

Review Article

Food safety in the digital age: Blockchain technology for enhanced quality management

Abstract

Supply chains are becoming more competitive with one other as organizational rivalry changes, and in order to thrive, businesses must provide value to their clients. One of the most important indicators of operational effectiveness in supply chains and, eventually, customer service is traceability. This study shows how blockchain can lower the risk of contamination, increase recall effectiveness, and foster consumer confidence. This paper is talk about the advantages, difficulties, and potential future developments of this cutting-edge method of managing food safety in this digital age. The monitoring and management of all stakeholder communications and transactions inside the supply chain network is entirely dependent on this method, which uses smart contracts. All of the transactions are logged and kept in a centralized interplanetary file system database, and this method verifies each one. It provides stakeholders with a safe and economical supply chain system. As a result, this suggested model provides a traceable, accurate, and transparent supply chain system. It also shows the convergence time of 4.82 seconds and a throughput of 161 transactions per second, the suggested solution was judged to be effective in terms of agricultural product traceability. In order to guarantee the availability of a tamper-proof audit trail, this article offers a supply chain architecture enabled by blockchain technology. This unchangeable audit trail ensures that every precaution is taken to reduce the possibility of bacteria, fungus, and parasites entering the food supply chain. The consensus algorithm is used in the blockchain approach to produce a nonce value when data from different stakeholders throughout the food supply chain is first collected, separated, and then applied. When determining if a food item is suitable for eating within a given range, the value can be useful. Food safety authorities have established standard storage and handling guidelines, from which the safe food quality is obtained. This value is then checked to see if it falls within the acceptable range. This study investigates how blockchain technology can be used to improve food safety and uplift quality of the food throughout the supply chain. Food goods can be tracked from farm

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to table using blockchain's decentralised, transparent, and unchangeable record, guaranteeing freshness, authenticity, and adherence to safety standards.

Key words: Digital age, Food safety, Blockchain, Decentralized Ledger, online Food delivery.

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1. Introduction

The 21st century has brought about incredible technological advancements, and blockchain is one of the most important. Initially created to support digital currencies like Bitcoin, blockchain is now being used in many different fields. At its core, blockchain is a way to securely record and share information across multiple computers, making it nearly impossible to alter or hack. This technology is important because it can make processes faster, cheaper, and more secure in areas like finance, supply chains, and healthcare. The manner that we grow, prepare, and eat food has changed dramatically in the digital age. The food sector has grown more intertwined with the advent of social media, e-commerce, and online meal delivery. Although there are many advantages to this digital revolution, like easier accessibility and convenience, there are also new difficulties in maintaining food safety. The likelihood of contamination and food borne illnesses has increased with the complexity and globalization of food production and distribution. Thus, by removing the need for middlemen and providing a trustworthy system for transactions, blockchain is changing the way we do business and handle information in today's world and in order to improve food safety regulations and safeguard the public's health, it is imperative to make use of digital technology, data analytics, and creative solutions. Blockchain is an unchangeable shared ledger that facilitates asset tracking and transaction recording among a network of companies. Anything of value may be tracked and traded on the Blockchain network. A blockchain is a distributed database that is shared over a computer network. Blockchain ensures the security of transactions by electronically storing data in a digital format (MINISTRY OF ELECTRONICS & INFORMATION TECHNOLOGY, 2024). It is referred to as a distributed ledger technology (DLT) supported by five essential principles: Decentralization, Integrity, Cryptography, Security, Inclusive (Toufaily et al., 2021). The advent of blockchain technology has been hailed as the next big thing that will change how businesses operate, including their size and structure, and how transactions are carried out (Behnke & Janssen, 2019; Cermeño, 2016). Blockchain systems allow for the storage of data

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that is difficult to alter, the introduction of tokens that can be transferred between parties without the need for an intermediary or trusted third party, and the automatic execution of "smart contracts" in response to predetermined conditions (Marsal-Llacuna, 2018 ; Janssen et al., 2020). Among the many difficulties facing the global food sector are food fraud, contamination, and waste. Blockchain technology provides a transparent, traceable, and unchangeable record of food production, processing, and distribution, which presents a revolutionary way to improve food safety. Through the use of blockchain technology, food product authenticity and quality may be guaranteed by stakeholders, lowering the possibility of contamination and enhancing public health.

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2. Importance of food safety:

Food safety is a fundamental human right because food is vital for survival. Unsafe food threatens billions of people worldwide, leading to millions of illnesses and hundreds of thousands of deaths each year. The food supply chain spans from farm to table, encompassing microbiological, chemical, personal, and environmental hygiene issues (Fung et al., 2018). In the food industry, food safety plays a critical role in various aspects, including evaluating management systems, achieving certifications for specific safety and quality standards, ensuring legal compliance, and assessing the condition of premises and products. The growing consumer concern for food safety, largely driven by recent food crises, has prompted both public and private sectors to adopt various food safety standards (Kotsanopoulos et al., 2017). These standards are crucial for protecting consumers from health risks related to common allergens and foodborne illnesses such as Salmonellosis, Listeriosis, Campylobacteriosis, Botulism.

Blockchain technology is significantly enhancing food safety by offering detailed and transparent tracking of food products throughout the supply chain. Blockchain provides a digital ledger that records every transaction related to a food product, from its origin to its final destination. Each time the product changes hands be it harvested, processed, packaged, or sold an entry is made in the blockchain. This record is permanent, tamper-proof, and accessible to all authorized participants in the supply chain. In the event of a food safety issue, time is critical. Traditional methods of tracing contaminated products can be slow and labor-intensive, involving paperwork and communication across multiple entities. Food

fraud, such as mislabeling or counterfeiting, is a significant concern in the industry. Blockchain helps combat this by providing a secure and verifiable record of a product's history. Blockchain also simplifies compliance with food safety regulations. It automatically logs all necessary data, such as temperature control during transportation or organic certification, making it easier for companies to prove compliance during audits. Consumers are increasingly concerned about the safety and origins of their food. Blockchain allows them to verify the authenticity and safety of products before purchasing. For example, they can use a smartphone app to scan a product's QR code and see detailed information about its source, processing, and journey. This transparency builds trust and can even become a selling point for brands that prioritize food safety.

3. Food safety programs

Programs for ensuring food safety are the actions, circumstances, and guidelines required both before and after a food safety system is put into place. There are some programs listed below:



Fig 1: Food Safety Programs

HACCP: Biological, chemical, and physical risks are analysed and controlled in the HACCP management system from raw material production, procurement, and handling to manufacture, distribution, and final product consumption to ensure food safety (FDA.2022). Adopted in 1993, the Codex guidelines on the use of HACCP underwent updates in 1995, 1997, and 2003.

