How an IoT – Blockchain Enabled Supply Chain Improves Resiliency in the Food & Beverage Industry?

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Abstract

Over the past couple of years, particularly because of the impact of COVID-19, there have been several complications affecting resiliency factors across various global supply chains. Among them, the food supply chain (FSC) seems to be one of vital importance, given how any hurdles in the FSC can severely impact millions of people. This paper seeks to understand the fundamental issues inhibiting food and beverage supply chains from achieving maximum resiliency and study how the implementation of emerging technologies in supply chain management can improve end-to-end resiliency across the FSC. For this, a relevant literature review has been carried out on the current FSC, with a particular focus on the following themes – issues impacting end-to-end resiliency, current solutions addressing these issues, and how these technology-based solutions align with business goals. Based on the literature review, five different technologies have been identified, some that are well established while the others are still nascent. The technologies reviewed within the scope of this paper are Internet of Things (IoT), blockchain, Artificial Intelligence (AI), RFID, and IoT-blockchain. Findings from the literature review suggest that there is little to no research conducted to compare these technologies along elements such as impact on resiliency factors, time & cost involved, and benefits achieved. Therefore, this positions the paper well to examine these technologies, the role they play in FSC resiliency, and ultimately recommend an optimal solution through rigorous evaluation – an IoT-blockchain solution along with conceptual architecture and implementation considerations.

Keywords

Blockchain, IoT, Food Supply Chain, FSC, Supply chain, Visibility, Flexibility, Control, Collaboration, Impact, Resiliency, SCR

1. Introduction

Global food and beverage supply chains, which includes production, manufacturing or processing, distribution, and retail, face volatility across factors ranging from raw materials availability and costs, limited shelf life of raw materials or products, geopolitical crises, to climate changes (Dani & Deep, 2010). Food supply is required to adjust to food criteria as well as any supply chain interference due to transportation, supply network, and shortage of labour. COVID-19 has laid out bare supply chain vulnerabilities and their impact on the world economy, resulting in the urgent need for resiliency and agility in supply chains to reduce the impact of risk events (Barman et al., 2021). An interesting example of food shortage due to the pandemic is the shortage of eggs. The egg shortage was not only due to increased consumer demand, but also the lack of labelled packaging for retail in the USA (Aday & Seckin, 2020).

A resilient supply chain is defined by its capacity for resistance and recovery. In other words, supply chain resilience is the ability of a supply chain to return to customary operational performance levels within an acceptable period after facing a disruption (Christopher & Peck, 2004). The core factors of supply chain resilience are visibility, flexibility, control, and collaboration (Al-Talib et al., 2020).

The aim of this literature is to identify the core problems that exist in the FSC and provide a recommendation to achieve a resilient supply chain. To achieve this goal, a review of various research papers on the topic of FSC resiliency has been conducted. A major drawback of the FSC is the limited use of data and technology that helps with deriving insights and predicting supply and demand. Thus, further analysis of technological solutions has been performed to propose a conceptual architecture that would prove to be beneficial if implemented across the Food & Beverage industry.

2. Literature Review Methodology and Summary

The objective is to understand the current FSC, the issues faced in terms of resiliency, and critically evaluate the information available as well as the gaps or inconsistencies in the literature via the traditional or narrative literature review approach (Danson & Arshad, 2013).

To define the scope of the research, the following questions were identified.

1. What are the current issues faced by FSC in terms of resiliency?
2. What are the current solutions addressing the resiliency factors of FSC?
3. If the solutions are technology and data related, how does the technology architecture align with the business goals?

By narrowing the questions identified from the broad topic of FSC, research papers available on Google Scholar, University of Melbourne Library, and textbooks focusing on FSC resiliency issues, solutions, and solution architectures were identified. Through critical evaluation and review of the information available across 45 papers, the findings have been summarized and gaps have been identified in the sections below. A point to be noted is that this paper considers food supply chain and beverage supply chain to be similar for manufacturers, therefore food and beverage supply chain and FSC are used interchangeably.

2.1 Traditional FSC Issues

Supply chain resiliency (SCR) plays a crucial role in mitigating effects of disruptions such as the pandemic, climate changes, and changing consumer demands (Kumar et al., 2022). Supply chain resilience is equivalent to human body immunity – the lower the immune system, the lower is the resiliency, thus leading to poor health. Similarly, low SCR decreases profitability, mismatches the supply and demand, and disrupts daily operations such as procurement of raw materials, production, inventory and warehouse, and distribution (Ivanov, 2018). From research across 20 papers, the following issues have been summarized and established.

2.1.1 Transparency and Collaboration

FSC resilience requires integrated engagement of supply chain actors at all stages of food production, distribution, and information exchange to control risks and vulnerabilities (Manning & Soon, 2016). However, in a traditional FSC, data and information are usually shared with only a single actor, which reduces transparency, communication, and collaboration with all the required actors.

2.1.2 Traceability

The ability to track any product across the entire supply chain, also known as traceability, is essential for the food industry as it enhances visibility and food safety as well as decreases the exposure to risk. Traceability requires the participation of all actors involved in the supply chain as there are many datasets. However, the current FSC lacks the system to share information regarding product history, specifications and transit locations within the entire network (Chen, 2015). Furthermore, lack of traceability can be attributed to outdated systems, paper tracking or manual inspections, which causes delays and inaccuracies in information sharing (Mantravadi & Singh, 2023).

2.1.3 Visibility

Traditional FSC also lacks visibility due to absence of real-time data, which increases the inaccuracies, errors, and distortions of information across supply chain actors (Al-Talib et al., 2020). FSC is usually complex, with links in numerous countries, thus the lack of end-to-end visibility negatively impacts the dependability, control of supply chain, and trust among supply chain actors.

