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Optimizing Hotel Food Supply Chain Management Through Smart Contracts

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***Abstract*: The complex structure of hotel food supply chains presents significant challenges for monitoring product safety and quality, largely due to the involvement of numerous participants, lengthy supply chain cycles, and mistrust in both data and centralized systems. Traditional hotel food supply chains often suffer from poor communication and fragmented information, making traceability and rapid response to safety issues difficult. This paper addresses these challenges by proposing a framework based on Blockchain technology, smart contracts, and consortium models to enhance traceability, data authenticity, and operational transparency in hotel food supply chains. The framework leverages smart contracts to automate transactions and compliance, while the InterPlanetary File System (IPFS) is used for decentralized storage of environmental and crop growth data, with file hashes stored on-chain to improve data security and prevent blockchain storage explosion. By reducing reliance on central institutions and promoting data shareability, the proposed system dismantles information silos and increases trust among supply chain participants. The paper includes a comparative analysis of hotel food supply chain issues and practices in India, China, and the United States, providing a case study for each country. Furthermore, it discusses future risks associated with implementing Blockchain-based traceability in hotel food supply chains and outlines strategies for risk mitigation.**

***Keywords*: Blockchain, smart contract, hotel food supply chain, traceability, food safety, InterPlanetary File System (IPFS).**

1. Introduction

The supply chain creates a complex network chain structure by linking numerous entities, including suppliers, logistics companies, processors, distributors, retailers, and consumers. This intricate supply chain can involve dozens or even hundreds of steps, consuming a significant amount of time and spanning multiple geographical locations. Thus, in this situation, the traceability process is very challenging if the product has safety or quality issues. Particularly in hotel food supply chains, the procedure guarantees the traceability of the finished goods, which not only protects the life and health of the consumer but also increases user confidence in the food and hotel chain. Food safety and quality have received increased attention in recent years due to a high number of food safety incidents. However, it is challenging to monitor and trace issues in a particular link because of the lengthy life cycle, many complex links, dynamic information, etc. that characterize the current hotel food supply chains. Hotel food is defined as food prepared by a hotel that is regularly consumed by guests and whose significance is obvious. Establishing and enhancing the hotel food supply chain traceability system "from farm to fork" is therefore crucial.

The current hotel food supply chains have three main issues. First, the supply chain has a lengthy cycle because there are numerous participants and communication between them is inconvenient. Subsequently, the data is not trusted by participants, and information sharing is inadequate due to the large number of participants and distribution across various links. Lastly, the hotel food supply chain is a system where power is centralized among the participants, making it easy to tamper with their data. Because of this, research on advanced traceability technology and its systems has significant research value to ensure the quality and safety of the food by efficiently tracking product information, ensuring product safety and quality, and ultimately ensuring consumer safety.

Blockchain is a distributed ledger system that comprises of separate individual blocks in the form of a decentralized database. Consequently, it exhibits the qualities of traceability, immutability, anti-tampering, and decentralization. Blockchain technology is incorporated into agricultural food traceability systems to monitor supply chain process data, enhance the credibility of the information, visualize supply chain process data, and ensure information traceability, respectively. In order to eliminate the need for central agencies and intermediaries and enhance transaction record integrity, reliability, and security, this paper suggests a framework based on consortium chain and smart contracts to track and trace workflows in hotel food supply chains, implement traceability and shareability of supply chains, and disrupt information islands between enterprises as much as possible. Farmers simultaneously enter crop growth data and environmental information into the InterPlanetary File System (IPFS). Smart contracts are used to store the file IPFS hash, which improves data security and mitigates the issue of blockchain storage explosion.

2. Preliminaries

A. Blockchain

Blockchain is a distributed ledger system that comprises separate individual blocks in the form of a decentralized

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database. Although this technology is still new to the worldwide market, the rise in popularity of bitcoin has helped blockchain technology to emerge into the public consciousness, due to which it has also become a hot topic in recent years. Blockchain offers advantages such as decentralization, anti-tampering, immutability, traceability, etc. It is popularly applied in the fields of medical treatment, finance and banking, education, and supply chain traceability.

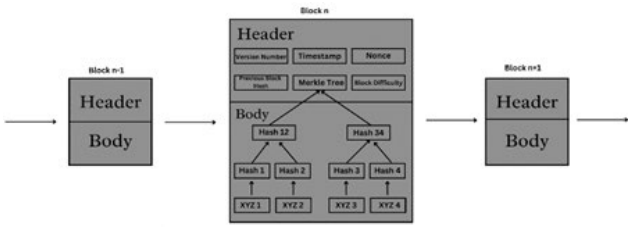

Fig. 1. Structure of blockchain
(Source: [1] Wang et al., 2021)

As seen in the figure, the connection of two blocks is produced by the hash value of each preceding block. The block comprises the header and the body of the block. The header of the block contains a version number, timestamp, nonce, previous block number, Merkle tree and block difficulty. The difficulty of mining of the block is dependent on the block difficulty. Nonce is a certain number that is used in the process of mining to generate a valid hash for a new block in the chain. The timestamp is the generation time of each block, which corresponds to the authentication of each transaction record, ensuring authenticity of the transaction record. The body comprises the transaction data.

A Merkle tree is a data structure used in blockchain to summarize, and efficiently and securely verify all the transactions in a block. Each leaf node makes the use of the hash of the data block as its tag. Every non-leaf node uses the encrypted hash of its child node's tag as its tag, while every leaf node uses the hash of the data block. Each transaction's hash value is used as a leaf node, as seen in the diagram's body. The parent node, or Merkle root, is created by combining the hash values of the two leaf nodes for a subsequent hash computation. If the transactions are tampered with, the value will be inconsistent. This ensures authenticity of the data and enables users to quickly find the data they are searching for. Blockchain technology is fundamentally transforming supply chain management by introducing decentralized, immutable ledgers that enhance transparency, traceability, and trust among stakeholders.

