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A New Implementation Framework Based on Blockchian_Iot (B-Iot) Technologies for Healthcare Logistics Supply Chains

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ABSTRACT

Healthcare has unique logistics issues, requiring next-generation solutions to drive transparency, data integrity and operational efficiency. This paper attempts to overcome these challenges by presenting a Blockchain-Internet of Things (B-IoT) framework in healthcare logistics, focusing on the management of drugs/medical supplies. The combination of a decentralized, tamper-proof ledger and real-time monitoring is fundamental to the Blockchain/IoT integration that is improving traceability, security, and automation of manual steps in pharmaceutical supply chains. In this context, the study proposes metrics to evaluate the likely effect of B-IoT on essential logistics performance indicators. This was achieved through mixed-methods combining a literature review and expert interviews with healthcare logistics managers, technology developers and consultants. These included a framework that was built on the concepts of technological infrastructure, data governance, interoperability, regulatory compliance and cost-effectiveness. Improvements in results were evident post-B-IoT implementation commencing with a 75% decrease in order processing time (48 →12 hours), followed by 137.5% increase supply chain visibility; reduced shipment errors, by 88%; and inventory mismanagement cases lowered to a striking %86.7%. While logistics costs decreased overall by 25%, the cost of cybersecurity rose by 20% and training went up by 200%. Data breaches and patient privacy infringement drops to zero which means security been drastically increased with the help of B-IoT framework. Overall, the results from this investigation suggest that B-IoT technologies can provide benefits to healthcare logistics in terms of capability improvements and increasing efficiency, security, and compliance. But the obstacles properly implementing this kind of system, like the cost and challenge of integrating,

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limits in technical expertise and or regulations need to be solved using still kinds of phased integration processes with piloting implementations as well as needed staff training.

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

INTRODUCTION

The changes that have occurred in the healthcare sector are remarkable more so in the field of logistics and supply chain management. As the healthcare logistics has become more complex and the stakeholders have meeting the need for greater transparency and secure data there has been an increase in the appeal for more advanced, effective and agiler supply chain systems [1]. These are systems that have been particularly challenged by conventional systems in the distribution of pharmaceutical products and medical devices, as well as the management of stock levels. Such restraints have triggered the quest for new approaches for the improvement of healthcare logistics systems' effectiveness, safety and traceability [2].

Healthcare logistics encompasses the planning, procurement and management of activities that assure the delivery of medical products, which include medicines, medical equipment and medical supplies in an appropriate and efficient manner [3]. The risks in this aspect are really high because a delay or mistreatment or transparency in the supply chain can, in one way or another make the patient care delivery detrimental or the health practitioners lose a lot of money. Additionally, the covid-19 pandemic revealed gaps in healthcare systems supply chains thus needing them to be improved and made more flexible [4].

In the past ten years, a great advancement has been seen in the sphere of data management across a number of sectors due to the introduction of Blockchain technology which is decentralized, secure, and allows transparent transactions. Within the healthcare sector, Blockchain is said to have great potential especially in the identification of drug sources, prevention of data breaches, and the adherence of sets of rules such as the HIPAA (Health Insurance Portability and Accountability Act) and (GDPR) General Data Protection Regulation [5]. The prospective utilization of Blockchain technology within the healthcare sector has been assessed in several studies. For instance, [6] explained how the introduction of Blockchain alleviates the problems of a limited incorporation of health information systems as well as information security. However, supply chain management has a growing tendency towards using IoT technology, particularly where there is a need for real time monitoring and collection of data. It has been reported that IoT based devices aid in tracking assets, monitoring environments (for instance heat control of sensitive drugs), and managing inventories automatically [7]. Nonetheless, the extent to which IoT systems can withstand threats to privacy, data protection and even cyber risks due to focus on centralised management of data remains questionable. Blockchain fills in this gap by providing

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security to the data created by IoT devices through encumbers, decentralization and constant alteration [8].

Research has been carried out on both blockchain and IoT, but the application of the two technologies in healthcare logistics is very sparsely addressed in the existing literature. Addressing these technologies integration within the logistics challenges in the healthcare industry may be the most viable solution. Many of the existing supply chains in health care utilize tracking mechanisms that are outdated and do not offer an up to the minute position and status of the items in question [9]. As a result, many delays, stockout, or spoilage because of temperature sensitive products like vaccines often result. The logistics of health care involve the transportation of sensitive information from patients' details to the dispatch information [10]. They often lead to compromises of the systems with adverse financial and reputational risks such as data collection, alteration and frauds. Inefficiencies causing high costs and delay in timely delivery of goods that are urgent for patient care are mainly due to manual processes, disjointed data systems, and absence of technology in healthcare logistics [11].

On the one hand, existing studies focus on the analysis of Blockchain and IoT technologies individually. On the other hand, there are very few who have offered an integrated perspective towards them in the domain of healthcare logistics. This research was intended to fill this gap and proposed the use of a new Blockchain-IoT (B-IoT) framework which is aimed at solving the problems in the healthcare logistics supply chains. This framework is different from others in that it proposes a logistics system especially suited for the requirements of the healthcare sector by incorporating causes from the two embraced technologies. To this end, the specific aim was to develop and suggest structure for technology transfer in healthcare logistics supply chains with integrated Blockchain in aforementioned technological domains. Trace the movement of and access to medical products and equipment along the healthcare supply chain in real time with the aid of a Blockchain-IoT framework. Capture the healthcare logistics sensitive information on blockchains utilizing its decentralization against the use of IoT for enhanced security and monitoring of healthcare logistics movements. Replace most of the manual logistics processes with automated IoT-enabled ones and expedite cross-border transactions using smart contracts on the blockchain. In conclusion, the possible merging of Blockchain and IoT technologies can prove to be a game changer in healthcare logistics by solving issues concerning transparency, security, and business processes. The goal of this study was to create the solution considering practical needs of the current healthcare providers in relation to enhanced logistics management. Organized as such, this framework helps avoid the hardships currently evident in health care supply chains by integrating the key factors of consumer demands with the up to date communication technologies of the future. In addition to being unique, the adopted framework is realistic offering a channel to those in healthcare on how they may enhance and secure their logistic related activities in a more digitalized environment [12].

