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An Innovative Internet-of-Things-Enabled HACCP-Based Real-Time Food Traceability System with Adaptive Threshold for Interoperability of Chains

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Abstract - Nutrition is vital for survival. Individuals frequently consumed indigenous, seasonal produce. Warehouses are a significant location for food waste due to inadequate food management. Refrigerators have had a significant impact, resulting in substantial changes. Individuals can now store and consume food not typically available during certain seasons. The advent of Internet technology has resulted in the emergence of several traceability solutions in supply chain management. Most existing systems exhibit centralization, characterized by monopolistic control, information asymmetry, and a lack of transparency. These characteristics can give rise to trust issues such as fraud, corruption, tampering, and the fabrication of information. The collapse of a centralized system can be attributed to a single point of failure, which has the potential to dismantle the system completely. Blockchain technology has fundamentally transformed the landscape of decentralized information technology, introducing a fresh and innovative approach. This project aims to develop a real-time food supply chain traceability system using HACCP, Blockchain, and IoT. An issue commonly encountered in Blockchain management is maintaining diverse chains that include nodes with identical characteristics. The main problem lies in the seamless integration of chains with minimal loss of node Blocks. This study will focus on the consolidation of the chains based on an adjustable threshold. The proposed system aims to provide an information platform that promotes openness, transparency, impartiality, trusrthiness, and security among supply chain participants.

Keywords: Internet of Things (IoT), Blockchain, Food traceability, Industry 4.0, Supply chain.

1.Introduction

Due to poor transportation and storage, 25–30% of India's fruit and vegetable production is squandered [1]. Cold chain industrial processes involve biological and chemical knowledge [2]. Due to food safety mishaps and scandals, client confidence in the food sector has plummeted in recent decades [3]. Cold chains preserve the quality and prevent spoiling of perishable commodities including fruits, vegetables, and meat. These items need precise temperatures to last and not spoil. Many Internet of Things (IoT) technologies, including RFID and wireless sensor nerk-based architectures and hardware, are being used to improve supply chain traceability and visibility due to food safety concerns [4]. Unresolved is the trusrthiness of food supply chain participants' information in traceability systems. Data ownership might give a centralised organization tremendous influence, raising worries about knowledge asymmetry between it and individuals. The system's bribery risk makes it prone to corruption. If an administrator is bribed, vital information may be compromised [5]. Thus, the system's credibility suffers. Exactly as reported, China's food markets are experiencing the Sanlu fatal milk powder tragedy. A single point of failure might expose the entire system to hackers and corruption. The current food supply chain efficiency from producer to retailer is shown in Figure 1.

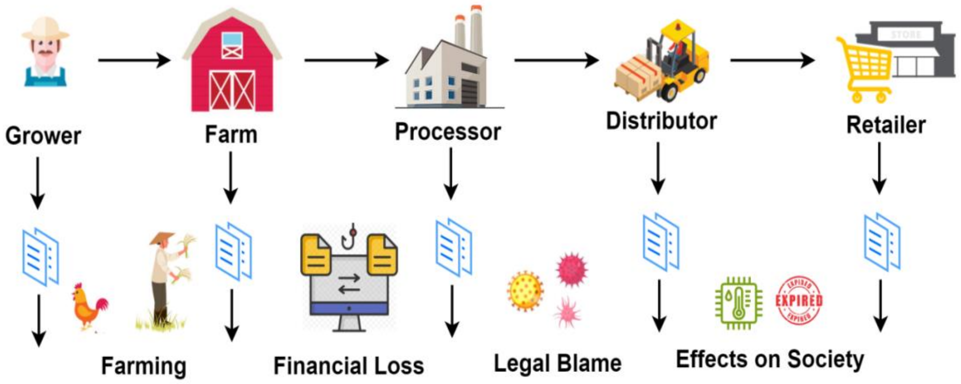


Fig. 1 Current food supply chain inefficiencies from grower to retailer

Blockchain technology might solve these problems by removing the requirement for a central authority [6]. Blockchain technology being a new data storage and transaction platform shows an inclination towards avoiding non-transparent nerk infrastructure [7]. In addition, Blockchain technology stores all food product information in a shared, transparent system accessible to supply chain partners. Despite the possessed potential towards decentralised storage, it suffers from some limitations as well. Scalability has been an urgent concern as its use grows [8]. The digital ledger has better security, immutability, transaction traceability, and decentralization. The current study examines the feasibility of storing the retail information of the foods in the Block chain based on distributed database systems along with the seamless integration of the chains of considerable heterogeneity. We want our technology to enable food tracking from production to consumption by implementing Blockchains even of heterogeneous structures, restoring public faith in the food supply chain. Figure 2 shows the Blockchain-enabled food chain system.

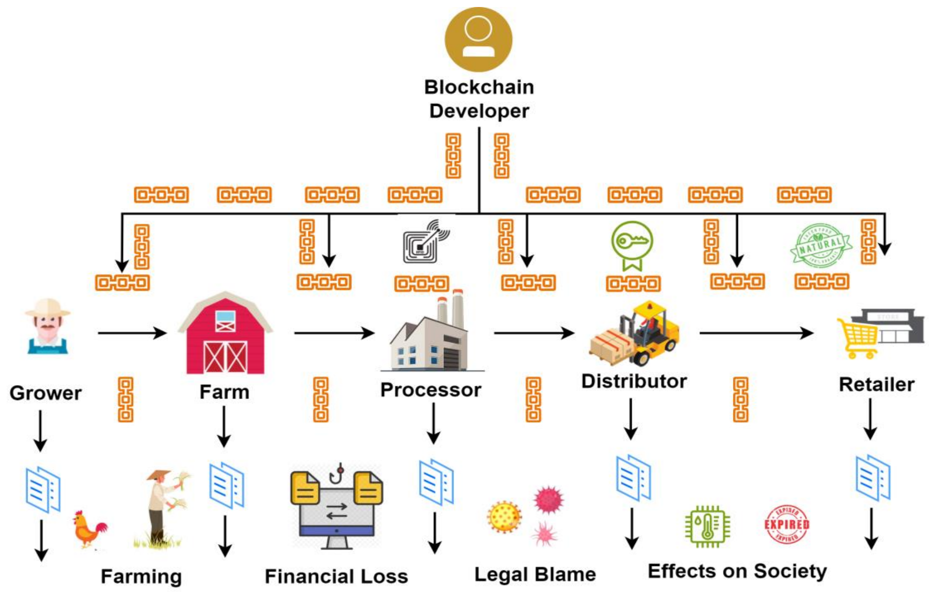


Fig. 2 Blockchain-enabled food supply chain with full food history

The presence of multiple Blockchains in a transaction causes the biggest issue. Multiple diverse food chains must be integrated for storing and accessing information over a potentially larger range, yet identical Blocks may hamper the process. Second, time and resource consumption for chain merging are critical as it requires some security and compatibility issues,especially during the data migration. Interoperable Blockchains are built under certainconducive conditions. This study proposes a novel IOT-based Blockchain implementation for real-time food traceability in diverse contexts.The problem is based on the study of previous scenarios and sufficient literature survey can lead to the requirement for the design of the system for food traceability procedure in the real-time system with the storage in terms of Blockchains by integrating Blockchains of heterogeneous structures and selection of the concerned eligible by applying the adaptive threshold value.

2. Literature Review

Research shows that traditional warehouses include basic subsystems for logistics and handling [9]. The company uses a manual or database-driven ledger. The entries include product arrival time at the warehouse, departure time, and quantity. The ledger system is vulnerable to data tampering and manipulation, making issue tracing impossible [10]. Most typical warehouses require a large investment for equipment like smoke detection sensors, which may be inefficient. Thus, typical warehouses require a system that integrates into the current infrastructure [11]. For food management and preservation, the typical warehouse system relies primarily on laboratory data. Warehouses may not have the conditions to keep food stable. Therefore, this allows the construction of a system that predicts expiry dates using environmental conditions.

Hazard Analysis and Critical Control Points (HACCP) emphasize risk management and preventative activities for food safety [12]. Food chain safety and operational management are related. The study aimed at high-quality milk production. HACCP was used across the dairy supply chain. Microbiological and chemical residues can impair milk quality, hence researchers concentrated on milk equipment and cooling tanks [13]. The study revealed HACCP improves dairy supply chain safety. This Pareto-analyzed study examines food safety assurance system research. The researchers documented key HACCP system adoption factors. The authors detected 32 HACCP implementation elements in 31 research [14]. Herath and Henson (2010) identified four HACCP implementation difficulties using a case study [15]. These included HACCP's relevance to the organization, the number of modifications needed to adopt it, food safety controls' narrow emphasis, and budgetary restraints.

