IJCDS 1571028392

International Journal of Computing and Digital Systems
ISSN (2210-142X)
Int. J. Com. Dig. Sys. , No. (Mon-20..)

http://dx.doi.org/10.12785/ijcds/XXXXXX

Enhancing Food Safety and Transparency in the Supply Chain through Polygon Blockchain and Cloud Integration

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Abstract: The food industry faces substantial challenges in guaranteeing the authenticity and safety of food items along the complex supply chain. These challenges are compounded by technological limitations and a tendency within the hotel industry to opt for lower-quality, less expensive products. Such practices, while seemingly cost-effective, ultimately endanger the health and safety of consumers. Through the utilization of blockchain's traceability characteristics, we can closely track the origins of food items and monitor their journey from farm to table. By leveraging the best of both worlds-current cloud technology for real-time data processing and blockchain for data storage-we can make the adoption of blockchain across a wide spectrum more feasible. This integration results in reduced costs and higher efficiency throughout the supply chain. Incorporating the system onto a decentralized database through the utilization of smart contracts enables the establishment of an immutable record encompassing the entire process. It facilitates the provision of readily accessible information pertaining to edible shelf life and harvesting dates, thus bolstering food safety and transparency within the supply chain. Polygon's compatibility with Ethereum and its sidechain networks, coupled with its superior transaction speeds and affordable transaction costs, position it as a promising solution for implementing blockchain technology in the food industry.

Keywords: Blockchain, Polygon, Web 3, Food Supply Chain, Supply Chain Management (SCM)

1. INTRODUCTION

A supply chain is a network of companies and individuals in charge of producing goods and getting them to consumers. It includes all processes involved in transferring and transforming items from raw materials to final consumers, as well as the information flows necessary to support these processes. This covers planning for information and material flow along the supply chain, including upstream activities like acquisition and locating, as well as downstream activities like sales and distribution. From the point of manufacturing commencement to the point of ultimate consumption, supply chain management (SCM) supervises all phases to guarantee a productive and efficient flow of goods and services.

Blockchain technology is a distributed, decentralized digital ledger that securely, transparently, and persistently records transactions across numerous computers. Every transaction is validated by other nodes on the peer-to-peer network before being published to a common public ledger. Blockchain operates by generating blocks of data that are linked together using cryptographic procedures. Each block comprises a list of transactions, a timestamp, and a link to the preceding block, producing a chain of blocks. Once a block is added to the chain, it cannot be changed retrospectively without affecting all following blocks, rendering the data resistant to modification.

Polygon is a protocol and framework for creating and connecting Ethereum-compatible blockchain networks. Polygon, formerly known as the Matic Network, intends to increase the scalability and usability of Ethereum by giving developers with tools and infrastructure for creating and deploying Layer 2 solutions, sidechains, and standalone blockchains.

Supply chain management (SCM) plays a crucial role in various industries, especially in ensuring the authenticity, quality, and safety of products as they move through complex supply chains. The food industry, in particular, faces significant challenges in maintaining these standards due to the intricate nature of its supply chain and the prevalence of lower-quality products in certain sectors like the hotel industry. The need for robust traceability and transparency mechanisms in food supply chains is paramount to safeguarding consumer health and trust.

Blockchain technology has emerged as a promising solution to address these challenges, offering features such as immutability, transparency, and traceability. In this research paper, we focus on leveraging the Polygon blockchain network to enhance traceability and authenticity in the food supply chain. Polygon, known for its scalability, low transaction costs, and interoperability with Ethereum, presents a suitable platform for implementing blockchain solutions in complex supply chain scenarios like the food industry.

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The flow of this paper follows a structured approach, starting with the Abstract that provides a concise overview of the research objectives and findings. The Introduction section sets the stage by discussing about Supply Chain and Supply Chain Management, blockchain technology, Polygon blockchain platform, the significance of supply chain management in ensuring food authenticity and safety, highlighting the challenges faced and the potential of blockchain technology, specifically Polygon, in addressing these challenges.

Following the Introduction, the paper delves into a comprehensive Literature Review, exploring existing research, frameworks, and technologies related to supply chain traceability and blockchain. The Methodology section outlines the research approach. The Architecture section focuses on the design aspects of integrating blockchain technology, particularly the Polygon network, into the food supply chain to enhance traceability and authenticity. It discusses the architecture, smart contracts, data flow, and interoperability considerations necessary for a successful implementation.

The Results section presents findings and insights derived from comparative analysis from existing systems proposed in literature survey of research papers to evaluate the effectiveness and feasibility of the proposed blockchain-based solution. Lastly, the Conclusion section outlines the most noteworthy findings, explores potential consequences, and presents proposals for future research. The paper concludes with a list of References citing relevant sources and literature referenced throughout the paper, providing readers with a comprehensive understanding of the research flow and contributions.

2. RELATED WORK

In this study, we investigate the many applications of blockchain technology with the purpose of addressing and eliminating common difficulties in Supply Chain Management (SCM) and logistics. We examine a variety of practical circumstances and difficulties, demonstrating blockchain solutions that improve visibility, tracking capabilities, and operational efficiency in SCM systems.

A Blockchain in Agricultural Supply Chains: The study draws attention to the supply chain management challenges faced by Indonesia's agriculture industry, which are typified by drawn-out distribution procedures that raise consumer costs while lowering farmer earnings. Farmers' situation is made worse by middlemen who take advantage of this system. The difficulties are exacerbated by the pervasive lack of transparency and transactional inefficiencies. The suggested remedy is for implementing a real game-based supply chain management system that makes use of blockchain smart contracts in order to solve these problems. By using digital signatures to assure data transparency and optimize pricing in line with market dynamics, this system seeks to improve transactional transparency and efficiency while streamlining distribution networks. By utilizing blockchain technology, safe transactions and decentralized data recording may be accomplished without the need for a third party. [1]. The research presents blockchain technology as offering a revolutionary way to improve agricultural supply chain transparency and traceability, meeting the increasing demand for premium, ethically sourced food goods. Through the utilization of its distributed ledger system and decentralized architecture, blockchain facilitates the easy documentation and validation of transactions throughout the entire production cycle, from farm to table. Notwithstanding obstacles such as technological complexity and interoperability problems, blockchain presents a promising framework for guaranteeing data security, fostering customer confidence, and reducing operational inefficiencies in the agri-food industry. Blockchain is emerging as a key tool for transforming the global food supply chain, enabling greater accountability, and creating positive social and environmental impact as consumer preferences shift towards healthier and more sustainable options.[2].

B Integrating blockchain with IoT in SCM: Blockchain technology is explored as a tool for optimizing inventory management and supply chain logistics. By providing real-time visibility into inventory levels, tracking product movements, and automating inventory reconciliation processes, blockchain improves accuracy, efficiency, and responsiveness in inventory management. Implementations include blockchain-based solutions that integrate with Internet of Things (IoT) devices, such as RFID tags and sensors, to enable seamless inventory tracking and management across multiple locations. These initiatives reduce stockouts, minimize excess inventory, and enhance overall supply chain performance[3]. The benefits of using blockchain and Internet of Things (IoT) technologies into supply chain management across several industries are explored in this review article. It offers insightful information about the joint potential of IoT and blockchain, especially in terms of improving supply chain visibility, traceability, and operational efficiency, by drawing on case examples. The study, clarifies how these technologies are revolutionizing supply chain procedures in the modern era[4]. The proof of concept for combining blockchain technology with IoT devices to improve supply chain efficiency, security, and visibility is presented in this article. The suggested approach enables proactive decision-making and risk reduction in supply chain operations by utilizing blockchain technology for transparent and secure data storage and Internet of Things sensors for real-time data gathering. The analysis shows how this integration has the power to completely transform supply chain management procedures[5].