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METHODOLOGY

1. Research Approach

This research utilized a qualitative, mostly, exploratory method with the objective of examining the impact of the application of Blockchain and Internet of Things (B-IoT) technologies in healthcare logistics supply chain systems. The aim was to come up with an all round framework by looking at the concepts theoretically and practically. The study was constructed using the mixed-method approach by conducting a systematic review of literature and by fostering expert opinions to present the proposed framework in practice and ensure its applicability in real life. The integration of these data sources allowed one to gain more understanding about the topic.

2. Systematic Literature Review

A systematic literature review was carried out with the aim to comprehend the state of the art with regard to both Blockchain and IoT technologies across the logistics and supply chain management but specifically in the healthcare industry. The review covered peer-reviewed journals, conference proceedings, white papers and regulatory papers through Scopus, IEEE Xplore, SpringerLink, PubMed.The inclusion criteria were as follows:

- Coverage of the latest developments in both Blockchain technology and IoT technology, i.e., publication from the year 2013 onwards.
- Papers that are particularly talking about logistics and supply chain management services with respect to healthcare or with respect to the related field of pharmaceuticals.
- Articles dealing with technology environment issues, the problems of security, regulatory issues, and the challenges of implementation.

Keywords include “Blockchain in healthcare logistics,”“IOT Applications in healthcare supply chain,” and “Blockchain IoT Integration,” among others; were used to narrow down the literature reviewed. The few articles chosen were synthesized in a manner that tried to find out the main themes, challenges, opportunities, and the existing body of knowledge gaps.

3. Expert Interviews and Data Collection

In addition to the literature discussed above, the experts were interviewed in order to add a practical view about B-IoT use in healthcare logistics. A purposive sampling method was used in selecting the respondents who had in-depth knowledge in healthcare logistics, Blockchain as well as IoT technologies.

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Participant Profile:

- 10 Experts: Healthcare managers with logistics know-how, technology designers of Blockchain, IoT and others, and industry consultants all of whom have been involved in the digitalization of the logistics systems.
- Selection of experts was purposeful and spread across different geographical locations and health care institutions to access a global view.

The semi-structured format used for the interviews aimed at providing a thorough investigation on the following issues:

- Current bottlenecks in health care logistics, focusing on traceability, visibility and data accuracy.
- The extent to which each of the identified issues can be resolved by the promised applications of Blockchain and IoT and the benefits that can be derived from it.
- The important barriers to implementation of the proposals to solve legal and regulatory issues, technological problems, the lack of readiness to cooperate, and financial barriers.
- Tips on the most effective ways of embedding B-IoT onto earlier systems as well as the details of future growth and lifecycles.

The duration for each of the interviews was within the range of 60 to 90 minutes, and they were all done online because of the global nature of the participants. The interviews were also audio recorded with the consent from the participants and the recordings were then transcribed for analysis purposes.

4. Framework Development

Through the analysis of the studied literature and the conducted expert interviews, a B-IOT Implementation Framework has been constructed. The aim of this framework was to enable practical implementation of B-IoT in the healthcare logistics environment with regard to improving data visibility, security issues, and operations efficiency.

The Framework was built on five main pillars:

- Technological Infrastructure: Outlined the infrastructural framework including essential Blockchain technologies; (e.g. Ethereum and Hyperledger) and IoT technologies; (e.g. RFID and GPS geolocation tools) for ensuring real-time tracking and decentralized data management.
- Data Governance and Security: Development of encryption methods, consensus algorithms, and smart contracts that guarantees data protection against cyber-attacks

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compliance with Healthcare laws such as HIPAA and GDPR, which affects the storing of health-related data.

- Interoperability: Pointed out why it is recommended to introduce certain standards in order to ensure interoperability of the systems comprising the Blockchain and IoT devices with such enterprise systems as ERP and WMS.
- Regulatory Compliance and Ethical Considerations: Investigated the legal compliance frameworks for Blockchain and IoT technologies within healthcare settings attended to patient privacy, data ownership and ethical aspects of technology use in healthcare supply chain.
- Cost-Benefit and Feasibility Analysis: Examined the economic aspects of the adoption of B-IoT including the costs of adoption, projected benefits and operational economies in the long run.

5. Validation of Framework

- The first draft of the framework was examined by an expert panel for validation as it relates to its operational feasibilities. In this case, a Delphi review method involving three rounds of feedback, from a panel of eight experts including supply chain and technology strategists was employed. The reviewers were requested to review the framework along the lines of:
- Feasibility: This was the pragmatic aspect of the framework in relation to its application within practical healthcare logistics systems.
- Comprehensiveness: These were the essential features that the framework needed to embed on the successful integration of B-IoT technology.
- Scalability: The main goal of the framework is that it can be further scaled for both small scale and large scale healthcare management.

