# ROLE OF IOT & BLOCKCHAIN IN ENHANCING PERISHABLE GOODS LIFE

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**Abstract**

In this article, the potential of Internet of Things (IoT) and blockchain technology in transforming supply chains and warehouses of perishable goods has been discussed. As the global perishable goods market is worth 1.93 billion USD a year (2023) with an anticipated CAGR of 2.8% (2023–2027), these technologies directly pertain to some of the key challenges in the industry, including traceability, data integrity, as well as quality management. Blockchain provides transparency and traceability via its decentralized, immutable ledger, and IoT allows for real-time monitoring of eco-friendly conditions (e.g., temperature and humidity) to guarantee product freshness and safety. The combined value of IoT and blockchain allows for greater efficiency in the food supply chain by providing complete transparency for each item propagating through a supply chain, from farm to fork, while enabling food safety and quality certification. Smart indentures automate further, reducing intermediaries and reducing human error in organizational logistics. The study highlights the increasing importance of these technologies to meet the growing global demand for fresh seafood. It assesses their collective influence towards transparency, traceability, and efficiency whilst overcoming challenges including data integrity, scalability, and environmental impact. The study investigates, via literature review and case studies, existing implementations, identifies gaps, and outlines best practices around improving the perishable goods lifecycle.

***Keywords*:** Blockchain, Internet of Things (IOT), Perishable Goods, Supply Chain Management (SCM) & Traceability.

## Introduction

The worldwide perishable goods market is valued at about 1.93 billion USD in 2023 and will grow at a staggering compound annual growth rate (CAGR) of 2.8% duration of 2023 and 2027 (Statista, 2023). This expansion mirrors an increase in consumer demand for fresh and high-quality products, powered by growing awareness around food safety and sustainability. Nevertheless, there are major challenges that the supply chain of perishable goods confronts, specifically efficiencies in traceability, data integrity, and quality management, causing huge losses in such perishable goods as well as waste of raw materials. A third proportion of the food supplied for one person's consumption is wasted or lost every year, according to the Food and Agriculture Organization (FAO), a United Nations organisation. Global food loss was estimated to be 13.2 percent in 2021, from farm to transport and towards wholesale and processing levels after harvest. Perishable goods are particularly vulnerable due to short shelf-lives and environmental sensitivity (FAO, 2021), comparable to prior periods' estimates of 13.3% and 13% in 2020 and 2016, respectively (Global Food Losses | SDG Indicators Data Portal | Food and Agriculture Organization of the United Nations, n.d.).

IoT and blockchain are emerging technologies that provide revolutionary solutions to cope with these issues. The use of IoT ensures that product freshness and safety are maintained through the real-time observation of environmental conditions like temperature and humidity, during transportation and storage (Ben-Daya et al., 2019). Graph-based supply chain management provides a decentralized and immutable ledger that enhances flow traceability and transparency of products and people from farm, across the supply chain, to fork (Saberi et al., 2019). Combined, these technologies tackle challenges including fraud prevention, operational inefficiencies, and regulatory compliance.

Existing applications illustrate the capabilities. For example, it has used blockchain to trace the origins of food, thus allowing the time needed to track contamination to be reduced from days to seconds (Casey & Wong, 2017). In parallel, Maersk and IBM have simplified global shipping logistics, cutting down on the paperwork and delays (Eljazzar et al.,2018). However, widespread adoption is limited by challenges including scalability, expensive implementation, regulatory uncertainty and energy consumption (Eisenhardt & Graebner, 2007). Moreover, integration is further complicated by the absence of standardized protocols and interoperability among various IoT devices (Majid et al., 2022). Overcoming these barriers requires an understanding of the technical and regulatory environment and building best practices for implementation.

**Research Problem Formulation.** The perishable goods supply chain faces critical challenges, including:

- High spoilage rates (13.2% global food loss as per FAO 2021)
- Traceability gaps leading to food safety risks (Casey & Wong, 2017)
- Operational inefficiencies due to manual processes (Eljazzar et al., 2018)
- Data integrity vulnerabilities in current tracking systems (Majid et al., 2022)

**Research Aim:** The research aims to explore and evaluate the transformative potential of integrating Internet of Things (IoT) and blockchain technology in enhancing perishable goods. The study seeks to understand how this synergy can enhance efficiency, transparency, and sustainability in supply chain operations, while addressing critical challenges such as data integrity, traceability, and environmental impact.