The global market for blockchain in supply chains is projected to reach approximately USD 3.15 billion by 2028, growing at a compound annual growth rate (CAGR) of 51.3% between 2022 and 2028. *(Zion Market Research, 2022)*

B. Hotel Food Supply Chain

The hotel food supply chain is a long and complex process involving several steps to ensure efficient and reliable options. Few key steps in this supply chain include sourcing, production, distribution, preparing and retail. Fig. 2 shows the structure of the hotel's food supply chain.

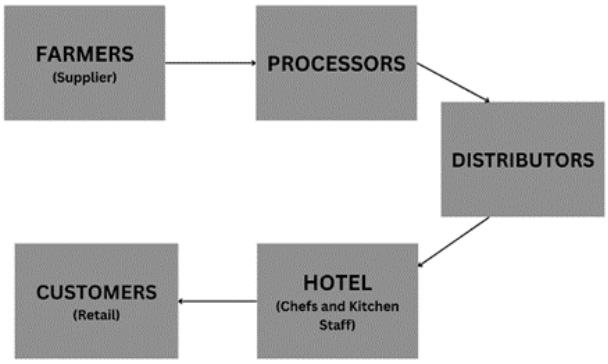

Fig. 2. Hotel's food supply chain diagram
(Source: Authors Own Work)

Hotels source ingredients and food products from various suppliers, including farmers, wholesalers, and distributors. Having knowledge about the origin of raw food products is essential for both the customers as well as hotels.

The food products sent by the suppliers aren't always ready to be used by the hotel chefs and kitchen staff. Accordingly, these products have to be processed into final products as per the requirements of the hotel.

Logistics and transportation are vital for moving the supplies from suppliers (or processors) to the hotel. This is dealt with by the distributors. The distributor is responsible for selling the goods to different hotels effectively and in minimum time possible.

The hotel's chefs and kitchen staff have to handle the task of preparing the sourced ingredients into final products that can be served to the customers. Kitchen staff play a critical role in this process, ensuring that food is prepared according to the hotel's standard and menu specifications.

The final step, i.e. retail, is serving the guests the food prepared by the hotel's staff. Ensuring the customers satisfaction and meeting their expectations is one of the most important tasks of a hotel.

Although this supply chain is the most commonly used method of supply of food from farm to fork, there are several limitations regarding the conventional method. Food traceability, ensuring maintained quality, transparency, safety risks relating to food items, etc, are the most commonly found drawbacks. Even large hotel chains like Marriott International's The Luxury Collection has recognised the challenges posed by conventional food supply chains, particularly concerning food traceability and quality maintenance. **(Walker, 2020)*

In the food industry, blockchain-based traceability systems have been implemented to address food scandals and recalls. For example, the IBM Food Trust platform enables food companies to track products from farm to table. *(Leswing, 2017)* This system allows rapid identification of contamination sources—such as in the 2017 US papaya Salmonella outbreak—helping to prevent the spread and reduce recall times.

C. Consortium Chain

The blockchain is divided into private chain, public chain and consortium chain. The private chain, which has the least amount

of decentralization and is typically the blockchain inside an organization, is primarily controlled by an individual or group. In the public chain, anyone can see transactions and participate in the consensus process. This has an open network without any authorisation and is regarded as complete decentralization.

In order to preserve the distributed structure, restrict the number of participants, and ensure security, the consortium chain, which sits between the public and private chains, is a unique blockchain that requires registration and authorization. It is only accessible by designated organizations or institutions. By using pre-selected nodes to validate data and blocks instead of all nodes in the network, the consensus algorithm is implemented, speeding up block generation and reducing the time needed to validate data and reach consensus. As a result, the consortium chain has traits like few consensus nodes, high system operation efficiency, and quick transaction rate. The use of smart contracts in conjunction with hotel's food traceability systems can effectively address the problem that current systems are built on the foundation of a single enterprise development, disrupting the information islands between enterprises and making the adoption of consortium chains in hotel's food traceability systems more appropriate. Hotel's food traceability systems have high requirements with regard to privacy protection, transaction speed, and internal supervision.

IBM Food Trust is a consortium blockchain platform connecting farmers, processors, distributors, retailers, and others in the food supply chain. Major retailers like Carrefour have joined this network, which enables participants to track food products' origins, movements, and certifications. For example, Carrefour uses the system to trace products across its 12,000 stores in 33 countries, ensuring compliance, reducing food waste, and building consumer trust. *(Pedd, 2018)*

D. Hyperledger

The Linux Foundation launched the open-source collaborative project Hyperledger in 2015 with the goal of advancing blockchain technology and transaction verification. For enterprise application scenarios involving tech and financial behemoths like IBM, Intel, Cisco, and R3, it is the first distributed ledger platform. Hyperledger is separated into tools, libraries, and distributed ledger technology. The most significant Hyperledger application project is Fabric, a general license blockchain with extensible and modular features that essentially departs from the order-execution model and adheres to the execution-sequence-validation paradigm. Four components make up Fabric: (1) Outlining the functions of the nodes in the infrastructure; (2) Putting the smart contracts into action; (3) Configurable Consensus; and (4) Membership Services, whose modular design offers a high level of secrecy, adaptability, and extensibility suitable for any sector. HyperLedger uses a membership service provider (MSP) to control node permissions and creates a consortium chain via a channel. A crucial communication tool, the channel is a separate channel for members to communicate with one another; only channel members can view transactions sent through it. The network may have more than one channel, and each channel keeps track of its own account.

3. Challenges in Hotel Food Supply Chains Globally

In this section, we show the food supply chain prevalently used by the hotel industry in three different countries (India, China and United States of America) and display the problems in their food supply chains. This section also gives case studies for each country.