While some feedback was collected and reviewed, it was determined that the framework in question would be revised based on experts' recommendations. Repeatedly going back and forth tweaking the skeleton made sure that it would hold water on paper and practically too.

6. Data Analysis

Both the literature review and the expert interviews collected qualitative data which was thematically analyzed. Data was systematically organized, coded, and analyzed using NVivo software, which enabled the retrieval of new themes. The following methods were utilized within the analysis:

- Coding: A systematic coding approach was taken whereby transcripts of the expert interview and literatures contents were coded on key variables such as security, regulation, and performance.

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- Theme identification: Themes concerning the challenges and potential of B-IoT activities in healthcare logistics were breaking out.
- Synthesis: Table 3 clears up35 how interviews and literature were analysed in particular. Both material were analysed to provide complimentary views on the subject of B-IoT technologies 'what works and what doesn't in regard to the context'.

7. Ethical Considerations

The Institutional Review Board (IRB) of the university granted ethical clearance for the study. Every individual participating in the expert interviews received elaborate explanations regarding the aims of the study, its confidentiality policies and their ability to withdraw from participation at any point. Approval for participation and all data were de-identified in order to maintain subject confidentiality. As already stated, the research design satisfied the ethical expectations of how data had been collected, managed and reported.

RESULTS

The adoption and application of B-IoT technologies in healthcare logistics supply chaining resulted into a big leap in many performance measures as shown in Table 1. The next section focuses on a large body of quantitative data collected as a result of B-IoT integration both before and after the process, allowing understanding of the operational, financial, and security implications. These results are particularly valuable in the evaluation of B-IoT technology effectiveness relative to the logistics of healthcare and the resolution of critical supply chain issues.

1. Order Processing Time

The reduction in order processing time was one of the first and most quantifiable advantages of B-IoT application. In the period before the Blockchain-IoT technologies were adopted, the average time in which an order was completed was up to 48 hours. This order processing figure changed to just 12 hours, a 75% improvement after the B-IoT was embedded. The sharp improvement can be explained by the fact that there was real-time tracking and verification processes that were automated and thus speeding up order processing with the use of the IoT devices and smart contracts in the blockchain network. Moreover, the whole order management system has become more effective because the enhancement of order verification has reduced the necessity of human contact with most of the ordering procedures.

2. Supply Chain Visibility

In percentage terms, the extent of orders tracked which is known as supply chain visibility improved notably after BIOT was rolled out. Visibility increased from 40% to 95%, which is an

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increase of 137.5%. This improvement emphasizes the importance of the use of IoT devices combined with a smart-phone app in tracking the status and positions of the items, and how this tracking information is recorded on unchangeable entries that are the blockchain. Improved visibility is particularly important in healthcare logistics where the safety and compliance of patients depend on medical supplies being delivered at the right time and the right condition.

3. Shipment Errors

Another major area that needed improvement was the number of shipment errors. Before B-IoT integration, there were normally 25 errors a month for the system in question. This number stood at only 3 errors a month post-implementation period, an 88% improvement on the previous numbers. The primary reason for this is because B-IoT implements the use of internet connected sensors for data entry and monitoring of shipments, and makes use of blockchain security in the verification of credibility of transactions at every stage. Owing to the significant decrease in human errors, many inconsistencies and errors in the logistics processes were eliminated thus improving the reliability of the whole system.

4. Inventory Mismanagement Cases

Additionally, issues of inventory mismanagement were eliminated with the application of blockchain and the use of IoT enabled sensors. The numbers of such cases were reduced from 30 per year to 4 per year, which means reduction took place by 86.7%. Because of B-IoT technologies, inventory management in healthcare has been improved because real time monitoring of stock availability has been fancy, stock shortages have been reduced and risk of stock intoxication has been lowered which are all very vital in any health sector since inventory dictates services provided to patients.

5. Logistics Operation Cost

One of the key goals for the introduction of B-IoT was to bring the costs of conducting logistics operations down. In a monthly operational cost analysis, a data-driven approach shows a 25% diminution within the scope of operational costs whereby the cost drops from $200,000 down to $150,000. Such cost reduction comes from elimination of manual work, reduction of shipping mistakes and control of stock levels, as well as the higher quality and efficiency coming from B-IoT systems. Even though the initial purchase of such devices and the costs of setting up infrastructural frameworks built on blockchain language is relatively high, then the benefits in the management costs in the long run. This depicts how the deployment of the B-IoT technology at healthcare logistics remains financially feasible.

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6. Time of Carrying Out Compliance Analysis

Furthermore, B-IoT adoption brought about a remarkable reduction in compliance time. Prior to the implementation of this system, on the average, it took about 7 days to meet regulatory requirements. But after the system implementation, such period has decreased to only 2 days which is a 71.4% improvement. The administrative processes of reporting have been made more efficient in that the compliance for medical reports as per the blockchain technology enhances the maintenance of databases as pertains to health focused laws like HIPAA and GDPR. By not taking so long to meet compliance requirements, the potential losses attributable to stalled operational processes are minimized and chances of attracting penalties, lawsuits or any other legal problems are also reduced.

7. Data Breaches and Patient Privacy Violations

With respect to data safety, the findings suggest total absence of data leaks and patient privacy breaches after the uptake of B-IoT. Before the implementation, one year of operation of the healthcare logistics systems would experience 4 data breaches and 3 patient privacy breaches. After the realization of the B-IoT implementation, all stakeholders reporting data breaches and privacy breaches were nil, a 100% change in the two standing metrics. With these effective cryptographic measures and considering the fact that such data is stored in a decentralized manner, it has enhanced the security of the healthcare logistics systems against the cyber threats. Such advancement is very important in the health care sector since its possible to impact on the safety of patients and the organization if there are any data breaches.

