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A new blockchain and IoT based architecture of food safety system for confectionery supply chain in Industry 4.0 era

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A R T I C L E I N F O

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A B S T R A C T

The major challenges faced by confectionery supply chain are lack of information, traceability, managing the ownership of goods across supply chains, inability to track vendors in real-time. Blockchain and Internet of Things (IoT) in Industry 4.0 era help organisations to overcome these challenges by guaranteeing authentic information, real-time visibility, and transparency across the supply chain management. The extant literature has revealed that blockchain and IoT technologies are in their early stages of information management for the supply chain. This study explores the potential opportunities available with Blockchain and IoT in the confectionery supply chain. Utilising the inputs from the survey and interviews, the article identifies to present the gaps in the supply chain and proposes a new blockchain and IoT-based architecture of the food safety system for the confectionery supply chain. Typical blockchain architecture is designed for a food safety system, and the technical specifications required to implement blockchain are evaluated. Further, blockchain-assisted distribution information management is proposed to bring more visibility to the shipment of goods. Implications of deploying blockchain and IoT in the supply chain from a management perspective are discussed. The study distinguishes itself from existing literature in two ways: first, by introducing a tailored blockchain and IoT architecture specifically designed for food safety in the confectionery supply chain; and second, by demonstrating its practical implications in addressing real-time traceability, transparency, and operational efficiency in line with Industry 4.0 goals. This integrated approach helps organisations make informed decisions, reduce supply chain risks, and improve regulatory compliance across the confectionery value chain.

1. Introduction

Blockchain is a secure transaction ledger that transfers information in a distributed network shared by all parties. It makes every transaction secure that happens in the network, fundamentally avoiding the necessity for third-party systems (Uyar et al., 2025). Information is transferred in a distributed network of computers, termed as nodes, where each node contains a chain of blocks. Information is shared between nodes in a blockchain network - this information can be related to raw material, finished goods, and asset condition (Viriyasitavat & Hoonsopon, 2019). Blockchain uses a cryptography technique that ensures the genuineness, proof-of-identity and authorise access rights (Mandolla et al., 2019). The blockchain facilitates organisations to share information in a distributed and secured manner. The value drivers of blockchain are immutability, automation, auditability, security, cost reduction, and decentralised systems (Zyskind and Nathan, 2015; Babich and Hilary, 2019; Casino et al., 2019).

Blockchain can help businesses meet consumer's high expectations

Abbreviations: IoT, Internet of Things; RFID, Radio Frequency Identification; SCM, Supply Chain Management; ERP, Enterprise Resource Planning; DLT, Distributed Ledger Technology; API, Application Programming Interface; GPS, Global Positioning System; AI, Artificial Intelligence.

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for seamless product availability, provenance and personalised service. The challenge for every organisation is that stakeholders have exponentially increasing demands for better product stock visibility, proof of authenticity, seamless resale of products and integrated service offerings (Yue et al., 2014). Customers want to find specific products and there is no aggregated visibility for specific products across different retailers. Growing demand for product authenticity, sustainability and ethical sourcing have an impact on the buying behaviour of consumers (Duong et al., 2025). Further, it is a challenge to verify the status and location of goods across supply chain, during storage in the warehouse as well as transportation (Sun et al., 2025; Garcia and You, 2015; Melnyk et al., 2014; Bostrom et al., 2015).

Blockchain can be leveraged to drive the concept of a fully connected supply chain and unlock a host of opportunities to enhance the customer experience in the industry 4.0 era (Uztürk and Büyüközkan, 2024). As illustrated in Figure 1, blockchain can connect to multiple Enterprise Resource Planning (ERP) systems and inventory data can be shared with stakeholders across supply chain. The product origin can be traced at its point of purchase or during product selection. Blockchain also maintains the visibility of a product lifecycle giving stakeholders assurance that the product has gone through correct channels (Tseng et al., 2019, Barbosa-Povoa et al., 2018).

The transaction costs are eliminated in blockchain as there are no intermediaries due to shared ledger tracking of transaction across the entire lifecycle. Some of the key challenges in Supply Chain are visibility of goods, coordinating the transfer of ownership, monitoring product quality and verifying authenticity (Vazquez Melendez et al., 2024). With the help of blockchain, a shared ledger amongst vendor/trading partners can automatically track and trace goods through the supply chain, validate transactions, and verify the origin, blending and adherence to ethical standards (Akter et al., 2024). Initially, blockchain was established to support the cryptocurrency, now it is further developed to support a wide range of applications such as supply chain Management, pharmaceutical, oil and gas industries. The technology is set to grow/expand further in the coming years; thus, organisations need to be prepared and explore the opportunity (Hofmann et al., 2018; Leng et al., 2018).

Though various studies on blockchain have been explored, there exists a need to focus on the Food supply chain and confectionery products to get access on end-to-end supply chain information to minimise waste and monitor inventory storage in real-time (Treiblmaier, 2018; Büyüközkan and Göçer, 2018). The objective of this research is to understand the implications of blockchain and IoT in the confectionery industry. Additionally, it discusses the sustainability of supply chain by recycling and reusing the items, which improves production cost and making environment-friendly products. IoT can assist to monitor the condition of food products across supply chain from suppliers to consumers (Ehie and Chilton, 2020).

1.1. Contribution of this research

The supply chain members are expected to determine the forecast data as accurate as possible but, there is considerable variance between forecasted data and real demand. This effect results in excess inventory or not sufficient buffer stock, as well as underutilised resources. Organisations are using information systems to increase the visibility of the movement of goods and information availability. Despite using information systems, the supply chain performance is not improving as there is a low trust among supply chain members. Improving trust in the system is a long-term process and there is no fool proof mechanism to validate that all supply chain members are provided with accurate information. Some organisations provide inaccurate or false information intentionally or unintentionally which affects the entire supply chain ecosystem. This article proposes the opportunities that exist with blockchain to deliver the source of truth and accurate information communicated between supply chain members.

The literature shows that blockchain is initially implemented in financial institutions and now explored in the supply chain as it shows fruitful results in identifying and tracing the counterfeited items. The research reveals that blockchain in the supply chain is still in initial stages and it is worth to study and adopt this technology. A pilot study is needed for the stakeholders to understand the real benefits before the real implementation.

It is observed that very few papers published related to the food supply chain using blockchain-driven IoT (Vasileiou et al., 2025; Helo and Hao, 2019; Kamilaris et al., 2019; Bumblauskas et al., 2020; Bottani et al., 2020; Antonucci et al., 2019; Yadav et al., 2020; Bermeo et al., 2018). Besides, the published literature lacks research in confection nary supply chain specific to blockchain and IoT technologies. The confectionary supply chain involves a non-fully trusted ecosystem with various stakeholders and the final product in a confectionary supply chain has a shorter shelf life. Thus, the study on the confectionary supply chain is essential and explore the opportunities with Industry 4.0 technologies such as blockchain and IoT to mitigate the challenges faced by the industry.

The study tries to answer the following research questions:

RQ1. What are the specific challenges faced by the confectionery supply chain and how can blockchain and IoT help overcome them?
RQ2. Can blockchain and IoT improve transparency and trust among supply chain partners?

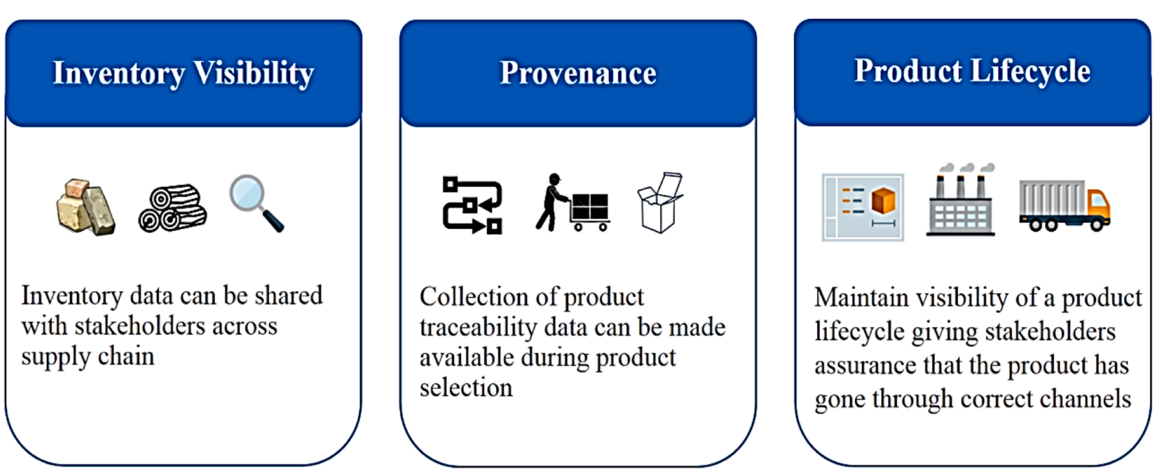

Fig. 1. Leverage blockchain for connected supply chain.

This study centres on the confectionery supply chain, where unique challenges such as limited visibility, traceability gaps, and insufficient trust among stakeholders are especially critical due to the short shelf life of products. It aims to investigate how blockchain and IoT technologies can address these issues by enabling real-time visibility, enhanced tracking, and robust data security throughout the supply chain. The research seeks to deepen understanding of current problems faced by confectionery manufacturers and partners, assess the potential of blockchain and IoT to solve these, propose a novel architecture for integrating these technologies into a food safety system, and discuss the practical benefits and operational implications for the confectionery industry

To answer these, the research follows four main objectives:

RQ3. Identify current gaps and challenges in the confectionery supply chain.
RQ4. Design a blockchain-based architecture suitable for food safety and traceability.
RQ5. Explain how IoT can improve real-time tracking and visibility.
RQ6. Analyse the overall impact and usefulness of blockchain and IoT in the confectionery industry.

