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*Research Article*

# Blockchain-Based IoT-Enabled System for Secure and Efficient Logistics Management in the Era of IR 4.0

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As the global logistics business expands as a result of the industrial 4.0 revolution, logistics operations continue to evolve as new technologies such as IoT, cloud, and big data are deployed. These IoT devices improve the logistics function by boosting real-time product tracking, improved data collection, smart storage of logistics data, etc. Some of these new technologies present an avenue for cyberattacks on these logistics systems due to their centralized database structure. Logistics operations entail the exchange of private consumer information (name, address, phone number, and bank account information) as well as product information amongst logistics stakeholders (manufacturers, suppliers, transporters, and customers). And the engagement of so many logistics stakeholders creates privacy and security issues for the private information because customer information, as well as product details, are transferred and shared across different logistical stakeholders during the logistics process. It faces unwanted access, which could lead to fraud or the creation of counterfeit products by a bad actor in the system. All of these challenges are significant because logistics data integrity is important for customer satisfaction. The deployment of Blockchain innovation will address these challenges with the application of its special feature such as immutability, efficient cryptography, and distributed decentralized storage system. In this paper, we highlighted the technology that enables smart logistics and reviewed smart logistics, Blockchain, and IoT in logistics; we present the significance of integrating Blockchain and IoT in logistics. We proposed a Blockchain-based IoT-enabled system framework for secure and efficient logistics management where logistics data can be captured with the use of IoT sensors, and we also designed and describe the sequence diagram for secured communication between the logistics stakeholder through a smart contract. In conclusion, Blockchain can provide security to logistics data and enhance operational efficiency with its key features.

## 1. Introduction

Logistics as part of the supply chain can be defined as a strategic management process of procurement, movement, and storage of goods, parts, and finished products, and the related information flows through the concerned organization and its marketing channels [1]. Logistics is a networking process that involves multiple stakeholders (logistics enterprise, suppliers, customers, transporters, distributors, and so on), and its objective is to attain the seven right conditions (to deliver the right product, in the right quantity, and the right condition, to the right place at the right time for the right customer at the right price).

Customers' and product information are continually transferred from one stakeholder to the other during the logistics operation. This information faces a lot of internal challenges due to unauthorized disclosure as it is being shared between the logistics stakeholders which can lead to fraud or misuse by a bad player in the system.

As the logistics industry is expanding globally due to the deployment of industrial 4.0 [2] technologies such as big data, cloud IoT, and Blockchain, the use of IoT-sensing devices keeps transforming logistics operations into smart operations with improvements in the real-time tracking of goods, digitalized data collection, and so on ([3]). But these IoT-enabled devices have privacy and security flaws [4] as they are prone to cyberattacks due to their centralized database storage system. Data can easily leak through one point of failure attack. All these issues are critical because logistics data contains customers' and products' information (product details, price, customer address, number, credit card, and so on) which are very sensitive information. All these threats to the logistics management system can be addressed with the deployment of Blockchain innovation.

Blockchain is a distributed ([5]) and decentralized peer-to-peer technology that can be used in any type of transaction. It was initially used in the Bitcoin financial application [6]. Recent research has it that the application of Blockchain innovation is being embraced in different areas ranging from the Internet of Things (IoT) [7], healthcare domain [8], financial sector [9], and supply chain management [10]. Supply chain management topics such as operations management and sustainability have also been investigated. There is, however, a lack of structure to provide the greatest results in terms of efficacy, efficiency, and long-term sustainability [11]. Big business leaders like IBM (International Business Machines) have a long history of success. Cyberattacks are now being transformed in the healthcare sector through Blockchain innovation [12].

Several challenges regarding the integration of Blockchain technology with logistics management remain unresolved. In a decentralized Blockchain system, achieving customer and product information security necessitates a new system design, which necessitates domain knowledge in logistics management. Blockchain technology, when combined with IoT, has made the logistics sector more smart, simple, and transparent. It facilitates tracking and verification by providing scalable, transparent, and trustworthy data across the transportation and logistics management system ([13]). But the large volume of data created by IoT in logistics operations necessitates a more effective Blockchain structure paradigm. The Blockchain-based open access system's security issue is also significant. New data encryption techniques and key management systems should be developed to protect data security in logistics management.

To provide a secure, efficient logistics management system, a Blockchain-based IoT-enabled solution approach is required. In this study, we are proposing a Blockchain-based IoT-enabled system framework to provide privacy and security to customers' information and enhance efficiency in logistics management with the use of a Blockchain smart contract.

