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Integrating Blockchain and Internet of Things for Supply Chain Traceability: Toward a Conceptual Framework

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Abstract:

Traceability has become a central requirement in modern supply chains as organizations seek to guarantee product quality, safety, transparency, and compliance across increasingly complex global networks. Traditional traceability tools such as barcodes, RFID, magnetic markers, and data loggers have improved product identification and monitoring, yet they still face limitations related to data reliability, security, and interoperability.

This article adopts a narrative conceptual literature review approach to analyze the role of blockchain and the Internet of Things (IoT) in enhancing supply chain traceability. By synthesizing existing academic contributions and practical applications, the study examines how these technologies address the limitations of traditional traceability systems.

Blockchain provides an immutable and decentralized infrastructure for recording transactions, ensuring transparency and trust among supply chain stakeholders. Meanwhile, IoT enables real-time monitoring through interconnected sensors that collect critical data such as location, temperature, and handling conditions.

The analysis highlights the complementarities between blockchain and IoT and discusses how their integration can improve transparency, operational efficiency, and product security across sectors such as agri-food, pharmaceuticals, and logistics. The study contributes to the literature by providing a conceptual synthesis of the mechanisms through which these technologies support end-to-end traceability in modern supply chains.

Keywords: Blockchain, Internet of Things, Traceability, Supply Chains.
Classification JEL: M15
Paper type: Theoretical Research

Résumé :

La traçabilité est devenue une exigence centrale au sein des chaînes logistiques modernes, dans un contexte où les organisations cherchent à garantir la qualité des produits, la sécurité, la transparence et la conformité à travers des réseaux mondiaux de plus en plus complexes. Les outils traditionnels de traçabilité, tels que les codes-barres, la RFID, les marqueurs magnétiques et les enregistreurs de données, ont permis d'améliorer l'identification et le suivi des produits. Toutefois, ces solutions présentent encore des limites liées à la fiabilité des données, à la sécurité et à l'interopérabilité des systèmes.

Cet article adopte une revue conceptuelle narrative de la littérature afin d'analyser le rôle de la blockchain et de l'Internet des objets (IoT) dans l'amélioration de la traçabilité des chaînes logistiques. En synthétisant les contributions académiques existantes ainsi que certaines applications pratiques, l'étude examine comment ces technologies permettent de surmonter les limites des systèmes de traçabilité traditionnels.

La blockchain offre une infrastructure décentralisée et immuable pour l'enregistrement des transactions, garantissant ainsi la transparence et la confiance entre les différents acteurs de la chaîne logistique. Parallèlement, l'Internet des objets permet un suivi en temps réel grâce à des capteurs interconnectés capables de collecter des données essentielles telles que la localisation, la température ou les conditions de manipulation des produits.

L'analyse met en évidence les complémentarités entre la blockchain et l'IoT et montre comment leur intégration peut améliorer la transparence, l'efficacité opérationnelle et la sécurité des produits dans différents secteurs tels que l'agroalimentaire, l'industrie pharmaceutique et la logistique. L'étude contribue à la littérature en proposant une synthèse conceptuelle des mécanismes par lesquels ces technologies permettent de soutenir une traçabilité de bout en bout dans les chaînes logistiques modernes.

Mots clés : Blockchain, Internet des Objets, Traçabilité, Chaînes logistiques.
JEL Classification : M15
Type du papier : Recherche Théorique

1. Introduction

Traceability has become a central requirement in modern supply chains as organizations increasingly seek to ensure product quality, safety, transparency, and regulatory compliance across complex and globalized networks. In many industries, including agri-food, pharmaceuticals, and logistics, the ability to track products throughout their lifecycle has become essential for managing risks, ensuring consumer protection, and improving operational efficiency. Effective traceability systems allow organizations to monitor product origins, production processes, and distribution pathways, thereby enhancing accountability and supporting better decision-making throughout the supply chain (Gani et al., 2022; Vidigal et al., 2023).

Historically, traceability has relied on traditional technologies such as barcodes, radio-frequency identification (RFID), magnetic markers, and data loggers. These tools have significantly improved product identification and monitoring capabilities, enabling firms to manage inventories, control product flows, and respond to safety incidents more effectively. However, despite these advances, traditional traceability systems still face several limitations related to data reliability, information fragmentation, lack of interoperability between systems, and vulnerability to fraud or data manipulation (Fatorachian & Kazemi, 2021; Galvez et al., 2018). As supply chains become increasingly global and multi-actor, these limitations create challenges for ensuring transparent and trustworthy information sharing among stakeholders.

In recent years, emerging digital technologies associated with Industry 4.0 have opened new perspectives for improving supply chain traceability. Among these technologies, blockchain and the Internet of Things (IoT) have attracted considerable attention from both researchers and practitioners. Blockchain provides a decentralized and immutable infrastructure for recording transactions, enabling secure data sharing and improving trust among supply chain partners (Kshetri, 2018; Kamble et al., 2020). At the same time, IoT technologies allow real-time monitoring of products through connected sensors capable of collecting operational data such as location, temperature, humidity, and handling conditions (Jayaram, 2017; Motlagh et al., 2016). When combined, these technologies have the potential to significantly enhance transparency, traceability, and operational efficiency within supply chains.