As IoT expands, experts are studying appropriate technologies for food supply chain traceability [16]. The paper underlined that a traceability system must track each product and logistical item. Products may be tracked from manufacture to disposal. The authors tracked livestock from farm to slaughterhouse using RFID [17]. RFID might identify individual animals to overcome incomplete traceability data and livestock industry fraud. This project will test an RFID smart tag for real-time food traceability and cold chain monitoring [18]. Develop an automated system that combines online traceability and cool chain condition monitoring data. International fresh fish logistics nerk case study. Mattoli et al. (2010) developed the Flexible Tag data logger (FTD) to measure wine bottle light, humidity, and temperature [19]. This system aims to monitor wine bottles from the supply chain to stores. A smartphone or PDA with an infrared connection may retrieve FTD historical data [20]. This facilitates wine bottle safety evaluation. All of the above studies recommend a centralized system, which was the only way to achieve supply chain information openness until recently. In recent years, Blockchain has garnered the attention of experts from several academic fields. The authors evaluated Blockchain's potential benefits in manufacturing supply chains [21]. The authors claimed that Blockchain technology's inherent qualities build confidence by increasing transparency and traceability in data, commodities, and financial transactions [22]. It might also create a new foundation for decentralized and transparent transaction systems in numerous sectors and businesses. An example shows how Blockchain technology may be used in a global supply chain [23]. The discussion is about nerks. Integration is hindered by distrust. Management of business processes across organizations. Blockchain could be a major technological advancement for decentralized and transactional data sharing over a nerk, which involves distributing and exchanging data without a central authority or intermediary. The researchers developed a mechanism to integrate Blockchain technology into process orchestration for seamless integration and efficiency [24]. One option is to reduce the need for a central authority while maintaining confidence. Further research has addressed one of Blockchain technology's main drawbacks, scalability. The paper described BigchainDB, as a technology. Incorporate Blockchain into the DB [25]. Clarity is lacking in the user's text. Databases are efficient because throughput and capacity rise linearly. Querying and Blockchain technologies are of interest. Decentralization, immutability, and digital asset generation and mobility are essential principles in digital technology. In their study, analysed asset bottlenecks. Increased transaction processing speeds and capacities using Blockchain technology [26]. Their analysis found that Block and interval sizes should be considered only a starting point. Blockchain approaches from five viewpoints were discussed for scalability. Academic discourse emphasizes nerk, consensus, storage, view, and side planes. These planes are important in distributed systems, Blockchain, and computer nerks. According to the previous debate, the Internet of Things (IoT) is a hot issue [27]. Numerous supply chain traceability systems are used. However, most of these systems are centralized, therefore food supply nerks lack decentralized mechanisms. HACCP, Blockchain, and the internet were used to create the system. The food supply chain may be monitored and traced using several ways. Compared to centralized systems, this unique technology might become a disruptive innovation with a plethora of knowledge.

Transparency, fairness, dependability, and security are crucial. Additionally, Blockchain technology's scalability was considered. When handling large business data. We feel our method is new and can add to current knowledge. Implementing strong Supply Chain Monitoring and Traceability Solutions may considerably enhance food safety throughout food supply nerks.

Blockchain interoperability is the key research gap where the seamless integration of the diverse block chains hasve been realised with the adaptive technique depending on the number of transactions involved in the blockchains and the number of transactions as well. The response of blockchain accuracy performance varies in synchronisation with the different participating nodes and their behaviours. The Blockchain food traceability method is popular, however, combining Blockchains for optimized resource access is difficult in heterogeneous domains. The biggest research need is optimizing Blockchain management scalability in merging chains with low time criticality has become the prime factor for finding performance of the block chain network. The information contens of the network is directly proportional to the storage structure utilised in the network. The present research is focussed on the strategic optimisation of the storage for maximising the overall information contents .

The contribution of the paper towards the unique solutions is

i) A food traceability procedure in the real-time system.

ii) The storage solution by implementing the Blockchain technology.

iii) Provision for the interoperability of heterogeneous Blockchains.

iv) The unique way of implementing the adaptive threshold technique depending on the number of transactions and the overlapping points picked up by the network.

Table 1 represents brief literature survey for the works.

Table 1 Literature Survey

Researcher's Name	**Methodology Used**	**Accuracy in Results**
Tian, F. (2017)	Developed a food supply chain traceability system using HACCP, Blockchain, and IoT.	Provided a robust system for food traceability and cold chain monitoring.
Mattoli et al. (2010)	Flexible Tag Datalogger (FTD) to measure light, humidity, and temperature in wine logistics.	Accurate monitoring of environmental conditions along the supply chain.
Herath & Henson (2010)	Case study approach to assess barriers to HACCP implementation.	Identified key barriers including organizational relevance and budgetary constraints.
Zhao et al. (2019)	Used Blockchain technology to improve agri-food value chain management.	Demonstrated enhanced transparency and traceability in supply chains.

Viriyasitavat et al. (2022)	Explored Blockchain for the interoperation of business processes in smart supply chains.	Proposed methods for efficient business process integration.
Hossain, Standing, & Chan (2017)	Developed a -staged adoption model of RFID technology in livestock businesses.	Improved traceability in livestock supply chains with accurate tracking.
Vilar et al. (2012)	Implementation of HACCP in dairy supply chains for controlling equipment and cooling tanks.	Ensured high milk quality through reduced microbiological contamination.
Hader et al. (2022)	Combined Blockchain and Big Data technologies for textile sector traceability.	Improved traceability and information sharing.
Collart& Canales (2022)	Investigated the impact of Blockchain on the fresh produce supply chain.	Highlighted the potential for improved traceability and supply chain transparency.
Köhler &Pizzol (2020)	Technology assessment of Blockchain-based technologies in the food supply chain.	Showed potential for improved food safety and reduced food fraud.

2.1 ERP Systems for the food supply chain

ERP integration into the food supply chain might improve operational efficiency, traceability, and management effectiveness [28]. ERP solutions integrate procurement, production, distribution, and sales operations throughout the supply chain. The following list covers the most important considerations when choosing a food supply chain ERP system. The system should provide batch monitoring, expiry date management, quality control, and HACCP and FDA compliance. Supply chain integration requires seamless ERP system connection with suppliers, distributors, and retailers. The suggested system supports demand forecasting, inventory management, and order processing with immediate data transfer. Effective inventory management is crucial in the company. The ERP system should improve inventory optimisation, reduce waste, and make FIFO and FEFO deployment easier [29]. It should do rigorous quality control checks and track the supplier chain. This involves tracking resources and items from their source to shop shelves.

Production planning optimization is crucial for efficiency. The search should find traits that help organize production runs, manage recipes/formulas, and handle variable demand. The ERP system should aid food safety and regulatory compliance. This function requires document management and labelling accuracy. Supplier Relationship Management (SRM) entails managing supplier relationships, evaluating vendor performance, and ensuring supplier quality. Route optimization, vehicle monitoring, and warehouse management can improve distribution and logistics operations. The ERP system should offer extensive reporting and analytics. Real-time data and KPIs can improve decision-making. Mobile accessibility is important for field workers and supply chain managers on the go. The ERP system must have mobile apps or a responsive online interface. Scalability is important when choosing a system since it lets the system grow with the company. Scalability is essential for managing the increased volume and complexity of a food supply chain [30]. A user-friendly interface is crucial for system or application adoption. Employees must be able to use the ERP system without any training.

Assess the whole cost of ownership, including license, implementation, training, and support. Comparing cloud-based and on-premises ERP options is wise. The ERP system must integrate with accounting, CRM, and e-commerce applications [31]. The ERP system's customization capabilities and industry-specific requirements must be considered. Customization choices and frequent updates and support must be balanced. Food business ERP vendors must be chosen based on reputation and support. Choose a vendor with a good reputation and a track record of food ERP solutions. Evaluate their support and maintenance services. ERP data protection is paramount. The system must have strong data security to protect sensitive data including client data and proprietary recipes/formulas.