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7 Principles of HACCP for food safety:

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1. Analyse potential hazards
2. Find the crucial control points (CCP)
3. Determine critical boundaries
4. Create a system to keep an eye on CCP control.
5. Determine the necessary remedial measures
6. Create procedures for verification.
7. Create records

SQF: A strict and reliable programme for food safety and quality is the Safe Quality Food (SQF) Programme. Ensure that food has been handled, prepared, and manufactured in accordance with the most widely accepted guidelines. Show that you are dedicated to high-quality procedures and ongoing development (NSF. 2024). The food facility demonstrates its ability to handle food items in accordance with recognised industry, governmental, and SQF norms by following the SQF auditing requirements (Odugbemi, 2017).

Good Agricultural Practices (GAPs): were created to give farmers fundamental instructions on how to lower the hazards to food safety on their property (Bihn et al., 2006). The FDA's (1998) Guide to Minimize Microbial Food Safety Hazards for Fresh Fruits and Vegetables is where GAPs first appeared (Food and Drug Administration, 1998; Schmit et al., 2020).

Good Manufacturing Practices (GAPs): In order to achieve food safety, good manufacturing processes bring harmony to all areas of the plant. Food quality, safety, and all pre-, during-, and post-processing activities are inextricably linked. This includes facility design, on-site system monitoring, documentation and recording, staff dedication and

understanding, and so forth. The safety of the items being made depends on every step of the production process. These include suppliers, processing, packaging, distribution, and raw materials. The bond that the manufacturer builds with clients is another crucial factor.

4. **Current challenges in food safety:** The food and culinary industries have to deal with a variety of challenges when it comes to food safety, from poor sanitation and unclear labelling to unskilled workers and hazardous food storage (Yen, 2024). The following are some of the most common food safety concerns in the 2024 culinary scene to be aware of:

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Fig 2. Current issues in Food safety

Food borne illness: One of the most common food safety problems in the world is food contamination, which can be brought on by bacteria, parasites, viruses, or chemical compounds. Numerous food borne infections carry the risk of permanent harm or even death.

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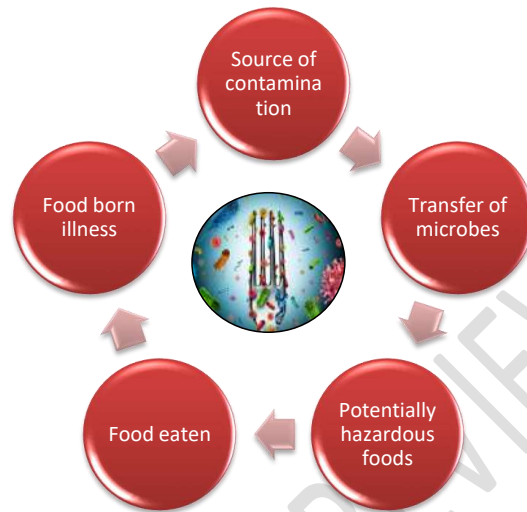


Fig 3. Cycle of food borne illness

Risk assessment: Hazard identification and characterisation, exposure assessment, and risk characterisation are all included in a risk assessment of a product or component. This prepares the reader for the judgement of whether or not this product or ingredient warrants legal action to avert injury (Henson, 1999).

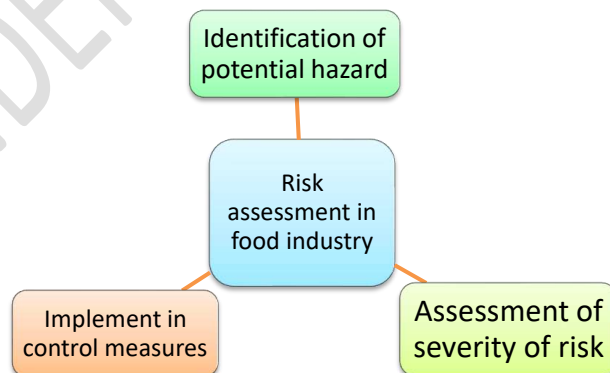


Fig 4: Components of Risk assessment in Food Industry

Food safety management: Individual food enterprises have diverse arrangements for their FSMS, which are subject to external inspections or audits, such as government inspections or third-party audits. Improvements must be done following an audit or inspection in order to meet the requirements set forth by these outside parties (Jacxsens, Devlieghere et al., 2009; Luning & Marcelis, 2009; Jacxsens et al., 2011).

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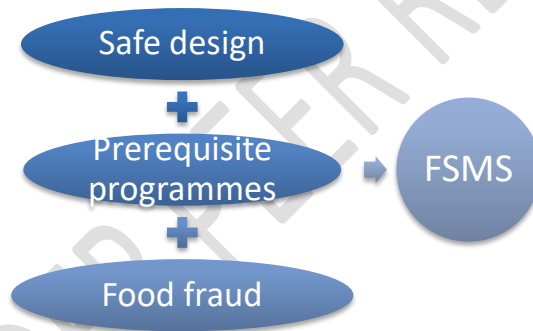


Fig 5: Structure of Food safety management system

Hazards: Hazards are biological, chemical, or physical agents that have a reasonable probability of causing disease or harm if they are not controlled (Lawley et al.,2012).

Types of hazards:

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Physical hazards: Unsafe equipment, improperly used equipment, and cutlery

Chemical hazards: The material's chemical and poisonous characteristics

Biological hazards: Bacteria, insects, viruses, plants, animals, birds, humans, etc. (Nemmers, 2018).

Blockchain Technology: The digital world has created efficiencies, new creative goods, and close consumer contacts globally through the effective use of mobile, IoT (Internet of Things), social media, analytics, and cloud technology to form models for smarter decisions. The introduction of blockchain technology has revolutionized the digital world by offering a fresh viewpoint on system efficiency, resilience, and security. Despite being made widely known by Bitcoin at first, Blockchain is much more than just a platform for virtual currencies (Ahram et al., 2017). Blockchain is collection of blocks that store data in hash functions together with a date and a link to the preceding block (Crosby *et.al*, 2016). Blockchain enables the creation of tokens that can be transferred between parties without the use of a middleman or other reliable party, the storage of hard-to-alter data, and the automatic execution of "smart contracts" in response to preset conditions (Marsal-Llacuna, 2018).

***Token:** It is an asset. Although Ethereum and Bitcoin are also technically tokens, the term "token" is frequently used to describe any cryptocurrency other than those two. It's helpful to have a term to characterise the universe of other coins because Bitcoin and Ethereum are by far the two largest cryptocurrencies. (You may also hear the term "altcoin," which has almost the same meaning.) (Coinbase,2024).

