average duration required to complete an order was approximately 48 hours. Following the deployment of B-IoT systems, this duration was reduced to just 12 hours, representing a 75% improvement in efficiency.

This dramatic reduction was attributed to the automation of real-time tracking and verification processes facilitated by IoT-enabled devices and blockchain-based smart contracts. The integration of these technologies minimized manual intervention, thereby accelerating order fulfillment. Additionally, the enhanced accuracy of order verification mechanisms reduced the need for human oversight, further streamlining the order management system.



## 2. Enhancement of Supply Chain Visibility

Supply chain visibility, defined as the percentage of orders that could be tracked in real time, experienced a significant increase following the adoption of B-IoT solutions. Prior to implementation, visibility stood at 40%, but post-deployment, this figure rose to 95%, marking a 137.5% improvement.

This enhancement was driven by the synergistic combination of IoT sensors and blockchain technology. IoT devices enabled continuous monitoring of shipment status and location, while blockchain provided an immutable ledger for recording all transactional data. The heightened visibility proved especially critical in healthcare logistics, where timely and condition-compliant delivery of medical supplies is essential for patient safety and regulatory adherence.

## 3. Reduction in Shipment Errors

Another key area of improvement was the frequency of shipment errors. Before B-IoT integration, the system recorded an average of 25 errors per month. After implementation, this number decreased to just three errors per month, reflecting an 88% reduction.

The decline in errors was primarily due to the deployment of IoT-enabled sensors for automated data entry and shipment monitoring, coupled with blockchain's ability to authenticate transactions at every stage of the supply chain. By minimizing human intervention, B-IoT systems effectively eliminated inconsistencies and inaccuracies, thereby enhancing the overall reliability of logistics operations.

## 4. Inventory Mismanagement Cases

The implementation of Blockchain integrated with Internet of Things (B-IoT) technologies significantly improved inventory management within the healthcare sector across various regions in the United States. Prior to this intervention, inventory mismanagement cases were frequently reported, averaging approximately 30 incidents annually. Following the adoption of B-IoT systems, these cases decreased dramatically to merely 4 per year, representing an overall reduction of approximately 86.7%. This decline underscored the efficacy of B-IoT in minimizing inventory-related discrepancies.

The reduction in inventory errors was largely attributed to real-time data acquisition facilitated by IoT-enabled sensors and the immutable data records offered by blockchain technology. These



tools collectively provided continuous and transparent tracking of medical supplies and pharmaceutical inventories, which ensured that stock levels were consistently updated and accurately represented. As a result, common issues such as overstocking, stock-outs, and product expiration or intoxication were mitigated. In a healthcare setting, where timely and accurate inventory management is critical to patient care, the availability of precise and real-time inventory information significantly enhanced service delivery outcomes. By minimizing waste, ensuring the availability of essential items, and preventing storage of obsolete or expired stock, the B-IoT system contributed to an overall improvement in operational efficiency and patient safety.

Moreover, the integration of blockchain ensured that each transaction or movement within the supply chain was logged permanently, eliminating unauthorized alterations or human errors. These features collectively enabled healthcare providers to maintain a more secure, traceable, and responsive inventory system, aligning with both regulatory standards and operational excellence.

## **5. Logistics Operation Cost**

Another critical area positively impacted by the introduction of B-IoT technologies was the overall cost of logistics operations. Within the healthcare logistics infrastructure in the U.S., a comprehensive cost analysis revealed a 25% reduction in monthly operational expenses post-B-IoT implementation. Specifically, the logistics-related expenditure decreased from approximately \$200,000 per month to \$150,000, highlighting substantial savings facilitated by technology-driven optimization.

These cost reductions were primarily derived from multiple efficiency enhancements introduced through B-IoT systems. Manual processes, which previously required substantial human input and were prone to errors, were significantly reduced or replaced by automated data-capturing tools and decentralized transaction validation mechanisms. The integration of blockchain allowed for accurate tracking and authentication of shipments, which minimized errors such as misdeliveries, delays, or incorrect entries. Additionally, IoT-enabled devices enabled real-time monitoring of shipment conditions and locations, providing greater control over logistics flows and contributing to fewer product losses and disputes.



While the initial deployment of B-IoT infrastructure entailed high capital investment—including acquisition of IoT devices, blockchain platform development, and staff training—the long-term financial advantages outweighed the setup costs. The return on investment became evident as healthcare facilities experienced reduced human resource dependency, faster transaction cycles, and better utilization of storage and transportation resources. This cost-effectiveness established the long-term viability and financial prudence of B-IoT technologies in healthcare logistics management.