Despite the growing body of research on blockchain and IoT in supply chain management, the existing literature remains fragmented in several respects. First, many studies examine blockchain-based traceability solutions in specific sectors such as agri-food or pharmaceuticals, without providing a broader conceptual perspective applicable to different supply chain contexts (Kamilaris et al., 2019; Salah et al., 2019). Second, other studies focus primarily on IoT-enabled monitoring systems that collect real-time data but do not fully address issues related to data governance, trust, and interoperability across multiple actors (Zhang & Li, 2021). Third, the literature often analyzes blockchain and IoT technologies separately, while relatively few studies propose an integrated conceptual understanding of how these technologies interact to support end-to-end traceability in supply chains.

Several empirical studies have demonstrated the potential benefits of blockchain-IoT integration in specific applications such as food traceability, cold chain monitoring, and pharmaceutical product tracking (Caro et al., 2018; Hasan et al., 2019; Lin et al., 2022). While these contributions provide valuable insights, they are often limited to particular case studies or technological implementations and do not fully conceptualize the mechanisms through which blockchain and IoT jointly enhance traceability and supply chain governance. As a result, there remains a need for a structured theoretical synthesis that clarifies the roles, complementarities, and integration mechanisms of these technologies within modern supply chains.

In response to this gap, the present study aims to provide a conceptual synthesis of the role of blockchain and the Internet of Things in improving supply chain traceability. More specifically, the article seeks to analyze how these technologies address the limitations of traditional traceability systems and how their integration can support more transparent, reliable, and efficient supply chain management.

Methodologically, this research adopts a narrative conceptual literature review approach. The study synthesizes academic and institutional literature on blockchain- and IoT-based traceability systems published primarily between 2015 and 2024. The review draws on publications indexed in major academic databases such as Scopus, Web of Science, and Google Scholar using keywords including “blockchain”, “Internet of Things”, “traceability”, and “supply chain”. This approach allows the identification of key technological mechanisms, applications, and theoretical perspectives related to the integration of these technologies in supply chain traceability.

The article contributes to the literature by proposing a structured analysis of the complementarities between blockchain and IoT technologies and by highlighting the mechanisms through which their integration can enhance transparency, trust, and operational coordination in supply chains. By providing a conceptual synthesis of existing studies, this research aims to support a better understanding of traceability systems in the context of digital transformation and Industry 4.0.

The remainder of the article is structured as follows. Section 2 reviews the concept of traceability and examines the main definitions proposed in academic literature and international standards. Section 3 analyzes traditional traceability tools and their limitations within supply chains. Section 4 introduces the fundamental principles of blockchain technology and discusses its applications in supply chain management. Section 5 examines the role of the Internet of Things in enabling real-time data collection and monitoring within logistics systems. Section 6 explores the integration of blockchain and IoT technologies and discusses their complementarities in enhancing supply chain traceability. Finally, the conclusion summarizes the main findings, outlines managerial implications, and identifies future research directions.

2. Literature review

2.1 What is traceability ?

Traceability can be understood in various ways depending on perspective, holding significant importance in ensuring accountability and transparency in a range of applications. ISO 8402 describes traceability as "the ability to trace the history, application, or location of an entity by means of recorded identifications" (ISO, 1994).

This definition specifies the aspects to be tracked, including history, usage, and location, along with the process of tracing. However, it suffers from a lack of clarity due to the recursion of the term "trace."

Conversely, ISO 9000 and ISO 22005 (ISO, 2005) provide a more generalized definition, defining traceability as "the ability to trace the history, application, or location of what is under consideration." This updated definition omits references to "recorded identifications," which may influence the way traceability is implemented.

According to ISO/IEC 15944-9:2023 (ISO, 2023), traceability is a crucial element in transactions, allowing for precise tracking of the journey of products, services, or information throughout their lifecycle. This precise tracking helps build trust among parties, prevent errors and fraud, and facilitate risk management.

In the legislative realm, the European Union's General Food Law (Regulation 178/2002) (EU, 2002) defines traceability as "the ability to trace and follow a food, feed, food-producing animal, or any substance intended to be, or expected to be, incorporated into a food or feed, through all stages of production, processing, and distribution." This definition outlines what must be traced and followed but is less specific about relevant properties or practical implementation.

Dictionaries offer general definitions of traceability, often describing it as "the ability to trace." Cambridge Dictionaries Online (Cambridge University Press, 2024) defines traceability as "the ability to discover information about the origin and the manufacturing process of a product." This definition emphasizes the importance of knowing a product's history and journey, providing increased transparency and assurance to consumers.

In the scientific field, a commonly cited definition, from an article by Moe (1998), describes traceability as "the ability to follow a batch of products and its history through all or part of a production chain, from harvesting to sale." This definition emphasizes "chain traceability," offering a useful distinction from "internal traceability," which focuses on tracing within a single organization or process.

In 2013, Olsen and Borit examined various definitions of traceability and proposed a universal and modern definition: "Traceability (n): The ability to access all information relating to what is under consideration throughout its life cycle, by means of recorded identifications." This definition highlights the need to trace all relevant information about a product throughout its supply chain, using systematic records to ensure effective traceability.