2.1.4 Flexibility

Flexibility is the ability to reconfigure supply chain especially with respect to the systems, products, and processes to adapt to the changing supply and demand, economic crises, and technological innovation. According to data by Nielsen, food and beverage retailers missed $82 billion in sales from out-of-stock items during the pandemic in 2021 (NIQ, 2022). The reason for the loss is the lack of systems that utilize data to automate portions of decision making and better forecast the supply and demand as well as potential disruptions. This is a persistent problem prevalent throughout the industry, as mentioned by Leslie Sarasin, CEO of The Food Industry Association (Danley, 2022).

2.1.5 Control

The most frequent problem that leads to supply chain failure in the food and beverage industry is the lack of control in every area of supply chain – planning, quality, inventory, and distribution (Lambert & Cooper, 2000). FSC currently lacks real time control, which is crucial to minimize costs, increase productivity, and better forecast (Lee, 2015). The aftermath of COVID-19 emphasized the lack of command and control, where organizations were unable to find alternative distribution routes to market leading to loss of sales and inability to meet customer demands as well as improve business performance (Rehman Khan et al., 2022).

From the issues mentioned above, the root cause is the lack of real-time information sharing among supply chain actors. To summarise, data in the FSC is often non-existent, disorganised, or inaccessible. Either the data is maintained manually, or the data infrastructure is based on legacy operating systems, which would not be compatible with modern software architectures. Without real time data and visibility across all areas of supply chain as well as the actors, food and beverage manufacturers increase their exposure to supply chain risks and disruptions. An example that emphasises the need for data is the shortage of iceberg lettuces in the United States because of climate change. Salinas-Watsonville region of California, which is known for iceberg lettuce production, faced inexorably rising temperatures in 2019 that led to a drop in production by 19%. This issue could have been resolved by accessing weather and temperature data to predict and make adjustments in the buying strategy from more favourable areas (Montoya, 2022). This proves that in uncertain times, where demand is volatile, supply is uncertain, and capacity is short, real-time data or end-to-end visibility plays a crucial role in effective decision making. To conclude, lack of real time data and information sharing among all actors of food and beverage supply chain has led to reduced visibility and transparency, flexibility, communication and collaboration, and control, which are the crucial factors of SCR as shown pictographically in the Figure 1 below.

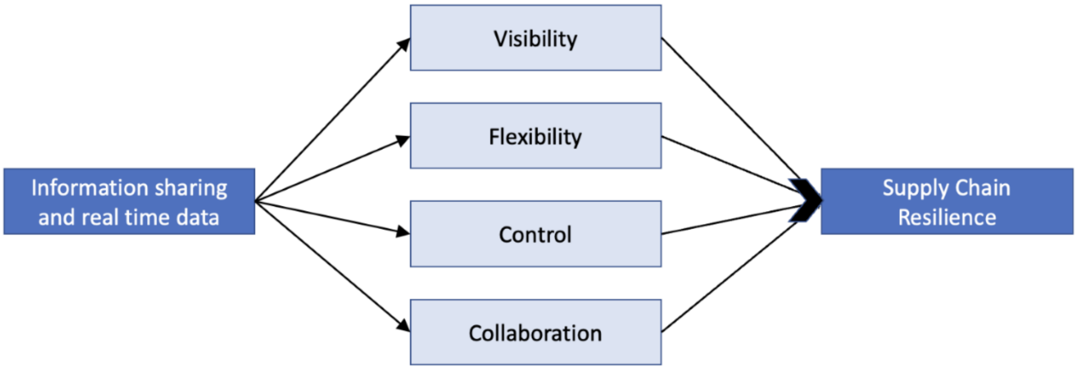

Figure 1. SCR factors and relation with data

2.2 Resilience Enablers

Based on research of 15 papers, the common technology solutions in the post pandemic world, some of which are mature such as RFID and IoT sensors, and some emerging such as blockchain, AI, and IoT-Blockchain combination, have been identified and analysed. RFID, IoT, Blockchain, AI, and IoT-Blockchain technologies have been leveraged in the FSC currently, however, the adoption level is low. Therefore, through literature review of technology enablers for FSC resiliency, the impact has been assessed and summarized as below.

1. According to research, RFID helps streamline assembly lines, reduce throughput time, and amplify visibility of products (Unhelkar et al., 2022).
2. AI can be used to improve FSC resilience by developing business continuity capabilities. To elaborate, AI has the possibility to develop better visibility and therefore lowers risk by improving sourcing and distribution capabilities (Modgil et al., 2022).
3. Blockchain can speed up forecasting and scheduling, increase supply chain visibility, trace reliably, and simplify contract designs by using smart contracts (Choi et al., 2019). Furthermore, it has been proposed that the use of such technology can successfully reduce ripple effects and improve the efficiency of recording data for preparing responses to disturbances. (Ivanov et al., 2019). For instance, executing a blockchain approach has the possibility to identify food lots that need product recalls, therefore, facilitating a quick and reliable removal of unsafe food from store shelves (Queiroz et al., 2020)

4. IoT has emerged as a significant technology for boosting SCR at the current state of research and technology (Tu, 2018; Lam & Ip, 2019). IoT components allow for real-time tracking of movement of products, packaging, and items as well as collection of extensive data on the performance of supply chain operations, which helps with fast and accurate data for supply chain risk management, risk transparency, and faster response to risks (Birkel & Hartmann, 2020). Incorporating IoT into the FSC could provide a reduction in costs, complexity, and inaccuracies. Further, IoT will improve food safety by collecting and analysing food safety data. (Ben-Daya et al., 2019)
5. The IoT-blockchain technology has received some scholarly attention (Al-Rakhami & Al-Mashari, 2021; Awan et al., 2021; Kumar & Pundir, 2020), in which the solution has been proposed to enhance SCR in terms of visibility, transparency, and reliability.