A. India

Farmers are the first link in India's hotel food supply chain, which is frequently governed by state Agricultural Produce Market Committees (APMCs) under the APMC Act. This can result in inefficiencies and fragmentation. Next are processors, who are overseen for quality compliance by the Food Safety and Standards Authority of India (FSSAI). Distributors oversee inventory and last-mile hotel deliveries, including logistics companies like Gati. After that, hotels buy ingredients either through decentralized hotel-level ordering or through centralized procurement systems, such as collaborations with Gati. Lastly, the food is consumed by people who are becoming more worried about safety and traceability. The supply chain's fragmented structure, which results from many relying on APMC-regulated mandis (markets), is a major obstacle that makes it difficult to track the origins of food. For example, while about 33% of India's restaurant sector is organized, many hotels still use manual inventory systems, leading to stockouts or excess inventory. *(Kapur & Krishnamurthy, 2014)*

For instance, if a hotel in Mumbai purchases basmati rice from a farmer in Punjab, it would be challenging to pinpoint the rice's precise origin and growing conditions because it goes through several middlemen at various mandis. Startups are testing blockchain-based live kitchen visibility systems to give customers greater transparency, while some businesses, like Gati, are attempting to combine forecasting, warehousing, and last-mile delivery to expedite the process.

B. China

The China Food and Drug Administration (CFDA) oversees processors after farmers, who are overseen by provincial agricultural bureaus, in the country's hotel food supply chain. Distribution frequently depends on hotel-owned centralized purchasing systems or supermarket networks like Hema. While domestic hotels rely more on dispersed suppliers, international hotel chains such as Marriott usually have strong internal procurement procedures. In the end, the food is consumed by people who want safer, more traceable food options, particularly in the wake of COVID-19. The absence of a nationwide distributor comparable to Sysco in the US is a major obstacle that makes tracking ingredients difficult. Blockchain integration is frequently absent from domestic hotels, which reduces transparency. *(Xian & Flemings, 2023).*

For instance, a hotel in Shanghai may purchase seafood from a supplier in Shandong province, but it would be challenging to track the seafood's precise origin and handling without blockchain technology or a centralized system. Concerns regarding adulteration or inappropriate storage may arise from this. However, by allowing farm-to-table tracking through their integrated systems, supermarket chains like Hema are

attempting to increase transparency.

C. United States of America

The USDA regulates farmers at the beginning of the food supply chain for US hotels, and the FDA monitors processors to ensure that safety regulations are met. Companies like Sysco, which supply about 60% of the US foodservice market, dominate the distribution sector and offer a streamlined, effective connection to hotels *(Sysco Corporation, 2024)*. In order to improve supply chain visibility, these hotels frequently employ tech-driven inventory systems, such as IoT sensors for real-time tracking. Lastly, as demonstrated by Walmart's IBM Food Trust program, the food reaches customers who have high standards for local and organic sourcing as well as blockchain-based traceability. Even with these sophisticated systems, there are still issues, like recalls (like the E. coli outbreaks in lettuce) that draw attention to weaknesses in farm-to-fork tracking. *(Centers for Disease Control and Prevention, 2018)*

For instance, a five-star hotel in California purchases avocados from a nearby farm but depends on Sysco for other ingredients. Although they can guarantee the traceability and quality of the local avocados, auditing every supplier for Sysco becomes more challenging, possibly increasing the risk of noncompliance. By tracking leafy greens from farm to store, businesses like Walmart are able to increase transparency through the use of blockchain systems like IBM Food Trust.

D. Common Problems

Hotels' food supply chains face many challenges in maintaining the quality and safety of their food. A lack of transparency brought on by centralized systems that encourage mistrust and restrict information sharing is one of these issues, as is a lack of end-to-end traceability brought on by the involvement of multiple parties and intricate procedures. Moreover, the ineffective communication among the many stakeholders causes delays and inaccurate information exchange, and the current centralized systems are vulnerable to data tampering, jeopardizing data integrity. This paper proposes a solution leveraging blockchain technology to address these problems. Through the use of a consortium blockchain, the framework makes traceability easier by logging each transaction on a distributed, immutable ledger, enabling full tracking from farm to table. The shared nature of the blockchain, which gives authorized participants access to the same verified information, improves transparency. Smart contracts automate procedures, improve communication, and enforce agreements, while blockchain's built-in security features guard against data manipulation. These features increase the hotel food supply chain's overall effectiveness and trust.

4. Hotel Food Supply Chain Traceability Based on Blockchain

In this section, we build a consortium chain and smart contracts called chaincode using the hyperledger fabric to monitor and carry out transactions in the hotel's food supply chain.

Decentralization is achieved, the necessity for a central authority is removed, and comprehensive, trustworthy, and authenticity and dependability of the hotel's food information that eventually reaches the consumer are guaranteed by safe transaction records for the management and security of the hotel's food supply chain.

A. Overview

Smart contracts can guarantee the quality and safety of a hotel's food by combining the hotel's food supply chain steps and hotel's food safety into a single integrated intelligent system, ensuring the health safety of customers. An automated smart contract framework for the hyperledger platform is presented in this paper. Smart contracts automatically send out preset data resources, including the trigger condition events, when the trigger condition is met, as stated in the agreed contract. Instead of creating or altering smart contracts, this system of state mechanisms and transaction processing modules merely makes it possible for a complicated collection of digital commitments with trigger conditions to be carried out correctly in accordance with the participants' wishes. The smart contracts are executed by tens of thousands of nodes distributed around the world and are the result of agreement. Nodes, or participating entities in the hotel's food supply chain, are one of the blockchain network's constituents. These nodes have the ability to gather, verify, and carry out transactions. They can also store the information and outcomes of these transactions in a ledger, which will eventually be duplicated and synchronized by every node. Consequently, every node has identical ledger data without any exceptions. Consequently, smart contracts allow participating entities to continuously monitor, track, and receive the proper alerts when violations occur by receiving transactions and triggering events in the form of function calls.