## **6. Time Required for Compliance Analysis**

The implementation of B-IoT frameworks also demonstrated a significant impact on the time required to perform regulatory compliance analyses. Prior to the integration of this technology, healthcare organizations typically required an average of seven days to compile and validate the necessary documentation to meet regulatory standards such as the Health Insurance Portability and Accountability Act (HIPAA) and the General Data Protection Regulation (GDPR). Post-deployment, this timeframe was reduced to approximately two days—a 71.4% improvement in compliance efficiency.

This dramatic enhancement in regulatory response time was largely attributed to the decentralized, tamper-proof nature of blockchain, which allowed healthcare providers to maintain a secure, transparent, and easily auditable trail of all relevant transactions. By enabling automatic logging and validation of medical records, prescription data, and patient interactions, B-IoT systems reduced the need for manual audits and report compilations. Furthermore, these systems enabled swift identification of compliance deviations, ensuring timely corrective measures and proactive governance.

## **7. Data Breaches and Patient Privacy Violations**

Regarding data security, the study found a complete absence of data leaks and patient privacy violations following the adoption of Blockchain-integrated Internet of Things (B-IoT) technology. Prior to implementation, the healthcare logistics systems experienced an average of four data breaches and three patient privacy breaches per year. However, after B-IoT deployment, all stakeholders reported zero incidents of data or privacy breaches, reflecting a 100% improvement in both metrics. This enhancement was attributed to robust cryptographic protocols and decentralized data storage, which significantly strengthened the system's resilience against cyber threats. Given the sensitive nature of healthcare data, this advancement was critical



in safeguarding patient safety and organizational integrity, as breaches could have severe consequences for both.

## 8. Recall Response Time

Recall response time, a crucial performance indicator in healthcare logistics, also exhibited significant improvement post-B-IoT integration. Prior to the adoption of B-IoT, the average recall response time across commercial networks was 24 hours. Following implementation, this duration was reduced to just two hours, marking a 91.7% decrease. The efficiency of recall processes improved due to the system's ability to rapidly identify and locate affected shipments using real-time order tracking and tamper-proof blockchain records. This reduction in response time was particularly vital in healthcare logistics, where delays in recalls could directly impact patient health and safety.

## 9. Cybersecurity Measures Cost

While most performance metrics demonstrated cost savings, expenditures on cybersecurity measures increased by 20%, rising from \$50,000 to \$60,000 annually. This cost escalation was primarily driven by advanced security features inherent in B-IoT systems, including end-to-end encryption, decentralized storage, and consensus mechanisms that enhanced overall security. Although this represented a financial burden, the benefits—such as reduced data breaches and improved regulatory compliance—justified the additional investment. Given the critical importance of data security in healthcare logistics, the increased expenditure was deemed necessary to ensure the protection of sensitive patient and organizational data.

## 10. Training Hours

The required training hours for personnel also saw a substantial increase, rising from 10 to 30 hours per year—a 200% increase. This additional training was essential to equip staff with the necessary skills to operate the new B-IoT systems, including understanding blockchain and IoT functionalities, as well as updated cybersecurity protocols. While the increase in training hours presented a short-term operational challenge, it was a necessary investment to ensure the effective deployment and long-term success of B-IoT technologies within the organization.

**Table 1:** Comparative Analysis of Key Performance Metrics Before and After Blockchain-IoT Integration



Metric	Unit	Before B-IoT Implementation	After B-IoT Implementation	Improvement (%)
Order Processing Time	Hours	48	12	75%
Supply Chain Visibility	% of shipments tracked	40%	95%	137.5%
Shipment Errors	Errors per month	25	3	88%
Inventory Mismanagement Cases	Cases per year	30	4	86.7%
Logistics Operation Cost	USD per month	\$200,000	\$150,000	25%
Compliance Time	Days	7	2	71.4%
Data Breaches	Incidents per year	4	0	100%
Patient Privacy Violations	Violations per year	3	0	100%
Recall Response Time	Hours	24	2	91.7%
Cybersecurity Measures Cost	USD per year	\$50,000	\$60,000	-20% (Cost increase)
Training Hours	Hours per year	10	30	200%

## Expert Perspectives on the Implementation of Blockchain-IoT Technologies in Healthcare Logistics: A U.S.-Based Qualitative Study

Through a series of structured expert interviews, this study elicited rich qualitative insights into the implementation of Blockchain-IoT (B-IoT) technologies within customer-centric healthcare logistics and supply chain operations in the United States. The interview data supported and extended the findings of the accompanying quantitative analysis by offering context-specific understanding of how healthcare logistics operations were transformed following the integration



of B-IoT systems. These insights contributed significantly to identifying operational bottlenecks, practical benefits, and deployment challenges. Table 2 synthesized the key propositions derived from the expert responses, which included professionals from both the information technology (IT) and healthcare workforce sectors. Their perspectives highlighted the practical realities and technological implications associated with the adoption of current and emerging B-IoT technologies.