2.3 Comparison of Frameworks

To understand how an organization must implement the technology solutions with IT-business alignment, research papers related to Enterprise Architecture (EA) in Supply Chain as well as EA frameworks have been reviewed. The information with respect to implementation in FSC was scarce, thus frameworks leveraged in pharmaceutical and consumer packaged goods industries have been analysed. Leveraging Enterprise Architecture frameworks is invaluable when it comes to aligning business and technology. In this case, aligning the abovementioned technologies (IoT, Blockchain, AI, RFID, IoT + Blockchain) will pose a challenge for any organization which is not prepared for what it requires. Thus, frameworks like TOGAF and Zachman deliver a roadmap on how to process and progress a certain technology to deliver strategic goals in the most efficient, effective, fastest, and cheapest way (Qurratuaini, 2018). When choosing the right framework, it is important to recognize the two frameworks for what they bring to an organization. Summary of the findings for both the frameworks have been mentioned in Table 1 below to choose the best framework for the optimal solution recommended in the paper for a successful implementation by organizations in the Food & Beverage industry.

Table 1: Comparison of TOGAF and Zachman frameworks

Framework	Description	Advantages	Disadvantages
TOGAF	TOGAF is an IT Management framework/architecture that aims to assist companies in executing their IT goals. It helps organizations define and organize requirements beforehand, which allows them to be ready for commencing different projects. Consequently, this allows the process to progress quickly with minimal errors since the company is prepared beforehand (Manning, 2009). TOGAF provides an appreciated perspective that could be useful for companies who are making large-scale adjustments, thus improving the overall efficiency and effectiveness of a project (Grubich, 2016). For example, if a FSC wants to pursue a large-scale adjustment, such as implementing IoT devices, or a blockchain structure to invest in future resilience, TOGAF would provide a guide that examines the current and target architectures of that organization and prepares them for what to expect when implementing a large-scale adjustment (Grubich, 2016).	1.TOGAF is simple to use once learned and has plenty of documentation. 2.The framework is very flexible, and since it is open-sourced, it is continuously upgraded and adapted. 3.TOGAF is easily transferable, which means that it is applicable to multiple sectors. This makes it reliable for organizations who are involved in different sectors. 4. Sixty per cent of Fortune 500 companies have implemented TOGAF because it is very flexible and customisable (Qurratuaini, 2018)	1. Requires extensive knowledge to utilize correctly. 2. TOGAF is complex and might require a whole team to implement the principles and requirements, which will take time and resources (Manning, 2009). 3. TOGAF can be complex to learn.
Zachman	The Zachman framework is a matrix of two dimensions with six-column rows. The rows represent viewpoints, and the columns represent the questions. This approach provides an organization with the means to classify its architecture and infrastructure (O'rourke et al., 2003). This methodology is used as an	1. Increases the possibility of improving communication in the information systems field.	1. The strategies or utilization of the methodology will be document heavy and time intensive.

	ontology, which means that it is a set of structured statements defining how entities or substances can be classified, categorized, used, and altered/changed. Zachman can be adaptable as its purpose does not only revolve around architecture, but instead, is about assisting, organizing, and managing (O'Rourke et al., 2003). This means that when acquiring new technology, such as implementing IoT or Blockchain technology, it is important that one asks why, how, what, who, where, and when regarding integrated supply chain planning (Gerber et al., 2020). According to Zachman, "it is a holistic approach to system architecture that addresses key issues from all key perspectives that can significantly increase business value and flexibility" (Sergeev & Solodovnikov, 2020).	2. Producing better means for processes and architectural representations. 3. Ability to compare a wide range of tools and techniques.	2. Only a few developers have heard about the framework, this means it is more suited for bigger and more mature companies. 3. The Zachman framework favors data-centric methodologies, which are traditional approaches. 4. Zachman does not provide guidance on how to develop enterprise architecture.

2.4 Gaps in the Literature Review and Aim of this Research

Based on the literature review answering these three questions – issues faced by current FSC in terms of resiliency, resiliency enablers with respect to technology and data, and how organizations can implement the technology solutions whilst aligning with business goals, it is clear that FSC resiliency is an urgent issue that needs to be addressed and the technology solutions mentioned above have either been leveraged or are still in the research phase. However, researchers have ignored or neglected some aspects in the literature.

Throughout the literature review, there is little to no information on how these abovementioned technologies can enhance resiliency from the supply chain information-sharing dimension, which is vital especially in the post-pandemic era. Information related to overall implementation in an organization by leveraging frameworks especially for FSC is sparse. Furthermore, organizational considerations for solution architecture that is aligned with strategic business goals and architecture has not been stressed upon for FSC, even though FSC resiliency is the need of the hour. In addition, there is no comparison of technological solutions available. Organizations of different sizes require different technologies integrated in their supply chain. This is because certain players are bigger and can invest, some already have certain components implemented, and some are just getting started. Consequently, this results in a non-argued debate that requires much more information and evidence.

This research paper aims to resolve these gaps by providing a comparative analysis of the resilience enablers that would assist organizations in the industry to understand the best solution based on their SCR issues faced. Further, a conceptual framework of the technology solution chosen based on maximum impact with a focus on information sharing has been stressed upon along with the implementation necessities to ensure that organizations can achieve the maximum return on investment.

3. Technological Solutions Comparison

The methodology compares the effectiveness of adopting these abovementioned technologies both qualitatively and quantitatively. First, a comprehensive understanding of its working across the FSC is gained and the pros and cons of each are evaluated with careful consideration of the impact to the FSC. To arrive at the quantitative estimates, a review of organizational publications and expert interview excerpts was carried out to generate a sense of time and cost figures for a moderately complex FSC. Due to the fluctuating nature of data available, time to implement has been estimated in ranges. Cost has been estimated using a scale in comparison to all the technologies assessed, where '$' refers to a low-cost system and '$$$$' refers to a high-cost system.

The data presented below in Tables 2, 3 and 4 form the basis of our thesis, and the analysis that follows thereafter. The primary purpose of carrying out a qualitative as well as a quantitative analysis of the various technologies evaluated is to bring about the key advantages and disadvantages of these technologies, which in turn allows a critical evaluation of their impact, effectiveness and the potential ROI they could generate, from a F&B supply chain perspective. The insights from this follow on to act as the basis for the recommendations that have been synthesized to transform the adoption of emerging technologies in the FSC.