The contributions of the research are as follows:

(1) First, we present the definition of logistics management and smart logistics with its technology enablers

(2) Second, the previous works on smart logistics, applications of Blockchain, and IoT in logistics are reviewed and summarized, which demonstrate the impact of Blockchain and IoT on logistics management. We highlighted the drawbacks of the logistics management system and provide the need for integrating Blockchain and IoT to offer a solution to the aforementioned drawbacks

(3) Third, we proposed a new five-layered Blockchain-based IoT-enabled logistics management framework that utilizes a smart contract, and we draw and describe the interaction of the logistics stakeholders with the smart contract in a sequence diagram.

## 2. Background of Study

*2.1. Fundamentals of Logistics Management.* Logistics is the whole process involved in how goods are obtained, stored, and delivered to the final destination [1]. It also involves the transfer of information which consists of customer's personal information and product information with the major objective which is to attain the seven right conditions (to deliver the right product, in the right quantity and the right condition, to the right place at the right time for the right customer at the right price) as depicted in Figure 1. Due to the industrial 4.0 [2] revolution, different technologies are digitalizing logistics operations into smart logistics.

The definition of smart logistics varies widely, and no consensus has yet been reached (Yangke [14]). Smart logistics, on the other hand, usually refers to various logistical operations, such as transportation, warehousing, and customer support, that are planned, managed, and controlled more intelligently than traditional solutions.

*2.1.1. Technology Enabler of Smart Logistics.* The new technologies that are digitalizing the logistics systems consist of ICT, IoT, RFID, cloud, etc. [15–19] as follows:

(a) *ICT technology*: use information communication technology (ICT) to improve the tracking and tracing logistics process with a monitor

(b) *The IoT technology*: the IoT collects logistics data with the use of sensors

(c) *The RFID technology*: the RFID (Radio Frequency Identification) deploys tags for reverse logistics and inventory management

(d) *Cloud technology*: cloud logistics is used for intelligent logistics management and smart storage

*2.1.2. Logistics Management System.* Logistics management is the process of managing the flow of goods [1] from the point of production of goods to the final customer who is the end-user. This process is been facilitated by the use of logistics management systems (LMS). The LMS consists of multiple components (ordering, inventory, packing and packaging, and shipping) with the core purpose of choosing the best transportation route to deliver the products on time without damage for complete customer satisfaction. Figure 2 shows the operation flow of the logistics management system (LMS). But several existing issues challenge the logistics management system operation from meeting the goal of customers' satisfaction.

Table 1 summarizes the several drawbacks of the existing logistics management system.

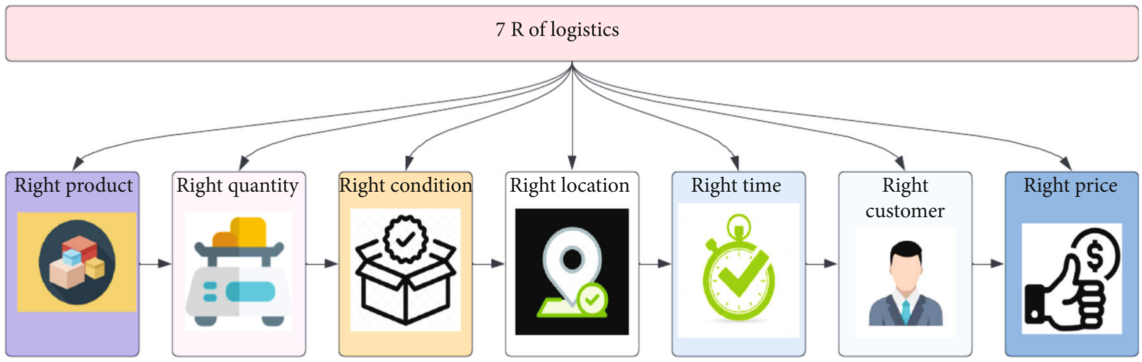


Figure 1: The 7 “right conditions” of logistics.