Fig. 3 shows a general overview of the structure of the supply chain. This includes the agriculture bureau, farmer, processor, quality supervisor bureau, distributor, hotels, the final consumer, and the blockchain imposing smart contracts.

As illustrated in Fig. 3, hyperledger smart contracts are used to record information and include all parties involved in the hotel's food supply chain in order to achieve traceability of the hotel's food. To guarantee the accuracy of source data, the agricultural bureau maintains records of farmer, seed, plot, yield, and other information. It also manages farmers' output in a unified manner. Farmers grow crops and enter environmental and growth detail data in IPFS, where timestamps are used to identify the crops' growth photos. Timestamps give the user electronic evidence of the creation date of some of their data since they represent complete and verifiable data that already exists at a specific moment in time. The IPFS hash for the file is stored in the smart contracts. When the crops mature, the farmer harvests them and sells them to a process for a series of processing to be done. The quality supervision bureau keeps an eye on the processing to guarantee the agricultural food's safety and quality. These food items are then purchased in bulk by a distributor, who helps distribute the food to several different hotels. These hotels' chefs and kitchen staff finally prepare the finished food product and serve it to their customers.

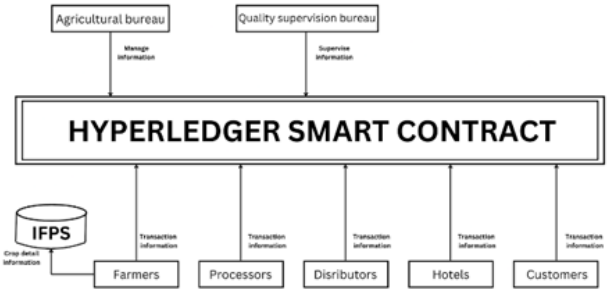

Fig. 3. A system overview for hotel's food traceability using hyperledger smart contracts
(Source: Authors Own Work)

The organization storing the data uses a digital signature to encrypt the data stored in the blockchain or IPFS, which has the following benefits: (1) Anti-tampering: Following signing, the integrity of the data is guaranteed by calculating and verifying the signature to ascertain the authenticity of the data; (2) Non-repudiation: A digital signature can be used as proof of the signer's activity or as the identity authentication of the stored data entity; (3) Confidentiality: Although digitally signed data must be decrypted in order to recover the original data, data loss is likely to result in data leakage. The blockchain uses smart contracts to automatically run programs, entities are in charge of their own data, and entities will carry out corrective actions if they engage in unlawful activity. During the planting phase, farmers use a range of sensors to send real-time crop details and information about the growing environment to the server. The data can be audited and trusted because it is not processed by humans, which improves its authenticity and anti-tampering properties.

B. System Design

The hotel food supply chain consists of several levels of production and transportation, i.e. "from farm to fork". It also comprises of the interaction of different persons with the process of production and transportation. This makes the process of traceability and authentication very challenging and time consuming. Thus, in order to facilitate traceability, we note the data and include the food's unique identity and lot number in every subsequent transaction, when the transaction is started, and the hash value is recorded to guarantee the transaction's legitimacy. This unique identity's lot numbers are given in batches. A batch is a group of food items that are brought in the warehouse at the same time period. In order to tackle the issues of IPFS limitations and blockchain data explosion, the transaction data is stored in IPFS, while the data hash is kept in the hyperledger. Blockchain reads and writes are restricted by access control policies, which improve data security by guaranteeing that only authorized users carry out transactions. Likewise, only particular entities can execute smart contracts. Entities communicate with one another via smart contracts after registering in the system. Fig. 4 shows the overview of the hotel food supply chain that is taken into consideration in this paper.

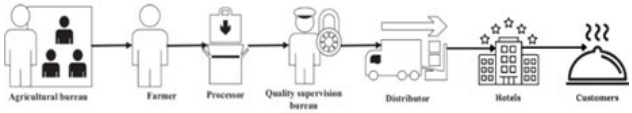

Fig. 4. The simple process in the hotel food supply chain
(Source: Authors Own Work)

1) Agricultural Bureau

The Agriculture Bureau is a management organization that maintains records of farmers, seed, plot, and yield data to guarantee the reliability of the information's original sources. Its hash value is kept on the chain, and the data is kept in the IPFS.

2) Farmer

The farmer is in charge of planting crops, monitoring and documenting crop growth data using sensors, including soil quality, sunlight, air, and water in the growing environment, and storing images or MPEG files in IPFS that contain information about the crop growth process. The farmer is also in charge of developing smart contracts and putting IPFS data hashes in them.

3) Processor

The processor transforms the raw crops into produce that the hotels buy after the farmer sells them. The processor then enters the batch, quantity, and inspection details of the final goods into IPFS.

4) Quality Supervisor Bureau

The implementation of product quality supervision and mandatory inspection of production companies are the primary responsibilities of the quality supervision bureau, which also oversees processing and provides guidance for quality supervision and inspection. Its data is recorded on the IPFS, and the hash value is kept on the blockchain, in order to look into and penalize infractions of laws and regulations pertaining to standardization, measurement, and quality as well as to combat illegal activities associated with counterfeiting and low-quality goods.

5) Distributor

Before the processed product reaches the hotels, it might pass through several distribution stages. The distributor is in charge of keeping processed foods in storage and supplying the hotels with them. IPFS stores company data, product selling hours, prices, and other details. Similar to the quality supervision bureau, blockchain stores the hash value to guarantee that the data that follows is not altered.

6) Hotel

Once the food item reaches the hotel, the hotel's chefs and kitchen staff make the final food item that is to be served to its customers. Information of time of processed food arrival, time of storage, name of the chefs and other information is recorded in IPFS, and the hash value is also recorded in the blockchain. After storing the data hash in the blockchain, the data label is created in the form of QR code and presented to the customer while serving the food item.