C Improving Efficiency in Cold Chain Management: Specific challenges in managing perishable goods within the cold chain are addressed through blockchain solutions. By leveraging blockchain's ability to record and track temperature data in an immutable manner, these solutions minimize economic losses and reduce food wastage. The implementation of blockchain in cold chain management ensures real-time monitoring and adherence to temperature regulations, thereby optimizing efficiency and preserving product quality. These initiatives contribute to reducing food spoilage, ensuring food safety, and maintaining product freshness[6].

D Addressing traceability challenges in the coffee industry: The research findings indicate a deficiency in transparency and traceability in the supply chain of the coffee business, posing difficulties for both customers and stakeholders. Because of the opaque supply chain procedures in place, end users are mainly dependent on retailers for product information. Consumers' concerns about safety were exacerbated by the use of chemicals and pesticides. To address these difficulties, a blockchain-based traceability paradigm was suggested by the research. This model tracked the flow of coffee beans across the supply chain using blockchain technology in an effort to improve transparency and traceability. In order to maintain information integrity, implementation required building a prototype application and utilizing smart contracts, payment features, and improved data security procedures[7].

E Enhancing Traceability in supply chain using blockchain: The paper emphasizes how important it is to have a strong and efficient food traceability system in order to address concerns about food safety, especially when it comes to product recalls. It emphasizes how crucial it is to carefully record and trace food product occurrences involving governmental agencies, supply chain partners, and end users throughout the whole food supply chain. The Traceability System for Product Recall (TSPR), a blockchain-based solution that combines a traceability system with the Ethereum blockchain-based product recall framework, is the suggested remedy. The goal of TSPR is to improve the process of product recalls' visibility and transparency for all parties involved, such as end-users, administrators, regulatory agencies in charge of food safety, and supply chain partners. It incorporates various components to furnish details on product traceability events, recall data, and status, all securely stored within the blockchain[8]. A number of studies investigate the application of blockchain technology to enhance the transparency of product authentication processes. By utilizing the immutable ledger, smart contracts, and decentralized architecture of blockchain technology, these methods ensure the authenticity and dependability of goods throughout supply chains. Real-world applications range from private blockchain-based traceability systems to collaborative networks involving several producers, distributors, and retailers. The goals of these programs are to protect brand integrity, promote consumer confidence, and fight counterfeiting[9].

F Blockchain's Potential in Supply Chain Management: This paper offers the results of a study that looked into the long-term opinions of a global panel of experts on the uses and benefits of blockchain technology in SCM. The study provides useful insights for future planning and decision-making by illuminating the predicted trajectory and ramifications of blockchain integration inside supply chains through expert viewpoints[10].The paper presents a thorough examination of supply chains enabled by blockchain technology, including potential directions and problems. The research offers an in-depth review of the potential and limitations of blockchain technology in supply chain management through a rigorous examination of these issues. The provided findings significantly advance the ongoing conversation on supply chain management's use of blockchain technology[11].This study compares academic and news sources on blockchain-enabled supply chain management using data-driven analysis. Through a thorough analysis of trends, gap analysis, and research needs, this study provides insightful information about the current state and potential future directions of blockchain usage in supply chains. The results enhance our comprehension of the dynamic field of blockchain technology in supply chain management[12].This paper explores the various ways that blockchain technology might improve supply chain management procedures. Blockchain offers supply chain operations security, traceability, and transparency, which could improve workflows, save expenses, and reduce risks. Examining this potential to boost productivity and encourage creativity in supply chains helps to highlight how blockchain technology is revolutionizing supply chain management today. [13]. An detailed analysis of several blockchain projects incorporated into supply chain management is presented in this report. Through a methodical examination of project implementations, obstacles faced, and results attained, the evaluation offers significant insights into the current state of affairs and potential future paths for blockchain adoption in supply chains. The results enhance our comprehension of the ways in which blockchain technology can be applied and developed to revolutionize supply chain operations[14].

G Implementation challenges for blockchain in SCM: The paper looks critically at supply chain applications of blockchain technology. It explores the effects, challenges, and implementation of these applications through in-depth examination. Through an examination of real-world examples, the paper provides useful information and suggestions for businesses considering implementing blockchain technology in their supply chain management[15]. Research investigates on how supply chain ecosystems' data silos and interoperability issues can be resolved by blockchain technology. Blockchain facilitates supply chain stakeholders' data interoperability and collaboration by creating common and standardized data formats, enabling data exchange protocols, and enabling seamless interaction with current IT systems. Blockchain platforms are examples of implementations that provide data sharing, validation, and synchronization amongst various systems, enhancing supply chain operations' efficiency, trustworthiness, and transparency. These programs increase process efficiency, supply chain visibility, and data-driven decision-making[16].

H Impact of blockchain on SCM in other industries: This study explores the unresolved issues and implications of blockchain technology in the context of the automotive component supply chain management. The research offers important insights into the potential uses and limitations of blockchain in the automotive industry by identifying obstacles and opportunities. These results advance our knowledge of how supply chain dynamics in the automotive component sector may be altered by blockchain technology[17]. The subject of study is the blockchain technology's potential to transform supply chain financing methods. Blockchain provides transparent and secure transactions, minimizes financial risks, and speeds up cash flow across supply chains by digitizing trade finance procedures and automating payment settlements. Blockchain-based solutions that enable peer-to-peer lending, give real-time visibility into trade finance transactions, and improve working capital management for companies of all sizes are examples of implementations. The aforementioned approaches aim to bridge funding gaps, enhance capital accessibility, and promote financial inclusion across supply chain ecosystems[18]. Research look into how blockchain technology might improve international supply chains and cross-border trade. These technologies seek to simplify international transactions by digitizing trade documentation, automating customs procedures, and maintaining data integrity. In order to facilitate smooth trade processes, practical implementations incorporate blockchain platforms that connect various parties, such as importers, exporters, freight forwarders, and customs agents. By reducing paperwork, speeding up clearing procedures, and lowering transaction costs, these initiatives eventually support economic growth and international trade[19].

I Enhancing Sustainability Practices with Blockchain: The paper investigates into the incorporation of blockchain technology into supply chains to bolster sustainability endeavors. Through furnishing transparent and immutable records of product origins, manufacturing procedures, and carbon footprints, blockchain empowers companies to validate their sustainability assertions. Practical applications encompass blockchain-driven solutions that incentivize environmentally conscious behaviors, advocate for ethical sourcing, and streamline carbon offsetting endeavors, thus bolstering environmental preservation initiatives. These undertakings align with corporate social responsibility objectives, elevate brand standing, and cater to consumer preferences for sustainable goods[20]. The research presented here looks into the patterns and potential directions of blockchain technology to improve supply chain sustainability. By means of meticulous examination, it pinpoints methods for utilizing blockchain technology in sustainable supply chain administration, offering significant perspectives on its possible uses and advantages in promoting ecological and societal accountability. The results enhance our comprehension of how blockchain technology might promote constructive modifications in supply chain procedures that lead to increased sustainability[21].