The background of Blockchain technology: A paper titled "New direction in cryptography" was published in 1976. Another key idea that influenced the creation of blockchain technology was "electronic cash," often known as "digital currency," which originated from a model put out by David Chaum. Adam Back invented the notion of

"hashcash" in 1997, providing a means of controlling spam emails. These give rise to the idea of manufacturing money using a peer-to-peer network, which Weight Dai refers to as "b-money". Blockchain technology is credited to **Satoshi Nakamoto**, who released a paper on bitcoin under the title "Bitcoin" in 2008. Since then, Bitcoin has grown significantly, and in 2013, investors began to pour money into businesses that are associated with the cryptocurrency. In 2015, the Ethereum platform was introduced, enabling blockchain technology to be used for contracts and loans. It was founded on a smart contract algorithm that guaranteed the execution of the agreement between two parties since Ethereum provided a quicker, safer, and more effective environment, which led to the widespread use of this technology (Sarmah,2018).

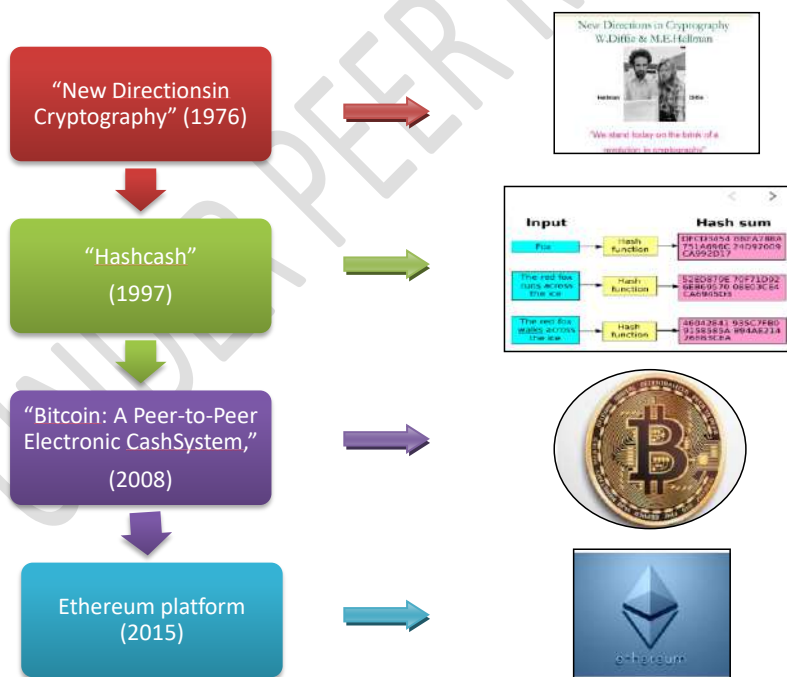


Fig 6: History of Blockchain technology Development

Components of Blockchain technology:

Block chain technology madeup of total 7 componenys.

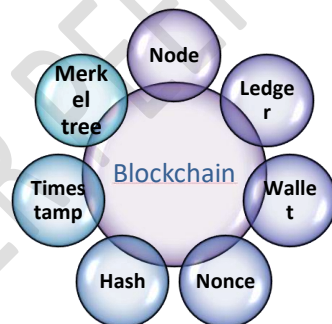


Fig 7: Seven main components of Blockchain Technology

Node: Record of every transaction. It is of 2 types.

Complete Node: It keeps an entire record of every transaction. It is able to verify, approve, and decline transactions.

Partial Node: Because it doesn't keep an entire copy of the blockchain ledger, it is sometimes referred to as a Lightweight Node. It just keeps the transaction's hash value. This hash value is the sole way to obtain the entire transaction. These nodes are computationally and storage-poor.

Ledger: This is an informational digital database. The word "digital" is used here because the money that is transferred between nodes is digital, or cryptocurrency. Three different kinds of ledgers exist. They're –

Public Ledger: It is available to everyone and is transparent. Anybody with access to the blockchain network can write or read content.

Distributed Ledger: A local copy of the database is kept on each node in this ledger. Here, a number of nodes work together to complete tasks like adding blocks to the blockchain and verifying transactions.

Decentralised Ledger: No single node or group of nodes has central authority in this ledger. Each node takes part in carrying out the task.

3. Wallet: Users can store their cryptocurrency in this digital wallet. In the blockchain network, a wallet is present on every node. Public and private key pairs are used in blockchain networks to protect wallet privacy. Currency conversion is not necessary while using a wallet because the money within is accepted anywhere. Wallets for cryptocurrencies mostly come in two varieties:

Hot Wallet: These wallets are utilised for regular online transactions that are linked to the internet. Because this wallet is linked to the internet, hackers could target it.

Cold Wallet: These wallets don't have an internet connection. Hackers are unable to breach its security. The user purchases these wallets. Examples are hardware wallets and paper wallets.

Nonce: A nonce is a number appended to a blockchain's hashed or encrypted block. This is an abbreviation meaning "one-time use of a number." The 32-bit integer that helps to validate a transaction or create a new block is created randomly just once. It serves to increase the security of the transaction.

Hash: Hashing is the process of mapping data to a predetermined size. It is crucial to the field of cryptography. A blockchain network uses a transaction's hash value as an input for subsequent transactions. The hash function's properties like Collision resistant, Hiding etc.

A timestamp is a brief piece of information that is uniquely serialised and saved in each block of a blockchain. This information determines when block mining started and was approved by the blockchain network. It's interesting to note that timestamps were first used in the past when people were looking for ways to track and authenticate papers.

Merkletree: A "Merkle tree" is a type of tree data structure used for cryptocurrencies in computer science applications and cryptography. Another name for it is "Binary Hash tree." (Bosamia, et al., 2018). In a blockchain network, the Merkle tree is the hash of all the hashes of all the transactions that make up a block.

Basic Principles of Blockchain: A list of all the blockchain technologies that have been developed to date would be neither exhaustive nor comprehensive given the current complex dynamic of the blockchain's architectural evolution. Consequently, an overview of the blockchain is conducted by examining its fundamental tenets (Aste et al., 2017; Tasca et al., 2017).

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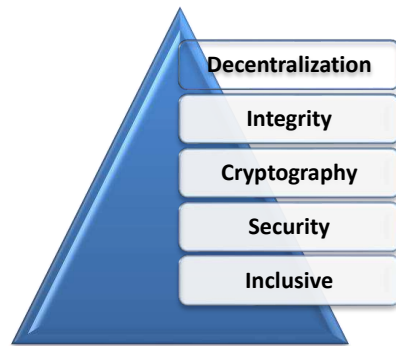


Fig 8: Principles of Blockchain technology

Decentralization: Blockchain is a peer-to-peer (P2P) network in which no single user or participant controls the transaction; instead, power is shared among all users. This implies that no single stakeholder can manipulate, hack, or close the chain of blocks, nor can they shut it down. This blockchain network is immune to fraud and hacking because of its distributed (decentralised) structure.