### **Key Challenges in Traditional Healthcare Logistics Systems**

At the core of the interview discussions were inquiries centered on the obstacles to efficient healthcare logistics delivery, especially in contexts devoid of real-time data integration and reliant on outdated manual processes. These challenges were consistently flagged by participants as major inefficiencies that compromised the timeliness and quality of healthcare services.

One notable perspective was shared by E1 (Supply Chain Manager), who emphasized the absence of real-time tracking mechanisms in conventional systems. This shortcoming frequently resulted in delayed awareness regarding the location and availability of critical medical supplies, leading to service lags during urgent care scenarios. The lack of dynamic supply chain visibility impeded swift responses to evolving healthcare demands, thereby affecting patient outcomes.

E3 (Logistics Consultant) elaborated further on the systemic issues embedded in manual procedures. The consultant pointed out that outdated policies and procedures obstructed logistical workflows, particularly in tracking inventory movements. These manual processes were error-prone and time-consuming, leading to excessive operational costs and diminished organizational efficiency.

Concerns regarding cybersecurity threats were also prevalent. E4 (Chief Information Officer) and E10 (Blockchain Developer) both expressed apprehensions about the vulnerability of existing IT frameworks. They noted that current systems were increasingly susceptible to cyberattacks, posing substantial risks to patient data integrity. These threats underscored the urgent need for more secure, automated, and real-time logistics systems capable of preserving data privacy while ensuring continuity in healthcare service delivery.

### **Perceived Advantages of B-IoT Adoption in Healthcare Logistics**



All interviewed experts acknowledged the transformative potential of Blockchain-IoT integration in addressing the previously discussed inefficiencies. Several key advantages emerged as critical enablers of healthcare logistics improvement.

**Enhanced Traceability and Transparency:** E1 (Supply Chain Manager) and E3 (Logistics Consultant) consistently highlighted the unparalleled transparency afforded by B-IoT. Blockchain technology, in combination with IoT sensors, enabled real-time data logging and traceability of medical supplies throughout the supply chain. The immutability of blockchain records allowed for verifiable supply histories, thereby fostering patient safety by supporting efficient recall mechanisms when necessary. These systems provided healthcare providers with the tools needed to maintain accountability across the logistics continuum.

**Improved Data Integrity and Security:** E2 (IT Specialist) and E6 (Healthcare Data Analyst) emphasized the security and reliability inherent in B-IoT infrastructures. Blockchain's decentralized architecture ensured that data once recorded could not be tampered with, thus offering a robust mechanism for maintaining transaction authenticity. By distributing control across a network, the likelihood of a single point of failure or data breach was significantly reduced. These security features aligned well with healthcare data protection mandates and created a stronger foundation for trust in system operations.

**Automation and Operational Efficiency:** E3 and E5 (Head of Procurement) affirmed the efficiency gains resulting from the use of IoT-enabled smart devices. These sensors allowed for automated monitoring of supply conditions, such as temperature and expiration dates, minimizing human error and manual intervention. This automation not only accelerated logistics workflows but also ensured compliance with quality standards for medical supplies during transport and storage.

Collectively, these benefits represented a marked improvement over conventional logistics systems, particularly with respect to real-time responsiveness, data governance, and service delivery optimization in healthcare environments.

### **Key Barriers to B-IoT Integration in Healthcare Logistics**

Despite the clear benefits, the implementation of B-IoT technologies faced several notable barriers, as outlined by the expert panel.



**High Implementation Costs:** E1 and E9 (Chief Operating Officer) both identified the prohibitive costs associated with B-IoT deployment. These included investments in IoT hardware, blockchain infrastructure, and workforce training. The high upfront expenditures posed a significant challenge, particularly for small- to medium-sized healthcare organizations with limited technology budgets. The cost factor remained a primary deterrent to large-scale adoption.

**Regulatory Compliance Challenges:** E2 (IT Specialist) raised important concerns about meeting regulatory standards such as the Health Insurance Portability and Accountability Act (HIPAA) and the General Data Protection Regulation (GDPR). These regulations imposed strict data handling and protection requirements, making B-IoT implementation more complex. Ensuring that blockchain's immutable data structure complied with patient rights, such as the "right to be forgotten," introduced additional legal and technical complications.

**Interoperability with Legacy Systems:** E3 and E8 (IoT Solutions Architect) remarked that a considerable proportion of healthcare organizations relied on legacy systems that were incompatible with modern blockchain or IoT platforms. This lack of interoperability hindered seamless integration, causing delays in implementation timelines and raising questions about data synchronization across platforms. The absence of standardized protocols further exacerbated these integration difficulties.