Traceability is of fundamental importance in various fields, from industry to legislation to science. The different definitions proposed by ISO standards, regulatory laws, and researchers all underscore the importance of being able to trace the history, application, or location of entities throughout their life cycle. This ability to precisely track products, services, or information helps build trust, ensure safety, and guarantee transparency for consumers, businesses, and regulatory authorities. By adopting effective traceability systems, organizations can better manage risks, prevent errors and fraud, and improve product quality and safety. Thus, traceability remains a key element in meeting growing demands for safety, quality, and social responsibility in an interconnected and globalized world.

To better understand the conceptual foundations of traceability, it is useful to compare the main definitions proposed in international standards, regulatory frameworks, and academic literature. These definitions emphasize different dimensions of traceability, including the object being traced, the type of information recorded, the scope of the supply chain involved, and the technological or informational infrastructure used to support traceability systems.

Table 1. Comparative definitions of traceability in the literature

Source	**Definition**	**Object traced**	**Type of information**	**Supply chain scope**	**Information support**
ISO 8402 (1994)	Traceability is the ability to trace the history, application, or location of an entity by means of recorded identifications.	Product or entity	Historical and identification data	Entire lifecycle	Recorded identification systems
ISO 9000 (2005)	Traceability refers to the ability to trace the history, application, or location of what is under consideration.	Product or process	Operational and historical data	Production and distribution stages	Quality management systems
ISO/IEC 15944-9 (2023)	Traceability allows the precise tracking of products, services, or information throughout their lifecycle.	Product, service, information	Lifecycle information	Entire supply chain	Digital transaction records
EU Regulation	The ability to trace and follow food, feed, animals, or	Food and agricultural	Production and distribution data	Farm-to-fork supply	Regulatory traceability

178/2002	substances through all stages of production, processing, and distribution.	products		chain	systems
Moe (1998)	Traceability is the ability to follow a batch of products and its history through all or part of a production chain.	Batch of products	Process and production data	Production chain	Production information systems
Olsen & Borit (2013)	Traceability is the ability to access all information relating to what is under consideration throughout its lifecycle using recorded identifications.	Product lifecycle	Comprehensive lifecycle data	Entire supply chain	Integrated information systems

Source: Author.

Based on the comparative analysis presented above, traceability can be defined as the ability to systematically record, access, and verify information related to a product, process, or batch throughout its lifecycle across the entire supply chain using reliable identification and information systems. This definition highlights several essential dimensions of traceability: the object being traced, the nature of the information recorded, the scope of the supply chain involved, and the technological infrastructure supporting the storage and transmission of information.

Such a multidimensional understanding of traceability is particularly relevant in contemporary supply chains characterized by increasing complexity, multiple actors, and growing regulatory requirements.

The literature also reveals different perspectives regarding the role of traceability within supply chains. On the one hand, traceability is often viewed as an internal control mechanism, allowing firms to monitor production processes, manage inventories, and ensure product quality within their own organizational boundaries. From this perspective, traceability systems serve primarily operational and managerial purposes.

On the other hand, traceability can also be interpreted as a mechanism of inter-organizational governance that facilitates coordination and information sharing among multiple actors across the supply chain. In this broader perspective, traceability contributes to reducing information asymmetries, improving transparency, and strengthening trust between suppliers, manufacturers, distributors, and regulators.

The increasing complexity of global supply chains reinforces the importance of this second perspective. As products move across multiple organizations and geographical regions, traceability systems must support not only internal monitoring but also reliable data exchange and verification across different actors.

Despite their importance, traditional traceability tools such as barcodes, RFID tags, and data loggers present several limitations when applied to complex and global supply chains. First, these systems often rely on centralized databases, which may create vulnerabilities in terms of data integrity and security. Second, interoperability issues between information systems can lead to fragmented data flows, limiting the visibility of product movements across the entire supply chain. Third, traditional systems may remain susceptible to data manipulation or counterfeiting, which can undermine trust among stakeholders.

These limitations highlight the need for more advanced technological solutions capable of ensuring secure, transparent, and reliable information sharing across supply chain actors. In this context, emerging technologies such as blockchain and the Internet of Things (IoT) offer promising opportunities to enhance traceability systems by combining real-time data collection with secure and immutable data storage infrastructures.

2.2 Traceability in the Supply Chain

Integrating traceability within supply chains is essential to ensure product reliability and compliance (Gani et al., 2022). Since the 1990s, this practice has gained increasing success. Traceability systems (Vidigal et al., 2023) are considered operational tools for supply chain management, as well as cross-functional concepts or strategic management processes (Fatorachian et Kazemi, 2021).

The main goal, according to Petrželová (2023), is to minimize information gaps about a product or process during its entire lifecycle. This approach facilitates real-time monitoring of product origins, the processes applied, and the materials used, along with the capacity to trace products throughout their journey from manufacturing to reverse logistics flows. Traceability offers several functions (Garcia-Torres et al., 2019), such as product origin tracking, usage history tracking, and product flow tracking. A strong ability to trace and locate products in the supply chain is crucial for operations management and performance improvement.

In supply chain management (Rahma et Hersugondo, 2022), information is a key economic asset. The ability to identify products throughout the supply chain equips businesses with crucial data across various management tiers. By implementing traceability systems, companies can more effectively oversee their products and processes, contributing to enhanced productivity and profitability.