7) Customers

Consumers are the users who purchase and consume the final food item, and can obtain the complete supply chain information of the food by scanning the QR code, given with

the food item, to realize the traceability function of the food information which they are about to eat. The QR code will be linked to a radio frequency identification device (RFID), which will track the supply chain and present the details.

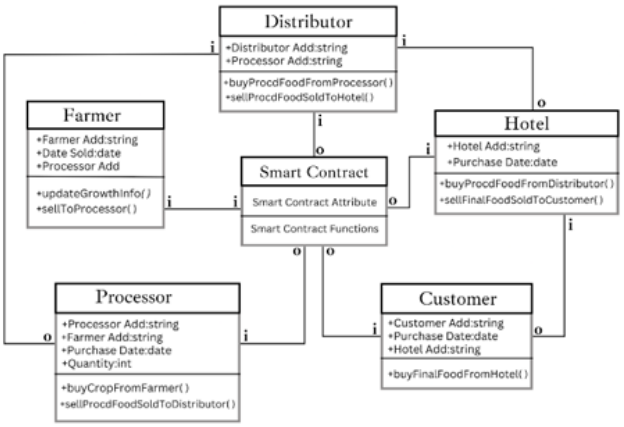

Fig. 5. Entity relationship diagram
(Source: Authors Own Work)

C. Food Supply Chain Interfaces

In software and system design, interfaces are standardized points of interaction that specify how various modules or components communicate with one another. They also specify what functions or operations must be provided by each module or component without imposing any particular implementation style. Interfaces are particularly helpful in the hotel food supply chain because they allow different players, including distributors, processors, farmers, and regulatory agencies, to communicate with the blockchain system without any problems, irrespective of the underlying technologies or procedures. This framework becomes modular and flexible by creating distinct interfaces for data submission, verification, and smart contract interaction. This enables various stakeholders to update or modify their internal systems without interfering with the supply chain traceability solution as a whole. As the food supply chain changes, this modularity guarantees that the blockchain-based system will continue to be reliable, compatible, and simple to maintain. It also facilitates scalability and the integration of new technologies.

1) Farmers

In this blockchain system, the farmer interface would be centered on documenting and validating important agricultural data. The farmer will get the supplier interface. On the blockchain, farmers would use functions to verify their identity and credentials, such as location and certifications. In order to provide a comprehensive record of the crop's lifecycle, they would use *updateGrowthInfo( )* to add information about their crops, including batchID, cropType, seedInfo, plantingDate, harvestDate, and yield qualityReport. This would include the crop type, seed information, and planting date for each batch, as well as results from crop harvesting, including yield and a quality report. Farmers would document growth information, environmental conditions, and pertinent photos stored on IPFS with the hash recorded on the blockchain to guarantee transparency and traceability.

2) Processor

The processor interface would manage the handling and transformation of raw agricultural products. When a crop batch gets delivered from a farmer, the processor notes the quantity and transportation details. The processor would record the crop batch's processing, including process details and quality control outcomes, while it was being processed.

3) Distributor

The distributor interface controls the products' storage and transportation. A product batch's receipt from the processor would be noted by the distributor, along with the quantity and transportation information. Then, in order to maintain quality, they would use the interface to record the product batch's storage conditions. The distribution process would then be completed by *sellProcdFoodToHotel( )*, which would document the product batch's delivery to the hotel along with the delivery conditions.

4) Hotel

Food product preparation, storage, and receipt for guests are the main functions of the hotel interface. When a product batch is received from the distributor, the hotel uses buyProcdFoodFromDistributor (productID, distributorID, quantity, deliveryDate, delivery Conditions) to record the delivery details and verify receipt. Lastly, the hotel would record the dish's preparation using sellFinalFoodToCustomer( ) (dishID, productIDs, preparationDate), which would link back to the original ingredients and their history.

5) Agricultural Bureau and Quality Supervision Bureau

A Regulatory & Compliance Interface is put in place to guarantee compliance with food safety regulations and make audits easier. Authorized regulatory agencies have direct access to unchangeable records of sourcing and handling procedures throughout the whole supply chain thanks to this interface. Features like real-time non-compliance alerts allow authorities to spot possible problems early and take appropriate action. Furthermore, the interface produces automated compliance reports, which guarantees that hotels are continuously fulfilling regulatory requirements and expedites the auditing process. By offering a tool for quick response and verification, this improves the transparency of the food supply chain data, increases its credibility, and helps ensure consumer health and safety.

6) Customer

For customer access, each product or dish can be tagged with a QR code, which is linked to RFID, that contains a unique identifier. By scanning the QR code, the blockchain would be queried using the productID or dishID to obtain all pertinent information, such as the ingredients' place of origin, growth information, processing specifics, quality certifications, storage and transportation conditions, and hotel preparation details. In order to ensure transparency and foster trust, the customer would be presented with this information in an easy-to-use format, giving them a comprehensive history of the food they are about to eat.

D. Entity Sequence Diagram

The connections between entities, as illustrated in Fig. 5,

highlight some of the main characteristics and functionalities of smart contracts in addition to the connections between entities and smart contracts. A function in the smart contracts is called by each participating entity in the hotel's food supply chain. The smart contracts are created by the hotel, in order to get traceability information and increase customer satisfaction. As part of the chain, the farmer grows the crop and calls *updateGrowthInfo( )* to upload the growing environment, information, and photos to the IPFS. This information is stored in the IPFS hash, and the *updateGrowthInfo( )* is updated until the crop is ready for harvest. The farmer and processor start trading as soon as the crops are harvested. The farmer agrees and sells the crop to the processor after the two parties have worked out the specifics of the agreement. Figure 6 displays the sequence diagrams of the processor and farmer running the *buyCropFromFarmer( )* and *sellToProcessor( )* functions, respectively. To begin with, the *buyCropFromFarmer( )* function is first executed by the processor, which then passes the processor address, quantity, and sales date parameters to activate the smart contract and notify the participants by triggering the *CropRequested( )* event. These parameters are then passed and recorded. Following the farmer's execution of the *sellToProcessor()* function, the smart contract triggers the *CropSold( )* event to notify the closure of the transaction, passing and recording the parameters of the farmer address, processor address, quantity, and sales date.