Table 2: Qualitative overview of selected technologies

IoT	**<u>Working in Supply Chain:</u>** An IoT based supply chain gathers useful real-time data using a combination of sensors, cameras, and GPS devices with cloud computing technology to provide accurate visibility across the FSC with respect to supply, demand, and actual consumption. This in turn helps manage inventory levels while also enhancing efficiencies (Nagarajan, n.d.). The real-time data gathered is then processed centrally on cloud systems to provide analytical insights across the supply chain, which in turn drives effective decision making. **<u>Pros:</u>** • The concept of IoT across the FSC will establish increased visibility connecting vehicles, infrastructure, and devices for end-to-end real time updates (Ashcroft, 2022) • In addition, it also allows for better collaboration by minimizing silos and increasing data and information sharing across the supply chain (Ashcroft, 2022) • Finally, it also provides real-time tracking, improved security & customer service, and higher forecasting accuracy. **<u>Cons:</u>** • IoT across the FSC could raise concerns of security as the devices used could be prone to hackers without appropriate cybersecurity measures (Fowler, 2023) • Increased costs owing to lack of standardization leading to low flexibility of solutions implemented • Limited control provided across the supply chain **<u>Notable Use Case Examples:</u>** • **Carlsberg**, a distinguished manufacturer of beers globally now makes use of IoT to optimize their demand and supply of products. The system now provides real time data on the consumption of beer using smart sensors which then automatically reorders replenished kegs as supply reduces. It also provides visibility into patterns of sales in the store allowing employees to better judge when to replenish on the floor stock as well as drinks to promote during that time (Carlsberg, 2023). • **PepsiCo** has also implemented IoT across their supply chain which provides real-time data, allowing for timely replenishment of stock. The usage of this technology in their smart coolers also provide them with consumer insights, thereby improving elements such as marketing and product strategies (Rooney, 2022)
Blockchain	**<u>Working in Supply Chain:</u>** Blockchain in the FSC is a chain of blocks in a database, called distributed shared ledger, where food products are recorded with a unique identifier to create secure and immutable records of transactions and operations. (Li et al., 2021) Their interactions are supported by smart contracts that are deployed across the blockchain platform. **<u>Pros:</u>** • Enables unprecedented visibility at each step of the FSC, helps increase transaction durability of the supply chain and food quality, and reduces food fraud and waste. (Li et al., 2021) • Data on a blockchain is immutable, resistant to tampering, and maintained by all participants within the supply chain network, preventing malicious modifications, which brings transparency, inventory control and trust to complex supply chains (Tian, 2016). • Smart contracts also trigger immediate automated actions such as payment, increasing the security and control of the execution of transactions and trust within the FSC. (Chen et al., 2021) **<u>Cons:</u>** • Since most of the supply chain represents more than a single company, successful adoption requires enough players willing to collaborate to harness the advantages of blockchain. (Stackpole, 2023; Chen et al., 2021)

	• The obligatory presence of a single standard of protocols and data formats between the parties, both at the organizational and interstate regulatory levels. (Lucas, 2018) • The investment in blockchain systems in the FSC incurs raised costs, due to the narrow profit margins in the F&B industry (Chen et al., 2021; Fitch, 2018) **Notable Use Case Example:** • **IBM and Walmart** use the blockchain-based platform Food Trust to provide end-to-end FSC visibility by tracking products from farm to table. The retail chain can track and record sources of food materials, temperatures, expiration dates and more. The speed of data sharing across the entire supply chain could be as fast as 2.2 seconds (Yiannas, 2018). • **Auchan** retail chain in collaboration with TE Food launched a global blockchain project. Every producer, transport company and distributor input data along the shipment, so upon arrival of the product to the store, the buyer could get and trace all information about it by scanning a QR code. Initially, the product line was limited to pork, chicken and eggs in Vietnam and organic carrots in France, but the retailer plans to expand the product range and geography (Auchan, 2018).
AI	**Working in Supply Chain:** With AI implemented across the FSC, the entire data analysis process can be enhanced. Using AI, algorithms are created to monitor shipments and transfer of goods using real-time insights from real-time data across the FSC. AI creates a platform for manufacturers to stay on top of customer demands and refresh their product lines accordingly. The algorithm also enables the system to learn from its interactions to generate continually enhanced solutions (Gray, 2022). **Pros:** • AI-powered forecasting tools can help reduce demand and supply fluctuations to give more control by leveraging data collected from customers, suppliers, manufacturers, and distributors (Yiannas, 2018) • Provides high quality alternative solutions even under dire circumstances that automatically notify actors across the supply chain about changes to be made, thereby improving the level of visibility. (Li et al., 2021) **Cons:** • AI is not a standalone technology, as other technologies are required to complement it. In general, an AI system relies on cameras, sensors, and IoT devices to gather data and make decisions. (Monteiro, et al. 2021) • Implementing an AI system requires significant investment and requires specialized expensive expertise and talent. This in combination with the lack of standard solutions in the market leads to a rebuttal in adoption. (Liu et al., 2021) **Notable Use Case Examples:** • **Walmart** implemented AI-powered demand forecasting for improving efficiency and optimized inventory management to predict when people are likely to shop and determine what products to use as substitutes when items are out of stock (Silverstein, 2020). They also integrate AI along with computer vision to optimize store operations. • **Amazon** uses an AI strategy for product recommendation based on previous purchases and browsing habits for their Amazon Fresh Products. The system stocks distribution centers for orders based on AI forecast even before it is placed, thus elevating supply chain control. (Mohapatra, 2021)
RFID	**Working in Supply Chain:** An RFID based supply chain uses radio waves to automatically identify objects. The process is done by storing a serial number or other information on a microchip that is attached to an antenna (Kelepouris, 2007). These elements further aid quality control, food safety and traceability. With the help of its automatic identification and data capture ability, it can identify packages that are not in the range of sight, which allows for mass serialization and identification of all product instances in the supply chain. This further creates a more efficient and automated process. **Pros:** • The compelling benefits of RFID across the FSC helps establish accurate and timely asset tracking. • Further, it increases security in the FSC where goods perishability is a key factor (Dolgui, 2009)