2.1.1 Drawback of ERP systems and the benefits of Blockchaintechnology for the food supply chain

ERP systems improve productivity and simplify operations in many industries, including the food supply chain. However, standard ERP systems have numerous drawbacks in this scenario. Blockchain technology offers several advances that might overcome constraints [32]. ERP system constraints in the food supply chain. It also examines how Blockchain technology might address these issues. ERP systems may lack real-time insight across the supply chain, making it difficult to track items and verify their provenance [33]. Data silos occur when an organisation stores and manages data in distinct systems or databases. Traditional ERP solutions may include several stakeholders with their systems and databases. Data silos in the supply chain may hinder collaboration and data exchange.

2.1.2 The Relationship between Traceability and Ensuring Food Safety

Food safety and traceability are crucial in the food industry. ERP systems may not be sufficient for tracking food origin and identifying contamination sources [34]. Establishing confidence among supply chain actors is crucial, but ERP systems alone may not be enough to verify items and transactions. Blockchain offers several answers to food supply chain ERP system restrictions. The state of being transparent implies openness. Blockchain technology allows the real-time recording of transactions and data in a transparent and immutable ledger. This system's openness let’s all stakeholders track and verify goods movement.

Decentralization is the distribution of power, authority, and decision-making across the supply chain. Blockchain technology eliminates the need for centralized intermediaries, reducing data silos and enabling secure, direct communication. Blockchain technology lets products have unique IDs like QR codes. This allows customers and stakeholders to trace the food from farm to table, offering transparency. This helps trace and verify food provenance and safety. Smart contracts using Blockchain technology can automate many tasks and enforce laws. Payments are automatically begun upon delivery and verification, reducing conflicts. Blockchain technology's cryptographic methods ensure data authenticity and unalteredness, fostering supply chain trust. It may also authenticate products using QR codes or RFID tags. Blockchain technology can help identify and remove harmed goods in the event of a food safety issue or product recall, eliminating health risks and reputation damage. Supplier verification verifies a supplier's credentials and skills to verify they fulfil needs and standards.

2.2 Interoperability in Blockchain

Interoperability in Blockchain means Blockchains can communicate easily. Rules defined in one Blockchain's domain make it shareable with the other. Most Blockchains interact by exchanging tokens, not transferring them. Transferring tokens may increase payload and compromise Blockchain security. To make Blockchains interoperable, certain conditions were devised. This article defines a specific condition with or more circumstances.

2.3 Food Supply Chain Hazard Controls

To guarantee food safety and quality, food supply chain dangers must be controlled. Hazard controls detect, prevent, and reduce food supply chain hazards [35]. Table 2 lists food supply hazard controls.

Table 2 Typical Food Supply Chain Hazard Controls

Hazard Type	Hazard Control Measures	Control Responsibility	Monitoring and Verification	Corrective Actions	Preventive Actions

Biological Hazards	Good Manufacturing Practices (GMPs)	Production and QA	Regular inspections and audits	Immediate removal of affected products	Continuous training and reinforcement of GMPs
	Pathogen Testing	Quality Assurance	Routine testing of raw materials and finished products	Isolation and sanitation of affected areas	Supplier approval and monitoring
	HACCP (Hazard Analysis and Critical Control Points)	Food Safety Team	Regular reviews and updates	Investigation of root causes	Periodic hazard analysis and reassessment
Chemical Hazards	Supplier Approval and Verification	Procurement and QA	Review of supplier certifications	Quarantine of affected ingredients	Ongoing supplier performance reviews
	Allergen Management	Production and QA	Labeling and segregation of allergenic ingredients	Product recall and label correction	Employee training on allergen handling
	Chemical Testing	Quality Assurance	Routine testing for chemical contaminants	Isolation of contaminated products	Review and update of testing methods
Physical Hazards	Metal Detection and X-ray Inspection	Production and QA	Continuous monitoring and calibration	Removal of contaminated products	Regular equipment maintenance
	Foreign Material Control	Production and QA	Employee training on foreign material detection	Immediate removal of foreign materials	Regular inspections and equipment checks
	Packaging Integrity Control	Packaging Department	Visual inspection and quality checks	Quarantine of affected batches	Supplier evaluation and improvement
All Hazards	Crisis Management and Recall Procedures	Crisis Management Team	Regular drills and simulations	Recall initiation and communication	Continuous improvement of crisis plans
	Employee Training and Awareness	HR and Training	Regular training and communication	Corrective action plans for non-compliance	Ongoing education and communication
	Traceability and Record-keeping	Quality Assurance	Record reviews and audits	Traceback and trace forward actions	Periodic record-keeping audits

2.4 Traceability and Performance evaluation of various Blockchain-based Food Supply Chain

Blockchain technology's end-to-end traceability, safe data exchange, and tamper-resistant records have made it popular in the food business. Its main focus is traceability, but it may help HACCP systems assure food safety [41, 42]. It usually works like this:

- **Data Recording:** Farmers, processors, distributors, and retailers record food product transactions and data on a Blockchain. These records can be stored securely in IBM Food Trust [43]. Immutable Blockchain records show HACCP and regulatory compliance.
- **Immutable Ledger:** Tamper-resistant decentralized ledgers record transactions, assuring data integrity [44]. HACCP involves rigorous food safety processes, techniques, and record documentation.
- **Transparency:** All authorized parties can access the Blockchain, ensuring supply chain transparency [45]. Suppliers, producers, and regulators may access and verify Blockchain data through IBM Food Trust, providing transparency. Transparency helps identify and mitigate hazards.
- **Traceability:** Food can be tracked from farm to table in real time with a unique product identity. HACCP relies on traceability to identify dangers, enable prompt recalls, and ensure remedial measures [46].
- **Smart Contracts:** Automated smart contracts can release money when products are delivered. Working with regulatory bodies and meeting food safety standards are common HACCP requirements [41]. IBM Food Trust's open and auditable Blockchain ledger simplifies compliance reporting and regulator engagement.
- **Authentication:** Consumers can verify product identity and provenance using QR codes or other means. According to HACCP, supplier ingredients and raw materials must be verified for safety. IBM Food Trust simplifies supplier verification by showing the complete supply chain, enabling producers to verify input safety.

3. Proposed Work

The proposed work to implement a food supply network using blockchain technology in a distributed system. Here are some excerpts:

Food supply in blockchain: The goal is to use blockchain in the food supply chain. Blockchain is a decentralized and secure ledger technology where data is stored in chunks, which are chained together. Each block contains a transaction or information record, and once added, cannot be changed without modifying all the blocks. This ensures transparency, security and traceability in the food chain.

Food Traceability Protocol: Traceability protocol refers to the rules and procedures for monitoring the movement of food products from source (farm) to consumer In this case the protocol will be built on Blockchain, ensuring the food journey steps each is documented and verifiable. If an issue arises (such as pollution), it will be easier to locate the incident.

Heterogeneous Ground: This means designing the system to work in a variety of locations. The food supply chain spans many sectors, including farmers, manufacturers, distributors, retailers and consumers. Each operates in different areas, using different technologies and standards. Systems must account for this heterogeneity to ensure that data changes and works seamlessly.

Specifically, the proposed project aims to provide a transparent, secure and efficient food tracking system throughout the supply chain using blockchain. This will increase food safety, reduce fraud and strengthen consumer confidence by providing an unbreakable record of every step in the food journey.

The Blockchain-based IBM Food Trust technology improves food supply chain transparency and traceability [47]. Although it uses Blockchain technology, it does not employ smart contracts like Ethereum. IBM Food Trust uses a permissioned Blockchain for data sharing and traceability. To commission, decommission, convert, aggregate, disaggregate, and observe HACCP-based data. However, add smart contract capability to this Blockchain (Figure 4).

3.1 Commission and Decommission:

- When a new food product is created, a unique digital identifier (e.g., a QR code or RFID tag) is generated.
- Record the product information (e.g., batch number, origin, and production date) on the Blockchain, associating it with the digital identifier.
- This process is equivalent to "commissioning" the product on the Blockchain.

- When a product is removed from the supply chain (e.g., sold or consumed), mark it as "decommissioned" on the Blockchain, updating its status.

3.2 Transformation:

- When a product undergoes a transformation (e.g., being processed into a different product or mixed with other ingredients), record this change on the Blockchain.
- Update the product's information and status to reflect the transformation.

3.3 Aggregation and Disaggregation:

- Aggregation involves grouping multiple products or batches into a single container or packaging.
- Disaggregation is the process of breaking down aggregated items into individual units or smaller batches.
- Record these actions on the Blockchain, specifying the relationship between the aggregated and disaggregated items.