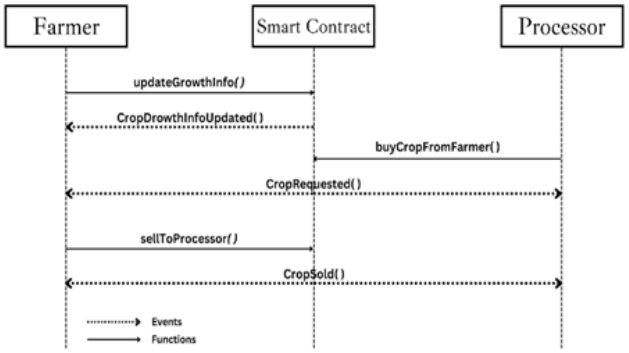

Fig. 6. Sequence diagram showing interactions among farmers, smart contracts, and processors
(Source: Authors Own Work)

A sequence diagram of the processor and distributor working together with smart contracts is displayed in Fig. 7. The distributor is a warehouse that sells processed produce to hotels after purchasing it in large quantities from different processors. The distributor first initiates the *ProcdFoodRequestedByDistributor( )* event, which notifies the processor selling processed food to it by passing distributor, processor, quantity, and sales date parameters. The processor then executes the *sellProcdFoodToDistributor( )* function, which activates the *ProcdFoodSoldToDistributor( )* event to notify interaction entities by passing processor, distributor, quantity, and sales date parameters.

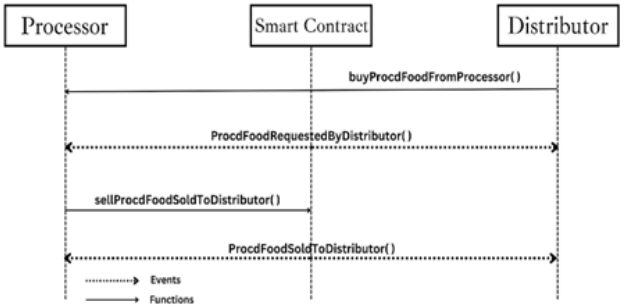

Fig. 7. Sequence diagram showing interactions among processors, smart contracts, and distributors
(Source: Authors Own Work)

By using the *buyProcdFoodFromDistr-ibutor( )* function and passing in the hotel address, distributor address, and quantity parameters, hotels purchase processed food from distributors. The distributor sells the processed food to the hotel using the *sellProcdFoodToHotel( )* function after being notified by the activation *ProcdFoodRequestedByHotel( )* event. The relevant participant in this process is then notified by the activated event *ProcdFoodSoldToHotel( )*. Passing the quantity, batch number, sales date, and both parties' addresses simultaneously. By using the *sellFinalFoodToCustomer( )* function and passing in the hotel address, customer name, cooked food name, and sales date parameters, the hotel sells the finished product, which was prepared on-site, to the customer. The *FinalFoodSold-ToCustomer( )* event is then used to broadcast the hotel's food preparation process. A distributor, hotel, and customer sequence diagram is displayed in Fig. 8.

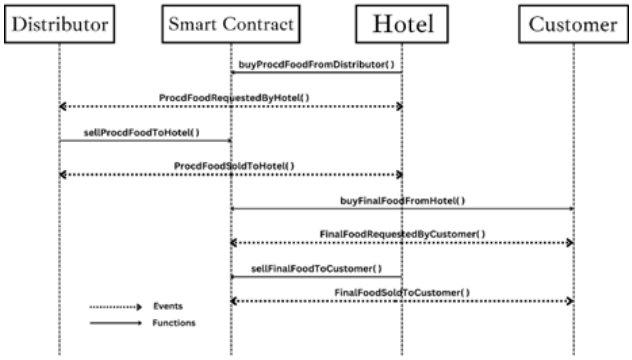

Fig. 8. Sequence diagram showing interactions among distributors, smart contracts, hotels and customers
(Source: Authors Own Work)

5. Post Implementation Consequences

After adopting a Hyperledger Fabric–IPFS system by a hotel for its operations, the hotel will gain many advantages over other hotels. A few of the most important and prevalent advantages are:

A. Operational Efficiency

The proposed system markedly enhances operational efficiency for hotels via automation, cost reduction, and optimized processes.

1) Time Saving

Smart contracts speed up workflows and minimize manual

intervention by automating crucial supply chain operations like payment processing, procurement, and compliance verification. Walmart's implementation of a Hyperledger Fabric-based blockchain system is a noteworthy real-world example, as it cut the time it took to track down the origins of food items like mangoes from days or weeks to just 2.2 seconds. *(Archana Sristy, 2021) (LF Decentralized Trust, 2023)*

Similar to this, hotels that implement this system could reduce interruptions and guarantee prompt service delivery by speeding up the identification of food sources during safety concerns. For example, tracking delivery statuses or confirming supplier compliance could be done almost instantly with blockchain queries instead of requiring hours of manual checks, improving responsiveness in busy hotel kitchens.