J Securing Digital Identities in Supply Chain Networks: The paper explores solutions aimed at securing digital identities and safeguarding data privacy within supply chain networks. Utilizing decentralized identity management systems and cryptographic methods, blockchain technology is identified as a means to bolster cybersecurity and shield sensitive data from unauthorized intrusion. Practical implementations involve blockchain platforms that facilitate secure and verifiable authentication of users, devices, and transactions, thereby diminishing the likelihood of data breaches and cyber threats in supply chain activities. These endeavors serve to protect intellectual property, thwart identity theft, and foster trust among participants in the supply chain ecosystem[22].

In the existing literature, it has been observed that the predominant challenge in current blockchain implementation lies in the significant cost associated with data operations on the blockchain. In this paper, we introduce an architecture aimed at addressing this particular issue.

3. METHODOLOGY

Based on the insights we acquired from our earlier research[23], we have improved our approach and addressed limitations in this study. In particular, we have improved our strategy by giving a more thorough explanation of the supply chain stakeholder actions. This improvement attempts to protect the privacy of private information supplied by stakeholders while improving supply chain operations' transparency. The suggested system configuration is shown in Figure 1, which is an essential point of reference for system development. The traceability endpoints are represented by the block diagram, which shows the flow of processes from the Farmer to the Customer. An explanation of the General Block Diagram at the stakeholder level is provided below.

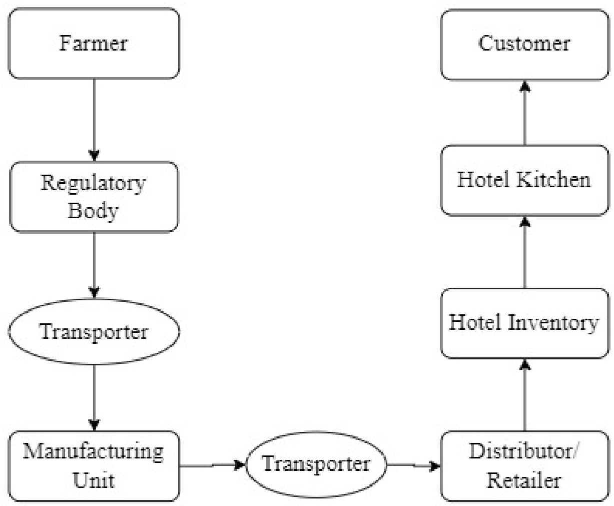

Figure 1. Flow diagram of stakeholders in the food supply chain

The above flow diagram demonstrates the way in which the supply chain moves along as well as the different parties involved. In our revamped flow diagram, we have added a new stakeholder called the transporter. This addition is significant as the transporter assumes a pivotal role in facilitating the movement of materials between stakeholders within the supply chain.

Below we propose the activities carried out by each stakeholder. These will help to understand how stakeholders use blockchain application and what data is stored by stakeholders in the supply chain.

a) Farmer: Grows food crops and provides data related to crop types, cultivation methods, harvest times, and quality parameters. Participates in quality control processes, such as testing for pesticides, contaminants, and organic certifications.

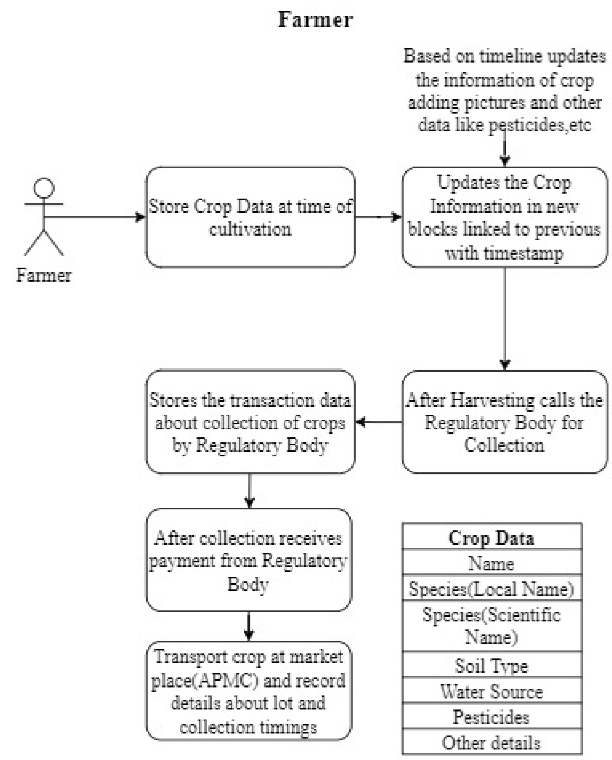

Figure 2. Farmer's Flow Diagram

b) Regulatory Body: Validates crop quality data provided by farmers and ensures compliance with regulatory standards (e.g., food safety, environmental regulations). Administers activities such as inspections, certifications, and enforcement of industry guidelines throughout the supply chain.

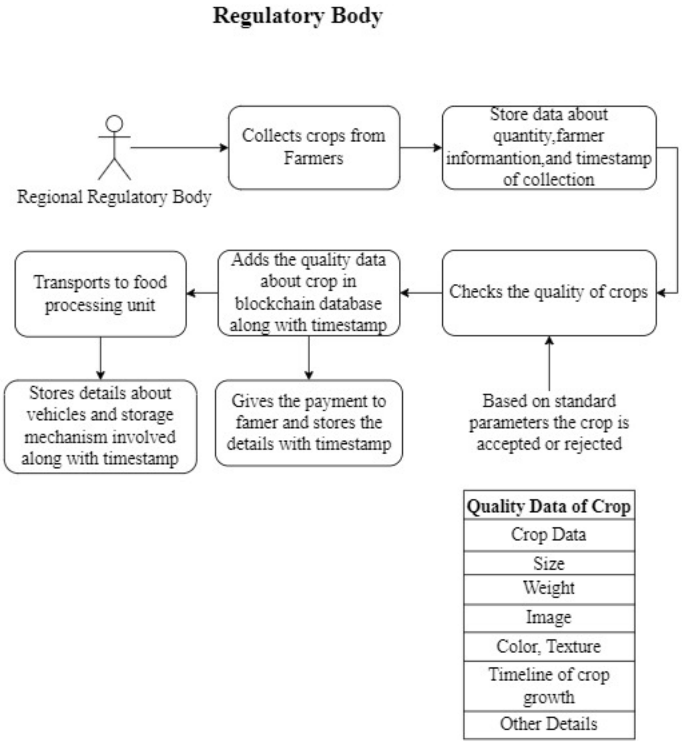

Figure 3. Regulatory Body Flow Diagram

c) Transporter: Responsible for transporting goods across supply chain. Tracks transportation routes, delivery times, and conditions (temperature, humidity) to ensure product quality and integrity.