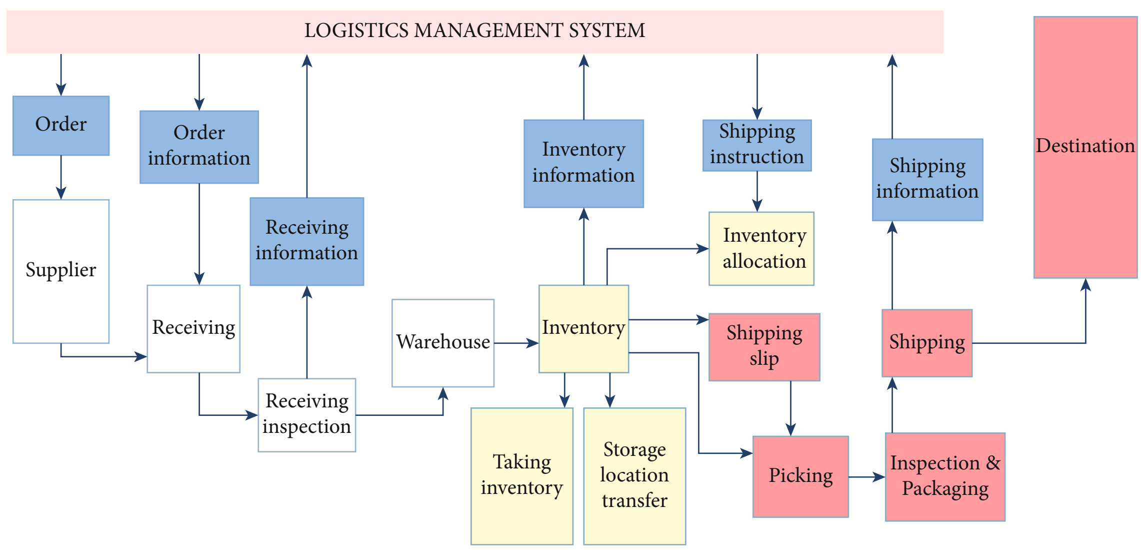


Figure 2: The operational flow of the logistics management system (LMS).

Table 1: Drawbacks of Exiting Logistics Management System.

| Issues | Description | Author |
|---|---|---|
| Lack of trust, security, and privacy | The logistics management system comprises different stakeholders or players (suppliers, distributors, logistics enterprises, and manufacturers). Maintaining the integrity of customer information and product data is a challenging task. | Akram and Bross [20] |
| Lack of end-to-end visibility | Due to a large number of agents or parties that keep joining the logistics cycle, it leads to a lack of end-to-end visibility of information thereby leading to the complexity of the process which in turn creates an avenue for delayed accurate decision-making. | Korpela et al. [21] |
| Lack of transparency | As information is being exchanged in the logistics operation, it lacks transparency because anyone can join without laid down verification. | Hasan et al. [22] |
| Lack of efficiency | As multiple parties keep joining the logistics operation, the operational time keeps rising. | Wu et al. [23] |
| Low level of automation | There is a low level of automation in the sorting process due to the global expansion of logistics operation. | Zhou [24] |
| Lack of proper authentication among the stakeholders | Different stakeholders across the global logistics network without a proper authentication process can lead to fraud. | Dwivedi and Vollala [25] |

With all these issues, the deployment of Blockchain innovation can transform the logistics management system operation and solve the identified problems. In the next section, we are going to review some papers on the Blockchain-based logistics framework.

*2.1.3. Blockchain Applications in Logistics Management.* The use of Blockchain innovation to manage logistics management and supply chains allows for the establishment of traceable supply chain systems while keeping the immutability of all data stored in the ledger [26]. Blockchain has the potential to add economic value to solve critical logistics management concerns by developing trust models between logistics management stakeholders (manufacturers, distributors, suppliers, etc.) protecting asset transactions, enabling real-time communication, improving quality management, enhanced forecasting, and inventory management, among other things [27]. Figure 3 summarizes the challenges of logistics and the capabilities of Blockchain technology to provide the solution.

*2.1.4. Integration of Blockchain with IoT: A Logistics Management System Solution.* The increasing demands of customers to send items securely and quickly can be met not only by using Blockchain technology but also by incorporating IoT devices. Blockchain technology is a type of decentralized architecture ([5]) that stores synchronized and validated data over peer-to-peer networks using sequential, encrypted, and linked blocks. In a Blockchain design, all client nodes are connected via peer-to-peer networks, and data is delivered, received, and encrypted using various hashing techniques before being broadcast. The broadcast transaction will only be received by a legitimate individual, which is only feasible because of Blockchain-enabled IoT sensors.

Blockchain technology in logistics not only ensures the integrity of transported goods but also retains a complete record of the entire shipping process. When Blockchain and IoT are combined, logistics derive a variety of benefits such as reduced costs, quick transactions, and trustworthiness among them. Similarly, successful IoT and Blockchain integration allows safe delivery of perishable commodities by monitoring temperature throughout the transit process [28, 29].

In a multipartner situation, Blockchain and IoT together easily integrate physical world data into the computing environment and store it in a distributed ledger, bridging the trust gap. The IoT device and its network are the data security threat in this IoT-Blockchain system. Once data is stored in a Blockchain network, it is tamper-proof and unchangeable, making it secure. Figure 4 depicts the significance to integrate Blockchain innovation and IoT in logistics which includes improved security, enhanced data accessibility, solution to scalability, and efficient and fast-tracking and traceability.