In sectors such as food and pharmaceuticals, traceability systems are crucial for anticipating and controlling health risks. In the forestry sector (Dessureault, 2019), traceability enables identification and tracking of products through the forestry supply chain, though its use remains limited in this field.

Integrating traceability into supply chains is crucial to ensure product reliability and compliance. Traceability systems enable real-time tracking of products, processes, and their location, improving operations management and performance. They provide valuable information for better product and process management while helping to anticipate and control health risks in sensitive sectors like food and pharmaceuticals.

2.3 Traceability Tools in Supply Chain

Traceability tools in supply chains offer a variety of means to ensure product provenance and authenticity (Drago et al.,2020). These include stable isotope technology, nanocapsules, magnetic markers, barcodes (1D and 2D), data loggers, and RFID technology. Each tool has its advantages and limitations in terms of efficiency, cost, and security.

Nanocapsules (Sharma et al., 2023) produce unique codes through molecular imprints embedded within a product, allowing for identification and authentication. These nanocapsules can hold multiple codes, enabling the decoding of complex sequences.

Magnetic markers (Takubo et al., 2023) involve silica-coated magnetic particles that are integrated into a product during manufacturing, aiding identification and secure information transfer across the supply chain. According to Müssig et al. (2021), this technology is simple, safe, effective, and generally cost-efficient, as magnetic markers generate an inherently unique, easily readable code for each product.

The advent of barcodes (Mishra et Mathuria, 2017) marked a revolution in traceability and product identification within supply chains. Barcodes, whether one (1D) or two-dimensional (2D), simplified and accelerated the process of tracking items by associating specific information with easily scannable graphic configurations (Saikouk et Spalanzani, 2016). 1D barcodes have been long-time pioneers of this technology, using the variation in width and spacing of black and white lines to represent data. They facilitated inventory management and error reduction in many industries. However, the emergence of 2D barcodes, especially QR codes, brought significant evolution (Musa et al., 2014). Using two-dimensional symbols and shapes, QR codes offer much higher encoding capacity, capable of containing several thousand characters. Moreover, their ability to conceal kanji and kana characters, along with their resistance to dirt and damage, makes them a versatile and robust tool for product traceability (Kumar et al., 2015).

Traceability tools in supply chains include stable isotope technology, nanocapsules, magnetic markers, barcodes (1D and 2D), data loggers, and RFID technology. Each tool has its advantages and limitations in terms of efficiency, cost, and security.

Radio-Frequency Identification technology (RFID) (Choong et al., 2021) is an automatic identification system used for tracking and collecting data on items without human intervention. It consists of tags equipped with electronic chips and antennas to transmit information via radio waves, as well as readers to capture and interpret this data (Boeck al., 2017). In supply chain management, RFID allows for the collection of information such as manufacturing dates, departure and arrival times, and business data, providing increased visibility within the supply chain when this data is shared among partners (Khattab et al., 2017).

RFID technology (Mabad et al., 2021) enables automatic identification of multiple items simultaneously, without requiring direct contact. However, its deployment requires high investment, which can deter most SMEs. Moreover, while RFID tags offer effective tracking, they are susceptible to counterfeiting and cloning, which can compromise their security when operating on wireless networks (Singh et Patro, 2021).

Traceability tools in supply chains offer diverse means to ensure product provenance and authenticity. Each tool has its advantages and limitations in terms of efficiency, cost, and security. These technologies facilitate real-time monitoring of product origins, the processes applied, and the materials used. They also provide the capability to track products throughout their journey in the supply chain. While these tools are essential for effective product and process management, their deployment may require significant investments and present risks of counterfeiting.

3. Blockchain

Blockchain, often viewed as a groundbreaking technology, extends beyond merely being a public ledger of transactions (Correia et al., 2011). It comprises a sophisticated ecosystem of core technologies (Lashkari and Musilek, 2021), such as the blockchain data structure, public key cryptography, distributed ledgers, and consensus mechanisms. This unique combination of elements provides the foundation for the countless applications and innovations of blockchain.

At its most basic essence, blockchain is a public ledger where transactions (Bano et al., 2017) are recorded and secured by a distributed network of nodes, eliminating the need for a central authority. This intrinsic decentralization (Swan, 2015) allows blockchain to operate without relying on trusted third parties, creating an immutable and tamper-proof database where anyone can view data and verify its accuracy.

From a supply chain traceability perspective, the value of blockchain lies primarily in several key attributes that support reliable information sharing across supply chain actors. These attributes include immutability, event traceability, auditability, and the use of smart contracts.

First, the immutability of blockchain records ensures that once information has been validated and stored within a block, it cannot be altered without modifying the entire chain of records. This characteristic strengthens the reliability and integrity of traceability data across the supply chain. In supply chain management terms, immutability contributes to the development of trust among supply chain partners by guaranteeing that recorded information remains tamper-proof and verifiable.

Second, blockchain supports detailed event traceability by recording each transaction or event related to a product as it moves through the supply chain. These sequential records enable the reconstruction of the entire lifecycle of a product, from production to final consumption. Such event-based traceability improves end-to-end visibility and reduces information asymmetries between supply chain actors.

Third, blockchain systems provide a high level of auditability, as all transactions recorded in the distributed ledger can be verified by authorized participants. This property facilitates regulatory compliance and strengthens governance mechanisms in supply chains by enabling transparent verification of operational activities and product movements.