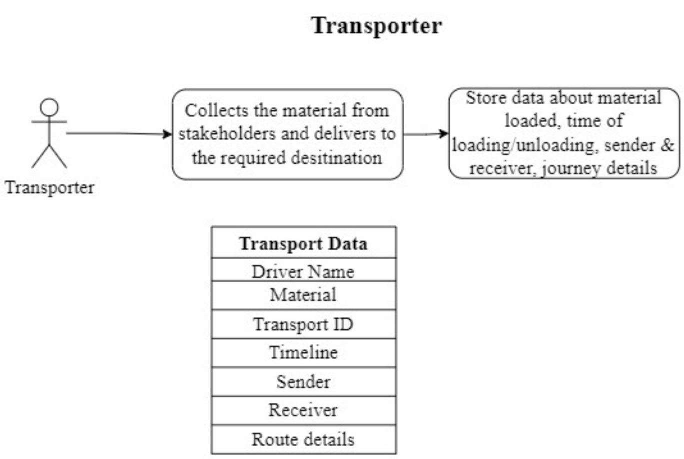

Figure 4. Transporter's Flow Diagram

d) Manufacturing Unit: Receives raw materials from farmers or distributors from APMC and processes them into final food products (e.g., milling grains, canning fruits, processing meat). Conducts quality checks, batch tracing, and packaging according to regulatory requirements before distribution.

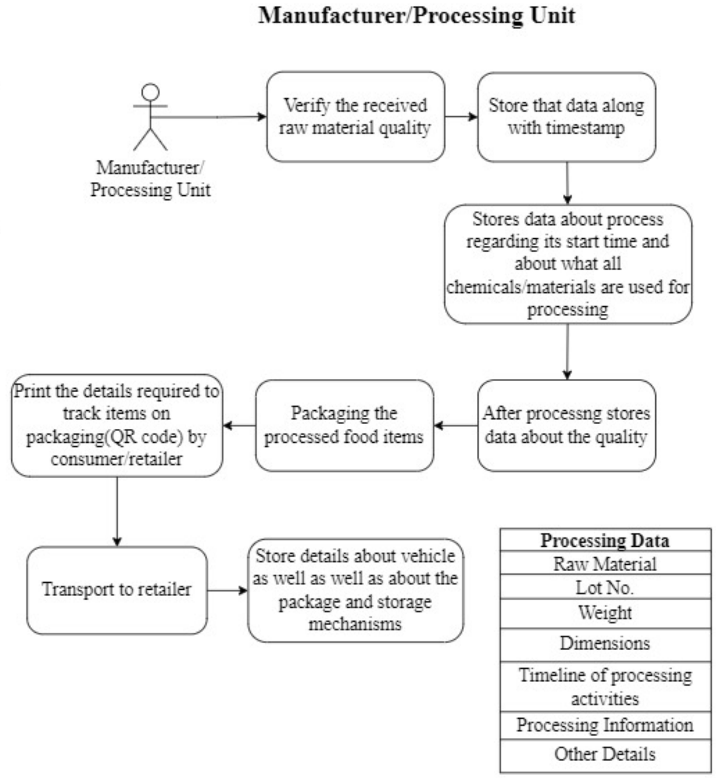

Figure 5. Manufacturer's Flow Diagram

e) Distributor/Retailer: Distributes processed or manufactured food items to retailers, wholesalers, or directly to consumers. Manages inventory, logistics, and sales transactions while ensuring product freshness, labeling accuracy, and compliance with storage conditions.

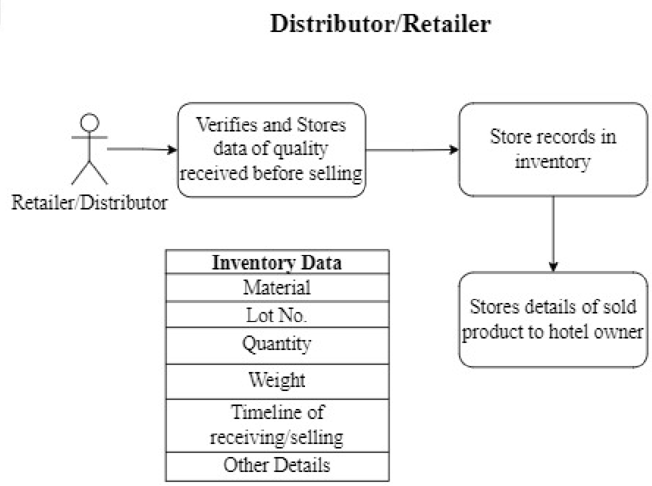

Figure 6. Distributor/Retailer Flow Diagram

f) Hotel Warehouse: Buys food items from distributors or retailers and stores them in controlled environments (e.g., refrigeration, dry storage) within the hotel premises. Tracks inventory levels, expiry dates, and batch numbers for efficient stock management and food safety compliance.

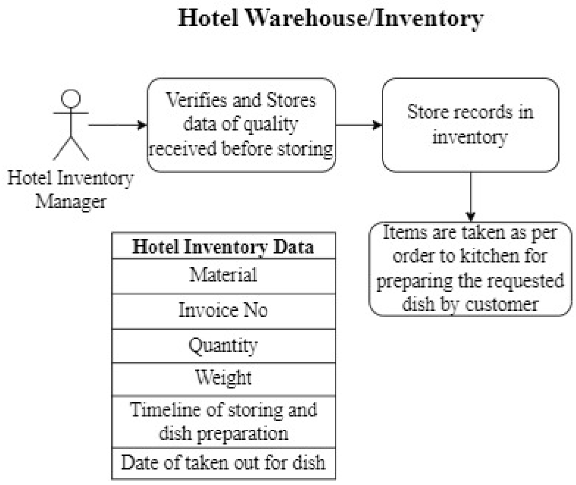

Figure 7. Hotel Inventory Flow Diagram

g) Hotel Kitchen: Prepares dishes using ingredients sourced from the hotel warehouse, ensuring menu consistency, food safety standards, and culinary quality. Utilizes real-time inventory data and supply chain information to plan menus, reduce waste, and maintain cost-effective operations.

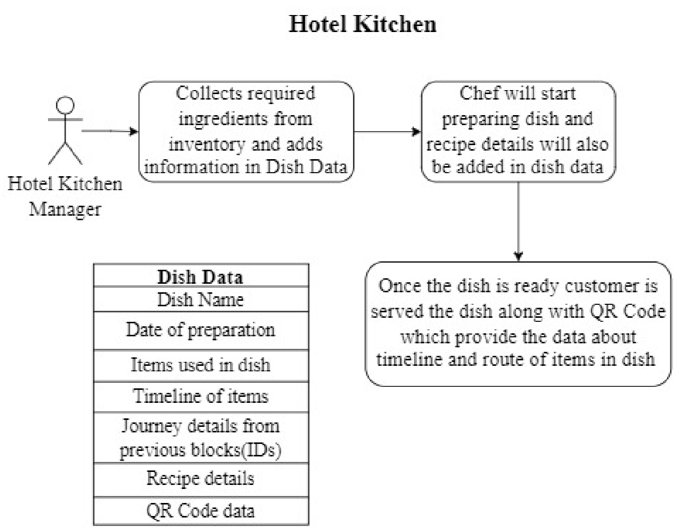

Figure 8. Hotel Kitchen Flow Diagram

h) Customer: Represents the end consumer who purchases and consumes dishes prepared in the hotel kitchen. Accesses information about the entire journey of the dish, including sourcing, production, and quality certifications through a QR code or similar tracking mechanism, ensuring food authenticity and transparency.