*(1) Solve Scalability Issues*. The large volume of logistics data from several connected IoT devices can be fed through a gateway, which then sends it to a Blockchain network using distributed ledger technology. Multiple data gateways will input data into the Blockchain network. The IoT gateway is being built to handle such a tremendous volume of data as a result; it is a scalable method for large-scale data-driven logistics enterprises to deal with the scalable issue of Blockchain.

*(2) Improve Security*. The IoT device and its network are usually challenged by cyberattacks that occur from the network layer, physical layer, and application layer which can lead to unauthorized data disclosure [30]. Once data is stored in a Blockchain network, it is tamper-proof and immutable, making it secure. IoT data is threatened by a variety of devices and their connection with gateways via Wi-Fi and other wireless communications. Data security breaches are more common in IoT networks, and the combination of these two technologies will guarantee the security and privacy of these networks.

*(3) Enhance Data Accessibility*. The large volumes of logistics data collected with the use of IoT devices are stored in the distributed Blockchain storage system. The Blockchain distributed network makes data accessible to all the stakeholders for fast decision-making.

*(4) Efficient Tracking and Traceability*. The IoT-enabled devices in logistics aid in the efficient and fast-tracking of goods and containers at any given time to determine the actual location.

## 3. Literature Review

In this area, we reviewed the related work in two streams. Firstly, we present the background of smart logistics systems. and we reviewed some works of literature about Blockchain applications in IoT and logistics scenarios.

*3.1. Smart Logistics System.* Logistics has become an essential aspect of the modern supply chain, thanks to the growth of e-commerce and the new retail industry. Many studies are aimed at enhancing the efficiency of logistics networks. Fog computing was first brought to logistics space by Lin and Yang [31]. They intended to address the issue of a centralized cloud computing system being unable to handle the tremendous processing load generated by thousands of IoT devices in factories. In addition, to lower the computational cost of IoT devices, they proposed an effective fog-computing deployment architecture. In 2018, Zhang et al. integrated IoT and cloud-based storage technologies into a device layer interconnection design and data processing to address energy waste and long wait times in the process of integrating production and logistics in industrial workshops. Zhang et al. [32] proposes a smart logistics framework that uses cyber-physical systems and the industrial Internet of Things (IIoT) to handle the problem of resource coordination in the logistics process. Furthermore, Zhang [33] focus on solving the integrated planning problem of smart food logistics systems, and the logistics planning is optimized using a fuzzy logic method. Recently, Blockchain technology has been employed to improve the performance of logistics systems as a potential method. Perboli et al. [34] proposed a Blockchain-based digital backbone logistics network. The adoption of Blockchain can improve the overall

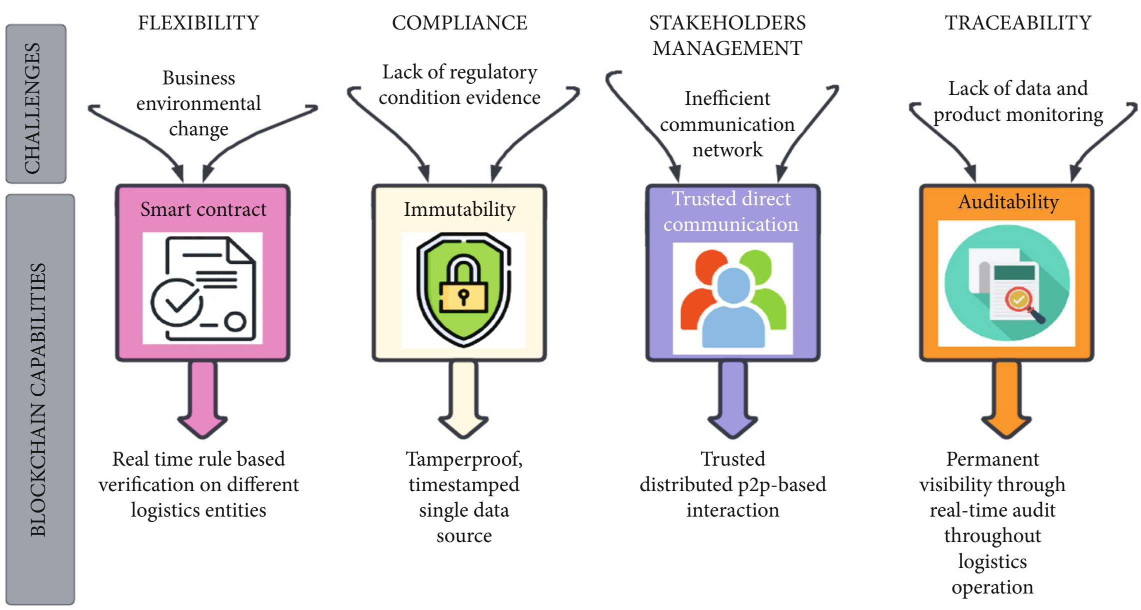


Figure 3: The challenges of logistics and the capabilities of Blockchain innovation.