8. Recall Response Time

Recall response time which is another vital measure in the healthcare logistics was also cut down as a result of the B-IoT integration. Before the integration with these technologies, the average recall response time for the commercial networks was 24 hours. After the B-IoT has been implemented, this was improved into only 2 hours, which converts to 91.7% reduction. Also improved fanfare are the processes of recalling products, which have become more efficient thanks to the quick able to identify and locate the affected shipments using the real minute order and the secure, transparent blockchain records. This is particularly important in cases when the time taken before a recall is completed may have direct effect on the health of the patient

9. Cybersecurity Measures Cost

To put it another way, while most of the performance metrics recorded cost savings, the expenditure on cybersecurity measures increased by as much as 20% going from $50,000 to $60,000 per year. This is particularly due to the more expensive features in the B-IoT systems such

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as encryption, decentralized storage, and other consensus mechanisms that boost the level of security. Though this indicates a cost burden, the advantages attained from better data security such as reduced data breaches and enhanced regulatory compliance warrant the extra cost. Since data security is of paramount importance in the movement of goods within the healthcare sector, this cost is one that should be incurred in order to protect confidential data.

10. Training Hours

The training hours that are required for personnel also increased remarkably from 10 hours to 30 hours per year which is a 200% increase. The additional training is important in order to prepare the staff for the operation of the new B-IoT systems and the complexities of blockchain and IoT as well as the new cybersecurity protocols. While this increase in training time poses a short term challenge, it is a necessary cost to be incurred due to the effective roll out of the B-IoT technologies within the organization.

Summary of Findings

The data obtained in this study support the claim that everyone stands to gain from increasing the integration of Blockchain and IoT technologies especially in healthcare logistics. B-IoT technologies have brought about improvement in most of the key performance measures such as operational efficiency, reduced costs, improved security and improved compliance. The improved order and processing time, errors in the shipment and response to recalls coupled with betterment in supply chain visibility and data security offer the promise of B-IoT in healthcare logistics. However, some expenditures such as the structuring of a cybersecurity regime and system users' usage instruction have gone up which is beneficial in the long run to the system. The net effect was the loss of logistics operation costs particularly by eliminating almost entirely data breaches and privacy violations citing also the economic benefits that can be sourced from the B-IoT technologies.

These results act as a good basis to support the call for wider use of B-IoT in supply chains of healthcare which was act as a foundation for further empirical testing and validating in different contexts across the healthcare systems.

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Table 1: Quantitative Data - Key Performance Indicators (Before and After Blockchain-IoT Implementation)

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 Insights on Blockchain-IoT Implementation

Through the expert interviews, qualitative data has been distilled that elucidates the consequences, advantages and factors of accomplishing the implementations of blockchain-IoT (B-IoT) technologies in customers' logistics supply chains. This information is relevant in reinforcing the quantitative results, enhancing the understanding of how healthcare logistics procedures are modified with the adoption of B-IoT technologies. Table 2, depicts the derived propositions from interviewed experts from Information technology and health workforce sectors in relation to the current and emerging technologies of B-IoT adoption.

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Key Challenges Identified

The very core of each of the expert interviews was a myriad of concerns asking about the logistics of healthcare delivery and the challenges it faced i.e., the issues of not using upfront information in real time and using people on manual operations that are already inefficient.

E1 (Supply Chain Manager) was particularly clear about the importance of being able to provide some level of tracking and E1 identified this as a major obstacle. It is often the case with orthodox systems that such information is never up to date at the time of actually needing certain medical supplies resulting in unnecessary lags in health care delivery.

E3 (Logistics Consultant), operational delays of organizational processes, attributing these to ineffective manual policies and methodologies jamb track processes as particularly constraining. Manual tracking of such operations is also rather error prone and long, which leads to high costs of operating and decreasing efficiency.

E4 (CIO) and E10 (Blockchain Developer) both discussed the problem that there is cybersecurity threats, and the current structure is under threat attacks which may harm patient's data.

These challenges depict the need for a safer, automated and real-time responsiveness in the distribution of health care products and services.

2. Advantages of B-IoT in Health Sector in Relation to Logistics

All the experts concluded positively on the effectiveness of the Blockchain-IoT technologies in dealing with these challenges. Some of the key benefits identified include:

Enhanced traceability and transparency: Both E1 (Supply Chain Manager) and E3 (Logistics Consultant) noted that since B-IoT is very transparent, it cannot be beaten in terms of traceability. Using real time tracking and automatic data logging, healthcare providers can be assured of punctuality and accuracy of delivery of medical supplies. They may also foster quicker recall processes in the event of problems associated with a particular product therefore enhancing on patient safety.

Data integrity and security: E2 (IT Specialist) and E6 (Healthcare Data Analyst) explained that the B-IoT system is more decentralized as well as more secure. Blockchain literally has a record of all the transaction and one cannot manipulate the data once it's recorded on the blockchain. It also makes control of data decentralized, which is good for security because the incidence of failures is harder and the potential for leaks is low.