One of the most intriguing features of blockchain is its capacity to execute smart contracts (Ante, 2021), which are pre-defined agreements between parties that are automated and stored on the blockchain. These contracts enable reliable transactions without third-party intervention, as they are automatically executed based on specific conditions. This feature has garnered significant attention, particularly in the context of decentralized finance and other innovative applications where transparency, automation, and security are paramount.

In supply chain contexts, smart contracts can automate key operational processes such as payments, delivery confirmations, or compliance verification. By reducing the need for intermediaries and enforcing contractual rules automatically, smart contracts improve coordination among supply chain partners and reduce the risks of opportunistic behavior.

Furthermore, blockchains use peer-to-peer networks (Mao et al., 2020) where all parties must reach a consensus on the validity of a transaction, avoiding inaccurate or fraudulent transactions in the database (Sankar et al., 2017). The immutability of data guarantees that once transactions are agreed upon, they are recorded permanently without alteration, ensuring traceability of assets throughout their entire lifecycle. From a supply chain governance perspective, blockchain technologies therefore contribute to strengthening coordination mechanisms, improving information transparency, and enhancing trust between supply chain stakeholders.

3.1 Applications of Blockchain in Supply Chains

Blockchain is emerging as a key player in reimagining logistics operations (Evren, 2023). It offers a range of potential applications that could revolutionize processes and interactions within supply chains.

A significant advantage of this technology is its capacity to enhance transparency and traceability of products. It allows for the immutable and secure recording of every transaction and product movement, enabling companies to accurately track the origin and journey of products. Across the literature, several blockchain-based applications share common dimensions that illustrate how this technology improves supply chain traceability. These dimensions include:

- end-to-end visibility of product flows across the supply chain;
- reduction of information asymmetries between supply chain actors;
- automation of contractual relationships through smart contracts.

In the food industry (Carrefour, 2018; IBM Hyperledger, 2019), the ability to precisely track the origin and journey of products not only provides consumers with peace of mind regarding food quality and safety but also allows companies to react rapidly and effectively in case of product recalls or food safety issues. Solutions like IBM Food Trust allow companies to quickly identify sources of contamination and take corrective actions, reducing public health risks and strengthening consumer confidence in brands.

By providing a secure and transparent means of data storage, blockchain also offers new ways to fight fraud and counterfeiting in the supply chain. For example, the luxury goods sector benefits from blockchain's immutability to guarantee product authenticity, protecting both consumers and businesses from counterfeit goods.

Moreover, blockchain facilitates greater collaboration among supply chain stakeholders, streamlining processes and reducing friction in cross-border transactions. This increased efficiency can lead to cost savings and improved supply chain resilience. As blockchain technology continues to evolve, its role in reimagining logistics operations and reshaping the supply chain landscape becomes increasingly significant.

Similarly, in the pharmaceutical industry (FDA, 2019), the authenticity of medications is crucial for patient safety. The Food and Drug Administration (FDA) states that blockchain offers a reliable solution for verifying the origin and integrity of pharmaceutical products. By recording each step of the manufacturing and distribution process on the blockchain, companies can ensure that only authentic medications reach patients, while also facilitating the detection and prevention of drug counterfeiting.

In logistics and shipping, blockchain technology has been trialed in Australia and Singapore (Australian Border Force, Infocomm Media Development Authority of Singapore, and Singapore Customs, 2021) to verify trade documents and streamline processes, reducing fraud in international trade.

These examples illustrate how blockchain-based traceability systems improve supply chain governance by enabling secure information sharing among stakeholders and reducing coordination frictions in complex supply networks.

Another significant application of blockchain in logistics is the optimization of processes and automation of tasks through smart contracts (Ante, 2021). Smart contracts (Chen et al., 2021) are computer programs that automatically execute when predetermined conditions are met. Blockchain secures these contracts against tampering, allowing them to be used in a range of supply chain applications. By promoting transparency and trust within the logistics chain (Betti et al., 2019), smart contracts enable secure data sharing among business partners.

4. Internet Of Things

The phrase "Internet of Things" was coined by Kevin Ashton in 1999 to refer to a realm of connected objects, devices, and sensors via the internet (Magee, 2006). IoT is viewed as a transformative shift in the domain of information technology, dramatically altering how computing devices, mechanical and digital machines, and unique systems interact and exchange data (Madakam et al., 2015). IoT can be seen as a worldwide network that facilitates communication among people, objects, and between objects themselves by providing each item with a distinct identity (Aggarwal and Das, 2012). The Cluster of European Research Projects on the Internet of Things (CERP-IoT) characterizes IoT as a flexible framework of a global network with self-configuring capabilities, built on interoperable communication standards and protocols (Cluster, CERP-IoT, 2010).

The Internet of Things (IoT) dissolves the barriers between computers and everyday objects as more people embrace computing resources and web-based services (Thebault, 2013). It creates a network where computing devices, mechanical and digital machines, objects, and even individuals are connected, enabling data transfer without necessarily relying on human-to-human or computer-to-human interactions (Challal, 2012). IoT devices gather data, exchange information about their status, and carry out tasks through built-in sensors (Laghari et al., 2021). Within the IoT ecosystem, internet-connected smart devices use embedded systems like processors, sensors, and communication hardware to collect, send, and act upon the data they generate (Laghari et al., 2021).