By addressing the above research questions and objectives, this research contributes to the blockchain and IoT based food safety systems literature by identifying the challenges in the confectionary supply chain. The outcome helps the organisations to understand the importance of blockchain especially the manufacturers who produce the perishable final products as they have a shorter shelf life.

This study presents a novel blockchain and IoT-based food safety architecture specifically tailored to the confectionery supply chain - an area that remains underexplored in existing literature. While prior works have generally focused on broader food supply chains, this article uniquely addresses the challenges associated with short shelf life, non-fully trusted supply chain ecosystems, and temperature sensitivity in confectionery products. The manuscript also proposes real-time IoT applications and waste recycling mechanisms which are rarely detailed in similar studies. This practical orientation and domain specificity make the study a unique contribution to the Industry 4.0 supply chain literature.

The paper is structured in seven sections; initially, the literature on the Blockchain, IoT, and supply chain are reviewed. Later a case study is conducted on a contemporary organisation and the present system of confectionery supply chain is studied. Further, the challenges faced with the present supply chain and key gaps identified are presented. Role of IoT and Blockchain on confectionery supply chain is analysed. Based on the analysis, architecture for blockchain assisted food safety system and technical specifications required to implement blockchain is evaluated. Finally, the implication of deploying blockchain and IoT in confectionery supply chain is discussed.

2. Literature

The literature has been studied from the perspectives of blockchain and IoT that influences supply chain. The articles are reviewed based on industrial impacts, applications, current research on key technologies, which can assist the organisation to transform itself into a digital organisation and meet Industry 4.0 requirements.

2.1. Evolution of blockchain

The evolution of blockchain started in 2009 as illustrated in Fig. 2, however, the research on distributed computing began in the early 1990s. In 1997, Nick Szabo introduced digital security system which is also termed as smart contracts. Initially, this was a targeted automobile industry using cryptographic keys (Szabo, 1997). The idea is to track the entire history of a car with proper security protocols. Organisations started exploring smart contracts, which are considered as secured and transparent with involved parties. In 2009, Satoshi Nakamoto has conceptualised blockchain. Initially, it was developed to support digital currencies by linking cryptography with peer-to-peer technology. Later, blockchain is used to register information in blocks. The algorithms for creating, updating are stored in a ledger which is difficult to alter. Eventually, the development of cryptocurrency came to existence. Cryptocurrency uses digital technology to exchange financial transactions (Alamsyah and Muhammad, 2024). Further, Smart Contracts are carried out based on blockchain technology, which controls the ledger and enforces rules (Shao and Marwa, 2024). In the 2012-13 period, transactions are being started with cryptocurrency and digital payments have been made. It uses a decentralised mechanism as opposed to core banking systems. In the 2013-14 period, financial markets and applications started using blockchain beyond cash transactions.

In the 2015-16 period, a private blockchain called permissioned blockchain came to an existence where users are granted access to the private network. In the 2016-18 period, various industries such as financial institutions, manufacturing, healthcare, automobile started exploring blockchain considering the capabilities of blockchain-like immutability, auditability, and security. Table 1 summarises the literature review with a focus on various areas.

The review shows that the blockchain can be leveraged in various industries. Many organisations are starting to form the standards and expand the blockchain solution boundaries. Initially, the focus was on banking systems to clear payments, insurance, settle assets related

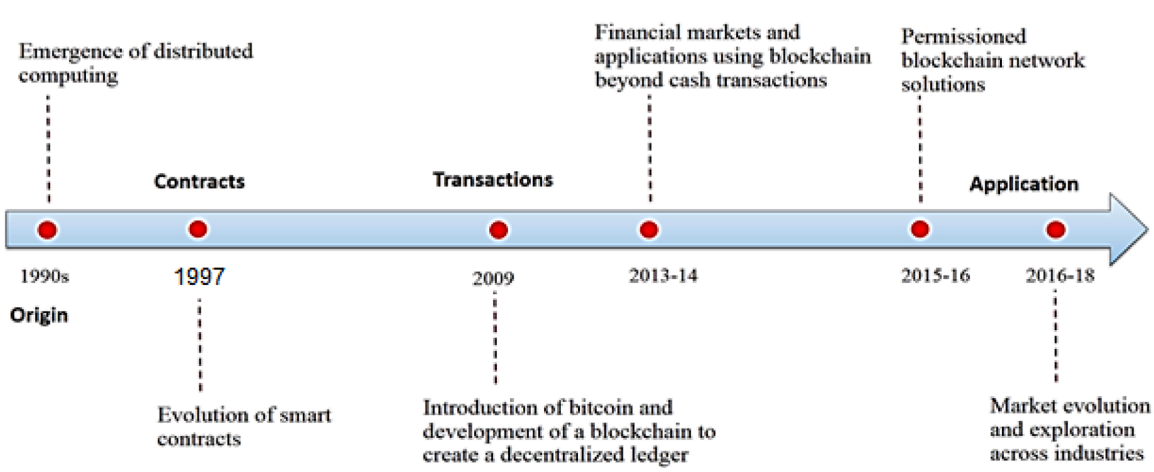

Fig. 2. Evolution of blockchain technology.

Table 1
Summary of literature review.

Focus Area	Description	Source
Pharmaceutical	Assess the implication of blockchain in the pharmaceutical industry. Combing blockchain with IoT helps organisations to track, execute smart contracts and secure the transactions.	Mettler (2016); Monteil (2019); Chiacchio et al. (2019); Chiacchio et al. (2020)
Food	Food safety is one of the key issues across the globe. Traceability is a challenge in traditional methods. Technologies such as Radio Frequency Identification (RFID) and blockchain are explored to trace the food supply chain and production, distribution and warehouses.	Tian (2016); Galvez et al. (2018); Casado-Vara et al. (2018); Behnke and Janssen (2020); Feng et al. (2020); Das et al., (2024)
Financial Services	Blockchain can be used in banking systems for clearing payment, monitoring credit information. A private blockchain is proposed with a set of industry standards and a regulatory system is established.	Peters and Panayi (2016); Dinh et al. (2018); Eyal (2017)
Manufacturing	Studied the current manufacturing industry challenges and explored blockchain technology to bring transparency and traceability in the supply chain network. Proposed smart contracts for manufacturing resource sharing and presented future manufacturing systems roadmap with technology and its benefits.	Ghobakhloo (2018); Li et al. (2018); Angrish et al. (2018); Westerkamp et al. (2018) (Agrawal et al., 2023)
Healthcare	Blockchain focus on healthcare is in the beginning stage. Considering the importance of drug counterfeiting, user-driven medical experimentations, blockchain is a key technology, which can be explored for public healthcare management.	Yue et al. (2016);
Logistics	Discussed the adoption of blockchain in transportation industry thereby logistics managers are benefited with real-time physical movements of goods.	Miller (2018); Saberi et al. (2018); Tijan et al. (2019); Koh et al. (2020); Wong et al. (2020)
Chemical	Explored blockchain in the chemical industry and established a proof of concept to implement blockchain on electricity producers and consumers.	Sikorski et al. (2017)
Defence	A reviewed cyber threat in defence systems. Explored the capabilities of blockchain, which can help in cyber defence strategy as a security solution.	Shackelford and Myers, 2017
Textile	Presented a blockchain based framework and smart contract to enable traceability in textile supply chain with example of organic cotton supply chain	Agrawal et al., (2021)

transactions. Later, the influence of blockchain technology in other industries is evolving gradually. There is a need for robust blockchain solution across industries considering the scalability and efficiency of the entire value chain.

2.2. IoT and recent developments across industries

Influence of IoT is gaining momentum in different industries such as logistics, manufacturing, retailing and pharmaceutics. Development in the field of internet and wireless technologies makes IoT a promising solution that is influenced in various sectors and bring disruption in organisations (Westergren et al., 2024). Initially, RFID technology is used to control inventory, production, shipment tracking. Later, wireless sensors started emerging with the advances in communication systems (Guchhait and Sarkar, 2024). In early 2000, the internet became the standard communication medium, and enterprises started to rely on technology to be more competitive. With Industry 4.0 revolution, usage of internet is leveraged to get real-time information about components, products, machines, and assets. In Table 2, recent developments in IoT across industries are studied.

The study shows that IoT technology is diversified and used for both industrial and domestic purposes. However, the focus on supply chain industry with IoT is not explored fully to its potential. IoT can be leveraged to communicate the information in real-time with supply chain members to improve the collaboration and reduce the wastes as well as costs.

Based on the available literature, blockchain and IoT technology is in its early stages but has huge disruptive potential for all sectors of the economy for Industry 4.0 requirements. Interest in blockchain continues to gain momentum in the marketplace. Organisation across a broad set of industries is exploring blockchain. Early adopters are actively creating pilots to gain real-world experience and understand its impact. The supply chain organisations across the economy have the potential to deploy blockchain and IoT technology in their business model (Halder et al., 2025). Within this context, the article is instigated and the opportunities with the adoption of blockchain and IoT in confectionery organisation is analysed.