	• Finally, it improves inventory flow and accurate information attainment. **Cons:** • One of the fundamental challenges of RFID is that ROI is not easily discerned. • The implementation is not cheap and is still on the expensive side relative to other enhanced technologies. • Difficult to implement with existing legacy systems. **Notable Use Case Example:** • **Walmart**, an American retail chain, makes use of RFID to further optimize their already efficient supply chain. It helps them to keep track of food and beverages so that it doesn't go against any health and safety regulations. • **Tesco** used RFID to increase productivity and efficiency, allowing them to execute product recalls or even restock in a timely and efficient manner (Wehr, 2007).
IoT-blockchain	**Working in Supply Chain:** With IoT-blockchain, the decentralization of blockchain and the high-speed information network connection of IoT improves the food supply network. The sensors can distinguish and decide, depending on the real time changes that are occurring due to the IoT-enabled sensors coupled with the cloud-based technology used to implement a blockchain system. **Pros:** • The combinatorial benefit of the technology allows for platform that is neutral in nature without the involvement of a third party (Aich, 2019). • In addition, it ensures that none of the supplies are tampered within the supply chain (Aich, 2019). • It aids in the end-to-end visibility of goods during the tracking and delivery stages, further with incorporation of blockchain it helps enhance the trust of connected IoT devices in supply chains (Rejeb, 2019). **Cons:** • Blockchain does not resolve the standing issue of data quality in IoT. • The complexity increases when the two technologies are combined. • It is expensive so can't be easily implemented. **Notable Use Case Example:** • **IBM Food Trust** uses IoT and Blockchain to gain insights and track shelf life, waste and optimized tracking of products (IBM, 2023) • **Nestle** incorporated IoT and Blockchain to improve food safety and transparency which aids in preventing food that has been contaminated from going out to the market, and then tracked to the source quickly (Kayikci, 2022)

Table 3: Quantitative overview of selected technologies

Table 3 focuses on the time to implement as well as the cost involved. For the purpose of simplicity and standardization for comparison, we have considered the relative cost (averaged across various industries) and have developed a 4-point scale. It is also important to note that the time to implement also depends on several other factors such as stakeholder interests, timely coordination, financial capacity and so on.

	IoT	**Blockchain**	**AI**	**RFID**	**IoT+Blockchain**
Time to Implement	18-24 months	6 – 24 months	6 – 24 months	3-18 months	18-24 months
Cost	$$	$$$	$$$	$	$$$$

Table 4: Pictorial representation of the comparison

Table 4 provides a summary of the benchmarked technologies along the five dimensions mentioned. After diligent research and assessment of various industry experiences of experts working on these technologies, these dimensions were chosen for comparison since they highlight key elements organizations generally consider before pursuing ambitious digital transformation projects. The text (not cells) highlighted in green and red represent some of the key differentiating factors.

	RFID	AI	Blockchain	IoT	IoT-Blockchain
Time to implement	Low	Medium	Medium	High	High
Cost	Low	Medium	Medium	Medium	High
Impact on FSC Resiliency	Low	Medium	Medium	Medium	High
Implementation difficulty	Medium	Medium	High	Medium	High
Potential ROI	Low	Medium	Medium	Medium	High

From the rigorous evaluation carried out, the following insights were derived:

- RFID based solution generates low ROI across the FSC and is shadowed by other powerful emerging technologies. However, the solution is easier to implement as compared to other technologies.
- AI based solutions, though effective, cannot exist by themselves and therefore would incur costs in addition to the assessed estimates. AI based solutions when combined with other technologies yield high-value results. It is also crucial to note that AI is increasingly being used in supply chains to enhance efficiency, accuracy, and decision-making.
- IoT and blockchain are effective solutions on their own, however, their combined impact across the FSC resiliency factors is significantly powerful and justifies the costs. However, this solution needs to be implemented in phases for success as implementation is significantly complex as compared to individual technologies.
- Though more expensive than the other technologies, a combined IoT and blockchain system positively impacts all resiliency factors and can be implemented in a realistic amount of time.

4.Discussion

Devising and implementing an IoT-enabled blockchain supply chain system in the food and beverage industry seems vital, given the radical transformation and advantages it can bring about as compared to using other technologies in silos. The recommendation thrives on generating a proactive strategy for supply chain resilience that helps food and beverage manufacturers to prepare for disruption, even before they occur.

4.1 Conceptual Architecture

To design the architecture of an IoT-Blockchain based FSC, the working and architecture of an IoT-enabled supply chain as well as Blockchain enabled supply chain are first analysed and discussed below.

4.1.1 IoT-enabled supply chain

Sensing devices such as barcodes, cameras, sensors, RFID, and GPS collect data and sends it to the cloud via methods like Wi-Fi, Bluetooth, and Low Power Wide Area Networks. The IoT platform then processes the information collected and analyses it to derive insights. The user can then leverage the insights generated through dashboards for effective decision making as depicted in Figure 2. The real-time information collected helps not only with tracking, but also with forecasting, identifying and mitigating risks before they occur, and enabling fast yet accurate decision-making.