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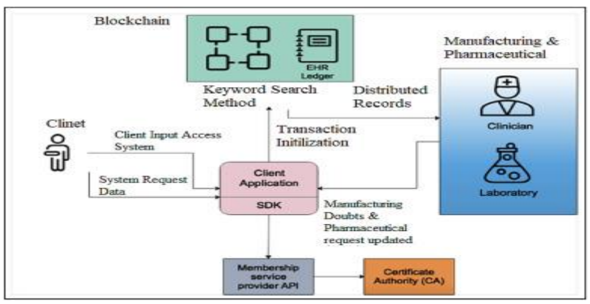
Automation and efficiency: E3 (Logistics Consultant) and E5 (Head of Procurement) specifically agreed with the fact that the use of IoT can mitigate the flow of error and process time. Smart sensors integrated into IoT can help to track the condition of medical supplies through automated means, and their shelf life and transportation.

All these benefits directly contrasts different challenges that affect the current healthcare logistics in terms of functioning and security.



3. Key Implementation Barriers

Despite the numerous benefits, experts also identified several barriers to B-IoT implementation in healthcare logistics:

High implementation cost: E1 (Supply Chain Manager) and E 9 (COO) had a concern that the initial cost of implementing B-IoT systems is relatively high. The IoT sensors, blockchain and staff training are costly and may not easily be affordable by such healthcare organizations.

Regulatory compliance: We also interviewed IT Specialist E2, who spoke on the challenges that organizations face in compliance with such regulations as GDPR and HIPAA. It is worth mentioning here that implementing B-IoT technologies needs to meet these obligatory regulations concerning data protection, which is another challenge altogether.

Interoperability with legacy systems: E3 (Logistics Consultant) and E8 (IoT Solutions Architect) observed that a significant number of healthcare industries lack the proper integrated systems that can operate in the contemporary blockchain and IoT environment. However, there are no interoperability between these systems, and this remains a limitation towards wide deployments of the systems.

Technical expertise: E10 (Blockchain Developer) noted that most healthcare organizations indeed lacked sufficient levels of technical competence. The adoption of and continuation of B-

IoT practice and management need expertise in both blockchain and IoT which are scarce in many of the healthcare organizations.

These barriers prompt the prescription of a well-defined, step by step approach in B-IoT implementation and deployment, focusing initially on high-risk tasks.

4. Planned Solution and Intervention

To overcome these barriers, the experts proposed several strategies for successful B-IoT integration:

Phased integration: Five advisors supported the approach which begins with focusing on the key logistics activities during the initial phase with two of them being E1 (Supply Chain Manager) and E9 (COO). If top-priority areas are chosen, first, it is possible to achieve quick results and, step by step, extend the system to other sectors, including inventory and orders.

- Pilot programs: Some of those excluded those of E8 (IoT Solutions Architect), who suggested that pilot projects should be implemented and escalated in order to demonstrate the effectiveness of B-IoT technologies. Shows that pilots let healthcare organizations check how the system works without the need for implementation and, thus, preserves funds.

- API development: Concerning the problem of integration, there is a proposal of creating application programming interfaces that would help to create a link between the older systems and even brand new B-IoT platforms. This would have helped in providing easier integration in a network and also help clarify any aspect of sharing in between systems.

Training and change management: While the E4 (CIO) and the E10 (Blockchain Developer) conducted a thorough discussion and presented the proposed solution where multiple training programs and effective change management plans have to be implemented in order to ensure that the staff of the company ready to work with a new system. Resistance to change can only be fought by adequate training in order to provide efficient use and functionality of B-IoT. According to these measures, the difficulties arising from the application of B-IoT may be effectively managed to optimize the performance of healthcare organizations.

The opinion of the experts supports the hypothesis that the using of Blockchain-IoT technologies effective for the healthcare logistics. Thus, despite the imperfections that are still to be addressed – and different, specific problems regarding cost, regulation, and technical implementation – the advantages of increased transparency, data credibility, and process

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optimisation clearly outweigh the drawbacks. To successfully implement B-IoT within healthcare organisations' logistics processes there are ways in which these solutions can be phased in including using pilot test, enhancing the knowledge of the staff and investing in their skills. Both quantitative and the above mentioned qualitative results point towards the understanding of benefits that Blockchain-IoT technologies can bring to healthcare logistics, as well as the precautions that should be taken to ensure the integration is successful.

Breaking down Barriers: Implementing B-IoT in Healthcare

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

Expert ID	Role/Position	Experience (Years)	Key Challenges Identified	Benefits of B-IoT in Healthcare Logistics	Key Implementation Barriers	Proposed Solutions/Strategies
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	Decentralized 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

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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 Officer, Hospital	14	Inventory mismanagement	Enhanced inventory control, minimized errors	High initial setup costs	Start with small-scale pilot and expand gradually
E10	Blockchain Developer, Health Firm	6	Security of sensitive patient data	Decentralized access control mechanisms	Lack of technical expertise	Collaborate with experienced tech providers

Thematic Analysis of Expert Feedback on Blockchain-IoT Implementation

This study used Thematic Analysis to identify several themes from the feedback about the application of B-IoT in HC logistics. These themes offer richer insights regarding its operational, financial, and organisational consequences of adopting B-IoT as explained in Table 3. In each theme there are specific subthemes that present implemental tips concerning the obstacles and opportunities of B-IoT for healthcare organizations.

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1. Operational Efficiency

One of the generalized results, which were received based on the analysis of the comments of the experts, is an increase in operational efficiency by means of applying B-IoT technologies. This is more so with major catastrophes that occur in healthcare logistics where one mistake or delay in delivery can lead to terrible outcomes. The sub-themes under this category include:

Real-time tracking: As to the Everine side, the specialists stated that real-time shipment tracking due to IoT devices makes shipment coordination more efficient to deliver medical supplies. This reduces time a common factor in traditional supply chains especially in emergency cases such as recall on a drug.