To achieve this, the following **objectives** are pursued:

1. To assess the impact of IoT and blockchain technology on enhancing transparency, traceability, and sustainability in perishable goods.
2. To highlight the use case of blockchain-IoT integration in supply chain management
3. To identify challenges and opportunities while implementing IoT-blockchain solutions

## Research Object & Methods

**Research Object:** The research object for this study is *"The Synergistic Role of IoT and Blockchain in Enhancing the Shelf Life, Traceability, and Sustainability of Perishable Goods in Global Supply Chains."*

This study adopts a mixed-methods approach that integrates a systematic literature review, case study analysis, and empirical validation to assess the incorporation of IoT and blockchain and SWOT analysis in perishable goods supply chains. Collectively, these methods will provide a thorough understanding of the transformative potential of IoT-blockchain synergy in perishable goods logistics.

## Research Result & Discussion

**IoT technology on enhancing transparency, traceability, and sustainability**

Consequently, the advent of IoT into supply chain management has indeed altered the SMB's dynamics, granting extreme levels of traceability and monitoring. Use of these IoT technologies allows for better tracking in the entire supply chain (Tan & Sidhu, 2022). IoT sensors and devices account for the position, condition, and quality of products in transit, yielding real-time conditions (Ben-Daya et al., 2019). (Rakshit & Ghosh, 2019) mentions, IoT also enhances the quality control and compliance in SCM. Real-Time Monitoring System Use of IoT sensors to monitor environmental conditions during the transportation of perishable goods will ensure the cargo meets quality specifications and regulatory requirements.

Whereas the challenges related to IoT implementation in SCM are inescapable (Majid et al., 2022a). Further studies indicate challenges such as issues of data safety and secrecy, along with a need for uniform procedures and interoperability between several IoT devices and platforms. IoT adoption in SCM extends beyond traceability to sustainability. Furthermore, IoT-enabled supply chains can decrease environmental effects through optimizing paths, gasoline consumption, and diminishing waste (Rejeb et al., 2020, 2021). Based on an extensive literature review on the current research in IoT and SCM, (Ali et al., 2023) reported 14 distinct drivers of IoT Implementation in supply chain management. Industrial plus academic background expert opinions were used to analyse the relative importance of the most significant drivers. The results illustrate that the top three driving factors {"Efficient logistics systems", "Business knowledge acumen", and "Information safety assurance"} are the clearest in recent works on IoT applications in SCM concerning traceability, as shown in Table 1.

**Table 1. Application of IoT in SCM**

| Domain | Issues | IoT Technology Focus | Application/Outcome |
|---|---|---|---|
| **Supply Chain Management** (Ben-Daya et al., 2019) | Enhanced traceability, real-time visibility | IoT sensors and devices | Traceability and real-time checking in SCM |
| **Quality Control, Logistics** (Golpîra et al., 2021) | Quality control, compliance, and environmental conditions monitoring | IoT sensors and data analysis | Quality control and compliance in logistics |
| **Supply Chain Management** (Ali et al., 2023) | Adoption of IoT | RFID | Detect and explore drivers of IoT implementation in SCM |
| **Industry 4.0** (Majid et al., 2022) | Data-driven decision assistance, optimization, and cost saving | Numerous IoT devices and data analytics tools | Data-driven decision support in Industry 4.0 |
| **Supply Chain Operations** (Rejeb et al., 2020) | Data security, privacy, standardization, interoperability | Several IoT devices and platforms | Application of IoT in supply chain operations |
| **Sustainable SCM** (Rejeb et al., 2021) | Environmental impact, optimization, sustainability | IoT devices and data analysis for sustainability | Sustainability in supply chain management |

*Source: Wong et al., 2024.*

This finding suggests that IoT has potential applications in traceability within SCM, based on characteristics such as better visibility, quality management, sustainability, and real-time decision verification (Rejeb et al., 2020), as seen in Table 1.