Integrity: Every member of the blockchain-powered network is empowered to make decisions, and user intuition serves as the only source of required confidence in the system. Both the way this complete P2P network operates and how each user is rewarded for their efforts exhibit strict honesty.

Cryptography: This fundamental idea of blockchain architecture is to give users an extremely high degree of security and authenticity. It makes use of cryptography's strength to provide closely knit security and data integrity. While the Blockchain transaction system is advantageous and lucrative for genuine users, it can be extremely punishing on careless users. This indicates that everyone who uses the blockchain system properly and behaves well will receive fair rewards. However, you will still face consequences if you use it improperly.

Security: Since blockchain is a distributed network, it lacks a single point of failure and no individual user can act irresponsibly in a way that compromises the network as a whole. Any password hacking incident that affects just one person will only cause harm to that person. Your network transaction is extremely safe when using the blockchain's PKI (Public Key Infrastructure) encryption mechanism—until you share your private key, for which there is currently no technological remedy. Therefore, you can generally rely on Blockchain technology to guarantee that your transactions are performed without being compromised.

Inclusive: The Blockchain is an inclusive technology that allows everyone to independently engage in the global economy without facing discrimination. Because Bitcoin eliminates the need for a bank account entirely, it enables everyone, affluent or poor, to invest to the best of their abilities and participate in the global economy. Without the involvement of a third party, they are free to choose to transact with anybody they like and pay either no transaction fees or very minimal ones.

4. Distributed ledger technology: Blockchain and other distributed ledger technologies (DLTs) provide a safe, central authority-free method of executing and documenting digital asset exchanges. DLT is called "distributed" because copies of the ledger are shared and synchronised by numerous users (individuals, companies, etc.) within a computer network. New transactions are added in a way that is permanent, secure with cryptography, and accessible to all users almost instantly. The reason distributed ledgers don't require a central, reliable authority is that new transactions are added and validated by a consensus procedure. Because every "block" of transactions on a blockchain is cryptographically connected to the one before it, any changes would notify all other users, guaranteeing the validity of the ledger. Once users have reached a consensus over that history, they can proceed with a fresh transaction knowing exactly who is in possession of what. There are two types of distributed ledgers: "permissioned" and "unpermissioned." Unpermissioned ledgers allow any participant to perform a transaction; these ledgers are typically public. Transactions can only be carried out by trustworthy users on permissioned ledgers, which may or may not be made public (GAO, 2019).

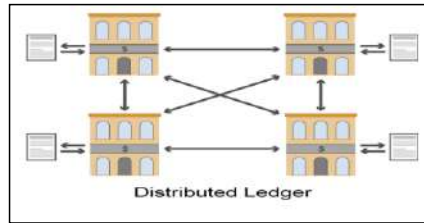


Fig 9: Distributed ledger technology

5. Smart Contracts: The terms and conditions (T&C) of a smart contract are written in blockchain-specific programming languages like Solidity, and they are a digital agreement that is signed, saved on a blockchain network, and that runs automatically when certain criteria are met. Another way to think of smart contracts is as blockchain programmes that let each party complete their portion of a transaction. Smart contract-powered apps are commonly called "decentralised applications," or "dapps." A set of digital commitments is defined by a smart contract (Zhang et al., 2019). Based on blockchain technology, the Ethereum system's smart contract is a programme control protocol for digital currency assets (Rouhani et al., 2019). When seen from a computer's point of view, a smart contract is a segment of code that deals with associated business transactions and algorithms. A related agreement is what the general public perceives as a smart contract. The smart contract is validated and executed automatically as soon as the preset criteria are met. In many other spheres of social life, including agricultural science and technical advancements, the Internet of Things, and other domains, smart contracts are employed in addition to financial transactions (Wu et al., 2022).

Consensus algorithm in blockchain technology: A network of computers, or nodes, can cooperate with each other in order to achieve the goal of obtaining identical copies of the

distributed database files, thanks to the consensus method, also known as the consensus mechanism. Consensus algorithms in blockchain technology are mostly employed for "Proof of Work" (PoW) and "Proof of Stakes" (PoS) (Patel et al., 2023).

Proof of work: The term “proof of work” was first used by **Markus Jakobsson** and **Ari Juels** in a publication in 1999. In a blockchain network, the Proof-of-Work, or PoW, consensus mechanism was first used. Users exchange digital tokens with one another to confirm transactions and add new blocks to the chain. All miners or validators take part in this process by carefully examining and confirming each transaction on the network in order to receive rewards. The distributed ledger gathers and organises all of the network's validated transactions into blocks. We term this process mining. A system called proof of work guards against cyberthreats like distributed denial-of-service attacks (DDoS), which aim to deplete computer resources by making a lot of bogus requests (Sheikh et al., 2018).

Working process of proof of work in block chain:

Every transaction is kept track of in a block



Each block's transactions are verified by miners.



Proof-of-work problems in mathematics are solved by miners and validators.



As the first winner to resolve a transaction running in each block, the miner/validator receives compensation.



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Eventually, verified transactions are added to the public blockchain.

Fig 10: Steps of Proof of Work

PoS: The PoS system allows users to mine and certify block transactions based on their stake value. The more stakes a user has, the more benefits they will receive from the system. Users must stake a certain amount of tokens to be selected for validation of transaction blocks, and they will receive rewards for validating the blocks (Saad et al., 2020). PoS makes an effort to address the issue with energy expenditure that PoW caused. In order to achieve this, PoS chooses participants at random to add to the blockchain, taking the place of PoW's rival. The Follow-the-Satoshi (FTS) algorithm, the simplest PoS implementation, has each blockchain branch choose uniformly and at random from the collection of native coins (Saleh, 2021).

Hash function in Blockchain technology: Hash functions are sometimes referred to as message digests, fingerprints, compression functions, one-way functions, and message authentication codes (MACs) (Damanik. 2017). A mathematical function called a hash function takes input of different sizes and outputs, typically a fixed length hexadecimal. Usually, a mix of letters (a to f) and numbers (0 to 9) is used to write hash. The hash function's output is known as the hash value or message digest (Munir. 2006). On the Blockchain, the hash links every block to the one before it. In this manner, the Blockchain transaction as a whole cannot be altered or removed. As a result, the Blockchain is secure against hackers. Rather than placing the assets or note on the blockchain, a direct note simply stores the hash in order to conserve space. The quantity of nodes

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in a blockchain enables greater energy and storage expenses, but the security is also increased (Riza.2020). The blockchain data structure can only be added; it cannot be changed. Every piece of data on this blockchain is interconnected; therefore any changes made to one block will have an impact on the subsequent blocks (Rahardja et al., 2021).