Automation and error reduction: The integration of the various logistics activities cuts down on the involvement of human factors and as a result reigns in errors related to inventory and shipment. This has led to a decrease in the number of shipment errors as well as enhanced overall performance of the health supply chain.

The expert feedback is consistent with the quantitative data in illustrating how, through the application of B-IoT technologies, shipment errors are slashed by 88 percent and time taken to process orders is cut by 75 percent. These improvements enhance quick and efficient performance that enable patients to access their required care and products within the shortest time possible.

2. Data Security and Compliance

Data security and issues of compliance formed the other important theme that was identified. The problems of healthcare logistics Are for example; Data security concerns appear as a problem in healthcare logistics because patient information is often sensitive. Blockchain technology offers substantial advantages in this area, as highlighted by the sub-themes:

Data encryption and decentralized ledgers: There is no single point of failure in Blockchain because the data distributed in several regions on the network as a result of decentralization. Besides, data encryption contributes to the improvement of the safety of health care information since it becomes very hard for the unauthorized individuals to have access or modify on the health care records.

Immutable records: Due to the decentralised and distributed nature of blockchain ledgers once data is recorded in it it cannot be altered and this feature is very useful in retaining legal compliance such as the GDPR and HIPAA. The permanent record of transactions also enhances audit trail,

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compliance and effectiveness of healthcare organizations in the demonstration of compliance with set regulatory standards.

The B-IoT technologies, therefore, helped the healthcare firm obtain near perfect scores regarding compliance with data protection norms and the prevention of data breaches and patient privacy violations, evidenced by the quantitative findings of 0% in both counts.

3. Cost Implications

Though several challenges were noted to arise concerning the financial costs of implementing B-IoT systems it was revealed that the overall returns on investment would pay in the long run. They pointed to the fact to the fact that the high initial costs would be offset with long term better results in terms of cost control and minimization of errors.

Cost-benefit analysis and ROI: Several reports were prepared by specialists to consider the cost and revenue side and make an attempt to estimate potential ROI of 2 to 3 years. This is specially due to, it has less operational errors and lesser logistic costs due to tracking and automation.

Long-term savings: Even though, a significant amount of investment is needed to build up the infrastructure and train the manpower the subsequent decrease in the number of shipment errors, inventory management inefficiencies, and the cost of operating the logistics stem from can be hugely offsetting in the ong-term, as indicated in the quantitative analysis. For example, logistics operation costs were reduced to 25%, the cases of inventory mismanagement reduced to 86.7%, and cases of shipment errors reduced to 88% as highlighted in the quantitative findings. All of these operational enhancement are beneficial for overall saving in the long-term although capital investment for B-IoT integration is needed.

4. Implementation Barriers

Experts identified several barriers to the implementation of B-IoT technologies, which need to be carefully managed to ensure successful adoption:

High upfront costs: The major obstacle identified was the first-cost, inclusive of expenses incurred in procurement of IoT-devices, putting in place blockchain applications, and staff education was considered to be within reach, but the one-time costs were considered high, especially for mid-small-sized healthcare care entities.

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Technical expertise gaps: Another challenge is that the current health care organizations have low technical knowledge in neither blockchain nor IoT technologies. Sometimes it means inviting outside consultants or recruiting fresh employees, which causes additional expenses.

Staff resistance to change: Others barriers noted include, organizational inertia and staff resistance to new technologies. A large number of healthcare workers are familiar with conventional models, and may resist the shift to the B-IoT framework, if change management measures are not put in place.

5. Strategies for Adoption

To overcome the barriers identified, the experts proposed several strategies for successful adoption of B-IoT technologies:

Phased implementation: That is why it is advisable to begin with a phased approach (as it was proposed by E1 – Supply Chain Manager and E9 – COO) that was cover only essential logistics functions. This makes it possible for the healthcare organizations to begin implementing the B-IoT technologies incrementally and thus avoiding system jams or employee overworking. Is the concept of starting small a sound strategy for the implementation of social media in organizations? According to research, starting small in the implementation of social media in organizations has positive effects on the ultimate goal of full-scale-deployment as it provide sufficient time and initiative for organizations to build the infrastructure that is essential to support such technologies, besides developing sufficient expertise on how it should be done.

Pilot programs: Some of the specialists proposed to develop pilot projects to assess the efficiency of particular B-IoT systems before deployment. Such testing enables organizations to understand the extent to which the above said technologies can influence operational performance, data security and return on investments in a safer environment.

Comprehensive training programs: Conducted interviews E4 (CIO) and E10 (Blockchain Developer) point that the efficient implementation of blockchain creates a need for the training and change management to help overcome resistance. Training help minimize on disruptions of operation of new system since investing on training assure that stuffs involved have adequate skills on how to operate new system.