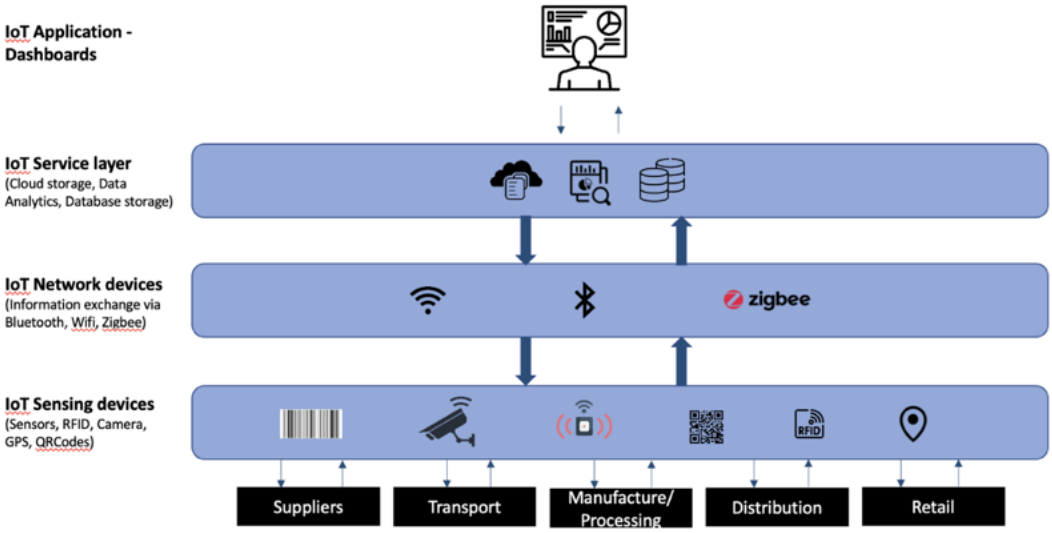

Figure 2. IoT enabled FSC

4.1.2 Blockchain-enabled supply chain

Blockchain can be described as a shared, immutable ledger or distributed ledger that enables the process of recording transactions and tracking assets across all actors in a network as illustrated in Figures 3 and 4. As the word suggests, it's a sequence or chain of blocks. Each block contains a set of transactions, block ID, timestamp of formation, hash of the previous block to connect, and a proof from consensus algorithm that is agreed upon by the network partners. The crucial components of blockchain are distributed shared ledger, smart contract, permissions, and consensus. In a supply chain environment, blockchain needs to have privacy and restricted access to only authorized partners of the network. Trust, transparency, and visibility can be achieved because of different levels of accessibility for each partner (Swan, 2015). While blockchain records each transaction, the information may only be accessed by partners who have the permissions.

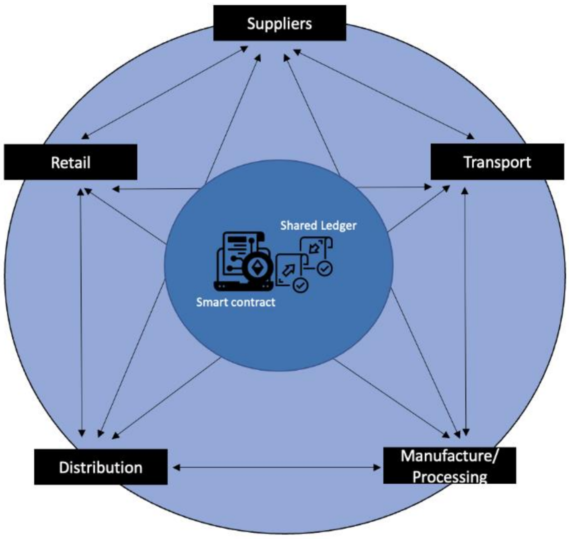

Figure 3. Standalone Blockchain enabled supply chain

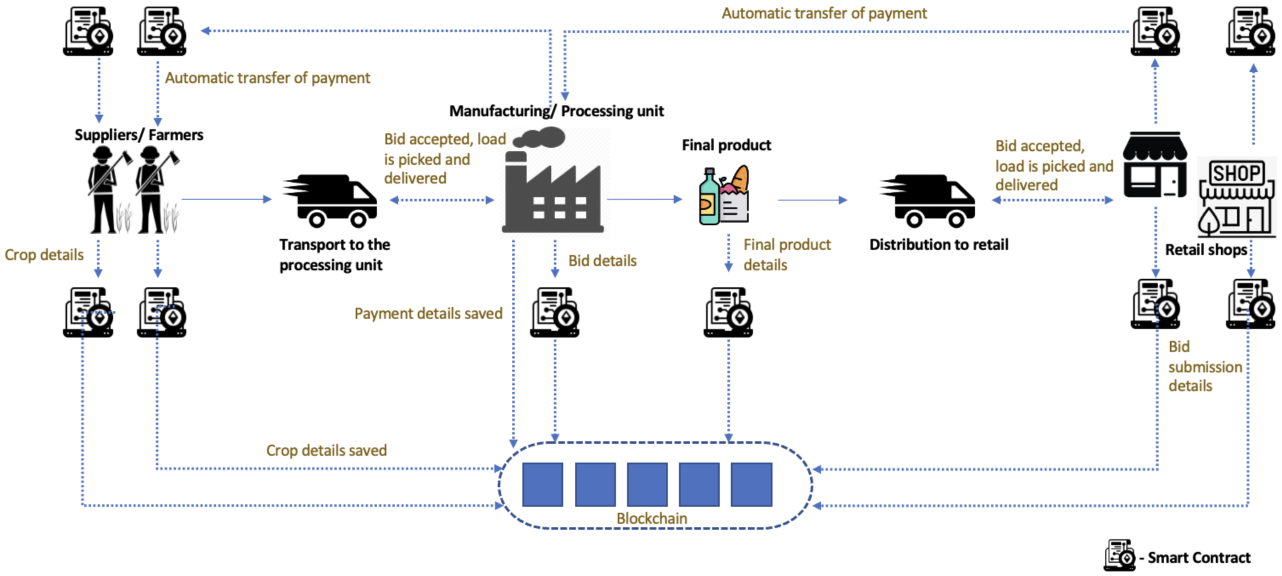

Figure 4. Blockchain enabled FSC

4.1.3 IoT – Blockchain enabled FSC

An IoT-blockchain solution provides an innovative way of solving issues of real-time information sharing, building trust and transparency in the network, and identifying and mitigating risks before they occur in a supply chain environment. Figure 5 illustrates the conceptual architecture of an IoT-Blockchain enabled FSC along with its working below.