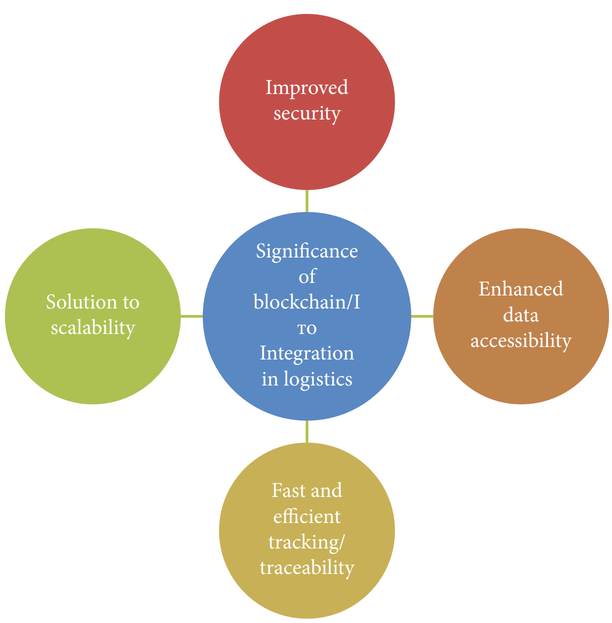


Figure 4: Significance of Blockchain and IoT integration in logistics.

supply chain's efficiency, reliability, and transparency by ensuring data immutability and public accessibility of data streams. Wang et al. [29] suggested a smart contract-based strategy for logistics systems, in which the prescribed smart contracts are triggered by an event response mechanism. As a result, smart contracts are used to record all product transfer histories on a distributed ledger. A plan for using Blockchain in smart logistics systems is proposed by Fu and Zhu [35], which addresses the current challenges of security risks and privacy breaches in smart logistics systems. To increase the traceability of logistics systems, smart contracts and Blockchain ledgers are deployed.

*3.2. Blockchain in IoT and Logistics.* Blockchain has emerged as one of the most promising innovations adopted to support the implementation of IoT; the IoT-connected smart devices are deployed for data collection for real-time decision-making. Although IoT technology is being challenged by security and privacy issues [4], a lot of industrial applications have been developed based on the integration of IoT and Blockchain. For example, Zhao et al. [36] combined Blockchain with the industrial IoT to establish trust between IoT components and business models and then used smart contracts to securely process and store data to build a dependable and safe environment. Li et al. [37] integrated Ethereum Blockchain and deep learning to design a Blockchain-based efficient data-gathering and secure-sharing scheme.

Many works have been done by different authors in logistics supply chain management with the deployment of Blockchain. For example, Venkatesh et al. [38] employed Blockchain to defend labor rights and offer safe workplaces in the global supply chain from a social sustainability perspective. A Blockchain-based supply chain quality approach was proposed by Chen et al. [39]; IoT devices, smart contracts, distributed ledgers, and business layers are all part of their system. Data was generated by IoT devices to monitor asset quality. And smart contracts protect data privacy and anticipate end-user expectations, and a business enterprise is included in the business layer. Kim and Laskowski [40] used the Blockchain method to apply ontologies to the supply chain. The required ontology axioms are represented as first-order logic, which is eventually turned into Ethereum-based smart contracts to provide traces of products. A Blockchain-based solution for the supply chain management system's information asymmetry and double marginalization concerns was proposed by Nakasumi [41]; they deployed the homomorphic encryption approach in their work to ensure the security of user data on the Blockchain. The mechanisms of smart contracts, as well as other legal difficulties, were not addressed by the writer.