3. Methodology

The approach/methodology for this research is illustrated in Fig. 3. The literature on the blockchain, IoT and SSC in the context of Industry 4.0 has been studied. A case organisation to study the opportunities of the blockchain has been identified. A qualitative survey is conducted in the case organization with middle and senior management employees to evaluate the current supply chain challenges faced by the organization. This study relies on responses obtained from 78 managers who are the stakeholders involved in the operations of confectionery supply chain. Based on the research purposes and objectives of the study, the survey was conducted in two stages. First, the process started with the preparation of a questionnaire with a cover letter mentioning the purposes and objectives of the research. The questionnaire is prepared to collect the qualitative responses from the managers to understand the present supply chain operations in terms of items visibility, quality of raw materials received by suppliers, experience with the transporters who carries the final product (Sharma et al., 2024). The questionnaire was sent to the managers who oversee supply chain operations. Second, based on the responses received, in-depth interviews are conducted with managers to study the end-to-end supply chain operations and challenges faced during day-to-day activities. The survey revealed that the organisation has taken a few initiatives to deploy technology in certain aspects, which indicates that they are in transition towards fulfilling Industry 4.0 requirements but lack the strategy to implement it. The entire supply chain process has been extensively studied. Both upstream and downstream supply chain challenges and their risks have been assessed. Later, the fit-gap analysis in the present supply chain practices has been identified. Based on the analysis, blockchain and IoT technologies are evaluated. Design of blockchain architecture is accomplished and IoT is proposed to increase the visibility on goods movement, ownership transfers and shipment details. Audit trail conducted to check supply chain members have the same information

Table 2
IoT across industries.

Area	Description	Author
Warehouse	A smart warehouse is equipped with advanced technologies such as IoT to manage stock, make decentralised decisions, and monitor the movement of goods remotely.	Reaidy et al. (2015)
Rescue Management	IoT is a reliable technology during emergencies by the rescue team to streamline the rescues operations with accurate information. It also helps to take faster judgements where time is crucial.	Yang et al. (2013)
Manufacturing Systems	Industry 4.0 is built on cutting edge technologies such as IoT, Cyber-Physical Systems (CPS), Artificial Intelligence (AI), Big Data, and Real-Time analytics. Manufacturing industry leverages the benefits of Industry 4.0 capabilities such as interoperability, dependability, trustworthiness to improve overall operational efficiency.	Nath et al, (2024); Sadeghi et al. (2015)
Healthcare	Healthcare supply chain needs to keep sufficient inventory all the time and management is exploring to deploy IoT system to optimise the resources and time.	Subasi et al. (2018); Moosavi et al. (2016)
Retail	Industries such as apparel and footwear want to make a big leap in terms of knowing consumer buying patterns and vendor managed inventories where timely availability of items are key. IoT helps them to achieve any time product availability that is up to date in terms of fashion and trend.	Majeed et al. (2017)
Engineering and Construction	Construction industries are facing multiple challenges such as worker shortage, protecting the environment with eco-friendly items, labour safety, and minimise idle worker time. IoT helps to overcome all these challenges and mitigate any supplier risk.	Li et al. (2016)
Health	Connecting people, equipment, and devices in real-time are important in healthcare services. IoT helps the healthcare system drastically as medicines and physicians can reach needy on time and health-related data can be communicated to stakeholders continuously.	Tyagi et al. (2016)
Transportation	The physical movement of objects is tracked in real-time. RFID, Sensors are used earlier but the information is static. With IoT, supplier shipments are monitored remotely which helps logistics manager to meet the on-time shipment and allows taking proactive measures to avoid stock out.	Zhang et al. (2012)
Domestic	From the sustainability perspective, IoT is used in households to conserve energy, reduce wastages, and improve the safety of society.	Perera et al. (2014)
E-commerce	Ecommerce vendors explore IoT to ensure on-time product delivery to consumers. It brings flexibility, traceability and keeps the consumers with up-to-date information.	Lin et al. (2017); Kravari and Bassiliades (2018)
Food safety management	Allows a food-processing company to monitor the right composition of ingredients in food, and alerts when the shelf life of a product is nearing the end date.	Nath et al., (2023); Doinea et al. (2015); Lezoche et al. (2020)
Mining	IoT devices detect the problem early and alert the stakeholders with disaster signals. Early warnings help organisations to avoid major accidents, improves the safety of workers.	Qiuping (2011)
Energy	Sustainability is one of the parameters used to measure industries by regulators and government agencies. Energy conservation is a key to build a smart factory. IoT helps to achieve this where it connects the physical and digital world. It helps to track energy consumptions and explores the option to save energy.	Shrouf (2014)
Production	Industrial IoT is emerging where assets and machines interact with each other and using artificial intelligence IoT devices are empowered to make decisions based on the situation. It improves the effectiveness of the entire ecosystem.	Qu et al. (2016)
Rescue Management	IoT is used to predict fire accidents and disasters with automated alarming communication systems.	Da et al. (2014)
Energy management	Consumers can get visibility into energy consumption patterns with IoT and take actions remotely to save energy from home appliances.	Tao et al. (2016)
Telecom	IoT is a viable option for telecom players who look for an efficient and scalable solution, which can be relied on for real-time updates.	Zarei et al. (2016)
Food	IoT plays a key role in the food processing industry as the items are perishable and keeping the item in good condition is crucial. Traceability and prompt response time help the industry to avoid wastes.	Pang et al. (2015)

in-terms of goods movement, inventory and sales to trust the technologies. Based on the assessment, recommendations are made to management for using blockchain and IoT.

4. A real application

The study was performed in a confectionery manufacturing organisation located in South India (hereafter stated as XYZ). XYZ produces chocolate bars and candies. XYZ is an ISO 22000:2005 certified organisation that distinguishes themselves as a quality organisation with high food safety system and keen on implementing new technologies to enhance SC sustainability. XYZ is a right fit for this case study, as the management is optimistic to develop a roadmap in deploying new technologies by leveraging Industry 4.0.

4.1. Present system of confectionery supply chain

A typical manufacturing process of a confectionery organisation is illustrated in Fig. 4. The raw materials to produce chocolates are cocoa beans, sugar and flavours like vanilla, milk powder, additional cocoa

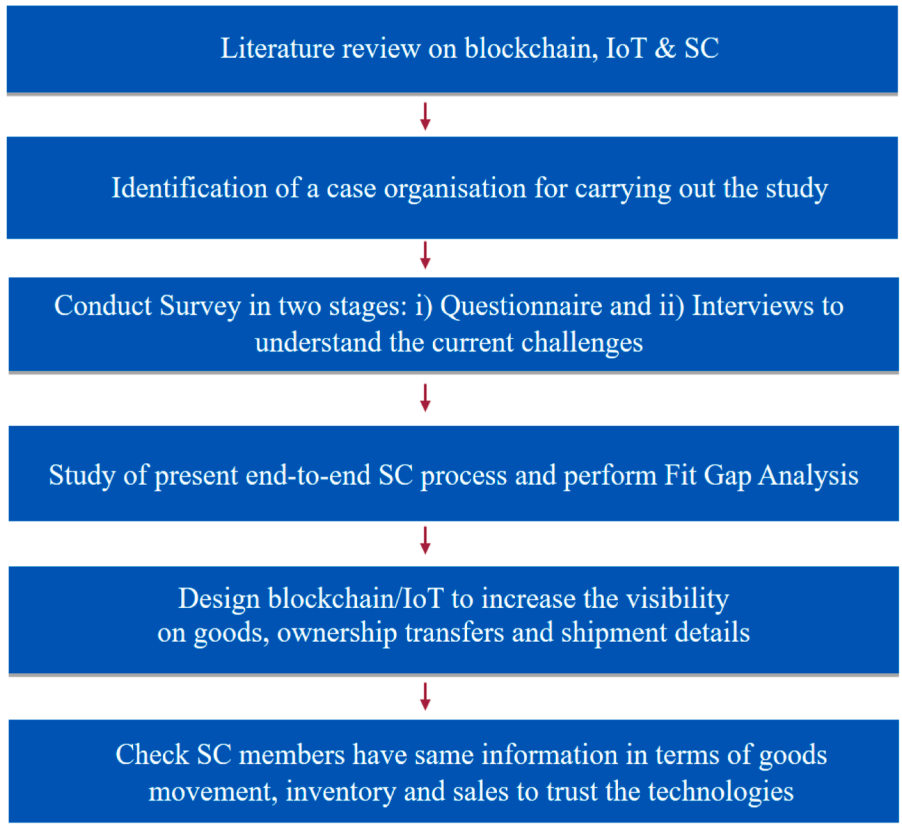

Fig. 3. Methodology on blockchain-enabled supply chain.

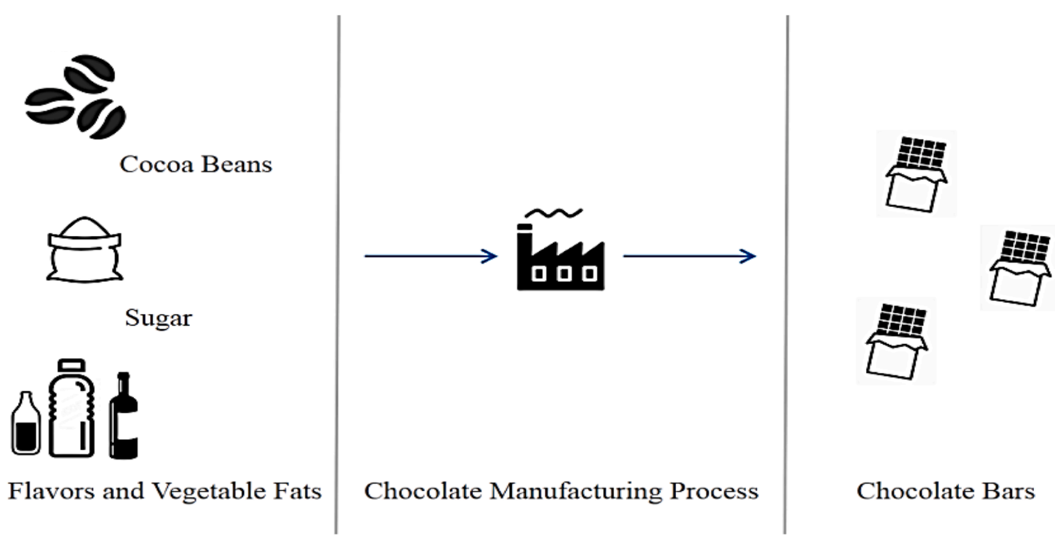

Fig. 4. Overview of confectionery supply chain.