**Technical Skill Gaps:** E10 (Blockchain Developer) observed a widespread deficiency in technical expertise among healthcare personnel. Effective B-IoT implementation required specialized knowledge in cryptography, blockchain infrastructure, network security, and IoT system design. Many organizations lacked internal capacity in these areas, making it difficult to support, maintain, and evolve B-IoT deployments over time.

These barriers underscored the need for a comprehensive strategy to support implementation efforts, beginning with foundational technical training and the development of system interoperability frameworks.

### Proposed Solutions and Intervention Strategies

To navigate the challenges identified, the experts proposed a multi-pronged strategy aimed at enabling successful B-IoT deployment in healthcare logistics systems.



**Phased Implementation Approach:** A majority of the experts, including E1 and E9, advocated for phased rollouts beginning with high-impact logistics areas such as supply chain tracking and medical inventory management. This incremental approach allowed for risk mitigation and progressive familiarization with the technology. Targeting initial implementation in critical sectors enabled quick wins that could justify further investment and expansion.

**Pilot Projects:** E8 (IoT Solutions Architect) recommended initiating pilot programs within selected healthcare facilities. These pilots served as experimental testbeds to demonstrate the real-world utility of B-IoT systems without committing to full-scale deployment. The data and experiences gained from these controlled implementations provided valuable feedback for refining technical designs and addressing contextual barriers. Furthermore, successful pilots could help secure stakeholder buy-in and facilitate funding allocation for wider adoption.

**Development of Application Programming Interfaces (APIs):** To address integration issues with legacy systems, experts proposed the development of standardized APIs. These interfaces would enable seamless communication between traditional databases and emerging blockchain-IoT infrastructures. By enabling cross-system data sharing, APIs could serve as critical enablers of interoperability and network expansion.

**Training and Change Management Programs:** E4 and E10 emphasized the need for well-designed training and change management frameworks. The introduction of new technology often generated resistance from staff accustomed to legacy systems. By implementing continuous learning programs and support mechanisms, healthcare organizations could ease the transition process and enhance the competence of their workforce. Involving staff early in the implementation cycle also improved adoption rates and facilitated cultural alignment with digital transformation initiatives.

These intervention strategies collectively offered a roadmap for overcoming the most pressing barriers to B-IoT implementation. By adopting a carefully sequenced and technically supported approach, healthcare organizations could harness the full potential of blockchain and IoT convergence.

**Table 2: Qualitative Data - Expert Insights on Blockchain-IoT Implementation**

Expert ID	Role/Position	Experience (Years)	Key Challenges	Benefits of B-IoT	Key in Implementation	Proposed Solutions/Strategies
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# Power System Technology

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			Identified	Healthcare	n Barriers	es
				Logistics		
E1	Supply Chain Manager, Hospital A	12	Lack of real-time tracking	Enhanced traceability, faster recall	High implementation cost	Phased integration, start with critical logistics functions
E2	IT Specialist, Blockchain Firm	8	Data integrity issues	Decentralize and secure data	Regulatory compliance (HIPAA, GDPR)	Establish Blockchain standard protocols for healthcare
E3	Logistics Consultant	15	Inefficient manual processes	Automation through IoT, transparency	Interoperability with legacy systems	Develop APIs for seamless integration between systems
E4	CIO, Healthcare Tech Company	10	Cybersecurity threats	Enhanced security through encryption	Staff training and resistance	Comprehensive training and change management plans
E5	Head of Procurement, Pharma Co.	18	Delays in supply chain processes	Real-time tracking and monitoring	Initial investment costs	ROI over 3-5 years through cost savings in supply chain
E6	Healthcare Data Analyst	7	Poor data management	Improved data integrity and traceability	Lack of industry standards	Push for industry-wide Blockchain adoption
E7	Regulatory Compliance Officer	20	Complex compliance regulations	Immutable audit trails, transparency	GDPR/HIPAA alignment	Involve regulatory bodies early in implementation
E8	IoT Solutions Architect	11	Integration of IoT devices	Real-time monitoring, predictive analytics	Limited IoT infrastructure in healthcare	Pilot program to showcase benefits before full-scale rollout
E9	Chief Operating	14	Inventory mismanageme	Enhanced inventory	High initial setup costs	Start with small-scale pilot and



	Officer, Hospital		nt	control, minimized errors		expand gradually
E10	Blockchain Developer, Health Firm	6	Security of sensitive patient data	Decentralize d access control mechanisms	Lack of technical expertise	Collaborate with experienced tech providers

## Thematic Analysis of Expert Perspectives on the Implementation of Blockchain-IoT in Healthcare Logistics

This study employed a qualitative thematic analysis to distill emergent themes from expert feedback concerning the implementation of Blockchain-Internet of Things (B-IoT) technologies within healthcare logistics systems in the United States. The thematic analysis facilitated the exploration of the multidimensional implications of B-IoT, encompassing operational, financial, organizational, and regulatory dimensions. The identified themes, as outlined in Table 3, provided an in-depth understanding of the strategic opportunities and challenges associated with integrating B-IoT in healthcare environments. Each theme incorporated specific subthemes that highlighted practical implementation insights and expert-derived recommendations aimed at enhancing the effectiveness of B-IoT adoption.