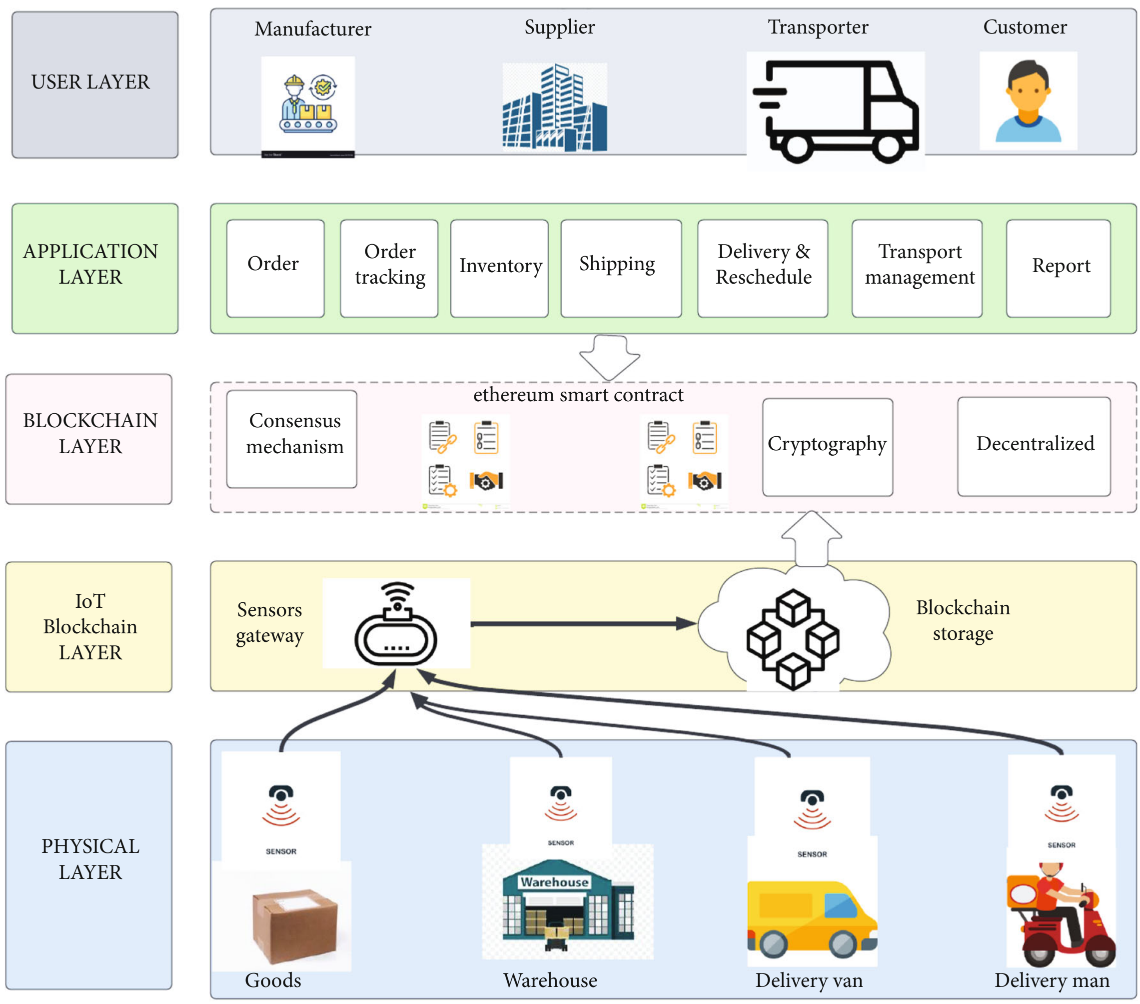


Figure 5: Blockchain-based framework for secure and efficient logistics management system (BFSELMS).

Figurili et al. [42] used the Azure Blockchain workbench to track wood from raw materials to finished goods. They use RFID sensor devices to collect data as part of their work. A Blockchain-based traceability system for an agri-food supply chain in China using RFID and a Blockchain mechanism were created by Tian [18]. According to the author, their solution allows for information tracing, product freshness assurance, and product information transparency.

We can summarize that the application of Blockchain innovation in logistics management has not received much attention even though Blockchain has been deployed widely in supply chain management. The majority of research on supply chain management is academically oriented as a result; this study proposes to fill the gap by developing a Blockchain-based IoT-enabled framework that deploys an Ethereum smart contract for a secured and efficient logistics management system.

## 4. Blockchain-Based IoT-Enabled Logistics System Framework

To capture data movement in a multilevel operation and real-time decision-making in logistics operation requires the use of IoT (Internet of Things). IoT is also deployed in logistics operations to interconnect delivery vehicles, freight, warehouse, and so on with the help of its sensors. And these sensors help in data collection, improve real-time tracking of delivery vans, and reduce congestion in the warehouse. However, these IoT devices have security and privacy challenges. The integration of Blockchain with IoT in logistics will solve this problem of data security and privacy with enhanced efficiency in logistics operations. Therefore, we proposed a Blockchain-based framework for the secured and efficient logistics management system (BFSELMS).

*4.1. Proposed Framework Overview.* The proposed framework (BFSELMS) as shown in Figure 5 integrates a smart contract with Blockchain and IoT for a secure transaction between the logistics stakeholders. It tries to solve the problem of data security and privacy in logistics operations. It comprises 5 layers (user layer, application layer, Blockchain layer, network layer, and physical layer).