In the IoT based sensing layer, all the raw materials and final products are given digital identifiers and the IoT nodes collect real time location, status, temperature, humidity, and other resourceful information with the help of digital identifiers. This real time information of location, status, properties are shared with the network to provide timely updates such as delivery time to warehouses or processing units. The challenge of securing the information shared can be solved easily with a blockchain data control layer. When any activity or information sharing is triggered, the parties concerned verify the actors, determine terms of the transaction and a smart contract is created, encoded, and saved in the blockchain once all the parties agree. Because of the distributed storage technology, transactions and information are copied and tamper-proofed at all participants who have access as well as credit records and the status of inventory and orders can be confirmed quickly, efficiently, and securely. The collected real-time information is transmitted across the network through IoT gateways and wireless routers to cloud or database storage. Meanwhile, transactions recorded in the blockchain ledgers integrate with the real time information data to analyse and generate insights. These datasets and insights help with understanding the current situation as well as forecasting supply, demand, risks, and discrepancies so that a proactive strategy can be designed rather than a reactive one in case of any disruptions.

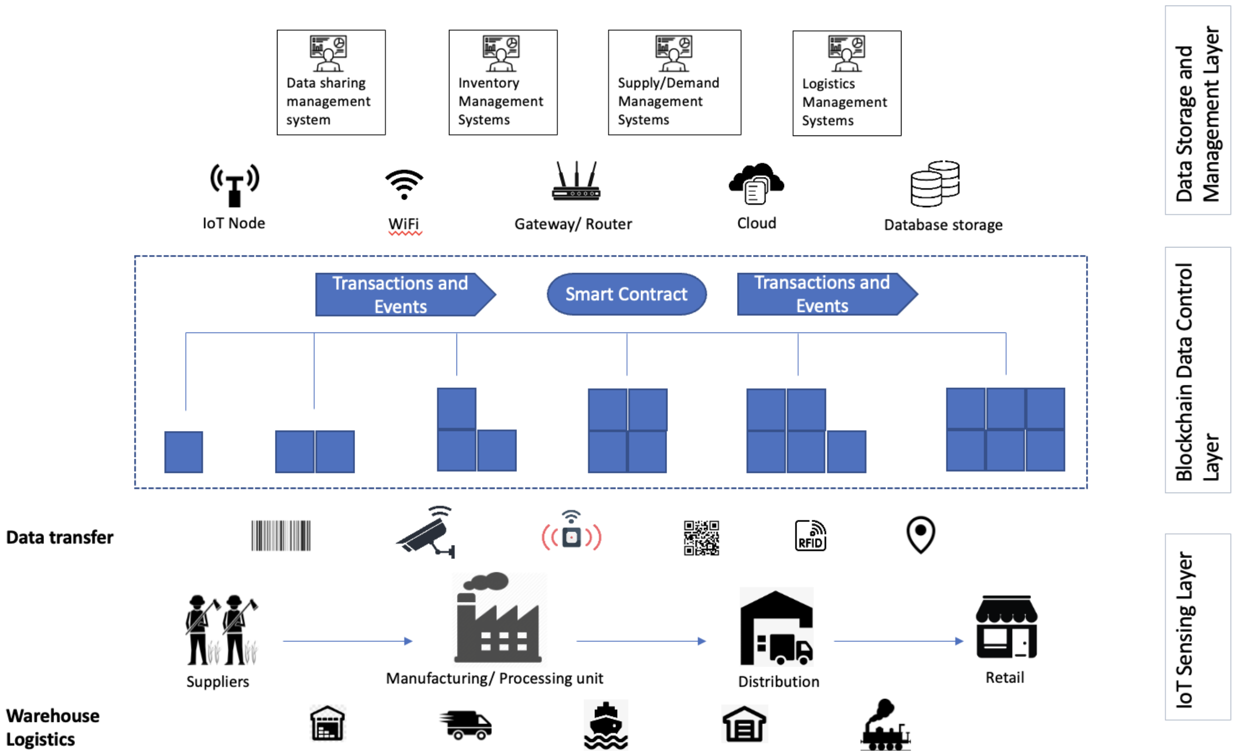

Figure 5. Conceptual architecture of IoT-Blockchain enabled FSC

4.2 Impact

The overall benefits of the IoT-Blockchain enabled supply chain are connectivity, transparency, end-to-end visibility, inventory monitoring and control, data privacy among participants in the supply chain network, secure information sharing by ensuring authenticity, timelines, and integrity of transactions as well as real time data.

4.2.1 Impact on Visibility

- Allows manufacturers in the FSC to achieve high levels of visibility into the materials and goods moved about, from production to the delivery of the final product.
- Creates an environment with high levels of integrity and visibility with real-time data combined with ledgers and records of activities and transactions across the supply chain (Kaur et al., 2022).

4.2.2 Impact on Flexibility

- Enables higher levels of flexibility in the supply chain, making it more resilient to changing circumstances such as volatility in raw material acquisition, regulatory environment, emergencies, and natural disasters.
- Real-time data can be leveraged for predictive analytics, automation of inventory management as well as enhanced logistics leading to supply and demand commitments being met regardless of the situation (Johnson, 2020).
- Blockchain integrates elements such as payments, distribution and order fulfilment allowing organizations to find the right suppliers at minimized costs, thereby enhancing the overall value of the FSC (Potnis et al., 2023).

4.2.3 Impact on Control

- Enhances control across the supply chain, particularly in terms of food quantity and quality as well as food safety.
- In addition to inventory control, blockchain technologies help keep track of all transactions, timeliness of payments, and instils accountability and control across the supply chain (Kaur et al., 2022).