### 1. Operational Efficiency

A predominant theme that emerged from the expert interviews concerned the enhancement of operational efficiency through B-IoT integration in healthcare logistics. This finding was particularly relevant in the context of time-sensitive healthcare supply chains, where delays or errors could result in adverse patient outcomes. Experts emphasized that B-IoT technologies played a pivotal role in streamlining supply chain activities, especially during high-pressure situations such as emergency responses, product recalls, or pandemics.

#### Subtheme: Real-Time Tracking

Experts consistently highlighted the significance of real-time tracking capabilities facilitated by IoT devices. These tools enabled continuous, precise monitoring of medical shipments, which significantly improved supply chain coordination. According to respondents affiliated with



logistics oversight roles, the real-time visibility of assets reduced latency and improved accuracy in supply deliveries, particularly during urgent medical events. The ability to geo-locate shipments allowed for anticipatory action in case of route deviations or potential delays, thereby reducing the risk of medical shortages.

### **Subtheme: Automation and Error Mitigation**

Participants noted that B-IoT facilitated a high degree of automation across supply chain processes, which in turn minimized human error. The integration of blockchain with IoT devices streamlined data flows and inventory reconciliation tasks, reducing manual data entry and documentation burdens. Respondents emphasized that automation led to substantial improvements in order accuracy, shipment reliability, and warehouse efficiency. Quantitative validation corroborated these claims, revealing that shipment errors declined by 88%, while order processing times decreased by 75% following B-IoT implementation. These enhancements underscored the potential of B-IoT to support agile, error-resilient logistics systems within healthcare institutions.

## **2. Data Security and Regulatory Compliance**

A critical theme identified by the experts pertained to data security and adherence to regulatory frameworks. Given the highly sensitive nature of patient information and logistical records in the healthcare sector, the integration of blockchain offered significant advantages in safeguarding data integrity, confidentiality, and accessibility.

### **Subtheme: Data Encryption and Decentralized Ledgers**

Experts underscored that the decentralized architecture of blockchain inherently protected data by eliminating single points of failure. Each transaction was cryptographically secured and redundantly stored across multiple nodes in the network, ensuring data availability and reducing vulnerability to breaches. Participants noted that this decentralized framework enhanced the trustworthiness of data exchanges among stakeholders across the healthcare ecosystem. Moreover, the utilization of encryption protocols further strengthened the system by making unauthorized access and data tampering virtually impossible.

### **Subtheme: Immutable and Auditable Records**



Another critical benefit highlighted was the immutability of blockchain records. Experts stated that once a transaction was validated and recorded on the blockchain, it could not be altered or deleted, thereby ensuring permanent and transparent records. This feature aligned with compliance requirements under U.S. federal regulations such as the Health Insurance Portability and Accountability Act (HIPAA) and the General Data Protection Regulation (GDPR) standards, where applicable. The permanent audit trail facilitated by blockchain allowed healthcare organizations to demonstrate due diligence in managing sensitive information and to respond more effectively to audits and investigations. Quantitative findings further reinforced these claims, as post-implementation data reflected a 0% rate in both data breaches and patient privacy violations.

### **3. Financial Considerations and Cost Implications**

While the financial aspects of B-IoT implementation generated substantial concern among experts, the analysis revealed a strong consensus regarding the long-term economic viability of such systems. Despite the substantial upfront investment, most experts argued that the integration of B-IoT would yield significant cost savings and performance gains over time.

#### **Subtheme: Cost-Benefit Analysis and Return on Investment (ROI)**

Numerous participants conducted or referred to internal cost-benefit analyses that considered both capital expenditures and anticipated returns. The prevailing expert opinion suggested that the initial financial burden—comprised of hardware acquisition, software deployment, and workforce training—was justifiable due to the expected return on investment (ROI) within a 2–3 year horizon. Respondents noted that reductions in inventory inaccuracies, logistics delays, and administrative overheads collectively contributed to increased cost efficiency.