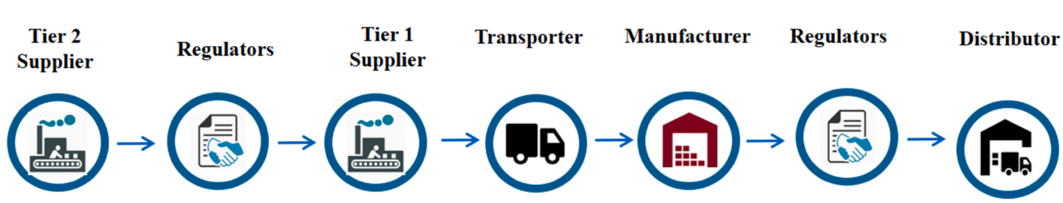

Fig. 5. Linear supply chain of the present organisation.

butter. The manufacturer also adds sunflower seeds and vegetable fats to make the cost more economical. The primary raw material to make chocolate is cocoa beans, which comes from cocoa fruit. The process starts with a proper fermentation process of cocoa beans where beans are dried, heated, shelled to make beans semi-liquid. Later sugar and other ingredients are grinded and added to semi-liquid cocoa to make it sweeter. Finally, it is poured into moulds as per standard specifications to make chocolates bars and candies.

The linear supply chain of the present XYZ organization is shown in Fig. 5. The confectionery manufacturer deals with many suppliers and traders. In general, cocoa beans are purchased from traders who procure it from international suppliers. The present supply chain has visibility up to tier 1 supplier. The trader fixes the price and grade of the materials and there is no formal process defined to fix the rate. After the finished goods are produced and packed, the manufacturer gets the food safety certification from the regulator and ships the products to distributors, based on the order. Later, the chocolate bars are received by reseller and reach the end customers.

In the present confectionery supply chain, one of the major challenges is that there is a lack of transparency regarding the origin of cocoa beans. Hundreds of farmers at the starting of supply chain extracts cocoa beans from cocoa fruit and sell it to brokers who purchase it at a very low price, which leads to cocoa farmers in poverty, resulting in child labour and modern slavery. The present confectionery supply chain is unevenly distributed.

The information sharing among stakeholders is a challenge and influences the traceability of raw material along the chain. Orders must be processed by cooperatives, exported, imported, and shipped to the requester. Each step in the supply chain is managed by a different party. Tracing the quality of beans and accountability across the complex supply chain are the major challenges as the stakeholders report the information inaccurately.

4.2. Challenges and issues in current supply chain

The upstream Supply Chain ecosystem of XYZ organisation is illustrated in Fig. 6. In the confectionery industry, tracking of raw material, cocoa beans all the way from farmer to the manufacturing plant is a challenge for the manufacturer. The farmer produces cocoa beans of a certain quality and cooperative assigns grade to raw materials. Cooperative fixes price and sell materials through a broker who is also an exporter. Then, the exporter loads materials and transports it to the nearest port. Materials are loaded on to a ship and transported too overseas. The importer who is a Tier 1 supplier for chocolate manufacturer unloads the materials and transports to the production plant where the raw material is transformed into a product.

The lack of transparency and traceability of the source of the cocoa beans brings a lack of trust in the ecosystem. Its further results in negative implications of safe products. Besides, real-time information of raw material condition, size of shipped goods, in-transit status is not available currently as each stakeholder uses different systems. It also leads to error-prone reconciliation with each other's records. No sustainability reports are provided by the supplier. There is a lack of ownership among multiple parties, a complete audit trail is not executed in the organisation and there are few complex trade policies followed. Further, following are the important aspects revealed by supply chain operations managers during a case study

- Importance of confectionary raw materials and finished product traceability
- The complexity involved in the present traceability practices.
- Trust ability of information provided by various supply chain members.

These challenges urge the organisation to explore the opportunities available with new technologies in Industry 4.0 era. IoT embedded Blockchain is suggested to management considering After a detailed study on the end-to-end supply chain process of the current system in XYZ organisation, it is proposed to leverage blockchain and IoT technologies to bring greater transparency and response across the supply chain. It accelerates tracking in weeks and days to seconds in real-time.

The following Table 3 provides the summary of challenges faced in current supply chain with the use cases.

4.3. Integration of current supply chain with blockchain and IoT

Blockchain and IoT technologies address many challenges of the current confectionery supply chain. For instance, the manufacturer imports the raw materials, but sources of supply are not transparent. With the blockchain technology, the origin of the source can be verified, and authorised information can be shared with supply chain members. In this case, it is important to monitor the item status to take immediate actions as the finished goods are perishable. IoT enables to track the status of the finished goods and notify the stakeholder when the operational parameters are nearing or out of threshold limit, thereby ensuring fewer wastages (Li and Wei, 2025). The integration of blockchain and IoT technologies combined with present information systems improves the data security, tracking of goods movement across supply chain (Tsang et al., 2019). With blockchain, the shared data cannot tamper, and it brings better transparency among supply chain members

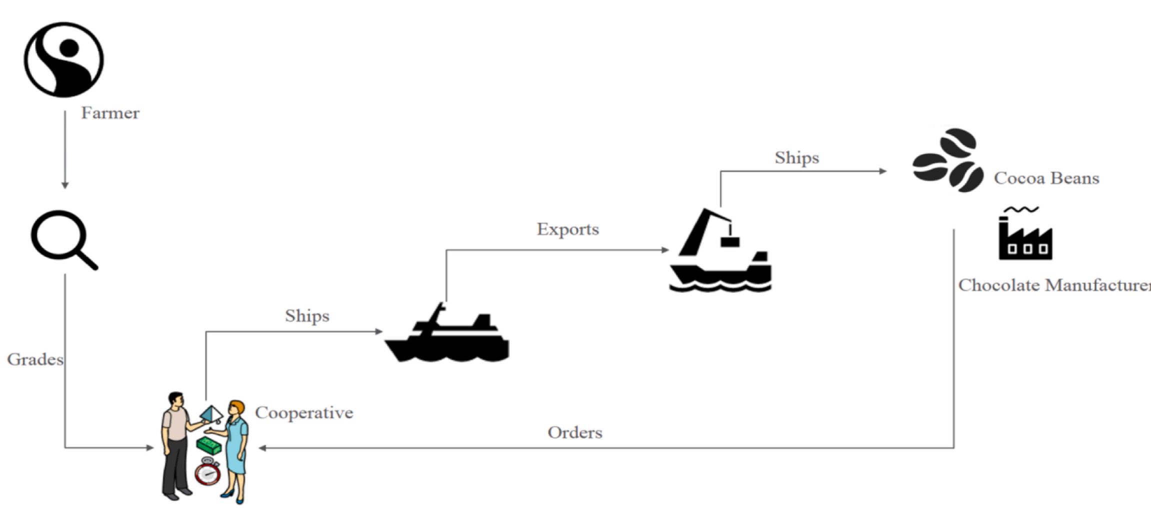

Fig. 6. Cocoa Beans Supply Chain workflow.

Table 3
Challenges in current supply chain.

Supply Chain Now	Use Case
Lack of Transparency	The farmers' extract cocoa beans from cocoa fruit and the broker decide the price. There is no minimum guaranteed price agreed by the broker (who is also the exporter of the goods), which leads to cocoa farmers in poverty, resulting in child labour and modern slavery. The present confectionery supply chain is unevenly distributed.
Lack of Traceability	The organization deals with many suppliers and traders which includes international suppliers. Although advanced shipment notice is given by the suppliers' shipments often get delayed because of multiple ownership transfers of the goods.
Misconception in the accountability across complex supply chains	There is a lack of ownership among multiple parties. The agreed terms and conditions on the trade policies are not always followed and the discrepancies are identified only during audit trail process.
Error-prone reconciliation with each other's transactions	Each supply chain member uses different systems to manage the inventory, sales, and logistics information. There are cases where inaccurate data is shared with or without any intention. Also, the response time taken by each supply chain member for sharing data is more.
Inability to monitor suppliers in real-time	There is no mechanism followed to know the in-transit raw material condition, disruptions occurred during transportation which causes a delay in the shipment arrival. At times, the size of shipped goods varies which makes manufacturer little difficult to plan for inbound logistics and managing the warehouse.

(Caro et al., 2018). Thus, it improves the overall relationship among supply chain members.

5. Design of blockchain-enabled food safety system

5.1. Proposed blockchain architecture overview

The proposed architecture is a multi-layered framework that consists of five-layer as illustrated in Fig. 7. The framework connects various technologies as well as technical components (Azzi et al., 2019; Helo and Hao, 2019; Longo et al., 2019).