3.4 Observation:

- Implement monitoring and data collection at critical control points in the food supply chain according to HACCP principles.
- Record observations, measurements, and data on the Blockchain in real time.
- Trigger alerts or actions based on predefined thresholds and conditions in the smart contract or monitoring system.

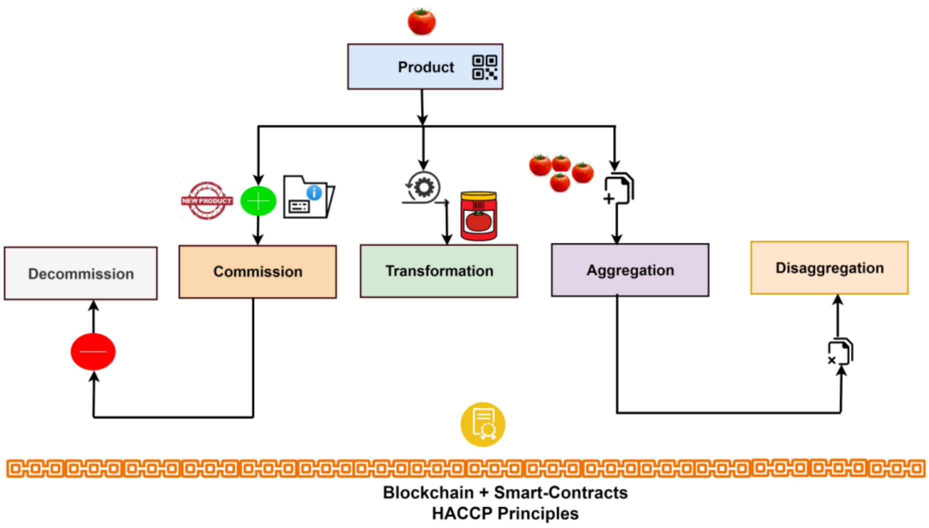


Fig. 3 Variety of operations for food supply chain based on HACCP principles

4. The Application of Smart Contracts in the Blockchain Technology Framework

The smart contract is a self-controlled and self-executing script to be executed automaticallyin termsof contracts bypassing any involved third parties. Some of the intendedtasks include monitorial exchanges, prompt delivery of services, unlocking of digital rights-protected contents, etc. The Blockchains are concerned with data development, distribution and management.

4.1Blockchain Technology

Recently, Blockchain and smart contracts have garnered interest due to coping with the decentralization of data and other business policies related to enhanced data management policies. Blockchain technology being used forthe Bitcoinconcept landed upon the ground of the decentralized and transparent recording and verification mechanism. Blockchains are distributed ledgers that securely and transparently record transactions over a nerk of computers [36]. Immutable Blockchain data cannot be changed. Each record, or "Block," contains a collection of transactions and is progressively connected, forming a chain.Blockchain technology is decentralized without any central authority to control the nerk operation. The Blockchain is maintained and validated by several computers connected in a distributed environment, called nodes. Cryptographic algorithms have been appointed to protect Blockchain transactions from malicious actors with a further increase in transaction visibility, transparency, and confidence.The immutability feature of the Blockchain for any uploaded transaction has been the prominent point leading to the more crucial challenge merging of the chains. Some of the important applications of Blockchain technology are being reflected in several industrial applications like Cryptocurrencies as Bitcoin is popular in banking, supply chain management, healthcare, voting systems, and other areas.

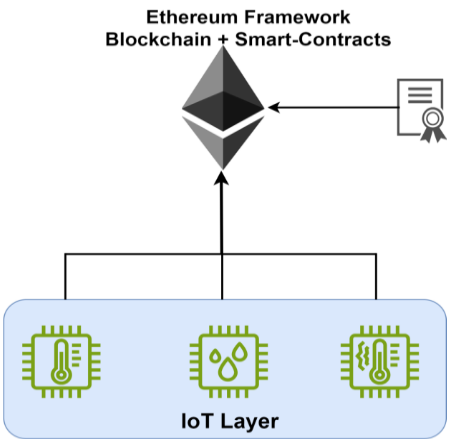


Fig. 4 Ethereum Framework for food supply chain with full food history

4.2 Smart Contracts

Smart contracts are computer programs that automatically enforce contract requirements. Smart contracts can automatically perform activities depending on specified rules and situations described in a code-based architecture [37]. An agreement is automatically executed and enforced upon meeting certain requirements, eliminating the need for middlemen.

Ethereum smart contracts are coded in solidity or other Blockchain-specific languages (Figure 3). Automation reduces human error and simplifies contract execution. The functions in a trustless environment where parties may trust the Blockchain code and consensus mechanism to execute agreements. Their immutability means they cannot be changed once they are on the Blockchain. Its application cases include supply chain management, legal agreements, insurance, real estate transactions, and others.

4.3 Scaling options for the Blockchain

Scalability is crucial to Blockchain technology. Scalability is a Blockchain system's ability to handle more transactions or users without sacrificing speed. There are several scalability concerns to consider while considering Blockchain. It is crucial to Blockchain technology and may be judged by transaction throughput, Block size, consensus process, and nerk performance (Table 3).

Blockchain nerks must process several transactions per second to be scalable. Traditional Blockchains like Bitcoin and Ethereum have low transaction per second (TPS), which prolongs confirmation times and raises transaction fees amid high demand [38]. Consensus processes affect Blockchain scalability. Bitcoin and Ethereum use Proof of Work (PoW), which requires a lot of resources and hinders scalability. Proof of Stake (PoS) and other consensus methods are designed for efficiency and scalability. The number of Blocks and the time needed to produce new Blocks affect scalability. Reducing Block sizes and speeding up Block formation increases Blockchain capacity.

Many Blockchain projects use Layer 2 technology to scale. The protocols above are added to the principal Blockchain to enable large off-chain or sidechain transactions with the Lightning Nerk for Bitcoin and other layer 2 resolutions for Ethereum being thesalient examples. Sharding divides Blockchain nerks into shards. Each shard may execute smart contracts and process transactions separately. This might boost throughput and scalability. Blockchain project Ethereum 2.0 uses sharding [39].

Nerk infrastructure—nodes, hardware, and bandwidth—affects Blockchain nerk scalability. A robust, decentralized infrastructure can handle more transactions and users. Effective governance and protocol updates are essential for addressing scalability issues. Communities and developers must work together to improve scalability and security. Blockchain nerks often use economic incentives to attract node operators. The above incentives may affect nerk capacity and scalability [40].

Table 3: Blockchain Platform Scalability Analysis

Blockchain Platform	Transaction Throughput	Block Size	Consensus Mechanism	Nerk Performance
Bitcoin	7-10 transactions per second (TPS)	1 MB (average)	Proof of Work (PoW)	Decentralized, slow
Ethereum (pre-ETH 2.0)	~15-30 TPS (varies)	~15-30 KB	PoW (transitioning to PoS)	Moderate, variable
Ethereum 2.0 (Post-Upgrade)	Expected to reach thousands of TPS	N/A	Proof of Stake (PoS)	Expected to be faster
Binance Smart Chain	~100-150 TPS	1-2 MB	PoS (Delegated)	Fast
Cardano	~250-1,000 TPS	Variable	PoS (Ouroboros)	Fast
Solana	Thousands to over 65,000 TPS	Variable	Proof of History (PoH) + PoS	Very fast
Polkadot	N/A (Parachain-specific)	Variable	PoS (Nominated PoS)	Variable

5. Pseudocode for Smart Contracts in the Blockchain Technology Framework

```
# Define a structure for Product
Define structure Product:
    name (string)
    batchNumber (string)
    producer (string)
    timestamp (uint256)
    owner (address)

# Define a Smart Contract for Food Traceability
Contract FoodTraceability:
    Declare mapping of batchNumber (string) to Product structure
    Declare owner (address)

    # Constructor to set contract owner
```

```
Function constructor:
    Set owner to contract creator

# Function to add a new product to the blockchain
Function addProduct(name, batchNumber, producer):
    Check if caller is the owner:
        If not, raise an error "Only the owner can add products"

    Retrieve product for the given batchNumber:
    If product's timestamp is not zero:
        Raise an error "Product with the same batch number already exists"

    Set product's name to the provided name
    Set product's batchNumber to the provided batchNumber
    Set product's producer to the provided producer
    Set product's timestamp to the current time
    Set product's owner to the caller's address

# Function to transfer ownership of a product
Function transferOwnership(batchNumber, newOwner):
    Retrieve product for the given batchNumber
    If product's timestamp is zero:
        Raise an error "Product with this batch number doesn't exist"

    Check if caller is the current owner of the product:
        If not, raise an error "Only the current owner can transfer ownership"

    Set product's owner to newOwner

# Function to retrieve product information
Function getProductInfo(batchNumber):
    Retrieve product for the given batchNumber
    If product's timestamp is zero:
        Raise an error "Product with this batch number doesn't exist"
```

Return product's name, batchNumber, producer, timestamp, and owner6 Traceability, Result Analysis and Performance evaluation of various Blockchain-based Food Supply Chain

In establishing the concerned data structure, a product symbolizes distinct culinary items, including characteristics such as the proprietor, batch number, name, and timestamp. Food Traceability is a smart contract developed to oversee food products' traceability. Contract provisions permit the addition of products, the transfer of ownership, and the retrieval of product information.