From a supply chain management perspective, IoT technologies can be understood primarily as a data generation infrastructure that enables real-time monitoring of logistics operations. Sensors embedded in products, containers, vehicles, or storage facilities continuously collect operational data such as location, temperature, humidity, shock exposure, and handling conditions. These data provide critical information about the physical flow of goods across supply chains and significantly improve operational visibility.

IoT can also integrate machine learning, making the data more practical and dynamic (Motlagh et al., 2016). This integration allows IoT systems to make informed decisions and automate processes based on patterns and insights derived from the data. Moreover, IoT is a significant source of big data analysis, as it generates and analyzes large amounts of real-time data, which can improve operations and performance across various sectors (Pinto et Prazeres, 2019). This capacity for data generation and analysis has led to widespread adoption in industries ranging from manufacturing to healthcare, where real-time insights can drive efficiency, innovation, and enhanced user experiences.

In supply chain and logistics contexts, IoT-generated data support several operational decision-making processes. Real-time monitoring of inventory levels allows firms to improve replenishment decisions and reduce stock shortages. Environmental sensors monitoring temperature or humidity enable better quality management, particularly in cold chain logistics and pharmaceutical distribution. In addition, the continuous monitoring of transport conditions and product movements helps organizations anticipate operational disruptions and improve risk management across supply chain activities.

IoT is presented as a technology that can revolutionize many aspects of everyday life by enabling communication and interaction among a multitude of objects and individuals (Piccialli et al., 2019). It is described as a powerful tool to improve efficiency, productivity, and security in different sectors, including logistics, manufacturing, agriculture, and healthcare (Jayaram, 2017). IoT is also seen as a catalyst for innovation, opening new perspectives in terms of smart products and services (Motlagh et al., 2016). It is emphasized that IoT can significantly contribute to the creation of smart and sustainable cities by optimizing resource use and enhancing the quality of life for residents (Pinto et Prazeres, 2019). Furthermore, IoT is considered a key driver of digital transformation, fostering economic growth and promoting new business models (Piccialli et al., 2019).

Within digital supply chains, IoT therefore plays a central role as the primary source of traceability data generated from physical products and logistics processes. However, while IoT technologies enable real-time data collection, the governance, security, and reliability of these data remain critical challenges when multiple actors are involved across the supply chain.

In this perspective, blockchain technologies can be considered as a complementary infrastructure responsible for recording, securing, and sharing IoT-generated data across supply chain stakeholders. While IoT captures real-time operational information from sensors and connected devices, blockchain ensures the integrity, immutability, and transparency of these data within a distributed ledger. This complementary relationship between IoT as a data collection layer and blockchain as a trusted recording infrastructure provides the technological foundation for integrated traceability systems in modern supply chains, which will be further examined in the following section.

5. Blockchain and Internet of Things integration

The convergence of blockchain and IoT is gaining traction as an effective research direction for enhancing logistics traceability. Hinckeldeyn and Kreutzfeldt (2018) suggested utilizing connected smart storage containers with blockchain-based smart contracts to improve logistics processes. These containers monitor stock levels through weight sensors. When the stock reaches a critical threshold, the container automatically places an order and triggers payment via cryptocurrencies. They developed a prototype using Ethereum smart contracts and Raspberry Pi-based controls.

Biswas et al. (2017) designed a blockchain-based system for tracking the wine supply chain. This technology is currently applied alongside RFID tags to authenticate and ensure the provenance of high-end wine bottles. By storing information on the blockchain and confirming the traceability of bottles, consumers can check the history and authenticity of the wine by entering the product ID into the system.

Wen et al. (2019) introduced a blockchain-based data-sharing model that uses attribute-based encryption (ABE) to safeguard privacy in the supply chain. This approach allows users with specific role attributes, meeting the defined access policy, to decrypt the encrypted data, thus ensuring controlled access while maintaining security.

Helo and Hao (2019) suggested a four-layer framework for tracking packages. The base layer comprises IoT devices responsible for collecting real-time data from GPS, RFID, sensors, and barcodes. The second layer manages logistical operational data, and the third layer addresses business logic, including logistics monitoring and access management. The top layer is dedicated to user administration. The authors chose Ethereum to develop their proposed architecture.

Moreover, studies like those by Wen et al. (2019), Helo and Hao (2019), Caro et al. (2018), and Salah et al. (2019) illustrate the diversity of approaches and architectures that leverage the synergies between IoT and blockchain. From privacy protection to package management and agricultural product traceability, these research efforts showcase the breadth of potential applications for these combined technologies.

Beyond these individual use cases, the literature highlights several common mechanisms through which the integration of IoT and blockchain enhances supply chain traceability. First, IoT technologies operate as a data acquisition layer that captures real-time information from physical products and logistics processes. These data include location information, environmental conditions (temperature, humidity), and operational events such as loading, transport, and delivery. Second, blockchain technologies provide a distributed infrastructure for securely recording and sharing these data across multiple actors in the supply chain. Through immutable ledgers and smart contracts, blockchain ensures the integrity, transparency, and verification of traceability information.

This interaction between IoT and blockchain can therefore be understood as a complementary technological architecture in which IoT generates operational data while blockchain ensures trusted data governance. At the supply chain level, this architecture enables improved coordination between actors, reduces information asymmetries, and strengthens trust within inter-organizational networks.