**Blockchain for the Supply Chain Management**

Blockchain has been applied across various supply chain sectors, including maritime shipping. (Howson, 2020), agri-food (Kayikci et al., 2022), and pharmaceuticals (Hastig & Sodhi, 2020), leveraging its immutable distributed ledger for secure product tracing. Often paired with IoT devices. (Venkatesh et al., 2020)Blockchain addresses security gaps in RFID and IoT systems. (Christidis & Devetsikiotis, 2016), enabling scalable networks without server bottlenecks (Reyna

et al., 2018). Smart contracts enhance IoT platforms by automating actions like supplier payments upon task completion (e.g., delivery verification). This integration also improves control over environmental conditions (e.g., temperature, pressure) for perishable goods, with smart contracts ensuring compliance and triggering alerts for anomalies. (Hasan et al., 2019). Blockchain's cryptographic capabilities ensure data validity and security, promoting transparency and sustainability in global supply chains. (Zelbst et al., 2019). Combined with RFID and IoT, blockchain enhances traceability, accountability, and ethical business practices, supporting environmental and social responsibility. (Saberi et al., 2019).

**Table 2. Application of Blockchain in SCM**

| Domain | Issues | Blockchain Type | Focus |
|---|---|---|---|
| **Supply Chain Management** (Moosavi et al., 2021) | Hard work and costly to keep. | Blockchain | Efficiency, transparency, security |
| **Supply Chain Management** (Brookbanks & Parry, 2022) | Fill in the gaps between third parties. | Blockchain | Product traceability, efficiency |
| **Medical Supply Chain** (Panda & Satapathy, 2024) | Create trust between stakeholders and consumers | Blockchain | Product traceability, transparency |
| **Supply Chain Management** (Kumar et al., 2021) | Addressing critical gaps in the existing supply chain, Traces products consummate efficiency. | Permissioned blockchain | Efficiency, security, transparency |
| **Supply Chain Management, Blockchain** (Bhutta & Ahmad, 2021) | Data security, traceability, trust | IoT devices and blockchain integration | Blockchain: Traceability and trust in supply chain |

*Source: Wong et al., 2024.*

As Table 2 depicts, Blockchain technology is growing as a very promising solution for the major SCM challenges of transparency, traceability, security, and preventing fraud (Kumar et al., 2021b). Blockchain technology is capable (Bhutta & Ahmad, 2021) of tracking the flow of shipments (movement of products through the supply chain) in real time, building a tamper-proof record of all transactions in a supply chain, and protecting sensitive data.

**Perishable Goods Research with Blockchain**

Introduction to Perishable Goods Blackburn and Scudder (2009) described perishable goods as the goods that at harvest or production have the most value and lose value by exponential decay until they are refrigerated to stave off decay (Blackburn & Scudder, 2009). Since the quality of perishable goods relies heavily on temperature and time, the transportation of perishable goods is known as cold chain transportation (Amorim et al., 2013). blockchain helps alleviate the loss of perishable goods (Vu et al., 2023). No other studies documented so far show the perishable goods supply chain and how these are affected by blockchain addition, as mentioned earlier. Using blockchain in a supply chain must be no exception. This is a portion of the loose zone, for example, where product falls through various stages of transacting back and forth between organizations far beyond what might happen if that facility had everything on hand to process a given order on the spot or near the small group (Li et al., 2023). Besides, Wu et al. (2021) studied the blockchain application in part of the food supply chain based on the loss rate of perishable goods.

According to Zhang et al. For perishable goods, the modes of transport in the maritime supply chain typically refer to bulk goods shipping or container shipping (Grould et al. Others have reviewed loss drivers of perishable products in the marine provides routes, and they concluded that congestion, customs procedures, and delays in transit are the main loss drivers (Kaptan & Bayazit, 2023). Such barrier reduction helps the customs clearance process through the incorporation of blockchain-enabled clearance efficiencies, thereby giving perishable commodities more time during this phase and bringing assistance to WMI (Sengupta et al., 2022). Recent blockchain-based simulations have also determined that when utilizing a blockchain-based beef cold chain system in collaboration with the traditional maritime supply chain system, the subsequent reduction in sea level supply chain loss of goods can be up to 42.1 %. There is, of course, very limited research involving blockchain in the perishables maritime supply chain. This involves making a blockchain-based cold chain system for beef shipping and simulating possible adjustments in loss and food waste using the platform for Blockchain (Jo et al., 2022). To stimulate those marine cold chain enterprises to adopt the blockchain from a macro perspective and enter an information sharing platform, this problem is solved by some scholars through the evolutionary game theory (Shen et al., 2022).