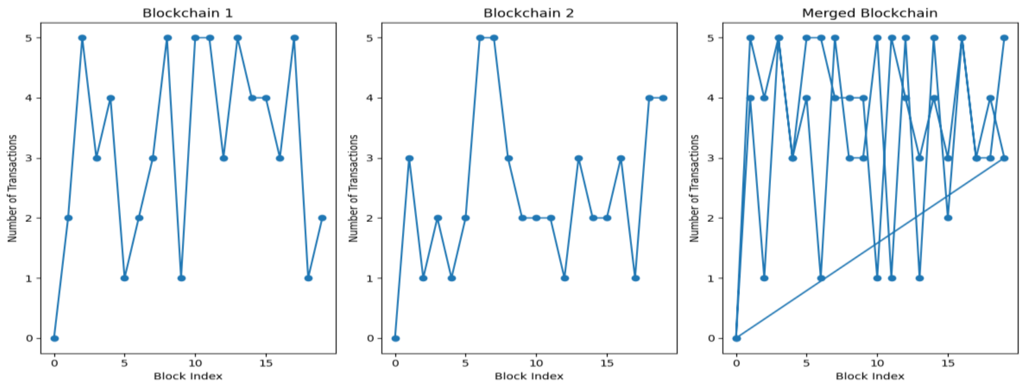
The function addProduct permits the administrator to incorporate additional products into the Blockchain by assigning the individual production number to each product.

By utilizing the transferOwnership function, the present proprietor of a product can instruct another address to acquire ownership. By inputting the batch number, the getProductInfo function enables any user to retrieve product information.

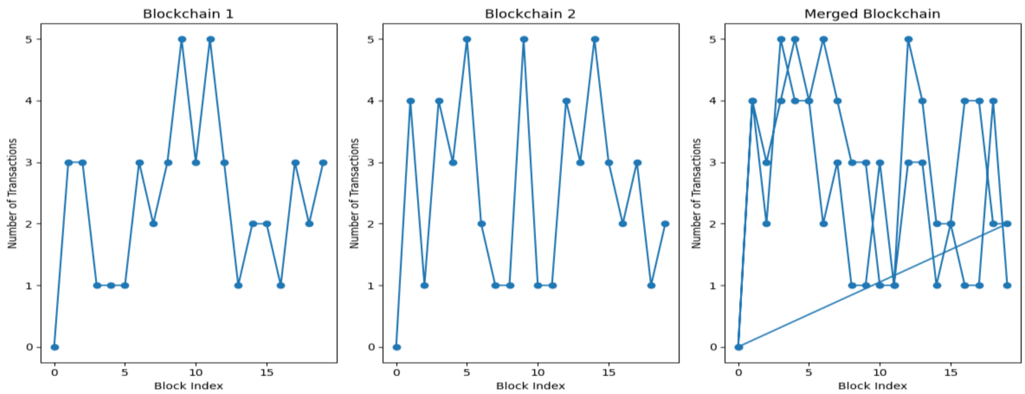
6. Result Analysis

The maximum number of overlapping points in different types of Blockchain-based transactions has been provided in Fig. 5. In each image,the individualBlock chains and their overlapped chain image have been shown.The important parameters ie, the maximum number of transactions per Block and number of overlapping points have been made to vary for each respective cases and the resultant chain model has been produced.

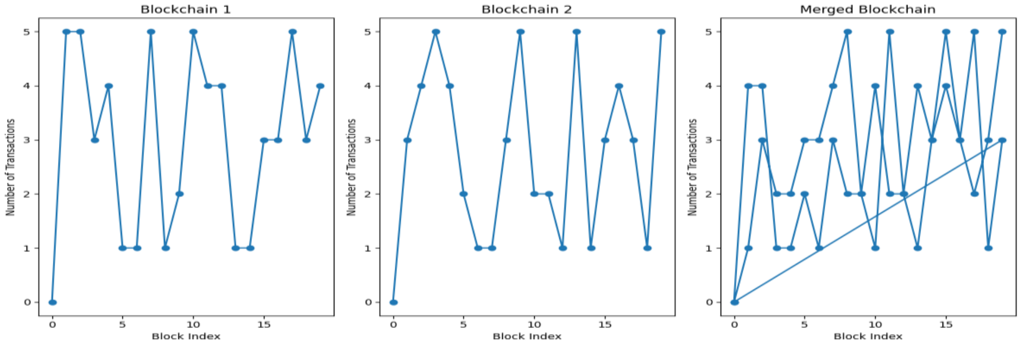
Graphs (Blockchain-1, Blockchain-2, Merged Blockchain)



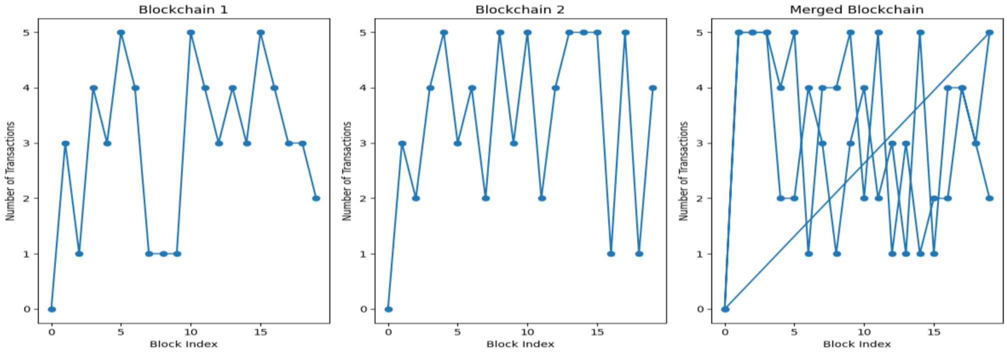
(a) Block chains with maximum number of transactions 5 and number of overlapping points 2.



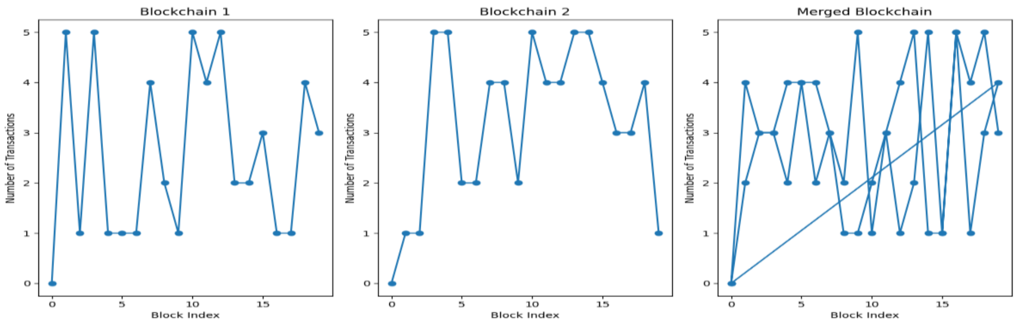
(b) Block chains with maximum number of transactions 5 and number of overlapping points 3.