Traceability in supply chains has significantly evolved with the adoption of innovative technologies like blockchain and the Internet of Things. Examples such as the smart storage containers proposed by Hinckeldeyn and Kreutzfeldt (2018), the blockchain-based wine supply chain traceability system developed by Biswas et al. (2017), and the shipment management solution created by Hasan et al. (2019) demonstrate how this combination can ensure the security and transparency of transactions while automating processes.

Based on the literature review, the integration of IoT and blockchain in supply chains can be conceptualized through a layered architecture that structures the flow of traceability data across different technological and organizational levels:

- **Data collection layer:** IoT sensors, RFID tags, and connected devices collect real-time information from physical products and logistics operations.
- **Data transmission and processing layer:** communication networks and analytics systems process and transmit operational data.
- **Trust and recording layer:** blockchain infrastructures store and verify traceability data through distributed ledgers and smart contracts.
- **Application and governance layer:** supply chain actors (manufacturers, logistics providers, distributors, regulators) access verified data to support decision-making, compliance, and coordination.

This layered architecture highlights the complementary roles of IoT and blockchain within digital supply chains: IoT enables real-time visibility of physical processes, while blockchain ensures the reliability, transparency, and governance of shared information.

From this conceptual synthesis, several design principles for traceability systems in Industry 4.0 can be identified. First, the principle of data minimization suggests that only critical traceability information should be recorded directly on the blockchain to reduce storage and scalability constraints. Second, the principle of shared governance implies that blockchain nodes should be distributed among multiple supply chain stakeholders in order to avoid centralized control and ensure trust among participants. Third, interoperability between IoT devices and blockchain infrastructures should be ensured through standardized data formats and communication protocols.

However, despite these promising perspectives, several challenges remain for the implementation of blockchain–IoT traceability systems.

First, scalability remains a major technological challenge. Public blockchain infrastructures may face limitations in processing large volumes of real-time IoT data generated by connected devices across global supply chains. Second, the costs associated with implementing IoT sensors and blockchain infrastructures may represent a barrier for small and medium-sized enterprises (SMEs). Third, issues related to data confidentiality and privacy must be carefully addressed, particularly when sensitive commercial information is shared across multiple actors.

Furthermore, the successful deployment of blockchain–IoT traceability systems requires the alignment of incentives among supply chain actors. Differences in technological capabilities, governance structures, and regulatory frameworks may hinder the adoption of shared digital infrastructures. Finally, the lack of standardized data models and interoperability frameworks remains an important obstacle for large-scale implementation.

These challenges highlight the need for further research on scalable architectures, governance models, and regulatory frameworks capable of supporting the development of integrated traceability systems in digital supply chains.

Overall, the synergy between blockchain and IoT opens up new possibilities for supply chain traceability and management. The potential to automate processes, improve product tracking, and ensure security and transparency offers businesses a significant opportunity to streamline their operations and build stronger customer relationships. As these technologies continue to evolve, they are likely to play an increasingly central role in the future of supply chain logistics and traceability.

6. Conclusion

In this era of globalization, where trust and transparency are essential, the quest for complete traceability in supply chains takes on crucial importance. The combination of IoT and blockchain offers a tangible solution to this challenge by providing unprecedented visibility over the entire logistics process.

Blockchain, with its ability to create immutable and verifiable records, forms the foundation upon which this complete traceability is built. Every step in the product journey can be transparently recorded, ensuring data integrity and reliable information. Additionally, the inherent decentralization of blockchain enhances trust by removing potential single points of failure in the system. IoT complements this approach by enabling real-time tracking of products and data collection throughout their journey in the supply chain. Connected sensors can monitor essential parameters, ensuring product quality and integrity during transit.

The findings of this study highlight the complementary roles of IoT and blockchain technologies in strengthening supply chain traceability. The literature review shows that IoT technologies primarily function as a data generation layer capable of capturing real-time information about product conditions, locations, and logistics events. In contrast, blockchain technologies provide a trusted infrastructure for storing, verifying, and sharing these data among supply chain stakeholders. By combining these two technological layers, organizations can improve end-to-end visibility, reduce information asymmetries between supply chain actors, and strengthen governance mechanisms across inter-organizational networks. The conceptual synthesis proposed in this article contributes to the literature by clarifying the mechanisms through which IoT and blockchain integration supports more transparent, reliable, and coordinated supply chain systems.

By combining these two technologies, companies can not only guarantee complete traceability but also meet the growing demands for quality, safety, and social responsibility. Consumers, increasingly concerned about the origin and quality of the products they buy, benefit from greater transparency, thus boosting trust in brands and products. From a managerial perspective, the integration of IoT and blockchain technologies can significantly improve supply chain operations. Real-time monitoring enabled by IoT sensors allows firms to improve inventory management, product quality control, and logistics risk management. At the same time, blockchain infrastructures facilitate secure information sharing among supply chain partners, strengthen trust, and automate coordination processes through smart contracts. For organizations operating in sectors such as agri-food, pharmaceuticals, and logistics, the implementation of blockchain-IoT traceability systems may therefore enhance operational efficiency, reduce fraud and counterfeiting risks, and improve regulatory compliance.