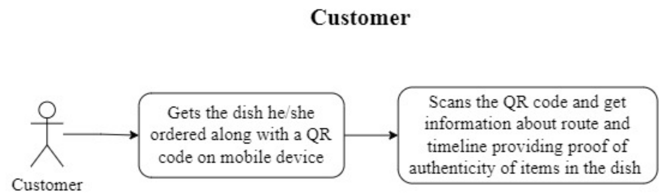

Figure 9. Customer Flow Diagram

4. Architecture

Despite its many advantages, the exorbitant expenses of data processing on blockchain have prevented it from being widely adopted. In order to tackle this problem, we suggest using blockchain mostly for data storage and leveraging current systems, including cloud services, for data processing and application handling duties. In order to guarantee the longevity of applications in practical situations, our method seeks to optimize blockchain network operations. Although our architecture is based on AWS Cloud services, developers, researchers, and system architects can easily switch to other cloud providers and select the cloud services that best fit their requirements and preferences.

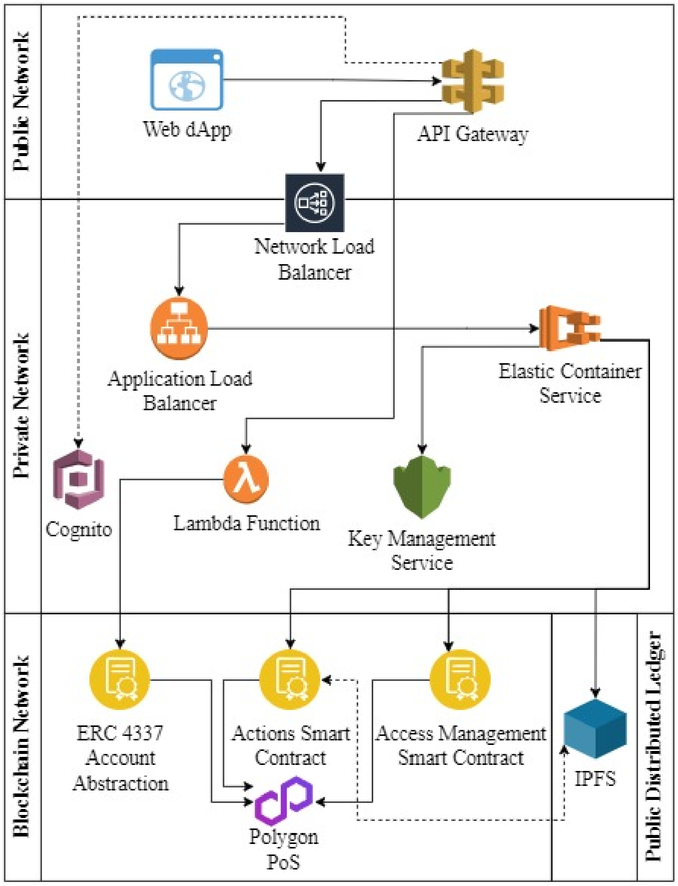

Figure 10. System Architecture

The architecture consists of 4 layers which will help to make the blockchain operations efficient and also secure the system by separation of operation at public and private network. Following is the detailed explanation of layers:

1) Public Network: This layer abstracts blockchain complexity and offers a user-friendly interface via a Web decentralized application (dApp). Stakeholder interactions are made easy by this dApp, which simplifies tasks of stakeholders for carrying out their activities on data in blockchain. API Gateways make supply chain data more accessible by enabling real-time data transmission between dApps and blockchain infrastructure. It prioritizes accessibility for all stakeholders and guarantees inclusion across platforms and devices. Data integrity and confidentiality are preserved via strong authentication and safe protocols. All things considered, this layer reduces blockchain complexity while promoting user-friendly navigation on platform.
2) Private Network Integrated between the Public Network and the Blockchain Network, this layer acts as a tactical bridge, precisely maximizing efficiency of data flow and computing operations. It dives into data processing mechanics, utilizing advanced computational frameworks and cloud services to manage jobs effectively, in contrast to the Public Network, which concentrates on user interaction. It guarantees the economic sustainability and scalability of the supply chain ecosystem by offloading data processing from the blockchain. Through encryption, access controls, and compliance procedures, this layer synchronizes and secures data in real time between the Public Network and blockchain. It essentially serves as the framework for the supply chain, allowing for cost-effectiveness, scalability, and agility while reducing the complexity of blockchain technology.
3) Blockchain Network This layer is a fundamental building block in architecture in our SCM application, which uses a decentralized ledger system to guarantee data integrity, immutability, and transparency. This layer uses blockchain's distributed consensus and cryptographic hashing to securely store important data, such as transaction records and product provenance. While consensus algorithms verify transactions without the need for centralized middlemen, smart contracts automate crucial tasks and enforce regulations and requirements throughout the ecosystem. Collaboration with cloud services in private network for data processing leads significant low burden and cost effective, also data insights are enhanced through integration with these external systems. In the end, this layer promotes efficiency, transparency, and trust, ushering in a decentralized and robust era of supply chain management.
4) Public Distributed Ledger As the last frontier in the supply chain architecture, this layer provides decentralized storage for additional data, enhancing the primary features of the blockchain network. It uses InterPlanetary File System (IPFS) technology to solve the cost and scalability issues related to storing non-transactional data on the blockchain. With decentralized storage offered by IPFS, accessibility and resilience are increased.

Following are components of architecture as per layers:

A. Public Network
1) Web dApp: The frontend aspect of the system will be constructed utilizing React JS. This component will furnish users with an intuitive interface through which they can engage with the supply chain management system seamlessly. Stakeholders will have the capability to observe and monitor the progress of diverse supply chain activities.
2) API Gateway: It will serve as the front door between the Web dApp and cloud services in a private network, offering a scalable and secure interface for users to communicate with backend services. It is placed on the public network to receive incoming client requests and

direct them to the relevant backend services. Reliable communication between the web application and backend services is ensured by the features of the API Gateway, which include traffic control, security, and monitoring.