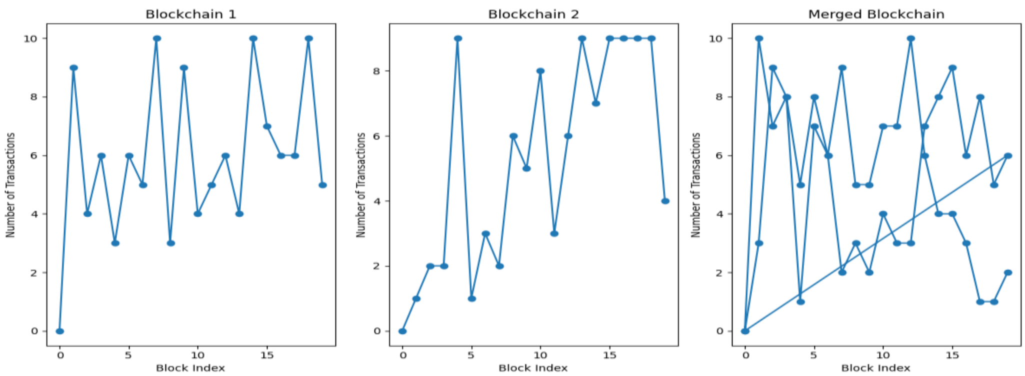
(c) Block chains with maximum number of transactions 5 and number of overlapping points 5.



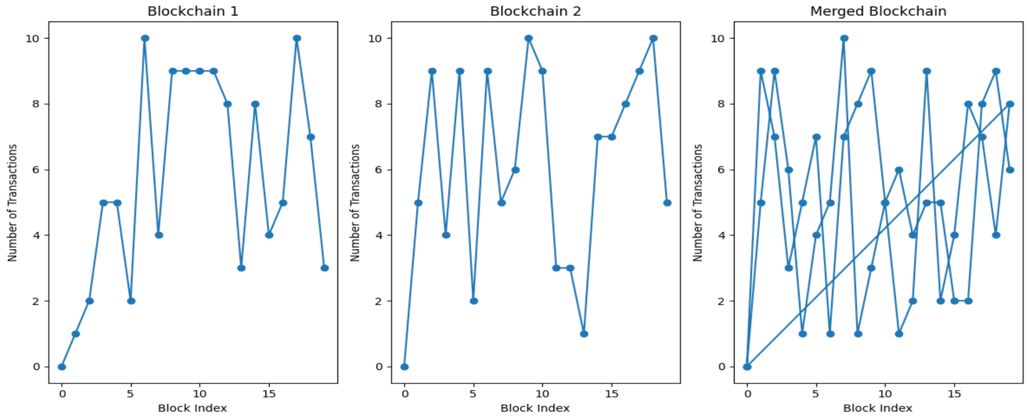
(d) Block chains with maximum number of transactions 5 and number of overlapping points 6.



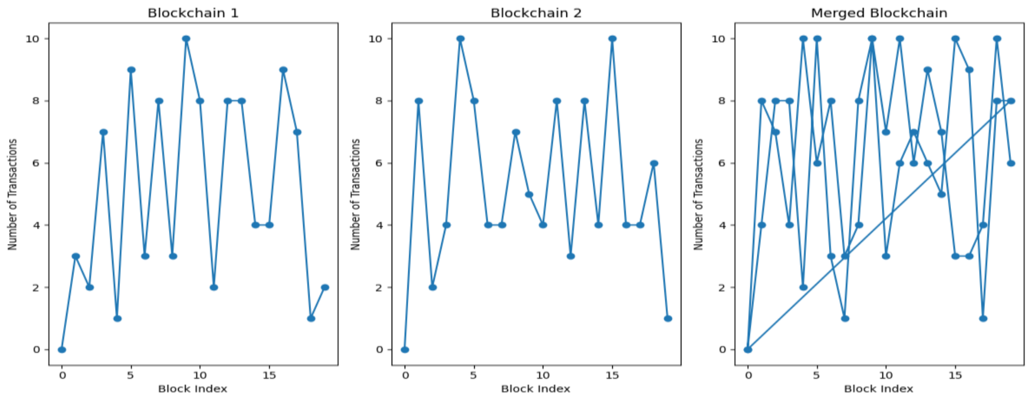
(e) Block chains with maximum number of transactions 5 and number of overlapping points 7.



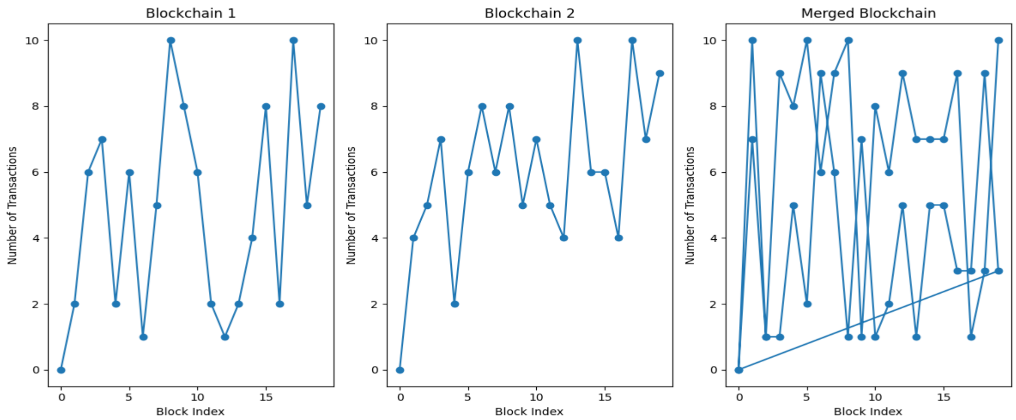
(f) Block chains with maximum number of transactions 10 and number of overlapping points 2.



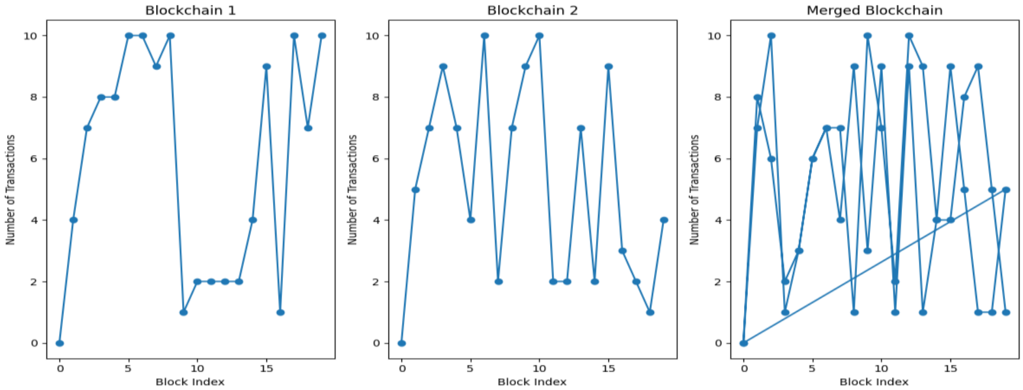
(g) Block chains with maximum number of transactions 10 and number of overlapping points 3.



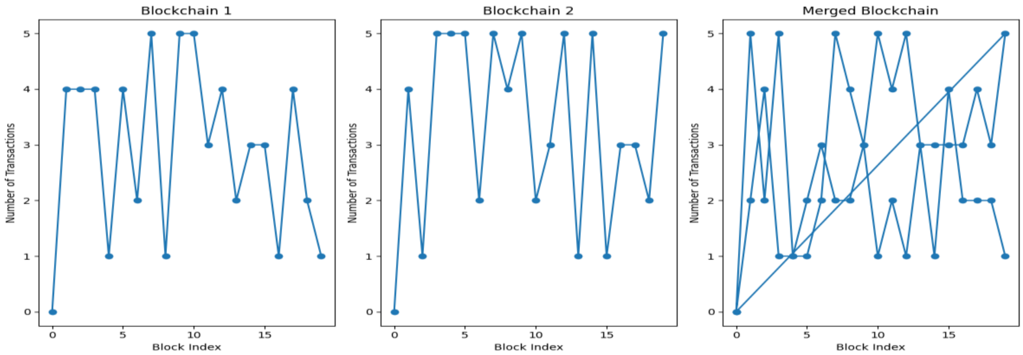
(h) Block chains with maximum number of transactions 10 and number of overlapping points 4.