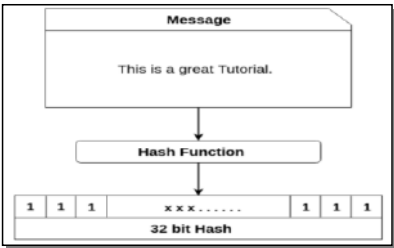


Fig 11: Conversion of message by Hash Function

Types of Blocks in Blockchain system:

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Genesis block: The initial block of a blockchain is called the "genesis block," which is appropriately titled since it implies "origin." It is possible for the blockchain to start building its history of transactions because of the genesis block. This building block allows the newly created block to be connected to an earlier state. This connection allows the blockchain to guarantee its immutability (Hanif et al., 2019; Dutta , 2021).

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Valid block: All of these mined and added to the blockchain blocks are considered valid blocks. Each mined block needs network authorization in order to report as a block that has resolved the specified cryptographic problem and become a valid block. The block is uploaded to the blockchain and sent to every node after the network obtains consensus. As a result, each node in the network has a fresh block and serves as the block's verification point.

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These blocks permit every activity and transaction that takes place in a cryptocurrency (Zheng et al., 2018).

Orphan block: Since orphan blocks are not a part of the blockchain network, their names are also appropriate. These are typically produced by two miners mixing blocks nearly simultaneously, although an attacker with sufficient processing power may also be to blame if they want to reverse any transaction. At this stage, the network consensus process is used to decide which blocks will be orphaned and which will be validated and added to the chain. Generally speaking, the longest blockchain with the most number of transactions and data will be chosen. Thus, simplifying the security procedure (Sharifian et al., 2023; Dutta, 2021).

Blockchain Architecture: It is complex structure made up of bunch of steps. Steps are given below.

To subsequently verify data integrity, the user hashes the transaction data using a hash function (Secure Hash Algorithms, 2019). The user's private key is then used to encrypt the hashed data, enabling user authentication. The resultant encrypted file is referred to as the transaction's digital signature. The network receives a broadcast of the signature and the transaction data. Every complete node in the network verifies the transaction through two processes: data integrity (by hashing the transaction data and comparing it with the encrypted signature) and user authentication (by utilising the public key of the user submitting the proposal to decrypt the digital signature). The network's miners, also known as block generators, receive notice of the successful transaction. The legitimate transactions are confirmed by a chosen miner (by consensus), who then groups them into a block such that the block size stays below a certain limit. The Merkle root hash value is calculated by the miner. An effective method for verifying a transaction in a block is provided by the Merkle root's summarised hash of all the transactions. A node employing Merkle root only needs $\log_2 n$ hash values to verify a transaction in a block of n transactions, as opposed to n hash values if Merkle root is not utilised (Antonopoulos, 2019). The block hash is produced subsequent to the Merkle root hash value computation. The block is broadcast to the network by the miner. The validating nodes confirm that the block is valid by examining the

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following: (1) the block hash; (2) the block height and size values; (3) the block timestamp is greater than the previous block timestamp; (4) the hash value of the previous block; and (5) the validity of every transaction in the block. The valid block is appended to each validating node's copy of the ledger.

Summary of steps:

- i. User create transaction
- ii. Hashing of data
- iii. Transaction proposal occurs
- iv. The hashed data is encrypted using the user's private key
- v. the encrypted output is known as the digital signature
- vi. Validation of transaction encrypted by public key.
- vii. Many valid transaction made Merkle root hashing
- viii. Formation of block
- ix. Block contain, Hash, Time stamp & transaction list
- x. Block validation

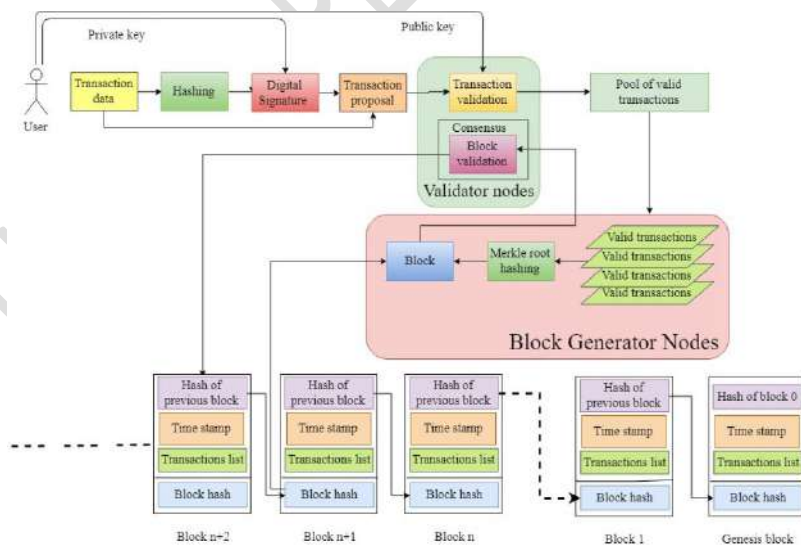


Fig 12: Block chain architecture.

Source: (Ismail et al., 2019)

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Advantage of blockchain technology:

The world has recently been enthralled with blockchain technology, a distributed digital ledger that can be used to securely manage ever-expanding lists of data records and transactions. Public or less authorised, private or authorised, and consortium are the three primary factors pertaining to blockchain identity and accessibility. The fact that the data is completely safe within the blocks of the blockchain's transactions is the most significant and distinctive feature of the blockchain idea (Singh et al., 2021).

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- Blockchain is a decentralised network, it can withstand any security attack because it lacks a central point of failure. Consistency, aliveness, and fault tolerance are the three primary characteristics of its decentralised consensus approach

- Because no transaction on a blockchain can be changed or removed, it offers transactions immutability and transparency (Porrás-González et al., 2019). The average time it takes to mine a new block varies between blockchains as an example, in Bitcoin it takes 10 minutes, means to change all the blocks of blockchain it takes more time.
- Users are enabled to govern their information and transaction.
- .
- Because blockchains are peer-to-peer, they are resistant to cyberattacks and can continue to function even in the event that a security breach affects or some nodes go offline. Peer-to-peer connections on blockchain facilitate the detection of distributed consensus and network fraud. A network can hardly be invaded because an attacker can only have an effect on it if they take over 51% of the nodes (Sarmah, 2018).
- Users can avoid keeping sensitive data in one location by storing many copies of the data in the blockchain. Customers are more likely to have faith in the blockchain system because of its improved security (Sarmah, 2018).

Disadvantage of blockchain technology:

- Because each node in a blockchain must repeat a process in order to obtain consensus, blockchains are costly and resource-intensive.
- The intricacy and difficulty of blockchain for the average person to comprehend is one of its drawbacks. Blockchain is still a work in progress, with many intricate ideas and procedures that the average person will find difficult to understand and apply.