(a) *User layer*: this layer is composed of all the legitimate members of the logistics management stakeholders including the manufacturer, supplier, transporter,

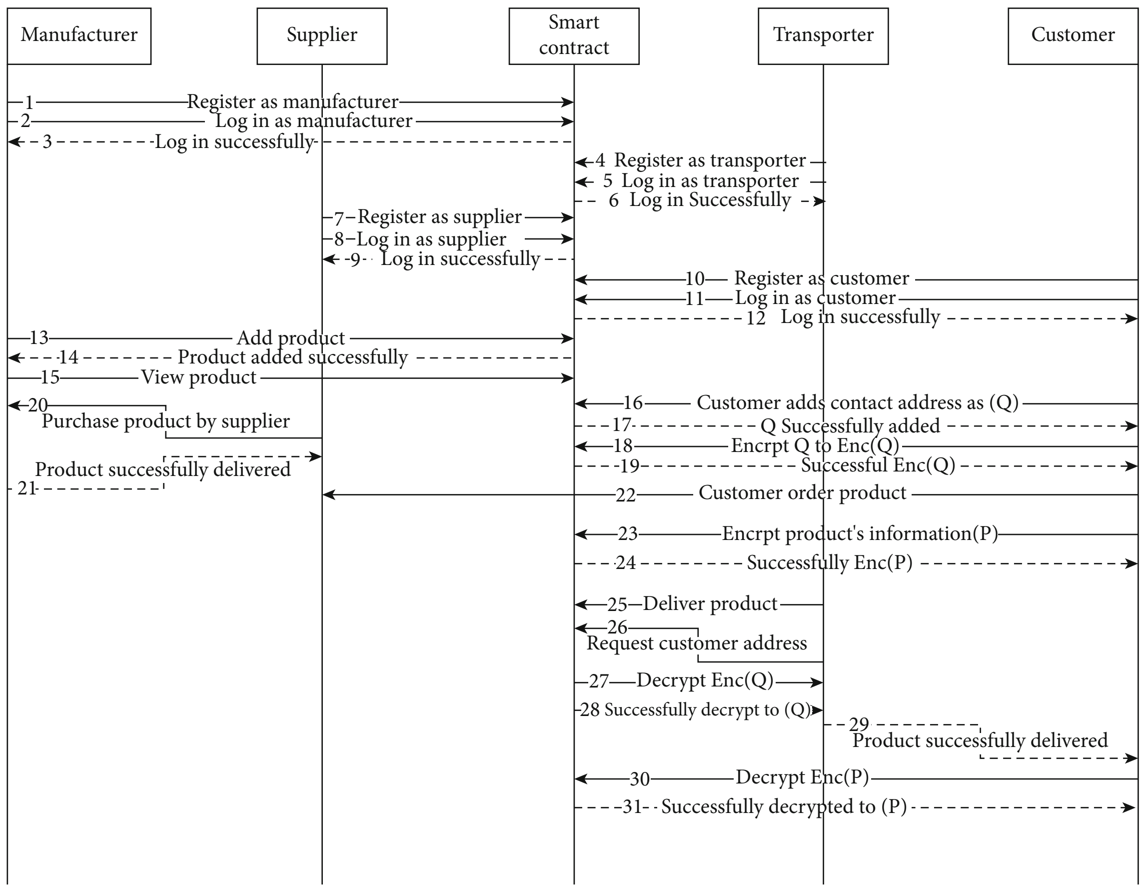


Figure 6: Sequence diagram of BFESLM.

and customers. They sign, contract, and submit their logistics requests through terminal devices (e.g., smartphones or desktop computers). It is important to note that users do not participate in the construction of the Blockchain and just connect to Blockchain nodes through terminal devices.

(b) *Application layer*: this layer provides different applications such as parcel tracking, send order, warehouse management, inventory management, and track order and vehicle routing. It provides service to the user.

(c) *Blockchain layer*: this layer provides a peer-to-peer distributed network for communication and transaction between logistics stakeholders. The Ethereum smart contract is for security and privacy of information and secured payment.

(d) *IoT/Blockchain layer*: the network layer provides communication channels between sensors and the Blockchain. Data collected from the physical layer will be transmitted to the Blockchain layer using these communication channels, such as 4G/5G networks and ZigBee.

(e) *Physical layer*: this is the lowest layer in BFSELMS; it collects data with the use of a sensor (RFID, GPS sensors, and scanning devices) fitted on the goods, the delivery vans, warehouses, and so on through a sensor getaway, and these devices are in charge of sending various logistics-related data to the data node regularly to be stored in the Blockchain storage.

*4.2. Proposed Framework Design Goals.* The goals of the proposed framework are as follows:

(a) *Supporting IoT devices*: IoT devices will be connected to generate logistics data. With these devices, users can make fast decisions, and the system should be able to connect massive IoT devices.