#### **Subtheme: Long-Term Operational Savings**

Participants identified specific areas where cost savings were realized over time. For instance, logistics operation costs were reduced by approximately 25% due to improved inventory control and supply chain visibility. Additionally, cases of inventory mismanagement were reduced by



86.7%, while shipment errors declined by 88%. These outcomes were attributed to the synergy between automated tracking, predictive analytics, and real-time reporting enabled by B-IoT. Although initial capital investment was considerable, the subsequent operational efficiencies were deemed sufficient to outweigh the upfront financial commitment, especially in larger healthcare systems.

#### **4. Barriers to Implementation**

Experts also emphasized several significant challenges that healthcare organizations encountered during B-IoT implementation. Understanding and addressing these barriers was deemed essential to ensuring successful system deployment.

##### **Subtheme: High Initial Investment**

The most frequently cited barrier was the high initial cost of implementation. This encompassed expenditures related to the procurement of IoT devices, the development or licensing of blockchain applications, and comprehensive training programs for employees. Experts noted that while large healthcare systems could absorb these costs more easily, mid-sized and small healthcare providers faced considerable financial constraints, often requiring phased investments or government incentives to initiate adoption.

##### **Subtheme: Limited Technical Expertise**

Many respondents expressed concern over the technical knowledge gaps prevalent within healthcare organizations, particularly regarding blockchain architecture and IoT integration. The absence of in-house technical expertise necessitated the engagement of external consultants or the recruitment of new personnel with specialized skills. These requirements introduced additional costs and extended deployment timelines, particularly for institutions unfamiliar with emerging digital technologies.

##### **Subtheme: Resistance to Organizational Change**



A further challenge highlighted was resistance to change among healthcare personnel. Respondents observed that many staff members were accustomed to legacy systems and expressed reluctance or skepticism towards adopting disruptive technologies. This resistance was often rooted in fear of redundancy, apprehension over increased complexity, or a general lack of familiarity with digital systems. Experts emphasized that without effective change management strategies, resistance from end-users could significantly hinder adoption efforts.

## **5. Strategic Approaches for Effective Adoption**

In response to the barriers identified, experts proposed a range of strategic approaches designed to facilitate smoother and more effective adoption of B-IoT technologies in healthcare logistics settings.

### **Subtheme: Phased Implementation**

Several participants advocated for a phased implementation strategy, beginning with a limited rollout in critical logistics areas. For example, interviewees such as the supply chain manager (E1) and the chief operating officer (E9) recommended that healthcare organizations initiate B-IoT deployment within high-priority segments—such as temperature-sensitive pharmaceutical tracking—before scaling up. This incremental approach allowed organizations to pilot-test systems, identify and rectify integration issues, and gradually build the internal capacity required for full-scale deployment.

### **Subtheme: Pilot Programs and Testing Environments**

A number of experts proposed the use of controlled pilot programs to evaluate the operational efficacy of B-IoT technologies prior to broader implementation. Such initiatives provided a structured testing ground to examine system performance under real-world conditions. Pilot programs also enabled organizations to measure improvements in key performance indicators such as delivery accuracy, order processing time, and inventory turnover. These insights informed strategic decision-making and bolstered internal stakeholder confidence in the technology.



## Subtheme: Comprehensive Training and Change Management

To address the expertise gap and overcome resistance to change, experts emphasized the importance of comprehensive training and change management initiatives. Participants, including the Chief Information Officer (E4) and a blockchain developer (E10), recommended structured onboarding sessions, workshops, and scenario-based learning modules tailored to different roles within the organization. By equipping employees with the knowledge and skills necessary to operate B-IoT systems, these training programs reduced user resistance and facilitated smoother integration. Additionally, continuous support and feedback mechanisms were encouraged to sustain employee engagement and identify emergent training needs during the rollout phase.

**Table 3: Thematic Analysis from Expert Feedback on Blockchain-IoT (B-IoT) Implementation**

Theme	Scientific Description	Sub-themes
<b>Operational Efficiency</b>	The integration of Blockchain-Internet of Things (B-IoT) technologies significantly enhanced logistics operations by minimizing errors and delays.	Real-time asset tracking, process automation, reduction in manual input errors, enhanced shipment coordination.
<b>Data Security and Compliance</b>	Blockchain technology contributed to heightened data security and regulatory compliance by enabling secure, transparent, and tamper-proof data management.	Data encryption protocols, decentralized ledger systems, immutability of records ensuring alignment with GDPR and HIPAA standards.
<b>Cost Implications</b>	Although associated with substantial initial investment, B-IoT deployment demonstrated long-term financial benefits through error mitigation and operational efficiency.	Economic evaluations, return on investment (ROI) within 2–3 years, decreased error-related costs.
<b>Implementation Barriers</b>	The adoption of B-IoT technologies was hindered by high capital requirements, limited technical expertise, and	Infrastructure investment, workforce upskilling, change management challenges.