5.1.1. Sensing layer

The sensing layer transforms the physical data into digital data using IoT devices and it can be transmitted in real-time (Pandey et al., 2025). In this layer, temperature monitoring sensors and relays are deployed to get data on the climatic conditions with a timestamp. It is proposed to implement the MT Connect agent-based IoT architecture model as Message Queuing Telemetry Transport (MQTT) M2M technology has more vocabularies and provides information in the device-readable format (Edrington et al., 2014; Garrido-Hidalgo et al., 2019). Blockchain provides the secured data transfer in a distributed network, and it takes care of data security (Novo, 2018; Viriyasitavat and Hoonsopon, 2019). In addition to that, the transactional data are communicated by the supply chain partners.

5.1.2. Information layer

The next layer is the information layer where there are different sets of information collected (Zhong et al., 2015; Chen et al., 2014). In general, the information layer consists of the legal agreement signed between supply chain parties. It can have purchase information along with contract terms and conditions, transportation provider information and service level agreement details, real-time analytics data, which is fed by sensing layer devices such as IoT, RFID. The communication between sensors and relays are performed by Wi-Fi and Bluetooth technologies.

5.1.3. Interface layer

The subsequent layer, the interface layer is the key element of the entire architecture. It uses 'Ethereum' blockchain which contains all the business rules deployed through smart contracts on the blockchain (Liu et al., 2024). In general, contracts are executed between two different parties with contractual terms and agreements. But it is difficult to trace the party who violates the contract. Blockchain helps to execute smart contracts. Smart contracts are applied on top of blockchains (Rachad et al., 2024). The agreed contractual terms and agreements are produced as an executable program. Every business information is recorded as an immutable transaction stored in the blockchain and compared with a smart contract. When the condition in a smart contract breached, the corresponding clause will be automatically executed in a predictable manner (Zheng et al., 2020). The code feed into Ethereum Virtual Machines provides contracts to work autonomously and without human interaction. Any communication between contracts is termed as 'transactions' (Daraghmi et al., 2024). It can send information and update the status of contracts. All elements in the Ethereum network are updated with the status change. Ethereum is recommended considering its capabilities such as universal accessibility and enables real-time data update (Wu et al., 2024; Chen, 2018; Kim et al., 2018; Kim and Laskowski,

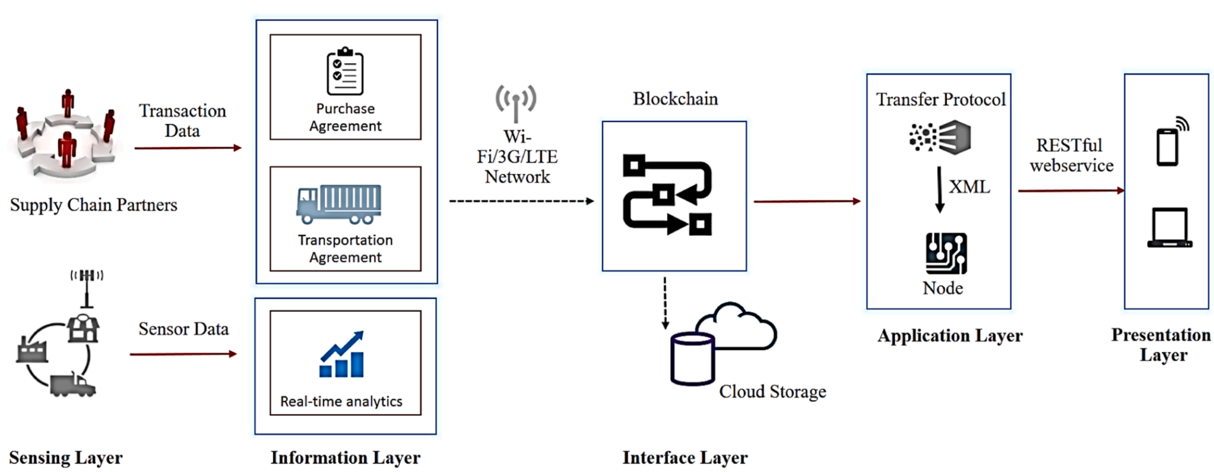

Fig. 7. Schematic of proposed blockchain system architecture.

2018). Moreover, it is scalable and works on the principle of interoperability (Kan et al., 2018; Abebe et al., 2019; Schulte et al., 2019). It helps to verify goods quality and shelf-life data as per agreed terms. After validation of data in a blockchain, information is stored in a structured format in the cloud database as it provides better performance.

5.1.4. Application layer

The application layer must add/update the legal documents such as purchase agreement, transportation agreement with authentic information. This action is performed by the blockchain zone, which is a node hosted by the transfer protocol. The transfer protocol connects with blockchain zone over XML. The transactional data communicated from the informational layer to a blockchain is validated. For example, the blockchain zone checks the raw materials supplied are as per purchase and transportation agreement. The real-time smart agreement consists of information about the items, requested delivery date, exception criteria. In case the items supplied by supplier are not meeting the agreement terms such as the acceptable condition of the items, shipment receiving date, the supply chain partners are notified.

5.1.5. Presentation layer

The communication between the application layer and presentation layer is performed through RESTful web services considering its lightweight and supports different web applications (Pautasso, 2009). The presentation layer act as a front end to the stakeholders and supply of goods condition can be monitored with the support of blockchain (Narayanan et al., 2024).

Theoretically, the data secured by blockchain are safe and manufacturers can trust the supply chain members as the maintained transaction history is consistent and accurate (Badakhshan and Ivanov, 2025; Min, 2019; Wamba and Queiroz, 2020). All supply chain members including customers have access to the item origin and various business activities performed to make the product. The proposed blockchain architecture is a generalized architecture that can be applied to any supply chain where accurate data management and eradicating frauds are necessary. Based on the requirement, the organization can adapt for the customized blockchain where different tracking systems such as RFIDs, IoT enabled sensors can be used (Sizan et al., 2025; Bahga and Madisetti, 2016). For instance, confectionery items need to be preserved at the right condition thus temperature tracking sensor is required. Organic sensors are required to check the freshness of the final product and assess food authenticity. The success of blockchain deployment depends on the data collected by the various system and the collected data should be transmitted to the cloud storage on-real time using communication protocols (Lee et al., 2019). The minimum requirement for communication protocol is to have a 3 G high-speed internet connection to ensure a smooth transition of data to the cloud. Security requirements should be taken care of before using wireless technologies to secure the data from hacking systems (Sharma and Dhiman, 2025). There are several blockchains available and it is imperative to understand the capabilities of each blockchain in terms of size, storage of data, supply chain network before selecting the right one (Helo and Shamsuzzoha, 2020; Zhang et al., 2020).

5.2. Tokens in confectionary supply chain

Tokens are used to map physical objects as digital entities in blockchain (Oliveira et al., 2018). A specific token represents the corresponding physical object. In the confectionary supply chain, the physical objects such as cocoa beans, sugar, cocoa butter, milk powder are assigned with tokens as per Ethereum Request for Comments, ERC-20 framework. The ERC-20 framework-based token system is used as it is compatible with the Ethereum network (Kim et al., 2018). With the digital token, transfer of ownership can be tracked on the blockchain network (Dasaklis et al., 2019). The transfer of ownership influences the set of incidents that updates the transaction status in the smart contract blockchain system. When the physical object is transferred in the real world, the digital token logs the ownership transfer and records the time stamp.

The significance of this article is the design of blockchain architecture for the confectionary supply chain. Implementing blockchain in the confectionary supply chain brings several merits especially, it improves the trust between farmers, transporters, importers, manufacturers and customers, reduces the administrative work as minimum manual intervention required on the ownership transfers, increases the material compliance defined by food safety regulators and thus improves the quality of the final product.

5.3. Information model for blockchain-enabled food safety system

The blockchain information model outlines the sequence of information flow. The blockchain-enabled food monitoring system has three components: Data, zone, and hub as illustrated in Fig. 8. Data consists of the supply of raw materials information such as item, quality, shelf-life, date, location. The zone is considered as a block that consolidates the information which needs to be included in the blockchain. In general, zone comprises of the header, set of data (history of hash and previous hash details) and various business transactions. Hub is considered as blockchain that includes all zone information registered in the digital ledger (Wang et al., 2016; Turk and Klinc, 2017). The information in blockchain can be accessed by the supply chain members.

5.4. Technology stack for blockchain assisted supply chain

Every physical transaction in the supply chain is recorded securely with public and private access to the stakeholders in a decentralised common platform. Blockchain enables us to get a holistic view from a single source and logged transactions cannot be altered. Based on the detailed study, technologies recommended as a part of technical specifications are blockchain, Infrastructure as a Service (IaaS) and Software as a Service (SaaS) cloud (Song et al., 2022; Zhu et al., 2019).

The proposed technology stack is illustrated in Fig. 9 for deploying blockchain-enabled supply chain application. The technology stack comprises of various levels of components or applications namely IaaS, Blockchain Platform, Integration Services, Middleware and SaaS (Dorsala et al., 2021; Mondal et al., 2019).

The fundamental platform required for supporting the blockchain is to deploy software applications on IaaS, which is an online cloud service. The next layer in the technical stack is the blockchain platform technically called as Distributed Ledger Technology (DLT), which works on distributed database concept whereby ledger information is stored. DLT core services act as an execution architecture, which uses cryptography as a method to verify and update each transaction across supply chain (Arslan et al., 2020). Then, Integration services such as Restful API, Cloud Middleware and Java Script Runtime Engine can be used as backend applications to link application layer and frontend presentation layer. A web-based HyperText Markup Language (HTML) 5 and Cascading Style Sheets (CSS) 3 frontend SaaS application can be used as a frontend application. This application can be used to enable visibility in order management, logistics management, warehouse management, real-time shipment status and payments related information.