B. Private Network

1) Network Load Balancer(NLB): This component is essential for efficiently handling large amounts of traffic. It ensures the continuous availability of the application by re-routing traffic to functional nodes. This method not only enhance performance and reduce latency to improve user experience, but it also fortifies network security by thwarting threats like Denial of Service (DoS) assaults and limiting access to authorized users only. Additionally, the application's fault tolerance is greatly enhanced by the NLB implementation, guaranteeing continuous service delivery even in the event of node failures or network interruptions.
2) Application Load Balancer(ALB): It performs an vital role in a blockchain-based web application architecture's scalability and effective load management. Without the need for upfront resource procurement, the ALB guarantees optimal resource use by dynamically scaling the application in response to changing levels of demand. The ALB smartly distributes incoming traffic by automatically scaling new instances or machines, thereby balancing the load throughout the application infrastructure as needed. Additionally, the ALB enhances overall system efficiency by facilitating exact traffic routing to critical components inside the system. The ALB efficiently lessens the burden on the blockchain network by controlling traffic off-chain, which improves operational cost-effectiveness. Furthermore, the ALB has extensive log monitoring features that makes monitoring, troubleshooting, and performance improvement tasks easy. The entire dependability and performance of the blockchain-based web application architecture are improved by this integrated monitoring capability, which also helps with maintenance and smooth operation.
3) Elastic Container Service: It serves as a platform that alleviates the deployment, management, and scaling of containers across the off-chain network. ECS makes it easier to perform critical activities across several components by integrating seamlessly with complementary private network layer components. It is an appealing option due to its adaptability for administering containerized apps in cloud environments.
4) Cognito: It is crucial for maintaining strong permission and authentication procedures in our blockchain-based web application architecture's cloud-based services. It gets credentials via the API Gateway from public layer, which it uses for authentication. It triggers Lambda function is used for user identity verification within the blockchain network with the help of ERC-4337 smart contract. This smart contract handles the complexities of blockchain operations at the private network and smart contract levels in addition to facilitating the integration of traditional Web 2.0 authentication methods with Cognito. Furthermore, it provides Identity Access Management (IAM) functionalities, which reduces blockchain computing overhead for access control across stakeholder in supply chain. It helps to facilitate the establishment of precise access controls for tasks carried out in the blockchain environment.
5) Lambda Function: They are fundamental components of our blockchain-powered web application's design, capable of carrying out actions in responding to events or triggers originating from various application components. They are essential because they act as backend integrations for API Gateway endpoints, each of which is connected to a lambda function that handles incoming HTTP requests, performs dynamic data processing, and generates responses. By allowing the customization of authentication workflows and performing validation on input and other parameters, lambda functions provide a substantial contribution to Cognito. Additionally, they provide as the foundation for initiating ECS operations or services in response to pre-established events, including changes to data in storage services or incoming messages from queues or streams. They are the backbone of our blockchain network components, providing the framework for controlling user requests, approving transactions, accessing blockchain data, and triggering smart contract operations through APIs. This feature is especially useful because it allows for real-time data processing outside the blockchain, which reduces the high costs involved in carrying out these activities directly on the blockchain network. Furthermore, lambda functions are used to communicate with the Key Management Service (KMS) in a seamless manner, enabling key management, encryption and decryption of sensitive data, and the enforcement of cryptographic policies—all of which improve security measures in the application architecture.
6) Key Management Service: The intent of using this service is to safely generate, store, and manage encryption keys. These keys are

essential for maintaining data secrecy in the framework of a web application architecture that is based on blockchain technology. Key Management Services (KMS) typically provide a centralized key management platform. But in a blockchain context, this can be expensive and require complex data processing tasks, which could lead to increased costs. However, KMS makes sure that encryption keys are stored securely, protecting them from loss or unwanted access. To do this, it leverages hardware security modules (HSMs) or other equivalent secure settings. We have used the KMS's automated key rotation feature to improve security. This reduces the dangers connected with long-term key usage by guaranteeing that keys are periodically refreshed without creating any disturbances. Beyond that, putting rigorous access restrictions in place to limit authorized entities' access to the encryption control in KMS. By safely sharing and managing encryption keys, it also makes it easier to establish secure communication routes between various application components, protecting data transferred over networks. Moreover, key usage recording and auditing are two elements that KMS incorporates to meet compliance standards, making it easier to comply with laws like GDPR and HIPAA. By allowing for the tracking of key access and usage, these features guarantee regulatory compliance.

C. Blockchain Network

1) Smart Contract: Solidity-written smart contracts serve as the bedrock for the system's backend. The rules and business logic that control supply chain operations are written down in these contracts. Their features include authentication, supply chain management activities like inventory control, procurement request supervision and other activities as discussed in methodology section above. Execution of these smart contracts will be facilitated by the Polygon Ethereum Virtual Machine(EVM).

a. ERC-4337 It is a smart contract standard also known as Account Abstraction, which aims to circumvent reliance on Externally Owned Accounts (EOAs) such as wallet providers like MetaMask. By doing so, it streamlines the management of accounts and transactions, reducing complexities for users. This standard effectively abstracts away the intricacies of blockchain account access and transaction handling, thereby enhancing the user-friendliness of our application and delivering a Web 2.0-like experience within the Web 3.0 paradigm, all without adding extra complexity. The smart contract efficiently manages blockchain operations, while data processing occurs within a private network facilitated by cloud services.

b. Actions Smart Contract: This smart contract contains the business logic for interacting with product supply chain blockchain data based on user-initiated events inside the application. It is important because it controls how data blocks on the blockchain are read and appended. It also interacts with InterPlanetary File System(IPFS) to store extra data like crop images and crop meta data which otherwise storing directly in blockchain is costly.For example, the contract initially validates the input in accordance with preset standards before permitting the data insertion when a farmer inputs data on a farmed crop and initiates the action to incorporate this data into the blockchain. In a similar vein, this contract manages how other stakeholders' requests to update or access data within the blockchain are validated and responded to.

c. Access Management Smart Contract: This smart contract specifies the permitted actions that stakeholders are allowed to perform on the blockchain and controls the distribution of those permissions. A farmer might, for example, be able to enter data on crops but not information about manufacturing operations. Sensitive information must also only be made available to specific stakeholders. In order to assure cost-effective operations, this smart contract works with Cognito to provide real-time validations for Identity Access Management (IAM) features. Validations exclusive to the blockchain, such address validations, are preserved for smart contract execution.

2) Polygon PoS: The Polygon network, formerly known as Matic Network, uses Polygon PoS, or Polygon Proof of Stake, as its consensus method. In order to validate transactions and produce new blocks, validators stake their tokens as collateral. This method improves scalability and lowers transaction costs while doing away with Ethereum's proof of work (PoW), which is energy-intensive. Polygon PoS addresses major issues facing the Ethereum ecosystem by putting efficiency and scalability first. This makes it easier and more affordable for users and decentralized applications (dApps) to interact with the Polygon network. The Polygon network's infrastructure is based primarily on smart contracts and Polygon PoS. Smart contracts allow programmable and self-

executing contracts to run on the network, whereas Polygon PoS uses a proof-of-stake consensus mechanism to handle block formation and transaction validation. When combined, these elements give developers the potential to create decentralized apps (dApps) that take advantage of the flexibility and scalability of Polygon's layer 2 solution as well as the security and functionality offered by smart contracts. The network provides a strong foundation for the creation of a variety of blockchain-based applications, from gaming platforms and supply chain management systems to decentralized finance (DeFi) protocols and non-fungible token (NFT) marketplaces. This process combines Polygon PoS with smart contracts to promote innovation and adoption within the blockchain ecosystem.

D. Public Distributed Ledger

1) IPFS : This layer functions as a storage for additional data that would be very expensive to store directly on the blockchain. This layer uses the InterPlanetary File System (IPFS) to store many kinds of data, including transaction metadata, images, and reports on supply chain activities. When compared to traditional cloud storage systems, IPFS provides a decentralized storage solution with content addressing, increased resilience, redundancy, and possible cost savings. IPFS distributes files among a network of nodes and uses content addressing to guarantee data integrity, immutability, and resistance to tampering. Peer-to-peer file sharing features combined with improvements in data privacy and management make it a desirable choice for our storage requirements.

5. Results

In this section we commence our research by comparing our design-based solution, Polygon PoS, with the well-established Ethereum blockchain using a combination of current blockchain statistics and insights from literature. By carefully examining transaction throughput, block time, scalability, and consensus methods, we outline the relative benefits and possible drawbacks of each platform. Through the integration of theoretical frameworks and empirical data, this study seeks to clarify the subtle differences in performance characteristics of Polygon PoS and Ethereum, laying the groundwork for a thorough examination.