(b) *Customer and product privacy and security*: logistics data which consist of customer and product information will be treated as the digital assets of users; thus, the sensitive information should be protected.

(c) *Efficiency*: logistics records need to be analyzed and stored in time. Hence, the system should satisfy the practical access requirements on effectiveness and scalability.

Contract signing with a smart contract for eligible secured transactions and interaction between the logistics stakeholders is shown in the sequence diagram in Figure 6.

Description of all steps of Figure 6 is as follows: (1) The manufacturer creates an account with decentralized smart contracts with the input such as ManufacturerName, ManufacturerEmailID, ManufacturerMobileNo, ManufacturerPassword, and Role. (2) Manufacturer details are added to the smart contract and ManufacturerID is generated. (3) The manufacturer successfully logs in to the account with the allocated ManufacturerID and password. (4) The transporter creates an account with decentralized smart contracts with the input such as TransporterName, TransporterEmailID, TransporterLocation, TransporterMobileNo, ManufacturerPassword, and Role. (5) The transporter details are added to the smart contract and the TransporterID is generated. (6) The transporter successfully logs in to the account with the allocated TransporterID and password. (7) The supplier creates an account with decentralized smart contracts with the input such SupplierName, SupplierEmailID, SupplierMobileNo, SupplierPassword, and Role. (8) Supplier details are added to the smart contract and a SupplierID is generated. (9) The supplier is successfully logged in to the account with the allocated SupplierID and password. (10) The customer creates an account with decentralized smart contracts with the input such as CustomerName, CustomerEmailID, CustomerMobileNo, CustomerPassword, and CustomerCreditcard. (11) Customer details are added to the smart contract and a CustomerID is generated. (12) The customer is successfully logged in to the account with the allocated CustomerID and password. (13) The manufacturer adds products with the following input: ProductName, ProductPrice, ProductWeight, and Colour. (14) Product details are successfully added with the assigned product code. (15) The product added can be viewed by all the registered stakeholders in the Blockchain smart contract. (16) The customer updates the customer contact address as Q. (17) Q is successfully updated. (18) The customer requests to encrypt Q to Enc(Q), through the Blockchain smart contract; the same encryption applies to customers' credit card details. (19) Encryption of (Q) is successful. (20) The supplier orders products from the manufacturer after both fulfilled and signed the contract conditions. (21) The manufacturer successfully delivers products to the supplier. (22) Customers order products from the supplier after signing a contract with each other. (23) The customer requests for encryption of ordered product details like the price and product code (p) through the Blockchain smart contract. (24) Product details are successfully encrypted to Enc(p). (25) The transporter requests to deliver products ordered by the customer through the Blockchain after signing and filling the contract condition with the supplier. (26) The transporter requests the customer's contact address through the Blockchain. (27) The Blockchain decrypts and sends the contact address of the customer only to the authorized transporter. (28) The transporter schedules and delivers products to the customer at the given address. (29) The product was successfully delivered to the customer's given address. (30) The customer requests to decrypt Enc(p) for the product details like the product code to confirm receiving a genuine-ordered product through the Blockchain. (31) The product details are successfully decrypted from Enc(p) to p.

## 5. Conclusion and Future Research

Logistic operations are getting smarter as a result of industrial 4.0 resolutions. Some of these emerging technologies responsible for these transformations are vulnerable to certain cyberattacks such as physical or network attacks. The privacy and security of customer private information and product information are a major concern as these types of information face unnecessary access when these logistics systems are attacked or when this private information is being shared or transferred from one logistics stakeholder to another. Blockchain, as a disruptive technology, has the potential to provide the solution to the identified issues. We define smart logistics and highlighted the technology enablers of smart logistics; we described the significance of integrating the Blockchain and IoT in logistics. We proposed a 5-layered Blockchain-based IoT-enabled logistics management framework. This framework will be able to capture data movement for multiple-level operations which involve multiple stakeholders in logistics management providing security and privacy of the customer and product information and also enhancing the efficiency of logistics operations. We describe in the details of the sequence diagram indicating the secured communication between the logistics stakeholders via the Blockchain smart contract. This study concludes that Blockchain can provide privacy and security to customers' private information and products from illegal access with the use of an encryption mechanism and enhance the efficiency of logistics operations.

Regarding the future research, the following should be the focus: implement and test the reliability of the proposed 5-layered Blockchain framework in this article; integrate the Blockchain and cloud technology in logistics to solve the scalability issues; and, finally, increase awareness of Blockchain capacity, promote government acceptance, and reduce the cost of implementation.

## Data Availability

Not applicable.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

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