6. Implementation of blockchain in the present confectionery supply chain

6.1. Single trusted source of information across confectionary supply chain

In the present supply chain, applying IoT and blockchain technologies guarantees traceability, integrity, and transparency over its transactions with various supply chain members. As such, the blockchain

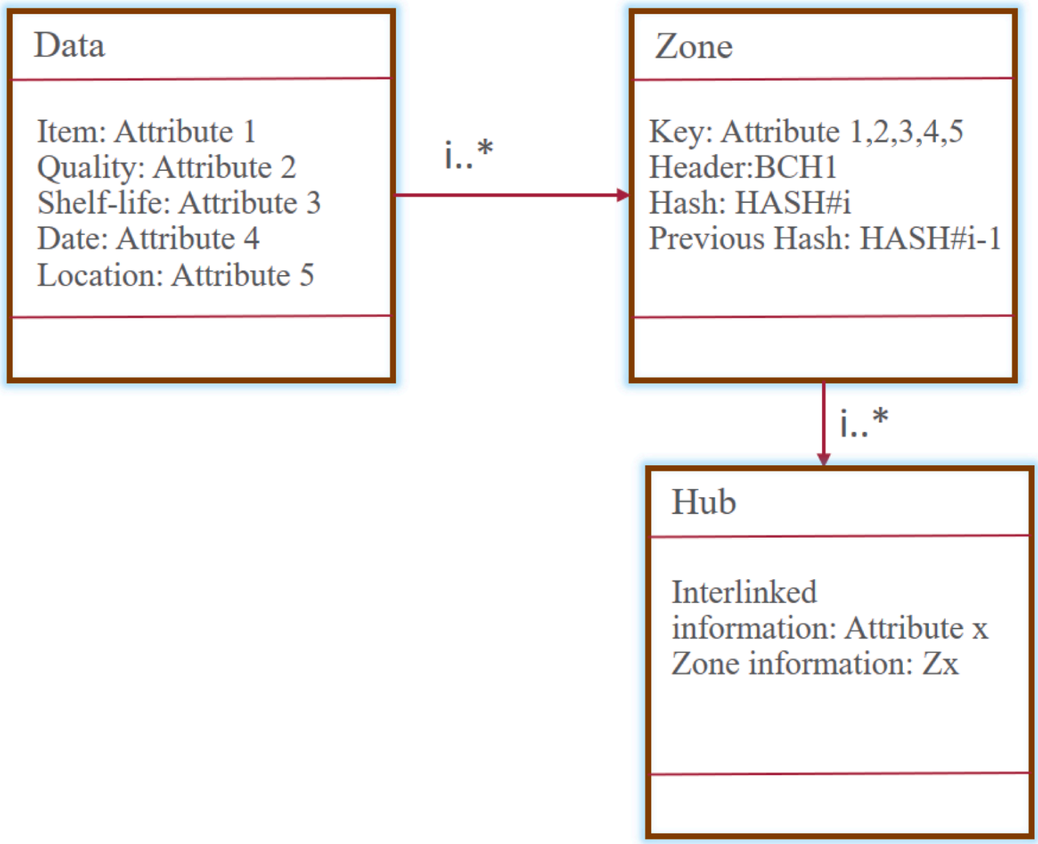

Fig. 8. Outline of a blockchain information model.

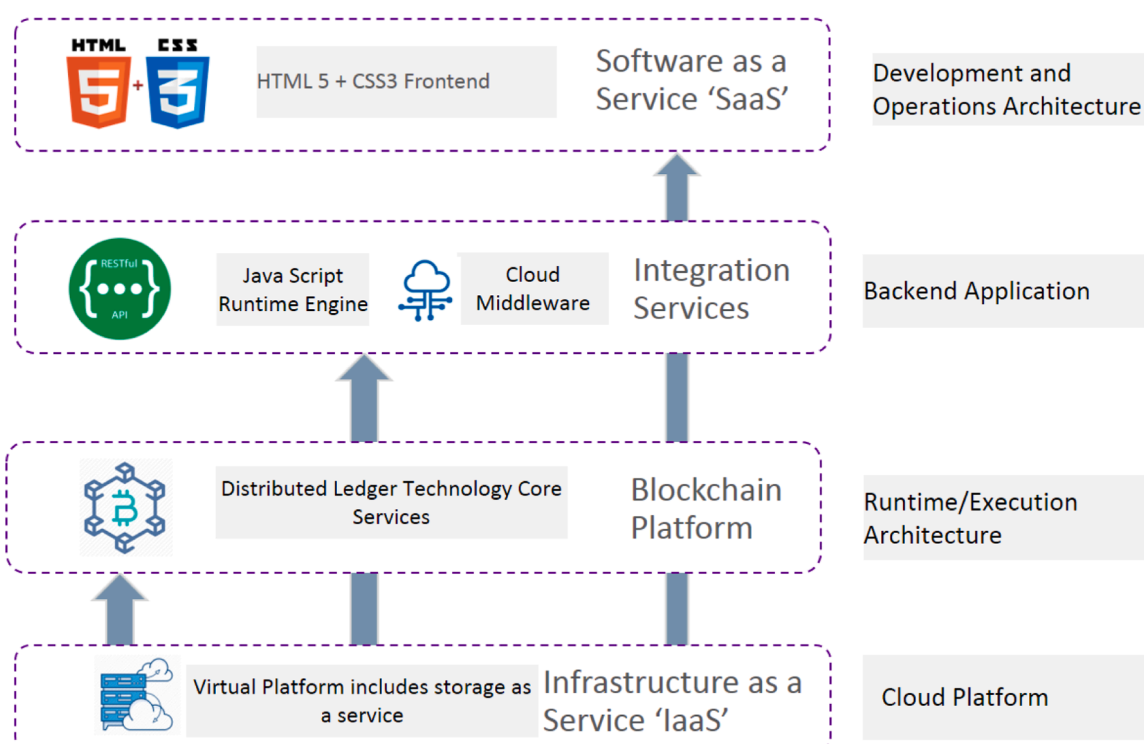

Fig. 9. Technology stack for blockchain assisted supply chain.

serves as an audit log for the actions performed in the intermediate steps of the supply chain. This allows any party requesting an order to verify the source of the cocoa beans and the quality grades associated with it.

Also, the status of a shipment is updated in the blockchain and available for all connected parties. If a link in the supply chain fails, it is trivial to trace back where the fault originates from, and all parties can be held accountable for their actions. With blockchain, multiple stakeholders will view a single source of truth as illustrated in Fig. 10.

6.2. Influence of blockchain and IoT in confectionery supply chain operations

In the confectionery industry, managing quality, safety, and traceability is crucial, particularly for temperature-sensitive products such as chocolate and caramel. Blockchain and IoT technologies offer practical solutions to these challenges by ensuring transparency, traceability, and automation across all stages of the supply chain, as illustrated in Fig. 11.

6.2.1. Raw material traceability and verification (Upstream)

Confectionery production begins with raw ingredients such as cocoa, milk solids, sugar, and emulsifiers. Using Blockchain, manufacturers can verify the origin of cocoa beans (e.g., Ghana, Ecuador) and ensure that it is certified (e.g., Fairtrade, Organic) and free from contaminants such as cadmium. Each batch of raw material is assigned a unique hash-based ID and recorded on the Blockchain ledger. For example, cocoa beans arriving at the manufacturing site are logged with timestamps, quality certificates (e.g., ISO 22000), and GPS-tracked shipment data. This transparency allows real-time auditing and strengthens supplier accountability. If a recall occurs due to contamination, the affected batch can be traced back within seconds rather than hours or days.

6.2.2. Monitoring sensitive parameters during production

IoT sensors embedded in production lines help monitor key parameters that directly impact product quality. For example:

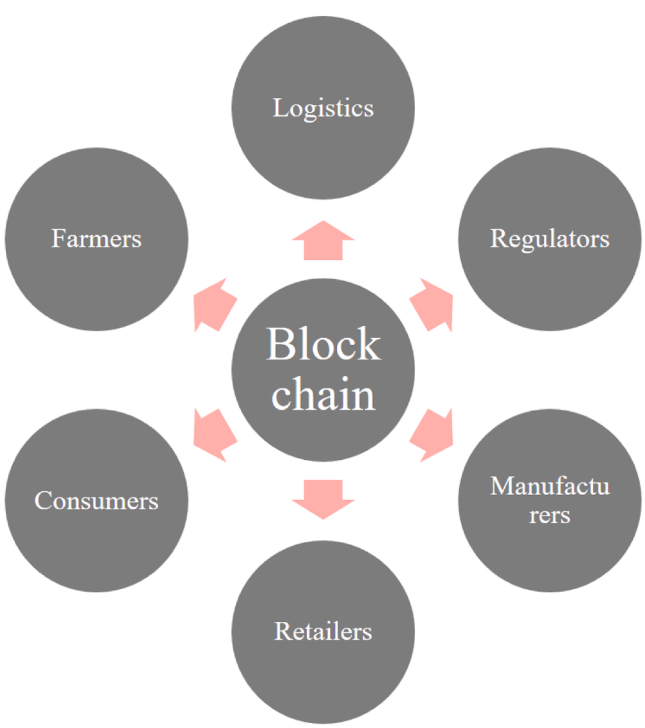

Fig. 10. Blockchain network shares a single trusted source of information.