A. Performance Evanluation

Following are metrics we have identified to compare our proposed blockchain solution

1) Transaction Throughput Transaction throughput, a key performance indicator in blockchain systems, is the number of transactions a network can handle in a given amount of time; it is commonly expressed in transactions per second (TPS). This measure is essential for assessing the effectiveness and scalability of blockchain systems. Block size, block time, consensus method, network congestion, and scalability solutions are some of the variables that affect it. A major obstacle to blockchain growth is increasing transaction throughput while maintaining security and decentralization, which highlights the continuous search for creative scalability solutions.
2) Block Time It is the average time needed to add a new block to the blockchain ledger, which is a crucial parameter in blockchain systems. Block time has a major impact on the speed at which transactions are confirmed and the scalability of the network, making it a crucial metric for assessing blockchain performance and efficiency. With distinctions seen across protocols and consensus methods, it acts as a standard for evaluating various blockchain systems. While shorter block times generally result in faster transaction confirmations, but might lead to issues including higher network congestion and the possibility of forks. As a result, strictly specifying block time is essential to guaranteeing precise platform comparisons and enabling well-informed decision-making in contexts related to blockchain development and deployment.
3) Transaction to Finality(TTF) It represents the moment when participants can be guaranteed that transactions are finalized safely and cannot be altered. Depending on the consensus technique used, such as Proof of Work (PoW) or Proof of Stake (PoS), there are different ways to reach finality. Finality is reached in PoW-based blockchains like Bitcoin as new blocks are added to the chain, whereas it is reached in PoS systems like Ethereum 2.0 through validator agreement.

	Polygon PoS	**Ethereum**
TPS(sec)	48	14
Block Time(sec)	2.25	12
TTF(min)	4.5	16

TABLE I. Metric Comparison

The most recent information on TPS, Block Time, and TTF as of April 2024 trends which was was obtained from Polygon's (https://polygonscan.com/) and Ethereum's (https://etherscan.io/) official websites. Following is the interpretation of results:

1) Transaction Per Second
   - Polygon PoS: This network is capable of processing transactions at a rate of 48 transactions per second (TPS). This indicates that it can handle a relatively significant number of transactions within a given time frame. It implies that has a reasonably high transaction

processing speed, which makes it appropriate for our SCM application that need quick and affordable transactions.

- Ethereum:Ethereum: In contrast, this comparison shows that Ethereum, one of the most widely used blockchain platforms, processes transactions at an average speed of 14 TPS. Ethereum's scalability has been hampered by issues with network congestion during spikes in demand, which cause long transaction processing times and expensive gas prices.

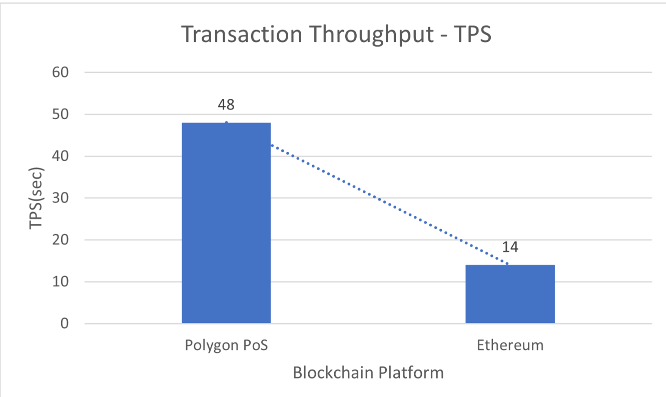

Figure 11. TPS Comparison Graph

2) Block Time

- Polygon PoS: In comparison to Ethereum, transactions on Polygon PoS are verified and put to the blockchain considerably faster, as evidenced by the low block duration of 2.5 seconds. Hence our SCM application on the Polygon network may benefit from faster transaction finality and improved user experience as a consequence.
- Ethereum: Compared to Polygon PoS, transactions for Ethereum can take longer to confirm and be uploaded to the blockchain because to its greater block period of 12 seconds. Ethereum's extended block time may result in slower transaction processing and possibly higher latency for some applications, despite the fact that it is still widely used and approved.

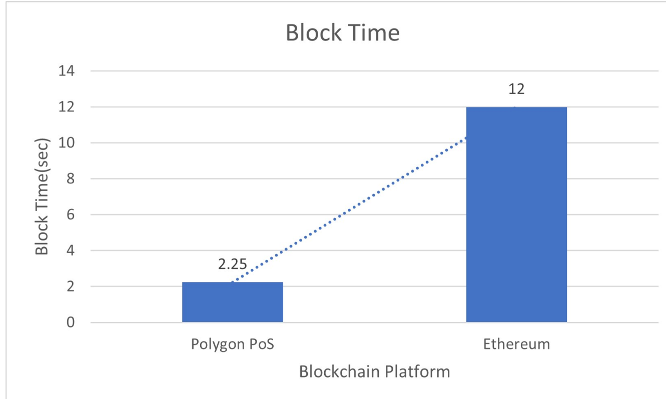

Figure 12. Block Time Comparison Graph

3) Transaction to Finality(TTF)

- Polygon PoS: The transaction finality time of 4.5 minutes is around 3times shorter than Ethereum, indicating that transactions on Polygon PoS are verified and deemed final rather rapidly. For our SCM application it is beneficial since it resolves transactions quickly.
- Ethereum: Compared to Polygon PoS, transactions on the Ethereum network require a longer time to reach finality, as evidenced by the lengthier transaction finality time of 16 minutes for Ethereum. This extended finality period could potentially affect the user experience for our application and cause delays in transaction settlement between stakeholders making SCM less productive.

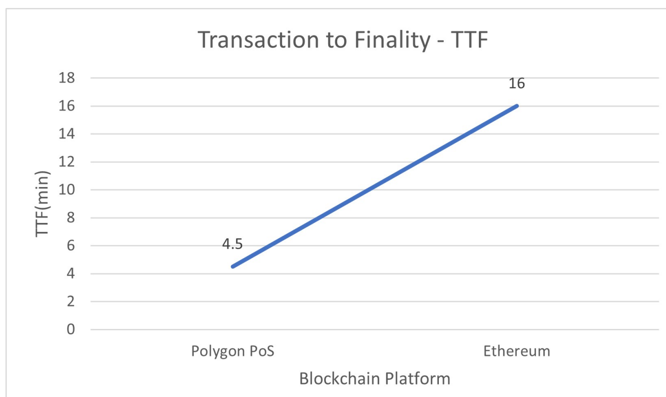

Figure 13. TTF Comparison Graph

6. Conclusion

In conclusion, our proposed architecture for food supply chain management offers an appealing approach that makes use of the advantages that blockchain technology and cloud services have to offer in order to boost supply chain efficiency, reduce risks, and improve transparency.

The adoption of smart contracts for automated governance and blockchain technology for tamper-proof data storage in our design allows for a high degree of transparency and accountability, which lowers the risk of food adulteration and safeguards public health. By incorporating cloud services for data processing, our solution overcomes a major financial obstacle to the widespread use of blockchain technology and makes it more affordable and widely applicable. Additionally, the incorporation of Account Abstraction guarantees a smooth user experience, allowing users to transition between Web2 and Web3 interfaces without encountering extra complexity. Polygon blockchain is a viable platform for scalable supply chain applications because it provides low costs and rapid transaction speeds as the underlying infrastructure. Its ability to work with other Ethereum side chains improves flexibility and interoperability even further, making it easier to integrate with different blockchain ecosystems. All things considered, our design has the potential to make a substantial contribution to society by protecting the food supply chain's integrity and thwarting illicit food adulteration. By clearly defining roles and involving additional stakeholders, our revised design improves efficiency and transparency while focusing on the advantages of our solution for the food sector and beyond.