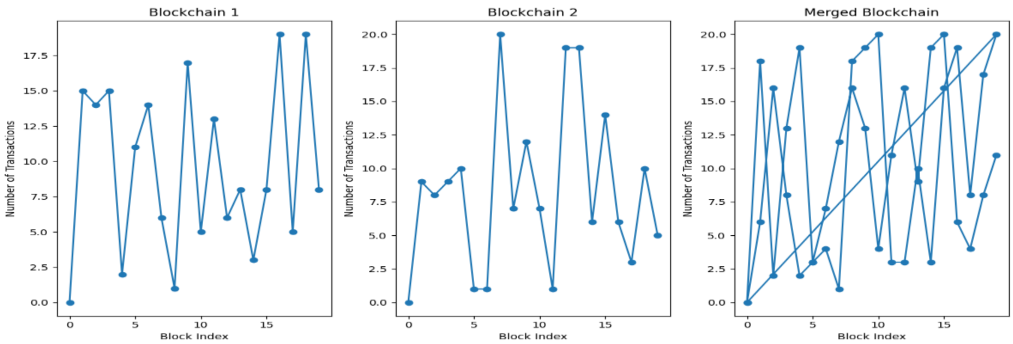
(i) Block chains with maximum number of transactions 10 and number of overlapping points 5.



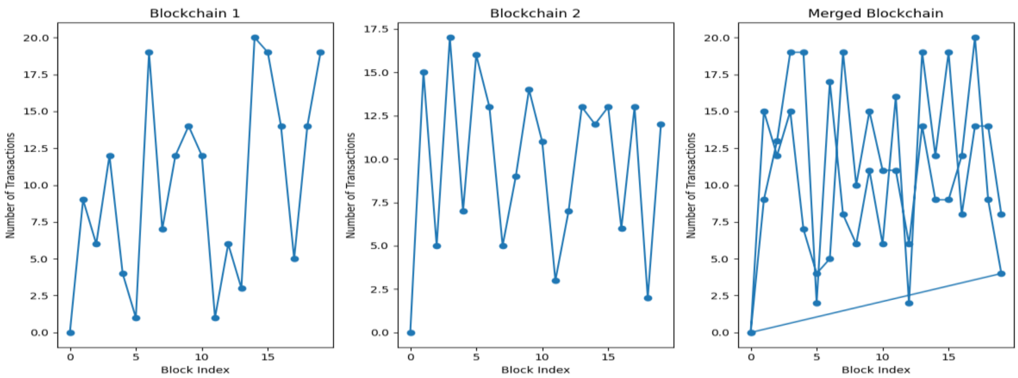
(j) Block chains with maximum number of transactions 10 and number of overlapping points 6.

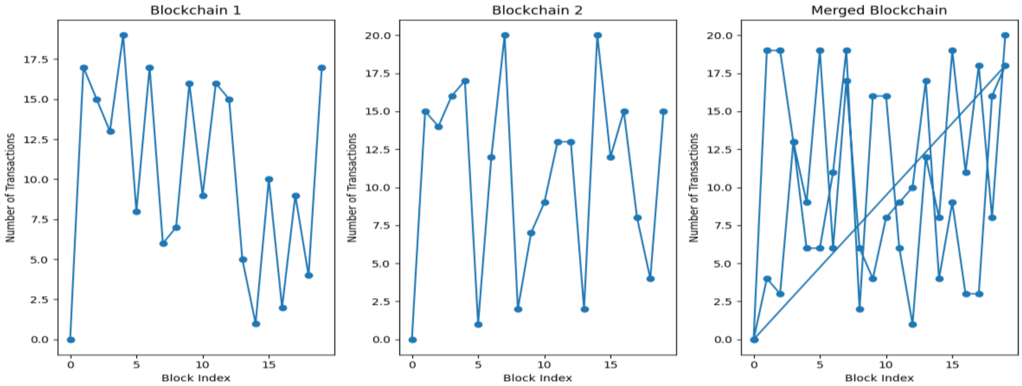


(k) Block chains with maximum number of transactions 10 and number of overlapping points 7.

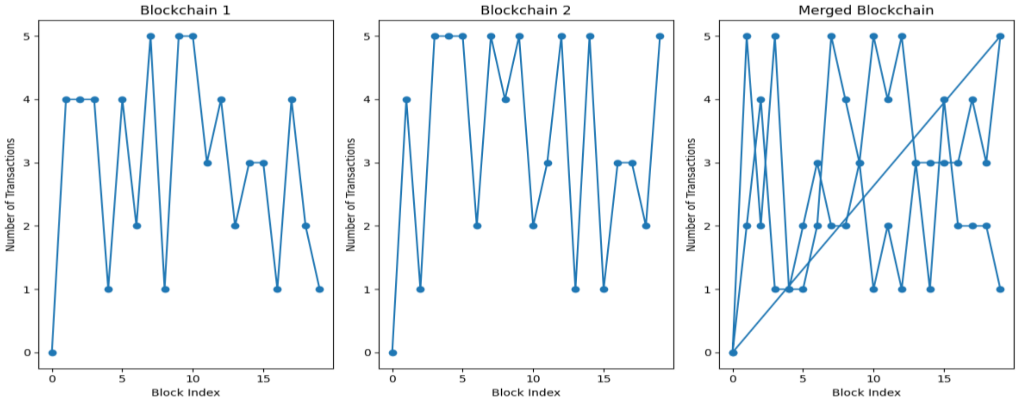


(l) Block chains with maximum number of transactions 20 and number of overlapping points 1.





(m) Block chains with maximum number of transactions 20 and number of overlapping points 3.



(n) Block chains with maximum number of transactions 20 and number of overlapping points 7.

Fig. 5. Analysis of block chains with different number of transactions and over lapping points in the memrged block chains.

Blockchains process transactions in full or in portions depending on transaction size. Special threshold values can be adaptively fixed. We combined heterogeneous Blockchains and counted their overlaps. Keeping the number of Blocks fixed in the n chains, the maximum transactions per Block change. Overlapping points have been calculated for each transaction value. For each Block-wise max transaction in fixed Blockchains, each algorithm run allows the number of overlaps. We used the least frequent count as the criteria. The chains with overlapping points below the threshold values will be merged if they meet the interoperability criteria. Table -3 shows Blockchain overlaps for threshold value choice. The data has been collected for the statistics of the Block count 20 and the maintenance of the beginning balance at 100.

7. Performance Analysis

Taking the mean of all overlapping count values yields the adaptive threshold. The threshold value selection pseudocode is below. The concerned chains have communication channels to exchange messages based on the threshold value. Transaction completed within the timeframe. Adapting the honey badger BFT consensus technique involves installing a group of participant Blockchains and coordinating their communications. Trust between participants and intended tradeoffs between scalability, security, and decentralization. The pseudo-code for the adaptive algorithm of interoperability of the heterogeneous chains has been presented below:

Pseudocode for adaptive threshold selection (Block_chain1, Block_chain2):

```
sum = 0
count = 0
```

```
overlapping_count = 0
point_frequency = {} // Dictionary to store the frequency of each point

// Count frequency of points in Block_chain1
for each point in Block_chain1:
    if point in point_frequency:
        point_frequency[point] += 1
    else:
        point_frequency[point] = 1

// Count frequency of points in Block-chain1 and check for overlapping points
for each point in Block_chain2:
    if point in point_frequency and point_frequency[point] > 0:
        overlapping_count += 1
        point_frequency[point] -= 1

    //Finding the overlapping counts
for each point in overlapping_count:
    sum = sum + point
    count = count + 1

if count == 0:
    return "No points provided"

mean = sum / count

threshold_val = mean
return threshold_val
```

The count variable counts iterations. The count might vary until no significant change is seen. The adaptive threshold determines the Blockchains to be combined. Table 4 shows the maximum Block transactions barrier.

Table 4 Performance analysis for adaptive threshold-based merging of Blockchains

Max_transactions per Block	No of overlapping points	Number of iterations	Selected threshold value	Selection status for the Blockchains (The chains with several overlapping points less than the threshold.)	Performance
5	1,2,5,6,7	5	4.5	1,2	96%

10	2,3,4,5,6,7	6	4.5	2,3,4	95%
20	1,2,3,7	4	3.25	1,2,3	94%

It has been found from the table 4, that the performance of the block chain model varies for different transactions per blocks. The maximum performance has been observed for the lowest numbe6r of the transaction value measured at 5.

The merged Blockchains based on the adaptive threshold value have been displayed in Fig.6.