- Since all transaction-related data in blockchain is accessible to the public, using distributed ledgers in sensitive settings—like handling patient medical or government data—can be quite risky. The ledgers must be changed, and only those with the appropriate clearance should be able to access those (Sarmah, 2018).
- To overcome the technical expertise problem One such choice is the **Modex Blockchain Database**, a tool made to help non-technical people take advantage of blockchain technology's advantages without having to worry about data loss.

Applications of blockchain technology in food industry:

Blockchain technology is being used by a number of industries, including insurance, education, ride-sharing and private transportation, government and public services, retail, real estate, and others, in an effort to save costs, promote transparency, and foster trust (Sarmah et al., 2018). Critical performance metrics for the supply chain might be significantly improved by using blockchain technology. Data on product creation, processing, transmission, and sales is dispersed in traditional food supply chains. Further communication with other players or the development of information-sharing systems run by a third-party organization are prerequisites for the accessibility of data that was once kept in the internal, centralized databases of supply chain participants (Montecchi et al., 2019). The agricultural upstream and downstream sectors from input supply to production, post-harvest handling, processing, transportation, marketing, distribution, and retailing are all included in food supply chains. Thus long, there has been little and challenging to verify information about the provenance, traceability, and dangers related to the entire supply chain of agri-food goods from production to consumer markets. Blockchain technology is starting to be used in food supply chains in certain early applications. For instance, Carrefour enables customers to obtain information on their smart-phone by scanning the QR Code on the label of some products, such as organic chickens and Sicilian oranges and lemons (Fortuna et al., 2019). That as consumer awareness of animal welfare and environmental impacts rises, transparent information about provenance and manufacturing practices can influence product selections

(Wünsche Et al., 2022). Additionally, if consumers are interested in changing their diet and receive knowledge, BCT can assist them in adopting a more sustainable and healthful diet. A major challenge is providing consumers with knowledge so they may make better judgements. (Adams, 2018).

Application of block chain technology in food safety: BCT is primarily used in the food industry for supply chain traceability systems, but it can also be useful for monitoring and identifying food fraud hotspots and verifying food safety in the food supply chain (FSC) management system from farm to fork. The BCT effectively promotes food safety and purchaser's reliance by timely and tamperproof sharing of data of product just like batch number, location and date of production, food safety certification, real-time hygienic and sanitary condition of a production site (Galvez et al., 2018). In FSC the food passes through multiple locations starting from production, processing, transportation, distribution, and retail store up to the consumer. The involvement of intermediators can make the food transactions vulnerable to food fraud and costly in above said supply chain (Lierow et al., 2017) because of improper maintenance of all records about food products from farm to fork. So till date, the current system of FSC is inefficient and unreliable (Tripoli et al., 2020). The use of various kinds of sensors and digital technologies (i.e. RFID tags, NFC, Automatic Identification and Data Capture (AIDC) systems, mechanical and biological sensors, time-temperature indicators, smart phones, digital signatures, etc ...) (Epelbaum et al., 2014; Tamplin et al., 2018) can produce real-time information about environmental, production, processing, packaging, storage, transportation and distribution condition of food products. Using BCT and smart contracts, all real-time data records can be moved to blocks once they have been agreed upon and confirmed by all parties through a consensus process. All participating parties acknowledge this as an unchangeable method of depositing data records (Kamilaris et al., 2019). This system's smart contracts can be used to manage food safety regulations, food quality certifications, HACCP applications, Good Agricultural and Manufacturing Practices, and other standards as needed at different food transaction stages (Casino et al., 2020; Tian et al., 2017; Chen et al., 2020). The food supply process will automatically be dismissed by the smart contract and information will not be

Commented [R30]: Revise your statement: Many food supply chains are functioning reliably with conventional systems (e.g., GS1, barcodes, ERP software), although they lack transparency and real-time tracking

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permitted to enter Blockchain if the necessary procedure and standards from manufacturing to the consumer's basket are not met (Mao et al., 2018). By scanning a QR code on the product, consumers can access all the information about the product, from its manufacturing to its retail location. This builds customer confidence and helps to ensure food safety and quality from farm to fork. The growers, processors, logistic suppliers, retailers, and buyers are the participants in the food chain. Every individual functions as a node, and all nodes have access to the information on the public service platform without being aware of the parties' or bodies' private information (Kshetri et al., 2018; Patel et al., 2023)

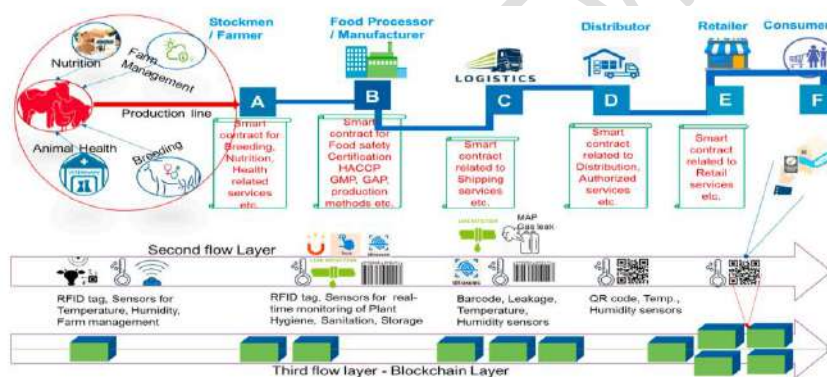


Fig 13: Three Flow layer of Blockchain technology. Source: Patel et al.,2023

A workable method for ensuring food safety:

The progress of information technology has made it possible to construct a blockchain-based food traceability system (Franz et al. Citation 2018). In several countries, traceability systems have been implemented to better monitor and manage the food supply chain, both in their day-to-day operations and in cases of food safety events (Mol Citation 2014). These technologies allow for the tracking of food at various stages, from the farm, which is the primary producer, to the end user (Badia-Melis et al. Citation2018). To regulate the quality and safety of the whole food supply chain, these systems, however, primarily rely on a centralized structural design. A reputable company collects, stores, and oversees the full process from manufacturing to sales (Badia-Melis et al. Citation2015). Since the major company maintains the databases where the data are kept, it has the authority to add, edit, and remove data as it sees fit. Due to a small number of individuals controlling the information, the traceability system is opaque and information about product quality, safety, or processing parameters is manipulated (Fu and Ying, Citation 2016).