- Melting tanks for chocolate must maintain a temperature between 31–32°C for tempering. IoT temperature sensors continuously log these values and send alerts if they cross thresholds.
- Grinders used for sugar and nut processing are fitted with vibration sensors to detect mechanical wear or uneven granulation.

These sensors feed data to a centralized dashboard, where production supervisors can take corrective action immediately. Early detection avoids large-scale wastage and maintains consistent product texture and flavour.

6.2.3. Cold storage and shelf-life monitoring (Midstream)

Chocolates are extremely sensitive to ambient conditions. Even short-term exposure to temperatures above 26°C can cause fat bloom and affect product appeal. In warehouse environments, IoT-enabled temperature and humidity sensors track real-time conditions.

As illustrated in Fig. 12, the system logs:

- Product Code: G26030
- Stock Count: 24 units.
- Temperature Status: Not OK (Above threshold)
- Humidity: OK

The moment temperature exceeds the limit; an automated alert is sent to the warehouse manager. This proactive approach helps avoid spoilage and ensures First-Expiry-First-Out (FEFO) handling.

6.2.4. Inventory management and retailer feedback (Downstream)

Each shipment is tagged using RFID or QR-based smart labels. As confectionery products move across distribution hubs to retail stores, Blockchain records the handover events—providing tamper-proof proof of delivery and ownership transfer.

Retailers also benefit from real-time inventory visibility. If stock drops below a predefined level (e.g., 10 units), the system triggers auto-replenishment requests to the manufacturer.

6.2.5. Sustainability and waste management

To promote circular economy practices, IoT-enabled smart bins are installed in partner retail stores. These bins detect when consumers dispose of chocolate wrappers or boxes. Once the bin reaches 80% capacity, it triggers an automated pickup request to the manufacturer. Collected waste is then sorted for:

- Recycling (plastic and foil packaging)
- Recovery (unsealed products)
- Reuse (outer cardboard containers)

Blockchain logs this reverse logistics cycle, certifying that waste is collected, transported, and processed as per environmental compliance norms.

6.3. Track confectionary food safety using blockchain

Blockchain network can transform confectionery processing business models in Industry 4.0. It improves the supply chain relationship and the trust between supply chain members as everyone across supply chain has the same information in terms of goods movement, inventory and sales. As illustrated in Fig. 13, it ensures that all testing documentation, certificates such as health certificate, Food Contact Materials (FCM) certificates, shipping record and other details related to food safety can be accessed by supply chain stakeholders including consumers. It brings better transparency, enabling food safety regulators to work efficiently and comply with government policies (Lin et al., 2018; Zhao et al., 2019). The XYZ organisation can report the following information to Food Safety Regulators accurately with the help of blockchain.

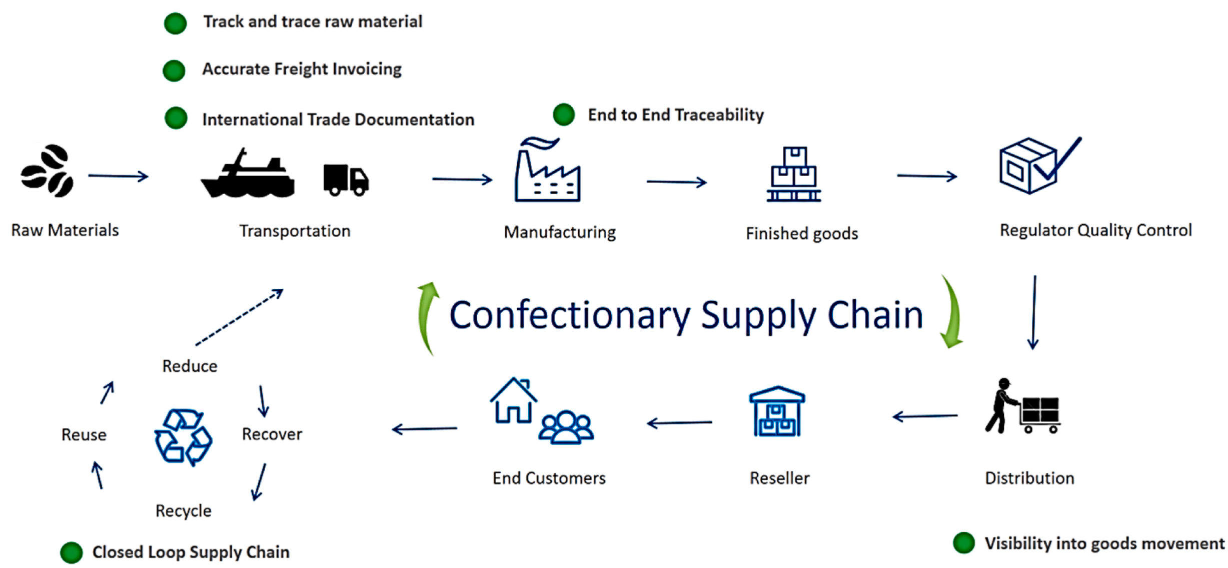

Fig. 11. Blockchain and IoT opportunities in Confectionery Supply Chain.

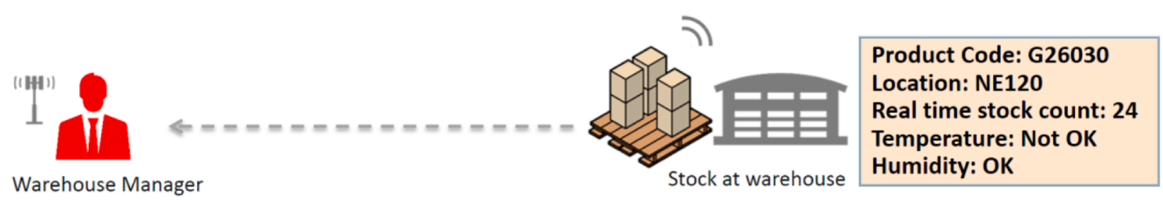

Fig. 12. IoT enabled smart warehouse.

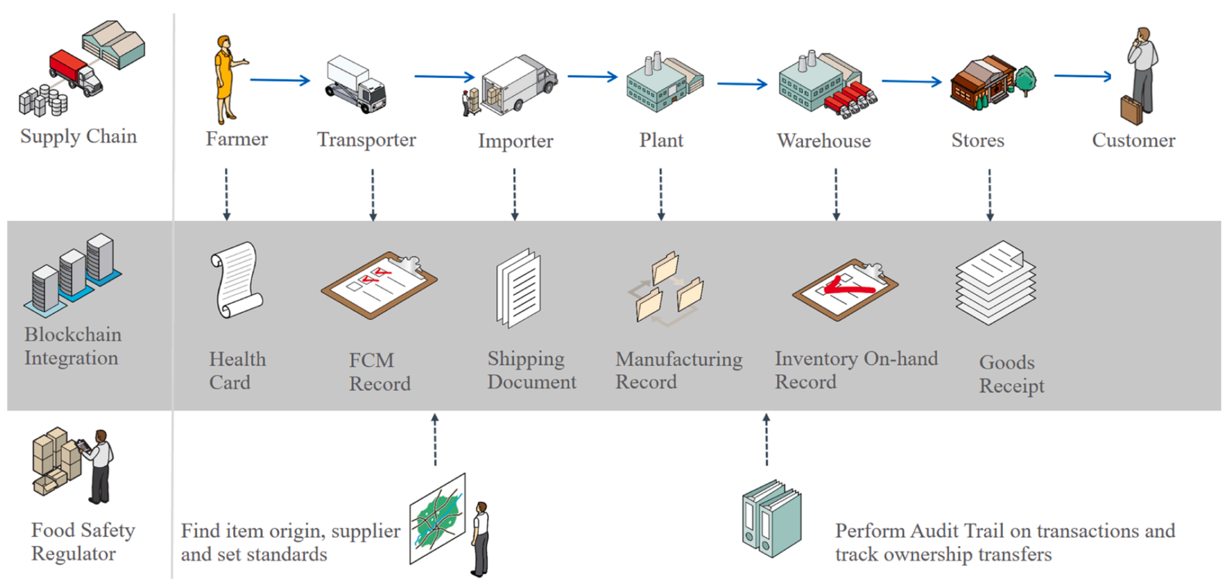

Fig. 13. Blockchain-enabled food safety system.

- Where does the product come from? Who is the supplier, and do they have the required certificates?
- Which stores received products from a specific farm in the last period?

With blockchain, distributors and retailers are provided with increased visibility about the shelf life of an item, shipment details, origin of food and ownership transfers. Food product condition is monitored continuously, and stakeholders are alerted when it reaches the threshold limit so that food wastages can be controlled. End customers can get visibility into the entire product life cycle and genuineness of the food consumed.