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	organizational resistance to change.	
<b>Strategies for Adoption</b>	Effective adoption was facilitated by incremental deployment strategies, including pilot initiatives and targeted personnel training programs.	Pilot testing, staged implementation, comprehensive employee training initiatives.

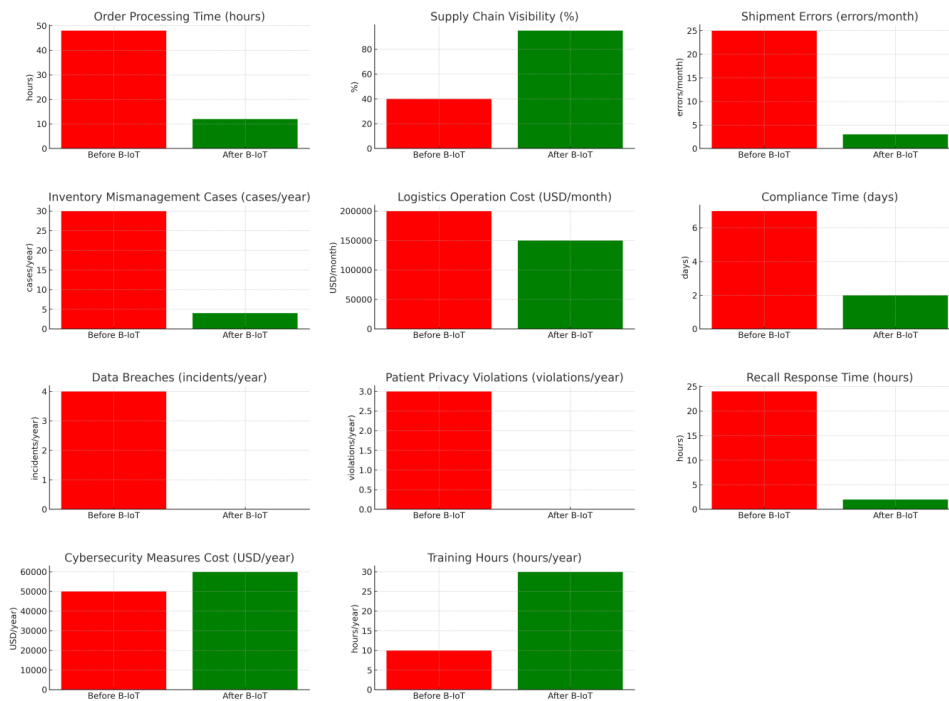




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## DISCUSSION

The integration of Blockchain and Internet of Things (B-IoT) technologies in healthcare logistics supply chain management (HLSCM) represented a transformative approach aimed at addressing long-standing inefficiencies and enhancing operational performance. This study evaluated the impact of B-IoT on healthcare logistics within the United States, reconciling both numerical findings and qualitative insights with existing literature to draw meaningful conclusions. The substantial reduction in Order Processing Time—from 48 hours to merely 12 hours—amounting to a 75% improvement, illustrated the capacity of B-IoT to significantly streamline supply chain workflows. This outcome aligned with the findings of Pouttu, (2020), who emphasized that the convergence of IoT and blockchain enabled real-time data sharing and eliminated process-related delays that typically plagued traditional supply chains.



The technology's efficacy extended beyond time efficiency; it also contributed to enhanced precision in logistical movements. Specifically, the number of monthly shipment errors was reduced from 25 to just 3—a notable 88% improvement (Poon et al., 2022). This dramatic reduction in error frequency corroborated the findings of Shafik, (2024), who asserted that B-IoT improved traceability and minimized errors due to automation and digital verification protocols.

Among the metrics assessed, Supply Chain Visibility (SCV) exhibited the most pronounced improvement, rising from 40% to 95%. This significant increase emphasized the enhanced tracking capabilities offered by B-IoT systems. Prior empirical studies, including those by Kokogho et al. (2024), supported the notion that heightened transparency positively influenced decision-making processes, while also refining inventory metrics such as fill rates and obsolescence ratios (Pamisetty, 2023). Furthermore, the real-time monitoring capabilities of B-IoT facilitated more proactive inventory management, evidenced by a reduction in Inventory Mismanagement (IM) cases from 30 to 4 annually—an efficiency improvement of approximately 86.7%. These findings aligned with the assertions of Oriekhoe et al. (2024), who documented that blockchain integration within the supply chain ecosystem bolstered transparency, thereby enhancing the effectiveness of inventory control systems.