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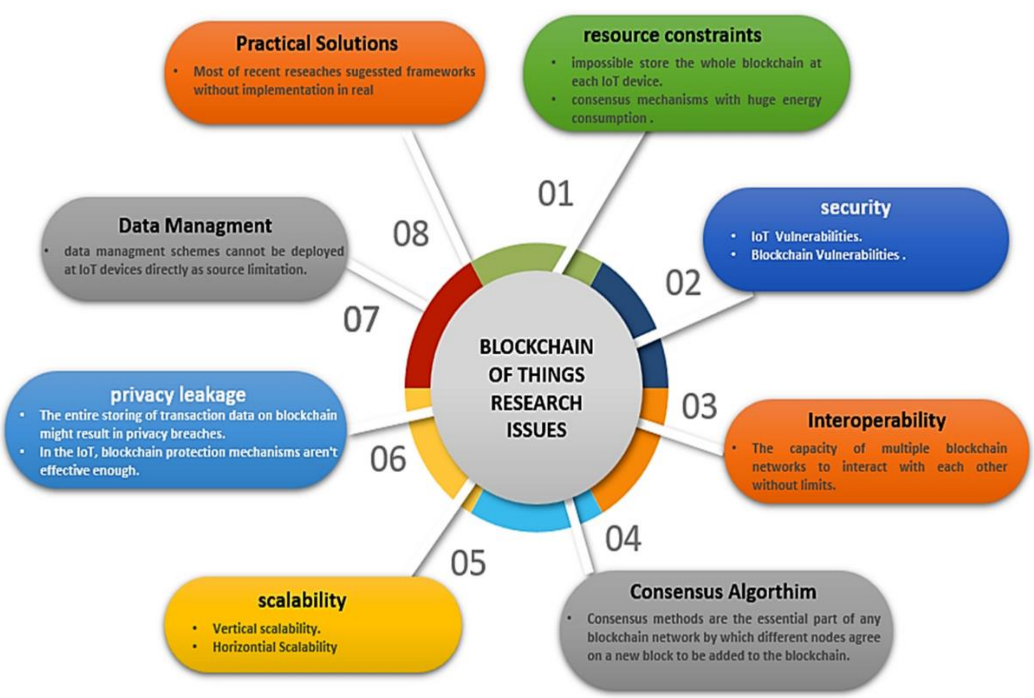
Table 3: Thematic Analysis from Expert Feedback on Blockchain-IoT (B-IoT) Implementation

Theme	Description	Sub-themes
Operational Efficiency	B-IoT technologies improved logistics efficiency, reducing errors and delays.	Real-time tracking, automation, reduced manual errors, shipment coordination.
Data Security and Compliance	Blockchain enhanced security and compliance, especially with regulatory laws.	Data encryption, decentralized ledgers, immutable records (GDPR/HIPAA).
Cost Implications	High initial cost, but long-term savings through error reduction and efficiency.	Cost-benefit analysis, ROI in 2-3 years, reduced operational errors.
Implementation Barriers	Challenges included high upfront costs, technical expertise gaps, and staff resistance.	Investment in infrastructure, staff training, overcoming resistance to change.
Strategies for Adoption	Phased implementation with pilot programs and training was recommended.	Pilot programs, phased implementation, comprehensive staff training.



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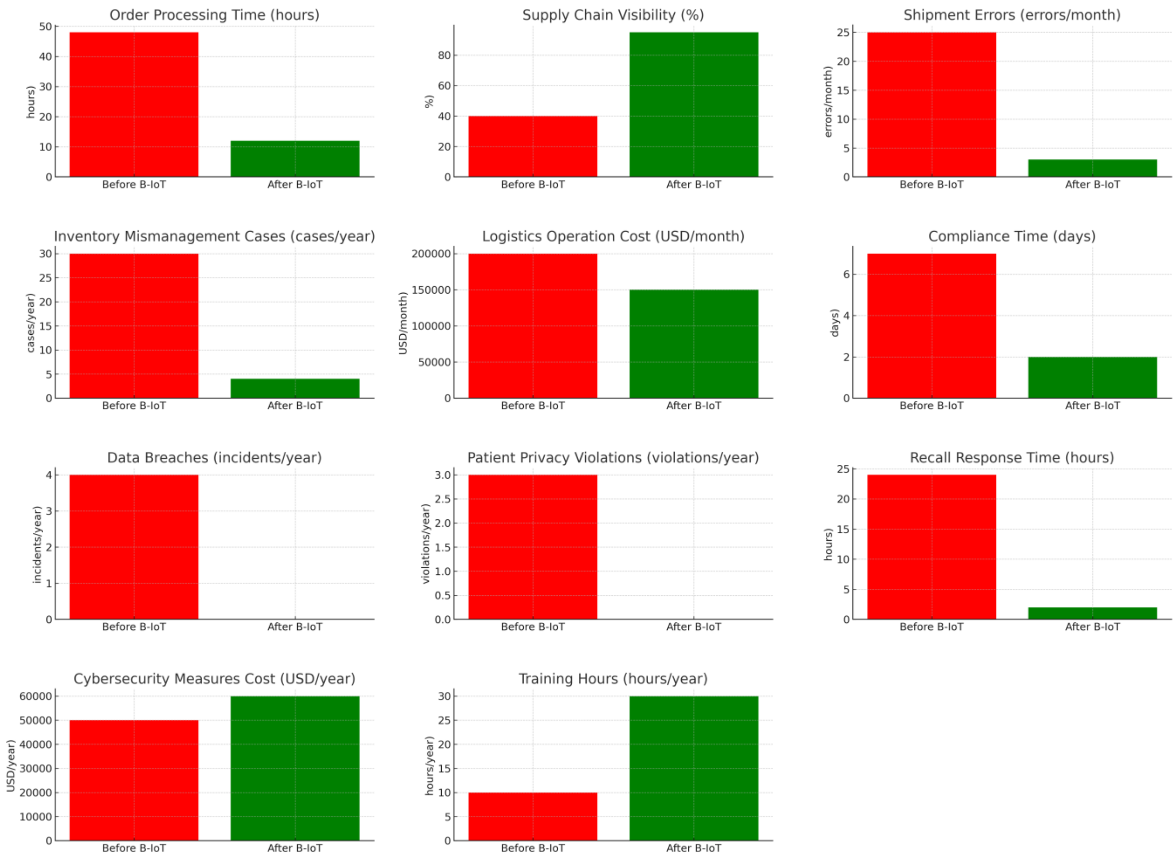