4.2.4 Impact on Collaboration

- Using combined IoT and blockchain technology in the FSC can help enable new business models, services, and value propositions, thereby enhancing collaboration across the FSC (LinkedIn, 2023)
- Blockchain technology combined with IoT allows not only the sharing of data across systems, but also records and transactions, thereby enforcing collaboration across all elements of the FSC.

4.3 Limitations

A combined IoT and blockchain system incurs significant investment costs due to which its adoption would currently be limited to companies that have already established at least some of the technological infrastructure required. In addition, such a system involving various components is quite complex and would require input from experts with experience implementing such systems to reach maximum potential. Finally, given the nature of issues the system is addressing, as well as the limited adoption of these technologies in the global FSC, measuring its ROI in a tangible form could be challenging.

4.4 Implementation and Risks

Leveraging EA frameworks while implementing IoT-Blockchain supply chain would help develop a thorough understanding between highly dependent subsets of enterprise systems, reduce overall complexity of the solution architecture, and establish a structured decision-making process that aligns IT and business goals. Since the TOGAF framework (The Open Group, 2018) offers a structured step-by-step architecture implementation and aids in creating a roadmap for iterative and rapid development, which is essential in the case of IoT-blockchain solution implementation, this framework has been chosen to guide any organization implementing this solution. The TOGAF framework has eight steps within the architectural process, known as the Architecture Development Method (ADM) as shown in Figure 6. An organization must consider the following for a successful implementation of the technologies.

- Evaluate the issues faced and clearly define the scope of project, identify stakeholders, and communicate effectively to ensure everyone is aligned. Define business architecture vision in collaboration with stakeholders by analysing how technology could solve specific pain points.
- ADM Phase C and D are extremely crucial to consider in this case. It is important to have a comprehensive understanding of data requirements and application architecture that aligns with business goals. Thus, an organization needs to understand data requirements, define architecture components and data interfaces, assess standards and tools to create architecture views, review, and finalize. As suggested for Phase D, technology architecture must be developed by reviewing business, data, and application components, identifying reusable assets, developing current and future states to understand gaps, and defining hardware/ software platforms. Careful consideration of these phases is critical.
- An Agile methodology needs to be followed as the solution is complex. Following data driven sequence, whereby application systems that create data are implemented first, followed by applications that process and store data, and finally applications that archive data, would resolve the risk of complexity and cost of the project created by implementing all at once.
- Consider diversifying suppliers, ecosystem partners, and sourcing options based on the data to increase flexibility and resiliency.
- Since there would be risk of vulnerabilities for a more theoretical solution, leveraging a stress-test model that quantifies SCR based on industry attractiveness, customer exposure, operations exposure, supply chain exposure, and corporate resilience would expose vulnerabilities beforehand to identify mitigation strategies (Boggess, n.d).

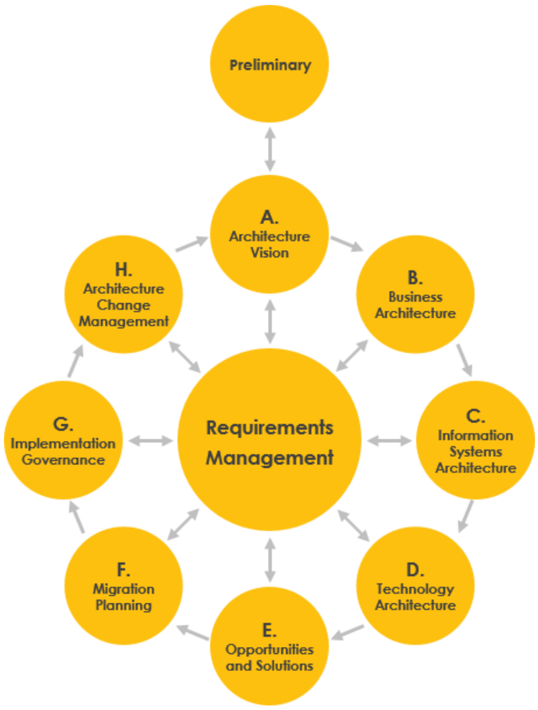

Figure 6. ADM phases of TOGAF framework (The Open Group, 2018)

5. Conclusion

In conclusion, the quest for resiliency in the Food Supply Chain (FSC) necessitates the strategic integration of emerging technologies, and as evidenced through a thorough literature review and practical use case examples, the combination of IoT and blockchain holds the key to achieving true resiliency. For this, its widespread adoption is necessary.

From the intricate literature review conducted, it is quite evident that the key issues concerning FSC resiliency can be broadly classified into four themes namely visibility, flexibility, control, and collaboration. The literature review as well as the use case examples assessed make it evident that emerging technologies can be leveraged efficiently to devise a strategy to improve the end-end durability of the FSC and through the rigorous analysis of the various technologies identified, IoT-blockchain seems to be the most effective solution to achieving maximum resiliency across the FSC.

- An IoT system integrated with blockchain provides FSC with great stability. The integration ensures that stakeholders across the supply chain have unprecedented visibility into processes, enabling them to make informed decisions. It also encourages flexibility by enabling rapid modifications as a stimulus to changing situations, allowing for better resource allocation and inventory management. Furthermore, the blockchain component ensures data confidentiality and authenticity, thus, increasing trust among stakeholders. Finally, collaboration is improved since technology allows for secure and transparent information sharing among stakeholders.
- Delivering such a sophisticated solution necessitates an organised strategy. The TOGAF framework emerges as a valuable guide, providing a well-defined path and architectural foundation for the successful implementation of IoT-blockchain solutions in the FSC.
- While there are still limitations to the recommended solution, the benefits bring about a massive transformation to the global FSC that would minimize the active disruptions it faces while also keeping it well-equipped in the wake of an emergency such as a pandemic.

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