2) Cost Reduction

Blockchain reduces costs across the food supply chain by streamlining processes and eliminating unnecessary steps. Fraud and administrative overhead are decreased by automating record-keeping and eliminating middlemen (such as separate paperwork and third-party certifiers). According to Deloitte, "blockchain generally offers increased efficiencies that can result in cost savings," such as by lowering administrative burdens and speeding up payment cycles. *(Deloitte Global, 2023)*

Because blockchain simplifies payments and lowers errors, it has been estimated that the restaurant industry can save up to 70% on supply chain handling costs. *(Loman AI. 5 ways blockchain boosts restaurant supply chains.)*

Automated smart contract payments to suppliers and less dependence on outside logistics coordinators could result in comparable cost savings for hotels. Furthermore, accurate inventory management reduces food waste, which is important because, according to the UN Environment Programme's Food Waste Index Report 2021, 13% of food waste worldwide happens at the retail level. *(United Nations Environment Programme, 2021)*

3) Operational Streamlining

The system's real-time data sharing via a consortium blockchain enhances coordination among stakeholders, reducing errors and improving operational flow. Immutable hashes on the blockchain ensure data integrity, while IPFS, for instance, stores massive datasets like logistics information or crop growth records off-chain. By doing this, hotels can prevent shortages or overstocking by maintaining precise inventory levels.

In a related case, Tyson Foods anticipates a positive return on investment by centralizing supplier documentation and automating food recalls using FoodLogiQ's Connect blockchain platform. Hotels could guarantee uniform food quality throughout their dining establishments by streamlining procurement and quality control in a similar manner. *(Sam Daley, 2023)*

B. Customer Perceived Benefits

The system delivers significant value to hotel guests by enhancing trust, safety, and engagement, aligning with modern consumer expectations for transparency and quality.

1) Increased Trust

The system promotes trust in food quality and authenticity by allowing customers to scan QR codes and access detailed supply chain histories, from farm origins to hotel preparation. Consumers are calling for more transparency, and research indicates that many are even willing to pay more for goods that come from ethical sources. *(Ling & Zahry, 2021)*

For instance, Nestlé works with the Rainforest Alliance to confirm sustainable cocoa sourcing and tracks the origin of products like Mousline purée using the IBM Food Trust blockchain. In a similar way, hotels could strengthen brand loyalty by guaranteeing ethical sourcing, such as sustainably farmed seafood or organic produce. *(Nestlé, 2020)*

2) Enhanced Safety

Rapid traceability of the system guarantees prompt isolation and identification of contaminated food, thus safeguarding the health of the consumers. For example, during outbreaks, Walmart's blockchain system enabled the precise disposal of only impacted produce, preventing widespread recalls. *(LF Decentralized Trust, 2023)*

The need for such capabilities was highlighted by the 18 foodborne illness outbreaks that the United States reported in 2018. By implementing this system in place, hotels could reduce risks, safeguard visitor trust, and prevent reputational harm from safety-related incidents. *(U.S. Food and Drug Administration, 2019)*

3) Engagement and Satisfaction

Guests can explore the journey of their meal thanks to the interactive QR code feature, which turns dining into an interesting experience. Customers are better informed as well as more satisfied, which promotes repeat visits. Positive word-of-mouth generated by the system's alignment with consumer trends toward sustainability and transparency can increase guest retention even more.

C. Competitive Advantage

Adopting this blockchain-based system positions hotels as industry innovators, offering a competitive edge through differentiation, enhanced brand image, and operational excellence.

1) Differentiation

Hotels can differentiate themselves by offering unparalleled transparency in their food supply chains, which will appeal to tech-savvy and environmentally conscious customers. By offering a unique value proposition, the hotel can stand out from the competition and draw in visitors who value safety and sustainability.

Because customers are willing to pay more for food that is produced responsibly, restaurants that use blockchain technology to verify organic or fair-trade ingredients report an increase in customer loyalty. *(Sun et al., 2017)*

2) Brand Image

Leveraging cutting-edge blockchain technology improves a hotel's reputation as an innovative, ethical company. As evidenced by projects like The Shilla Seoul's blockchain-based loyalty programs, which raise customer satisfaction through transparent reward structures, this is in line with the hospitality

sector's growing emphasis on sustainability. By demonstrating their dedication to food safety and ethical sourcing, hotels that implement this system could also enhance their brand. *(Chechi, 2024)*

3) Operational Excellence

Hotels are able to provide excellent service quality or competitive pricing thanks to the system's cost savings and efficiency improvements. Hotels can invest in high-quality ingredients or employee training to improve guest experiences by cutting waste and streamlining supply chain operations. As demonstrated by Walmart's ability to expand blockchain tracking to more than 25 products, increasing efficiency and fostering customer trust, this operational excellence strengthens market leadership. *(LF Decentralized Trust, 2023)*

A hypothetical case study of a hotel chain which adopts the Hyperledger Fabric–IPFS system proposed in the paper, highlighting the advantages that it gets over other hotel chain, is presented below:

For instance, Take Taj Hotels, a well-known hotel chain in India, which has already made a commitment to a "supply chain characterized by transparency, sustainability, and ethical responsibility". Taj could keep track of all food-supply transactions (from individual farmers to its kitchens) on a shared ledger by implementing a Hyperledger Fabric–IPFS traceability system. In one case, the blockchain could immediately track the origin of a batch of imported papaya and all subsequent destinations if it were suspected of being involved in a Salmonella outbreak. This is similar to how IBM's system enabled Walmart to quickly identify contaminated produce. Instead of discarding a lot of fresh produce, Taj would be able to remove just the impacted servings. A quantitative analysis of blockchain pilots by academics revealed that crisis response times decreased from weeks to minutes, along with associated cost savings. For instance, if Taj's Mumbai Branch experienced a contamination scare during its evening buffet, blockchain traceability could identify the source farm in less than a minute (as opposed to days normally), safeguarding consumer health and preventing an expensive, widespread recall. Moreover, Taj could guarantee uniform food quality throughout their dining establishments by streamlining procurement and quality control due to their procurement's history data being stored in the system.