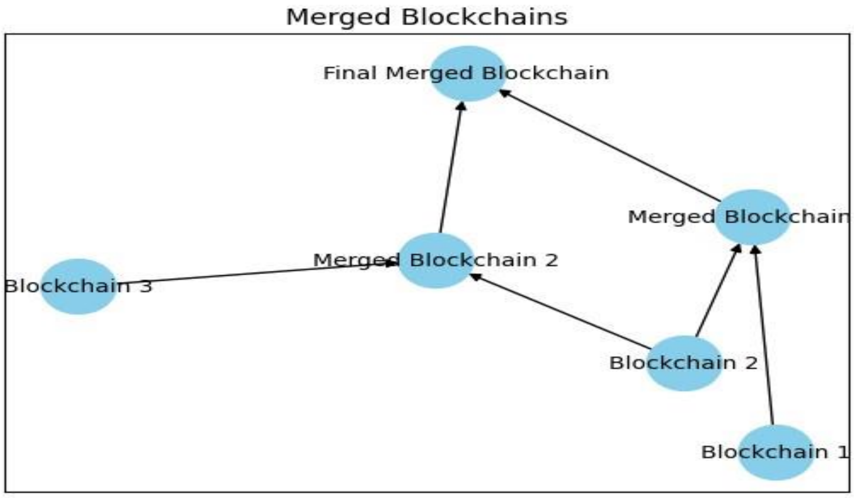


Fig. 6 Merged Blockchain

Performance measurements for Blockchain merging include bandwidth, throughput, scalability, security, latencies, Block propagation time, and decentralization. Throughput, latency, and Block propagation time were used to evaluate Blockchain structure performance. Blockchain food supply requires acceptable latency, fluid, and seamless integration to grow services. The equations offer performance measure formulas.

$$\text{Latency} = T_{\text{total}} \,/\, N_{\text{transactions}} \cdots\cdots \quad \text{(i)}$$

$$\text{Throughput} = TN_{\text{transactions}} \,/\, TT_{\text{total}} \cdots\cdots \text{(ii)}$$

$$\text{Latency} = T_{\text{received}} - T_{\text{mined}} \cdots\cdots \text{(iii)}$$

Where:

- T_{total} is the total time taken for transaction confirmation
- $N_{transactions}$ is the number of transactions
- $TN_{transactions}$ is total number of transactions
- TT_{total} is total time
- $T_{received}$ is the time when the Block is received
- T_{mined} is the time when the Block was mined

The performance value was computed using equations (i), (ii), and (iii). Fig.7 compares merging chains' performance for adaptive threshold-based and non-adaptive approaches.

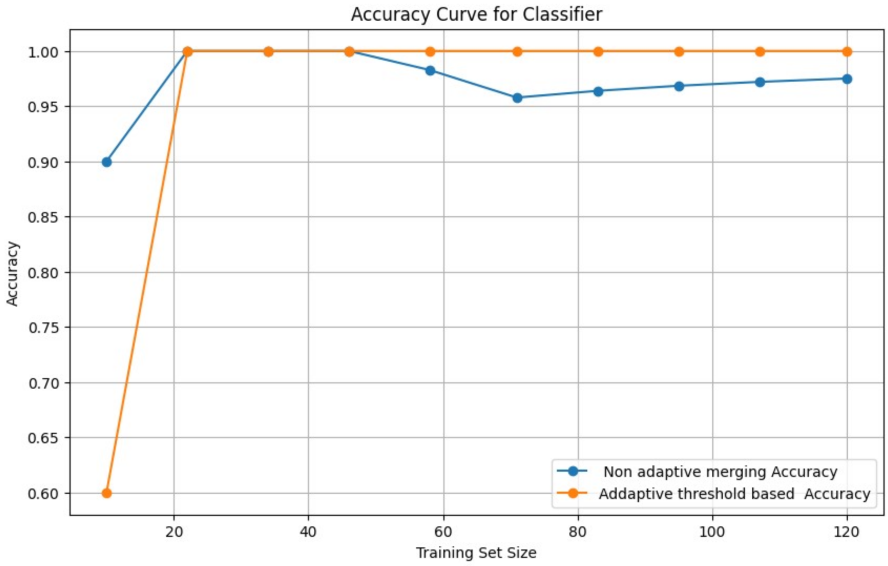


Fig. 7 Comparison of Merged Blockchain

The figure's graph shows that adaptive threshold-based Blockchain merging is more accurate than non-adaptive. The graph also shows higher-grade accuracy consistency.

When analyzing the performance of Blockchain-based food supply chain traceability systems, several key metrics and factors should be considered [44]:

- **Speed and Scalability:** Blockchain nerks must handle a high volume of transactions quickly to keep up with the demands of the food supply chain. Scalability solutions, such as sharding or sidechains, can be essential.
- **Data Privacy:** While transparency is vital, ensuring that sensitive business information is protected is equally important. Permissioned Blockchains can address this concern.
- **Cost-Efficiency:** The cost of using Blockchain technology, including transaction fees and infrastructure, should be evaluated against the benefits it brings in terms of reducing fraud and errors.
- **Integration:** The ease of integrating Blockchain with existing supply chain systems and processes can impact the adoption rate and overall performance.
- **Security:** Blockchain is known for its security features, but assessing vulnerabilities and ensuring robust security measures is crucial.
- **User Adoption:** The success of Blockchain-based traceability systems depends on the willingness of supply chain participants to adopt the technology.

This system provides transparency and reduces the time needed for tracing the source of contaminated products [48].

Table5Blockchain Performance Indicator Analysis

Performance Indicator	Measurement/Value	Benchmark/Target	Analysis/Comments
Traceability Accuracy	Percentage of successfully traced items	>95%	Measure the accuracy of item tracking from source to destination. This can help prevent errors and fraud in the supply chain.
Transparency and Visibility	Number of participants on the nerk	Increase over time	Evaluate the growth of participants, which can enhance transparency and data availability in the supply chain.

Transaction Speed	Average transaction confirmation time	<10 seconds	Faster transaction times lead to more efficient supply chain operations.
Data Security	Number of security breaches or incidents	0	Measure the effectiveness of security measures in protecting sensitive supply chain data.
Cost Reduction	Reduction in operational costs	Variable	Assess the impact of Blockchain on reducing operational expenses, including administrative and compliance costs.
Inventory Management Efficiency	Reduction in excess inventory	>15% reduction	Evaluate how Blockchain helps optimize inventory levels and reduce carrying costs.
Compliance with Regulations	Number of compliance violations	0	Ensure adherence to regulatory requirements related to food safety and traceability.
Real-time Monitoring	Average latency in real-time updates	<1 second	Analyze the responsiveness of the system in providing real-time updates and alerts.
Supply Chain Disruptions	Number of supply chain disruptions	Reduced instances	Measure how Blockchain minimizes disruptions and improves resilience in the supply chain.
Supplier Collaboration	Supplier onboarding time	<2 weeks	Evaluate the ease of bringing new suppliers into the nerk and enhancing collaboration.

8. Conclusions and Future Scopes

This manuscript addresses the challenges inherent in scaling Blockchains at large and presents an innovative decentralized provenance system based on Blockchain technology and the Internet of Things.

Since 2009, Blockchain technology has been primarily utilized and disseminated in the banking and cryptocurrency sectors, both pioneered by Bitcoin. The Linux Foundation commenced work on the Hyperledger initiative in December 2015. Many corporations, such as JD.com, IBM, Walmart, and Alibaba, have introduced novel solution services for food supply chain management since 2008. It is anticipated that this pattern will persist until 2018. The implementation of Blockchain technology in supply chains is in its nascent stages. Technological methodologies have dominated the majority of research devoted to Blockchain applications. Traceability of the food chain via Blockchain and chain merging on a heterogeneous platform are implemented in this paper. In comparison to extant methods, the performance evaluation of the merged Blockchain utilizing the adaptive threshold method has the potential to achieve high scores. The estimated performance result of this study is close to 95%, which predicts the value scaling as chains are merged adaptively. The ongoing investigation possesses the capacity to establish a foundation for subsequent behavioural studies concerning Blockchain applications. A HACCP scenario for the food supply chain was also provided. By providing up-to-the-minute food safety updates to every link in the supply chain, this system will significantly mitigate the vulnerabilities associated with centralized information systems and foster an environment that is safer, more decentralized, transparent, and conducive to collaboration. Our technology can significantly increase the transparency and efficacy of the food supply chains, restoring consumer confidence in the food industry and enhancing food safety. With the progression of future research, consideration can be given to incorporating Blockchain security measures. The application-based connecting Blockchains may also be a viable option for facilitating real-time data access.

Statement and Declaration

The authors have no competing interests to declare that are relevant to the content of this article.

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