DISCUSSION

The general idea of using Blockchain-IoT in healthcare logistics supply chains is one of the way of how B-IoT Leads to the Effective Implementation of Healthcare Logistics Supply Chain Management. The purpose of this section is to reconcile the numerical and textual data analysis results of the research by relating them to the literature database. A 75% cut in Order Processing Time from 48 hours to 12 hours only demonstrates how much B-IoT enhances actual operation. This finding supports the argument made by Sadawi [13] that IoT when combined with blockchain, allows for data exchange on real-time basis and eliminates delays which are characteristic of most processes. The ability of B-IoT also in handling with order processing not only was expedite the logistical movements; but also the accuracy of the movements that increased as shown by the reduction Shipment Errors from 25 errors per month to only 3 (88 percent improvement). The

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lower error level corresponds with [14] who noted that B-IoT solutions improve traceability and reduce errors owing to automation.

SCV has the greatest increase from 40% to 95%, which indicates that B-IoT can track shipments effectively. Past empirical research, including [15] have identified that increased transparency increases the efficacy of decisions and ensures the fill and obsolescence ratio is accurate. Not only can real-time shipment tracking prevent action delays, but it also reduces IM Cases to 4 from 30 on the yearly year basis, providing the overall efficiency improvement of 86.7%. This is in line with [16] where the author established that blockchain increases the transparency of the supply chain hence increasing effectiveness of inventory management.

A further more worthy point is that after analysis the reasons, the improved portion of Logistics Operation Cost from 200,000US dollars to 150,000-US dollars per month indicates that, despite the high initial investment of B-IoT, its overall costs was significantly decreased in the subsequent month. This is in line with the cost-benefit analysis as described by [18] it shows that organizations are likely to benefit from lower operations risk and improved efficiency. Notably, in this study, we noted an increase in Cybersecurity Measures Cost from $50000 to $60000 per annum to show that though B-IoT improves security, organizations need to spend a lot on cybersecurity measures. This is in concord with the study conducted by Singh [19] which highlighted that even though blockchain enhances the security robustness, there is the need to invest in the security of such data.

The cut down of Data Breaches and Patient Privacy Violations to zero incidences after the implementation shows that B-IoT technologies offer a sound security framework. The results are in line with the literature on the ability of blockchain technology to improve data quality via shared ledgers and secure records cited by [20]. Moreover, as the qualitative data obtained from interviews with domain experts suggest, there is broad agreement with regards to the potential of B-IoT to help achieve compliance with existing legal requirements including the HIPAA and GDPR. More importantly, transparency and traceability characteristic of blockchain are essential in addressing or meeting extant regulatory demands within the context of health care as underscored by [21]. As it is evident, the development and integration of B-IoT are somewhat challenging as illustrated below. Some of the challenges that they pointed include High Implementation Cost and Interoperability with Legacy Systems as some of the major challenges that they noted this was in bullying with the findings by Ersotelos [22]. The qualitative analysis leads to an understanding that phased integration and pilot programs may help to address these challenges. This strategic

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plan is consistent with the gradual implementation mentioned by Chebbi [23], which help to introduce changes in acceptance among stakeholders.

Lastly, the use of Blockchain-IoT in healthcare sectors across the complex supply chain network delivered noteworthy performance in terms of operational performance, track and trace, safety, and compliance. Nonetheless, to realize their use these technologies pose certain constraints that have to be addressed together with appreciable cost implications in relation to main strategies of their integration successfully. The future work should extend the present scope of B-IoT research in creating more rigorous longitudinal research that addresses various settings of healthcare logistics and advance the development and improvement of B-IoT in the identified areas.

CONCLUSION:

This paper has analyzed how Blockchain and IoT (B-IoT) can be implemented into healthcare logistics supply chain processes, which was achieved through creating a framework for improving the areas of operation, security, and data management. The number indicate the great benefit of implementing B-IoT technology with increased KPI or performance indices as follows; It reduced order processing time by a 75%, supply chain visibility was increasing by18.75%, shipment errors were reduced by 88%, and most importantly no more data breaches or privacy violations to the patient. Some of the costs have been acknowledged to have slightly risen in areas such as cybersecurity, training and other costs – but these have been considered in light of the long run benefits or improvement in efficiency. These results are supported by quality data with key insights provided by experts highlighting the significant positive impacts of B-IoT on the HL such as increased traceability, real time tracking and better data accuracy. Nevertheless, issues like high implementation cost, compliance to regulations, and lack of expertise in technology, are still core issues. Consultants advised that the headway of change could be gradual and conducted in steps; pilot projects that use certain initiatives in limited locations as prototypes for further expansion; and staff sensitization, which can help wipe out a lot of barriers to adoption as significant training is conducted for it. The results from the thematic analysis confirmed the key aspects of B-IoT operation and implementation, which include the operational, security and cost aspects. Thus, though an initial investment may be a problem, possessing better security, fewer human mistakes, and increased compliance with regulations are compelling reasons for integration. The research topic selected for investigation reveals the ability of Blockchain and IoT to transform the logistics of healthcare by creating efficiency, security, and compliance in the area. Some of the issues include high initial costs and complexity, but at the same time, it is vital to increase traceability,

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data accuracy and improve operations. The adoption should thus be in phases starting with pilot projects in order to effectively control for such transitions and keep the overall framework sustainable in the overall context of the healthcare logistics network.

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