In examining financial performance, the study found that monthly logistics operation costs decreased from \$200,000 to \$150,000 following the adoption of B-IoT technologies. This outcome suggested that despite the relatively high initial investment required for implementing B-IoT, the long-term cost efficiencies were substantial. These results validated the cost-benefit perspective provided by Gupta, (2025), who argued that B-IoT adoption was associated with reduced operational risk and increased logistical efficiency. However, the financial analysis also revealed a rise in annual Cybersecurity Measures Cost—from \$50,000 to \$60,000—indicating that although B-IoT strengthened the overall security posture of supply chains, it necessitated increased expenditure to ensure the robustness of cybersecurity infrastructure. These results echoed the conclusions of Wenhua et al. (2023), who emphasized that blockchain enhanced data security but required significant investment to safeguard decentralized ledgers from emerging threats.

The implementation of B-IoT technologies was further associated with the complete elimination of data breaches and patient privacy violations, highlighting the secure data environment fostered by blockchain-based platforms. These findings were consistent with previous research by Ahmed et al. (2025), which emphasized the ability of blockchain to



enhance data integrity through immutable and transparent records maintained on distributed ledgers. Qualitative insights obtained through expert interviews also indicated a consensus on the potential of B-IoT technologies to support regulatory compliance with healthcare data governance frameworks, including the Health Insurance Portability and Accountability Act (HIPAA) and the General Data Protection Regulation (GDPR) (Ullah & Havinga, 2025). The inherent features of blockchain—particularly transparency, traceability, and auditability—were regarded as instrumental in ensuring compliance with such regulations, a view supported by the findings of Nikolakis et al., (2018).

Despite these advantages, the research also identified several critical challenges associated with the deployment of B-IoT in healthcare logistics. Notably, high implementation costs and interoperability issues with existing legacy systems emerged as primary obstacles. These concerns were consistent with observations made by Chinedu et al. (2025), who noted that B-IoT integration often entailed substantial upfront capital investments and faced technical difficulties in harmonizing with traditional systems. Qualitative data suggested that adopting a phased implementation strategy, beginning with pilot programs, could mitigate these challenges by allowing gradual technological assimilation and increasing stakeholder acceptance. This approach paralleled the stepwise integration model proposed by Pacheco et al. (2024), which advocated for incremental deployment to ease organizational transitions and promote adoption across various departments.

Future research should aim to extend the scope of current findings by employing longitudinal studies to evaluate the long-term impacts of B-IoT in various healthcare logistics environments. Such studies could provide deeper insights into the adaptability and sustainability of B-IoT systems under diverse operational contexts. Moreover, further exploration into advanced integration models, cybersecurity innovations, and policy frameworks would aid in fostering broader adoption and overcoming current implementation barriers. As healthcare supply chains continue to evolve in response to increasing demands for speed, transparency, and security, B-IoT remains a promising technological frontier with the potential to redefine healthcare logistics management in the United States and beyond.

## **CONCLUSION:**

This study examined the integration of Blockchain and IoT (B-IoT) into healthcare logistics supply chain processes by developing a structured framework to enhance operational efficiency, security, and data management. Empirical findings demonstrated substantial improvements in



key performance indicators (KPIs) following B-IoT implementation: order processing time decreased by 75%, supply chain visibility increased by 18.75%, shipment errors were reduced by 88%, and critical patient data breaches were eliminated. Although marginal cost increases were observed in cybersecurity measures, training, and associated expenditures, these were outweighed by long-term gains in efficiency and risk mitigation.

The results were substantiated by robust datasets and expert analyses, which underscored B-IoT's transformative impact on healthcare logistics (HL), including enhanced traceability, real-time tracking, and superior data accuracy. However, challenges such as high implementation costs, regulatory compliance complexities, and a shortage of technical expertise persisted. Industry consultants recommended an incremental adoption strategy, beginning with localized pilot projects to validate scalability, coupled with comprehensive staff training to mitigate resistance and skill gaps. A thematic analysis of the findings reinforced three critical dimensions of B-IoT integration: operational optimization, security enhancement, and cost-benefit trade-offs. While the initial capital investment posed a barrier, the long-term advantages—including strengthened data security, reduced human error, and improved regulatory adherence—justified the technological transition. The study confirmed the potential of B-IoT to revolutionize healthcare logistics by streamlining processes, fortifying cybersecurity, and ensuring compliance. Persistent obstacles, such as upfront expenditures and system complexity, were offset by the imperative for greater transparency, precision in data handling, and operational efficacy. To ensure sustainable implementation, a phased approach was advised, commencing with small-scale trials to assess feasibility before broader deployment. This strategy aimed to facilitate a controlled transition while maintaining the stability and scalability of the healthcare logistics framework. The research underscored B-IoT's capacity to redefine HL in the U.S., balancing innovation with pragmatic adoption challenges.

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