By scanning a QR code, the food's data— detailed about supply chain histories, from farm origins to hotel preparation— would be accessible to the consumer. This would increase the trust of the consumer on Taj hotels. Additionally, the interactive QR code feature makes dining an engaging experience by allowing guests to follow the path of their meal. Consumers are happier and more knowledgeable, which encourages repeat business. Guest retention would be further enhanced by positive word-of-mouth brought about by the system's alignment with consumer trends toward sustainability and transparency.

Finally, this system would give Taj Hotels a competitive advantage over other hotel chain due to their tech-savy and eco-conscious appealing approach. This wold also make Taj Hotels stand out, creating a better and solid brand image.

In conclusion, a blockchain traceability initiative at Taj Hotels would not only support its sustainability mandate but also yield concrete benefits, all of which boost the hotel's bottom line and competitive standing in the luxury market.

6. Risks and Mitigations

When considering the system design outlined in this paper for blockchain-based traceability in hotel food supply chains, several potential risks and challenges might be faced in real-world implementation. Few of the biggest risks are:

1) Security Flaws in Smart Contracts

Since smart contracts are immutable once they are deployed, it is difficult to fix errors or vulnerabilities without redeployment. The fact that they are open-source reduces the barrier for hackers, and since smart contract technology is still in its infancy, there may be unidentified flaws that raise the possibility of exploits that threaten supply chain transactions or data integrity.

Industry reports, such as World Economic Forum: The rise of smart contracts and strategies for mitigating cyber and legal risks, highlight that even minor flaws can lead to severe consequences like unauthorized access or fund misappropriation, emphasizing the need for robust security measures. *(Desbonnet & Vanunu, 2024)*

Mitigation: To find vulnerabilities like re-entrancy attacks or integer overflows, rigorous testing and auditing are essential. This includes unit tests, integration tests, and formal verification. Similar procedures can be modeled for Hyperledger Fabric chaincode by using tools like Mythril or Slither, which are frequently used for Ethereum. Upgradeable smart contracts, which address the immutability challenge by utilizing models such as OpenZeppelin's upgradeable contracts modified for Fabric, permit fixes after deployment and are overseen by a group of reliable organizations (such as the Agricultural Bureau and Quality Supervisor Bureau) to prevent unwanted changes.

2) Data Privacy and Access Control Risks

The system involves several parties exchanging private information via IPFS and the consortium blockchain. Improper access control implementation may result in unauthorized access to private data, including processing information, hotel procurement records, and farmer yield data. If IPFS hashes are not strictly controlled or data is not completely encrypted, using IPFS for data storage creates additional risks that could expose private or confidential data.

Articles such as Practical Law the Journal, Blockchain: Data Privacy Issues and Mitigation Strategies examines the conflicts between data privacy laws and blockchain transparency, highlighting out that the immutability of blockchain makes it difficult to comply with regulations like GDPR, which is in line with the requirement for robust access controls in a multi-stakeholder environment. *(Bacal et al., 2023)*

Mitigation: By using Hyperledger Fabric's channel architecture, sensitive data can be stored in private channels that are only visible to those who are authorized. Data stored on IPFS is encrypted to maintain confidentiality, and only authorized individuals possess the decryption keys. This

complies with industry standards and data protection regulations. Frequent access control policy audits can identify configuration errors and improve security. Though they were taken into consideration, zero-knowledge proofs (ZKPs) are more appropriate for public blockchains; in this system, access controls and encryption are adequate due to the permissioned nature.

3) Scalability and Performance Limitations

The system may encounter scalability issues as the number of users (such as farmers, hotels, and distributors) and transactions increases. These issues could include storage limitations on IPFS or higher transaction processing latency. Although IPFS reduces the explosion of blockchain storage, the document points out that performance issues may occur, particularly when hotels or customers scan QR codes to retrieve data in real-time, which could impede adoption and efficiency.

Resources, such as Chainlink: Blockchain Scalability Approaches, address the necessity of scalability solutions, such as optimized consensus mechanisms and layer 2 protocols, which are pertinent to the enterprise use of Hyperledger Fabric, where high transaction volumes in supply chains demand effective performance. (*Chainlink, 2023)*

Mitigation: Hyperledger Fabric's multiple channels enable parallel processing and separate transactions, thereby reducing congestion (e.g., one channel for distributors and hotels, another for farmers and processors). For high-frequency transactions, such as uploads of sensor data, batch processing decreases network load. Particularly for customer QR code scans, IPFS clustering improves retrieval speeds by distributing data across nodes, and caching mechanisms (such as Content Delivery Networks) guarantee speedy access. Although IPFS is already used by the system for off-chain storage, hybrid storage—which combines IPFS with cloud storage for non-critical data—can further reduce load.

7. Conclusion

In order to meet the demand for traceability of the final food product, this research paper suggests a framework for tracking and carrying out transactions using hyperledger smart contracts. This model changes the centralized model of the hotel food supply chain, gets rid of middlemen and intermediate nodes, and acknowledges the decentralized model. The significance of food safety traceability is discussed in this paper along with blockchain and consortium chains, as well as a framework for tracking and implementing the agricultural food trade using hyperledger smart contracts. A comparison and case studies for the hotel food supply chain used in three different countries—India, China and United States of America—are given in the paper, highlighting the problems of the chain in each country. The system design is presented, and the relationships and interactions between the various entities in the hotel food supply chain are explained. The future risks and problems are also highlighted in this paper, presenting the mitigations for each of the risks, if the proposed system is implemented.

Globally chained Hotels, Michelin-starred hotels, and hotels or restaurants that aim at customer satisfaction maximisation can implement the system design proposed in this paper. This will result in a higher customer satisfaction level and make it easier for the hotels to have food traceability. This may, in turn, place these hotels in a better position in the industry in comparison to their competitors.

Therefore, this paper proposes a meaningful system design using hyperledger, smart contracts and IPFS. Thus, the framework proposed in this paper is of great significance and reference value for enterprises to ensure product quality and safety traceability.

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