For instance, the blockchain technology enables the prompt recall of unsafe food items in the event that food safety issues are discovered. In fact, microbial contamination from unhygienic product handling practices and pest infestations is the primary cause of food recalls (Perboli, Musso, and Rosano Citation 2018). One of the causes of microbial contamination is also the cold chain's anomalous temperature (Feng et al. Citation2020). Real-time data about every step of the food supply chain is recorded by the blockchain technology. Each member would then have access to the blockchain system of truth, enabling prompt identification of the source of contaminated food. Subsequently, the blockchain system's distribution and sales records can be used to track dangerous food, and chargeback can be allocated to the accountable party without the need for additional, drawn-out investigations or the exchange of needless paperwork (Perboli, Musso, and Rosano Citation 2018). Several miners verify the transaction information after a successful food transaction, and only validated and legitimate transactions are posted to the blockchain (Khan, Arshad, and Khan 2018). Food safety is effectively promoted and consumer trust is increased by the use of blockchain technology in the food industry, which allows for the timely sharing of information like origin, batch number, and production date as well as the openness and transparency of the production environment, food safety certification, and organic products (Galvez, Mejuto, and Simal-Gandara 2018; Xu et al., 2022).

several examples from different food industries where block-chain has been or is planning to be used in pilot-scale:

- [Nestlé](#) collaborated with [OpenSc](#), a blockchain platform, to trace milk from farms and producers in New Zealand to Nestlé factories and warehouses in the Middle East.

In 2019, the global food businesses Carrefour and Nestlé declared their partnership to integrate Mousline Purée, a well-known instant mashed potato mix sold in France, into the Food Trust blockchain network. France has liked mashed potatoes since they were created there in the 1800s. It is essential to French consumers that the potatoes used are of the best quality and are cultivated in France. As a result, Mousline Purée is the perfect food to provide traceability. Every 520g packet includes a barcode that a smartphone can read. This gives customers important details about the mix they are going to make, such as the types of potatoes used and the area where they were farmed. Together with giving customers greater knowledge about the food they eat, Carrefour and Nestlé's partnership seeks to decrease food waste and increase food safety. Through the use of blockchain technology, the businesses are able to pinpoint storage locations and dates as well as remove any potential hazards from the supply chain, guaranteeing that the Nestlé factory maintains quality control from farm to table (IBM, 2019).

According to the General Manager of IBM Food Trust, a lot of issues with food systems arise from a lack of transparency. This involves the information's visibility, people's comprehension of what's going on, and their prompt and suitable responses. By establishing a decentralized ledger to record transactions in an international food network, blockchain technology offers a level playing field on which all supply chain partners may exchange crucial information. By disentangling the intricate web of growers, suppliers, manufacturers, retailers, regulators, customers, and restaurants, this will help the entire food ecosystem. Participants can exchange permission-based information regarding food origin, processing, and shipping on the secure data-sharing platform, which guarantees that the information and insights obtained stay the property

and control of the individual enterprises. Nestlé has joined with the OpenSC blockchain network in addition to implementing private blockchain solutions to enhance supply chain transparency. With this action, Nestlé becomes the first significant food and beverage corporation to declare that it is conducting an open blockchain technology experiment. WWF-Australia and The Boston Consulting Group Digital Ventures established OpenSC, a platform that makes independently verified sustainability and supply chain data accessible to everyone, anytime (Nestlé, 2019). The first trial programme records milk as it travels from New Zealand farms and producers to Nestlé factories and storage facilities in the Middle East. Based on the Ethereum network, OpenSC is a public blockchain platform that offers transparency in the transaction chain between buyers and sellers. Customers can use this to follow a product's path from supplier to supermarket. Nestlé S.A.'s Executive Vice President and Head of Operations, Magdi Batato, states that the business wants to give its customers the knowledge they need to choose products wisely, especially those made ethically. Open blockchain technology holds promise for providing consumers with dependable information in an easily obtainable manner (Sergeevic, 2023).

Walmart and IBM's Food Trust Blockchain : IBM does not possess its own block chain. On the other hand, its Blockchain technology is immensely helpful for big, varied online shops. Walmart has consistently backed blockchain technology. Indeed, the company's supply chain operation is supported by IBM's supply chain technology, namely the hyper ledger Fabric platform. Additionally, they intend to track their food products back to the farmers who grow them and let customers confirm the provenance before making a purchase (Walmart has consistently backed blockchain technology. Indeed, the company's supply chain operation is supported by IBM's supply chain technology, namely the hyper ledger Fabric platform. Additionally, they intend to track their food products back to the farmers who grow them and let customers confirm the provenance before making a purchase.(Sharma et al., 2021). One of the best examples of how technology may change risk assessment in the food business is IBM Food Trust. Participants in the food supply chain can exchange reliable information about food goods thanks to this blockchain-based technology. IBM Food Trust helps identify potential risks and speeds up recalls in the event of contamination or quality issues by offering end-to-end traceability and visibility. All parties involved in risk assessment and mitigation are guaranteed to be actively involved thanks to this cooperative approach.

Use of block-chain technology in Seafood Industry:

2016 saw the launch of initiative Provenance Ltd. (Provenance), an early seafood value chain pilot initiative in Indonesia.

The first large-scale blockchain was introduced in 2018 by Atato, a Thailand blockchain-as-a-service (BaaS) platform, and the tuna market development company of Parties to the Nauru Agreement Office (PNAO).

Businesses like Fishcoin have recently joined forces with the SDG 2 Advocacy Hub of the UN Food Program to quicken their transition to sustainable seafood production.

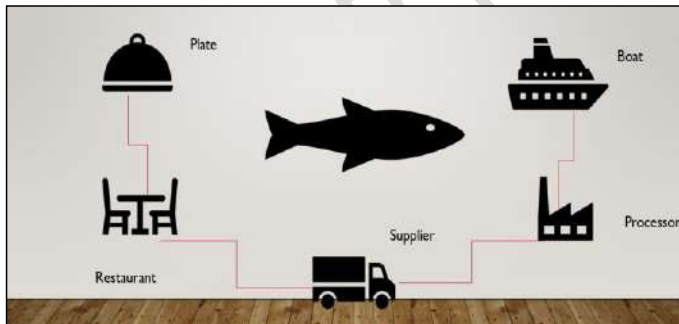


Fig 14: **Block-chain Network in Seafood Industry**

A typical case of blockchain application: Wuhan, China quickly emerged as the epicentre of the COVID-19 pandemic that swept the world in late 2019 (Zhang et al. Citation2020). The Wuhan administration has acted decisively to lessen traffic in the city. At last, the outbreak is under control. On June 12, 2020, it was discovered that the employees at the Beijing Xinfadi Market were infected with COVID-19. Studies showed that salmon exposure was a factor in COVID-19 infection. During this procedure, the blockchain system records data about each customer's salmon purchase. Consequently, the authorities implemented the blockchain technology to promptly identify all afflicted individuals within the Xinfadi Market. Every step of the process is documented by the blockchain system, including the origination data for sea farming, feed purchases, distribution, processing, and retail. From farming, to processing, refrigeration, packing, and consumer delivery, every piece of salmon is equipped with an RFID tag that can automatically gather data on the salmon and upload it in real time to the blockchain (Galvez, Mejuto, and Simal-Gandara Citation2018; Mondal et al. Citation 2019). A suitable aquaculture water region is selected by the smart contract based on its pre-set conditions, water quality, and other mariculture criteria. Processing manufacturers can search the blockchain system for processing data, such as processing parameters and worker wellness. The blockchain system ends with the retail contract. By scanning the QR codes, customers may get all the information about marine farming, processing, and distribution (Feng et al. Citation2020). The blockchain system's deployment not only reduces the time it takes to trace food, but it also boosts consumer confidence in food safety