**Companies utilizing blockchain-IoT integration in SCM**

Table 3 depicts the case of industry for IOT & blockchain in supply chain management, such as the diamond behemoth **De Beers** trained its miners in blockchain technology to authenticate diamonds. Maintaining a transparent public ledger of the supply chain empowers customers who can now be assured that what they are buying is untainted and fraud in that supply chain has become far more difficult, if not impossible, to perpetrate as there is a secure permanent record of the actions taken from origin to sale. The Danish shipping giant **Maersk** uses blockchain to track shipping containers around the world. Tech tracks location/ temp/ storage conditions, and cryptographic security prevents forgery of the signature (this will improve the efficiency of logistics). **Provenance** performed a Blockchain Pilot to Trace Fish in Indonesia using smart tagging, they tracked fish from fishermen to consumers, cutting fraud and illegal transport, and supporting sustainability claims. **Walmart** uses blockchain to track perishable goods such as pork. Technology enables

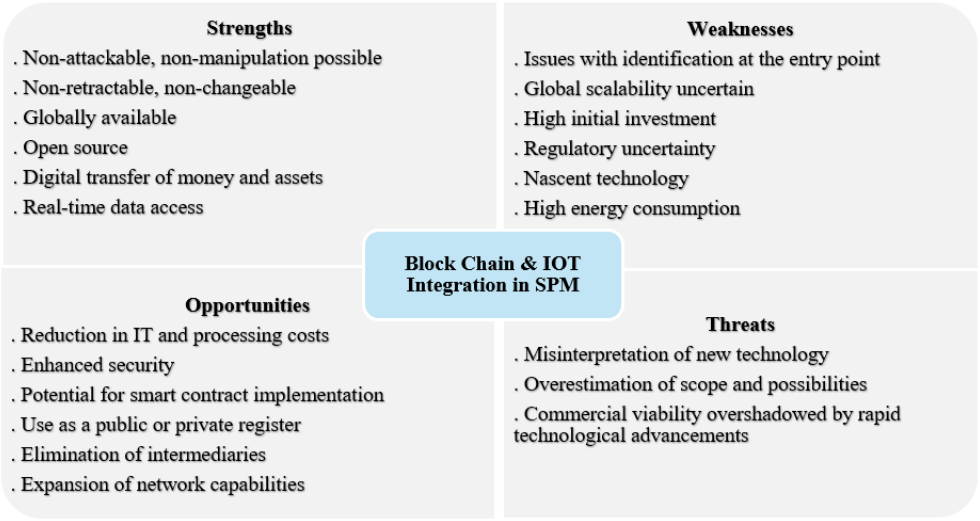
traceability to flow from minute to minute, so that recalls are immediate if contamination is found. Walmart's advancements for customer and courier authentication will also be done using blockchain to keep track of the condition of containers and products.

**Table 3.** Application & advantages of Blockchain-IoT in SCM

| Industry Name | Use of IoT-Blockchain in SCM | Description | Advantages and Notes |
|---|---|---|---|
| **De-Beers (Diamond Business)** (Kshetri, 2021) | Coaching diamond miners before the advance ordering of diamonds | De Beers traces the track of diamonds from the gold mine to the warehouse by preserving records at each touchpoint and storing original transactions in accounts. | For De Beers, it increased stock, and for consumers, it reassured them that diamonds were free from any flaws. |
| **Maersk (Shipping Business)** (Eljazzar et al., 2018) | Logistics – Tracking shipment packages worldwide | Using digital signatures, cryptography, and Hyperledger, IBM and Maersk tracked containers as they moved through the global SC. More than 200 processes and networks have been migrated towards blockchain. | Based on this pioneering initiative, we are creating a system that will solve challenges like paperwork, delays, loss, and fraud in container management. |
| **Provenance (Fishing Trade)** (Kim and Laskowski, 2018) | Following fish captured by fishermen | Provenance to trace fish from the point of catch using blockchain and smart tagging for pork. | Tackled problems like overfishing, fraud, lack of control, paperwork, and unlawful trades. |
| **Walmart (Online Supermarket)** (Casey and Wong, 2017) | Tracing manufacturers from the United States and China | Walmart utilized blockchain to log details about the farm, temperature, space environment, and logistics. This aided in confirming product authenticity and expiration dates. | Was able to track in a matter of minutes, increased food safety, prevention against contamination, and successful authentication. |