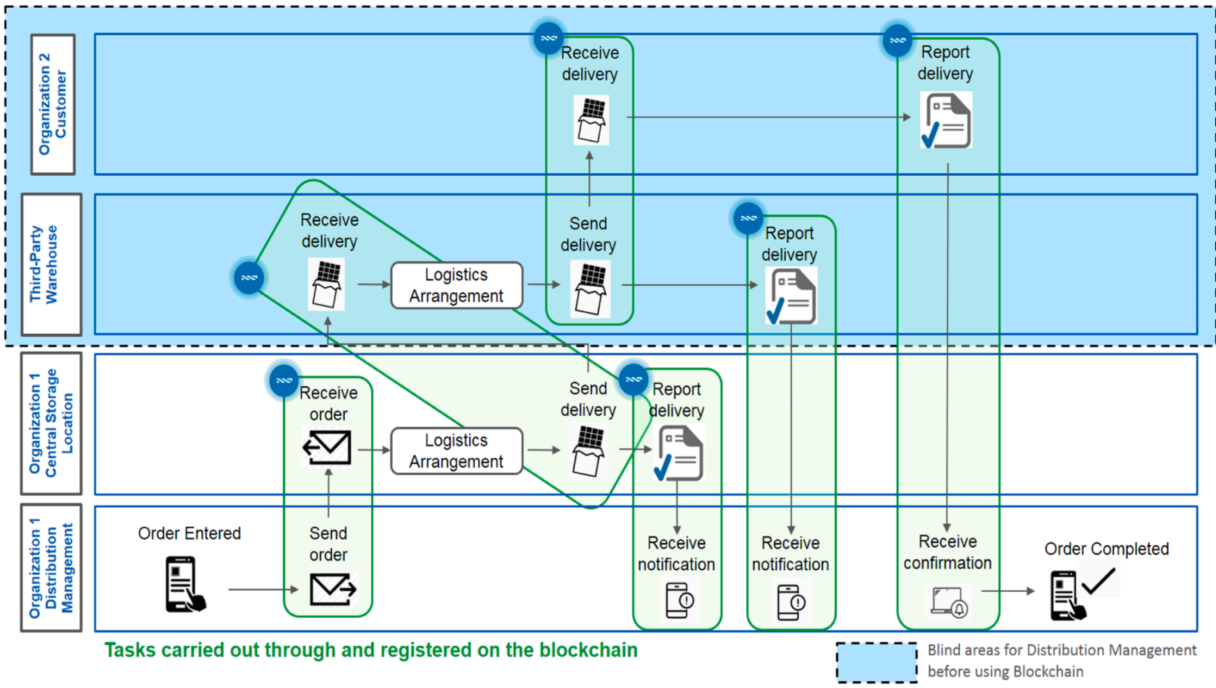

Fig. 14. Visibility in distribution management using blockchain.

6.4. Bringing blockchain in confectionary supply chain distribution management

Blockchain can be leveraged to drive the concept of a fully connected supply chain and unlock a host of opportunities to enhance the customer experience. As illustrated in Fig. 14, in the present supply chain of the XYZ organisation, delivery management is executed as follows. The sales order is booked in the system and central storage location is communicated with order and shipping details. Logistics group co-ordinates the transportation arrangements and goods are shipped. The third-party distributor receives the goods into their warehouse and acknowledges the received shipment. Later, third-party distributor ships the product to the customer. The customer receives the goods and confirms the product arrival, and the sales order is updated with received details and accounts team follows up with the customer to receive the payment. There is no visibility of goods movement, which happens at third party distributor and customer place in 'Order-to-Cash' business flow. Transactions executed by third party distributor and other supply chain members can be transmitted to the distributed ledger, which is controlled by blockchain. Thus, blockchain can be leveraged to bring visibility and transparency of activities by the organisation. Blockchain will also reveal where the product is at any point in time and who owns it. Encryptions can ensure that only the data that must be public is available to all users, while the remaining data is only readable for the process participants that require it. In the event of a product recall, the organisation can also see which batches are concerned and who bought them.

6.5. Key differences between traditional and proposed food safety systems in confectionery supply chain

In the conventional confectionery supply chain, most food safety systems are still dependent on paper records or disconnected digital systems. This creates difficulty in tracking the source of raw materials, identifying process-related issues, or responding quickly during recalls.

In contrast, the architecture proposed in this study integrates blockchain and IoT to address these gaps more effectively.

- Traceability – Traditional systems often rely on batch codes maintained manually. With blockchain, each step - from ingredient sourcing to nathaging is logged and time-stamped, offering complete traceability.
- Data Integrity – In legacy systems, data is vulnerable to manipulation or loss. Blockchain ensures the data is immutable and shared securely across all stakeholders.
- Real-time Monitoring – IoT sensors deployed at critical control points, such as boilers, grinding machines, and storage units, allow real-time data collection—something not feasible in earlier systems.
- Response Time – In case of deviations (like a temperature breach), IoT triggers immediate alerts, enabling quicker corrective action than traditional monitoring allows.
- Sustainability & Waste Management – The proposed system includes IoT-enabled reverse logistics for packaging waste, which is not part of most conventional setups.

This comparison highlights how the proposed system enhances transparency, accountability, and responsiveness - key elements in modern food safety practices, especially for temperature-sensitive products like chocolate and confectionery items.

7. Managerial and practical implications

With the result of the case study, the implications of deploying blockchain in XYZ organisation are described from management strategy and technology perspectives. The cutting-edge technologies such as Blockchain and IoT in Industry 4.0 era helps organisations to mitigate supplier risks and operational risk by guaranteeing untampered, authentic information.

The current supply chain challenges faced by confectionery manufacturing organisation that can be addressed by IoT and Blockchain are:

- The accurate flow of information from suppliers until end consumers – Properties of blockchain such as immutable and irrevocable ensures that information is shared effectively and essentially reduces business risks.

- Information Security – Blockchain is transparent, secured and scalable. Only authorised member in the supply chain can access the information.
- Combine digital and physical world of information – With the help of IoT, physical and digital world are connected, and information is transferred across the supply chain.
- Unearth policy violations and frauds – Blockchain features such as transparent and auditable ensure that every member of supply chain, which lowers the reputation risk, respects human rights and business ethics.

Benefits of shared distributed ledger help to regularise the raw materials and monitor its production. A consumer can easily check the origin of goods and gets the full life cycle of the purchased product. The following Table 4 helps to understand the challenges faced by confectionery supply chain now and suggestions for future supply chain with blockchain.

Based on the recommendations, XYZ management is keen on deploying pilot projects with IoT and blockchain tools, considering the value proposition it offers to make critical decisions on time. Further, stakeholders also believe that resources can be managed efficiently and remotely. They also believe that the investment in technology helps to improve their operational efficiency, thereby increasing the margins.

Table 4
Comparison of the supply chain today and tomorrow.

Supply Chain Now	Supply Chain Future with Blockchain
Lack of Transparency	Separately owned entities constantly validated the information, whose interests are not necessarily aligned. It eliminates discrepancies among Supply Chain partners as everyone shares universally shared ledger.
Lack of Traceability	Shipment details can be tracked on real-time, and transactions are updated constantly reducing unknown idle time and disruptions.
Misconception in the accountability across complex supply chains	Transactions are stored in distributed ledger and not controlled by a single member in the supply chain that resolves the disclosure and ownership related problems.
Error-prone reconciliation with each other's transactions	Digitalisation enables automation and instant availability of information regarding production, sales and raw materials; improves risk management and reduces response time.
Inability to monitor suppliers in real-time	When the product condition deteriorates more than threshold during shipment or storage in a warehouse, IoT will monitor the condition, and an automated replenishment order will be executed with the supplier to replace the items in real-time. Information is shared across the ecosystem, which eliminates exceptions.

8. Conclusion and future research directions

This manuscript presents a focused study on how Blockchain and IoT technologies can address food safety challenges in the confectionery supply chain, which is sensitive to temperature, hygiene, and traceability requirements. Our research provides a realistic architecture tailored to the needs of confectionery manufacturers, traders, logistics providers, and retailers, highlighting how end-to-end visibility, real-time monitoring, and data integrity can be achieved using these emerging technologies.

Through the case analysis, we demonstrate that integrating blockchain and IoT helps mitigate the risks of product adulteration, delays in cold chain monitoring, and inefficiencies in packaging material recovery. These solutions not only strengthen food safety compliance but also contribute to building trust with consumers by offering transparency in product origin, quality, and handling conditions.

The findings encourage confectionery businesses to explore pilot implementations and move toward a more digital and traceable ecosystem, ensuring better inventory accuracy, less wastage, and improved collaboration across partners.

8.1. Unique contributions of the study

- A Blockchain and IoT-enabled food safety system is designed specifically for the confectionery sector, offering real-time traceability of raw materials like cocoa, milk solids, and sugar.
- A blockchain architecture is proposed that allows confectionery manufacturers to track temperature-sensitive products, monitor warehouse conditions, and automate ownership transfer and compliance reporting.
- A distribution information management layer is introduced to improve visibility in confectionery logistics, especially during storage and retail handovers.
- The study also explores the implications and feasibility of implementing this architecture in confectionery supply chains, identifying the potential value and adoption barriers.
- This study is among the few that offer a blockchain-based IoT model specifically tailored for the confectionery industry, addressing its unique operational and food safety challenges.

While technology investment may initially be a hurdle, our study suggests that embracing these innovations can help confectionery companies reduce losses due to spoilage, maintain consistent product quality, and build long-term resilience in a highly competitive market.

This study opens up discussion on whether small and medium-scale confectionery businesses are ready to embrace blockchain and IoT, given challenges such as initial investment, data privacy, and trust among supply chain members - areas that merit further research and debate within the academic and industry community.

Future research can explore the integration of AI-enabled predictive analytics with blockchain for better demand planning and shelf-life management in the confectionery supply chain. Additionally, emerging standards and regulatory frameworks around food traceability using blockchain warrant further investigation to ensure compliance and interoperability across global supply networks.

Ethics statement

No experiments were conducted on human or animal subjects in the course of this research.

CRediT authorship contribution statement

Jayakrishna Kandasamy: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Manavalan Ethirajan:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Tarun Kumar Agrawal:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Funding acquisition, Conceptualization. **Sandeep Jagtap:** Writing – review & editing, Writing – original draft, Validation, Methodology, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

No data was used for the research described in the article.

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