BLOCKCHAIN IN ONLINE FOOD DELIVERY:

It is common knowledge that India offers a sizable population as well as tremendous development and success potential for food enterprises. Very soon, India is anticipated to hold the title of nation with the greatest GDP. Simultaneously, though, agriculture—which currently accounts for 50% of the workforce and 13.7% of India's GDP—is progressively

dwindling. Concerns about food security have been under intense attention recently. Assuring food security, safety, and sustainability is largely dependent on the intricate and valuable global food supply chain. The industry for online meal delivery has expanded quickly in India, where major competitors like Swiggy and Zomato are transforming how people get food. One of the main causes of the rise in popularity of meal delivery services is the COVID-19 epidemic, but there are other important factors as well, such as the quick development of technology. In December 2017, it was claimed by a report that around 65 out of 72 food testing labs of the Food Safety and Standards Authority of India (FSSAI) were illegal (Union Government, 2017). In October 2018, famous food companies like Zomato, Swiggy, and Food Panda removed 10,500 hotels and restaurants from food service, as the food quality in these restaurants and hotels was not up to the mark as per the standard prescribed by the Food Safety and Standards Act of 2006 (FSS Act) (FSSAI, 2020). In addition to this, these places did not have the basic food safety controller approvals from the Indian government (. It's crucial to remember that the idea of online meal delivery is not new, and business owners looking to get into the food delivery industry face a number of obstacles pertaining to data security, transparency, and trust. Therefore, as technology advances, this constantly changing scene unquestionably needs an upgrade. Blockchain technology has become a "ultra-legend" among several businesses, capable of providing the best answers to the problems that a specific industry faces. Blockchain technology can optimise critical areas of the delivery process and improve the entire user experience by using the principles of immutability, decentralisation, and transparency (Babukuttan, 2024). Technologies based on blockchain have the potential to completely change the food delivery industry. So gone are the days when folks were happy to receive a free pizza delivery in less than half an hour. Nowadays' customers need speed and ease of use. Over the past five years, meal delivery businesses have experienced significant growth as a result of digitization. "Wooberly Eats" is one of the newest technologies available; it combines blockchain and machine intelligence. An open-source UI framework called "Flutter" is used by Wooberly to offer a number of features, such as data exchange with the customer, driver, restaurant, and system administrator. There are two categories of online meal delivery services (Yeo et al., 2017). The first is a restaurant-to-customer delivery company, like McDonald's or Kentucky Fried Chicken, which may provide online meal delivery services directly or via affiliate businesses.

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The other is a platform for delivery services used by customers, like Foodpanda, Uber Eats, and Hungrynaki. Due to erratic ordering patterns and disgruntled patrons caused by the meal delivery apps' disregard for food safety and timeliness, the restaurant's image suffers. Restaurants may use smart contracts and blockchain technology to tackle these issues, which will also be a safe way to conduct transactions. The concept is based on blockchain technology and is designed to solve a number of valid issues with current online meal delivery platforms. It facilitates bitcoin transactions, which, as was said in the study discussion, offer security and decentralisation. Every transaction is protected by smart contracts. A smart contract is a piece of computer code that controls data transfers within predetermined parameters. Smart contract management ensures that no one, not even the administrator, can tamper with the data contained in Blockchain. To implement smart contracts, established protocols and ledgers are used. Blockchain-based systems are more secure than traditional database-based apps for the reasons described above (Talukde et al., 2022).

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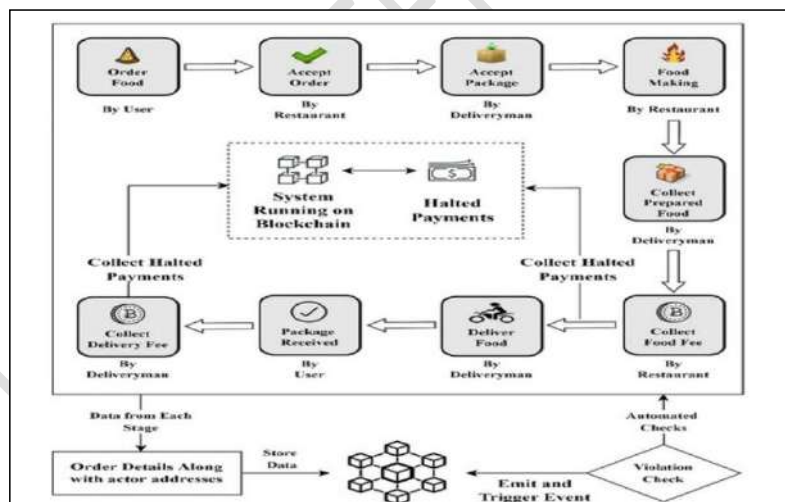


Fig 15: Blockchain technology in online food delivery. Source: (Talukde et al., 2022)

CONCLUSION: Through the use of Blockchain technology, real-time risk point detection for food safety can reduce food fraud and contamination while also strengthening the mechanism for recalling affected batches of products. Though it has some demerits but technology has an inherent ability to evolve and overcome obstacles, paving the way for a brighter future for blockchain adoption. This study advances knowledge, practice, and research on blockchain applications in food safety control by offering a thorough analysis of the technology's uses in this area. Food safety concerns can be addressed with the aid of blockchain technology, but putting this promise into action would involve overcoming a number of significant roadblocks and difficulties. Nonetheless, using blockchain technology to regulate food safety is promising. This study does, however, have certain limitations and is based on a review of the literature. The suggested rules and framework should be further evaluated and validated as they are based on existing literature. The recommendations made here are supported by the literature and need more research. This constraint offers opportunities for further study and application in the future.

Abbreviation:

BCT	Blockchain Technology
DLT	Distributed ledger technology
FSMS	Food Safety Management System
PoW	Proof of Work

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PoS	Proof of stake
HACCP	Hazard Analysis Critical Control Point
GAP	Good Agricultural Practices
FSC	Food supply chain
SQF	Safe quality food
GMP	Good manufacturing practices

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