7. Future Work

Our future advances will concentrate on implementing the proposed architecture into execution and improving it, paying close attention to the possibilities that Account Abstraction presents. Since this standard is still in its infancy and has not yet gained widespread traction, innovative efforts are required to create fully functional apps built upon this idea. It will be crucial to address scalability issues, especially in light of our SCM application's critical need for scalability. It will be necessary to employ creative implementation strategies for Account Abstraction in order to satisfy the demands of our expanding supply chain ecology.

Furthermore, blending Internet of Things (IoT) devices offers an intriguing possibility to enhance the system even further. We can improve visibility, traceability, and responsiveness in the supply chain by utilizing IoT devices to collect real-time data at different points. IoT sensors can follow the flow of commodities, monitor the environment, and identify anomalies or irregularities. These capabilities enable proactive decision-making and risk mitigation.

We can enhance our supply chain management system's efficiency, transparency, and robustness by fusing Account Abstraction with IoT integration. In order to meet changing possibilities and difficulties in the food supply chain and eventually contribute to safer, more secure, and more sustainable food systems going forward, future research and development activities will concentrate on utilizing these technologies.

References

[1] A. N. Putri, M. Hariadi, and R. F. Rachmadi, "Supply chain management serious game using blockchain smart contract," *IEEE Access*, vol. 11, pp. 131 089–131 113, 2023.

[2] D. Patel, A. Sinha, T. Bhansali, G. Usha, and S. Velliangiri, "Blockchain in food supply chain," *Procedia Computer Science*, vol. 215, pp. 321–330, 2022, 4th International Conference on Innovative Data Communication Technology and Application. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1877050922021056

[3] T. M. Tan and S. Saraniemi, "Trust in blockchain-enabled exchanges: Future directions in blockchain marketing," *Journal of the Academy of Marketing Science*, vol. 51, 07 2022.

[4] S. Aich, S. Chakraborty, M. Sain, H.-i. Lee, and H.-C. Kim, "A review on benefits of iot integrated blockchain based supply chain management implementations across different sectors with case study," in *2019 21st International Conference on Advanced Communication Technology (ICACT)*, 2019, pp. 138–141.

[5] Y. Madhwal, Y. Yanovich, S. Balachander, K. H. Poojaa, R. Saranya, and B. Subashini, "Enhancing supply chain efficiency and security: A proof of concept for iot device integration with blockchain," *IEEE Access*, vol. 11, pp. 121 173–121 189, 2023.

[6] N. Kshetri, *International Journal of Information Management*, vol. 60, p. 102376, 2021. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0268401221000694

[7] A. Alamsyah, S. Widiyanesti, P. Wulansari, E. Nurhazizah, A. S. Dewi, D. Rahadian, D. P. Ramadhani, M. N. Hakim, and P. Tyasamesi, "Blockchain traceability model in the coffee industry," *Journal of Open Innovation: Technology, Market, and Complexity*, vol. 9, no. 1, p. 100008, 2023. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2199853123001105

[8] S. Kravenkit and C. So-In, "Blockchain-based traceability system for product recall," *IEEE Access*, vol. 10, pp. 95 132–95 150, 2022.

[9] S. F. Wamba and M. M. Queiroz, "Blockchain in the operations and supply chain management: Benefits, challenges and future research opportunities," *International Journal of Information Management*, vol. 52, p. 102064, 2020. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S026840121931792X

[10] M. Kopyto, S. Lechler, H. A. von der Gracht, and E. Hartmann, "Potentials of blockchain technology in supply chain management: Long-term judgments of an international expert panel," *Technological Forecasting and Social Change*, vol. 161, p. 120330, 2020. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0040162520311562

[11] S. Jabbar, H. Lloyd, M. Hammoudeh, B. Adebisi, and U. Raza, "Blockchain-enabled supply chain: analysis, challenges, and future directions," *Multimedia Systems*, vol. 27, pp. 1–20, 08 2021.

[12] M. S. Sangari and A. Mashatan, "A data-driven, comparative review of the academic literature and news media on blockchain-enabled supply chain management: Trends, gaps, and research needs," *Computers in Industry*, vol. 143, p. 103769, 2022. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0166361522001658

[13] G. Narayanan, I. Cvitić, D. Peraković, and S. P. Raja, "Role of blockchain technology in supplychain management," *IEEE Access*, vol. 12, pp. 19 021–19 034, 2024.

[14] F. Dietrich, Y. Ge, A. Turgut, L. Louw, and D. Palm, "Review and analysis of blockchain projects in supply chain management," *Procedia Computer Science*, vol. 180, pp. 724–733, 2021,

proceedings of the 2nd International Conference on Industry 4.0 and Smart Manufacturing (ISM 2020). [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1877050921003446

[15] G. Casella, B. Bigliardi, S. Filippelli, and E. Bottani, "Cases of application of blockchain on the supply chain: a literature review," *Procedia Computer Science*, vol. 217, pp. 1416–1426, 2023, 4th International Conference on Industry 4.0 and Smart Manufacturing. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1877050922024255

[16] H. Yuan, H. Qiu, Y. Bi, S.-H. Chang, and A. Lam, "Retraction note: Analysis of coordination mechanism of supply chain management information system from the perspective of block chain," *Information Systems and e-Business Management*, vol. 21, 12 2022.

[17] Surjandy, Meyliana, H. L. H. Spits Warnars, and E. Abdurachman, "Blockchain technology open problems and impact to supply chain management in automotive component industry," in *2020 6th International Conference on Computing Engineering and Design (ICCED)*, 2020, pp. 1–4.

[18] S. Doguchaeva, S. Zubkova, and Y. Katrashova, "Blockchain in public supply chain management: advantages and risks," *Transportation Research Procedia*, vol. 63, pp. 2172–2178, 2022, x International Scientific Siberian Transport Forum — TransSiberia 2022. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2352146522004999

[19] Z. Liu and Z. Li, "A blockchain-based framework of cross-border e-commerce supply chain," *International Journal of Information Management*, vol. 52, p. 102059, 2020. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0268401219304657

[20] D. J. Ghode, R. Jain, G. Soni, S. K. Singh, and V. Yadav, "Architecture to enhance transparency in supply chain management using blockchain technology," *Procedia Manufacturing*, vol. 51, pp. 1614–1620, 2020, 30th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM2021). [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2351978920320965

[21] S. Sahoo, S. Kumar, U. Sivarajah, W. M. Lim, J. Westland, and A. Kumar, "Blockchain for sustainable supply chain management: Trends and ways forward," *Electronic Commerce Research*, 05 2022.

[22] U. Agarwal, V. Rishiwal, S. Tanwar, R. Chaudhary, G. Sharma, P. N. Bokoro, and R. Sharma, "Blockchain technology for secure supply chain management: A comprehensive review," *IEEE Access*, vol. 10, pp. 85 493–85 517, 2022.

[23] S. Kadam, R. Senta, R. K. Sah, A. Sawant, and S. Jain, "Blockchain revolution: A new horizon for supply chain management in hotel industry," in *2024 International Conference on Emerging Smart Computing and Informatics (ESCI)*, 2024, pp. 1–8.

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