*Source: Thakker et al., 2024*

According to Thakker et al. (2024), the SWOT analysis of Blockchain-IoT in SCM is shown in Figure 1.




*Source: Thakker et al., 2024*

**Fig. 1** SWOT Analysis

The SWOT analysis showed the six strengths, six weaknesses, six opportunities, and three threats of black chain and IOT integration in SPM.

## Practical Implementation of IoT-Blockchain Solutions

The above critical challenges in perishable goods supply chain management bred the following viable solutions. Integrating IoT-blockchain for the traceability of perishable goods: Equipping supply chains with sensors capable of real-time tracking of temperature, humidity, or location at any point along the supply chain, combined with blockchain capabilities for immutable, tamperproof recording and storage, will provide end-to-end visibility and enable rapid response to those that have been compromised. Second, smart contracts can be used to automate compliance checks and payments, thereby eliminating delays and human error, as shown by the 80% reduction in paperwork at Maersk. Third, create dynamic pricing models tied to shelf-life measures from IoT to avoid waste and maximize revenue. Educate End Users about Blockchain Solutions and Digital Apps, Fourth, enable those applications to fight against counterfeit goods via technology solutions that connect a product passport with the block chain (so consumers validate authenticity through QR/NFC Tags) Fifth, Encourage sustainability through gifting tokenized rewards for green actions like reduced emissions or energy-efficient logistics. Lastly, forge global standardization frameworks to address scalability and interoperability challenges, favouring low-energy block solutions, such as Proof-of-Stake. Backed by pilot testing in high-

loss sectors such as seafood and pharmaceuticals, these measures can 30–40% reduction in waste, improved trust, and lower operational costs, all leading to more intelligent, sustainable perishable goods supply chains.

## Conclusion

1. This study demonstrates that the integration of IoT and blockchain can greatly enhance visibility and traceability of perishable goods supply chains and increase their overall performance. Blockchain's immutable ledger enables end-to-end visibility along the supply chain and allows for rapid tracking of contamination points (as seen with Walmart) while IoT sensors help monitor critical conditions in real-time to mitigate spoilage risk. They work in tandem to create a system that is secure and is free of fraud, while also being fully compliant. Smart contracts automate workflows such as payment processing that streamline activities and eliminate delays and errors. Successful implementations, like Maersk's TradeLens, illustrate that these technologies can reduce paperwork by 80% and decrease food waste by 30-40%. But challenges surrounding scalability, energy use, and standardization must be solved for broader adoption. These findings support the potential for IoT and blockchain technology to transform perishable supply chains, but future implementations need to emphasize sustainable and scalable solutions.

2. Highlighting Use Cases of Blockchain-IoT Integration in Supply Chain Management: Through case studies such as De Beers, Maersk, Provenance, and Walmart, the study illustrated practical applications of IoT-blockchain integration. These examples showcased how the technologies reduce fraud, improve operational efficiency, and enhance product authenticity, validating their transformative potential in real-world scenarios.

3. Identifying Challenges and Opportunities in Implementing IoT-Blockchain Solutions: The research identified key challenges, including scalability issues, high initial financing, regulatory ambiguity, and energy utilization. However, it also highlighted significant opportunities, such as cost reduction, improved security, and alignment with global digitization trends. The SWOT analysis further reinforced these findings, providing a balanced view of the strengths, weaknesses, opportunities, and threats associated with IoT-blockchain integration.

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