However, to make this vision of complete traceability a reality, close collaboration among supply chain stakeholders is required. Moreover, rigorous measures must be taken to ensure data security and protect individual privacy.

Despite these promising perspectives, several limitations and challenges remain. The present study is based on a conceptual review of literature and does not rely on empirical data. Future research could therefore test the proposed conceptual mechanisms through case studies, surveys, or quantitative analyses in specific supply chain contexts. In addition, technological challenges such as blockchain scalability, data privacy protection, and the integration of heterogeneous IoT devices remain important issues for large-scale implementation. The high costs associated with deploying IoT infrastructures and blockchain networks may also represent barriers for small and medium-sized enterprises. Finally, future research should explore governance models, regulatory frameworks, and data standardization mechanisms that could facilitate the broader adoption of blockchain-IoT traceability systems in global supply chains.

Overall, the integration of IoT and blockchain technologies represents a promising pathway toward more transparent, resilient, and intelligent supply chains. By combining real-time data collection with secure and decentralized data governance, these technologies have the potential to transform traceability systems and support the development of more trustworthy and efficient supply chain ecosystems.

References:

(1). Abdelhamid, I. R., Abdel Halim, I. T., Ibrahim, I. A., & al. (2023). *Redefining governmental services through blockchain and smart contracts*. Mathematical Modelling of Engineering Problems, 10(5).

(2). Aggarwal, R., & Das, M. L. (2012). *RFID security in the context of internet of things*. In Proceedings of the First International Conference on Security of Internet of Things (pp. 51–56).

(3). Alaba, F. A., Sulaimon, H. A., Marisa, M. I., & al. (2024). *Smart contracts security application and challenges: A review*. Cloud Computing and Data Science, 15–41.

(4). Alqarni, M. A., Alkatheiri, M. S., Chauhdary, S. H., & al. (2023). *Use of blockchain-based smart contracts in logistics and supply chains*. Electronics, 12(6), 1340.

(5). Ante, L. (2021). *Smart contracts on the blockchain – A bibliometric analysis and*

review. Telematics and Informatics, 57, 101519.
(6). Abojeib, M., & Habib, F. (2021). *Blockchain for Islamic social responsibility institutions*. In Research Anthology on Blockchain Technology in Business, Healthcare, Education, and Government (pp. 1114–1128). IGI Global.
(7). Australian Border Force, Infocomm Media Development Authority of Singapore, & Singapore Customs. (2021). *Joint initiative on blockchain for trade documentation*. https://www.customs.gov.sg/
(8). Bano, S., Sonnino, A., Al-Bassam, M., & al. (2017). *Consensus in the age of blockchains*. arXiv:1711.03936.
(9). Betti, Q., Khoury, R., Hallé, S., & Montreuil, B. (2019). *Improving hyperconnected logistics with blockchains and smart contracts*. IT Professional, 21, 25–32.
(10). Bhatia, D., Mishra, A., & Mukherjee, M. (2021). *Amalgamation of blockchain technology and internet of things for healthcare applications*. In Blockchain for 5G-Enabled IoT (pp. 571–592).
(11). Biswas, K., Muthukkumarasamy, V., & Tan, W. L. (2017). *Blockchain-based wine supply chain traceability system*. In Future Technologies Conference (FTC) (pp. 56–62).
(12). Boeck, H., Lefebvre, L. A., & Lefebvre, É. (2017). *Technological requirements and derived benefits from RFID-enabled receiving in a supply chain*. In RFID Handbook (pp. 295–310). CRC Press.
(13). Cambridge University Press. (2024). *Cambridge Dictionaries Online*. http://dictionary.cambridge.org
(14). Caro, M. P., Ali, M. S., Vecchio, M., & al. (2018). *Blockchain-based traceability in agri-food supply chain management: A practical implementation*. In IoT Vertical and Topical Summit on Agriculture (pp. 1–4).
(15). Carrefour. (2018). *Food traceability: Carrefour joins IBM Food Trust*. https://www.carrefour.com/
(16). Chang, S. E., Chen, Y. C., & Lu, M. F. (2019). *Supply chain re-engineering using blockchain technology: A case of smart contract-based tracking process*. Technological Forecasting and Social Change, 144, 1–11.
(17). Chen, H., Zhao, X., Wang, Y., & al. (2021). *SafeCheck: Detecting smart contract vulnerabilities based on static program analysis*. Security and Privacy, e393.
(18). Challal, Y. (2012). *Sécurité de l'Internet des Objets: vers une approche cognitive et systémique* (Doctoral dissertation). Université de Technologie de Compiègne.
(19). Choong, C. S., Nasir, A. F. A., Abdul Majeed, A. P., & al. (2021). *Automatic identification and categorize zone of RFID reading in warehouse management systems*. Springer, 194–206.
(20). Cluster CERP-IoT. (2010). *Visions and challenges for realising the Internet of Things*. European Commission.
(21). Cui, P., Dixon, J., Guin, U., & al. (2019). *A blockchain-based framework for supply chain provenance*. IEEE Access, 7, 157113–157125.
(22). Della Valle, F., & Oliver, M. (2021). *Blockchain-based information management for supply chain data-platforms*. Applied Sciences, 11(17), 8161.
(23). Dessureault, S. (2019). *Costs, benefits and business value of traceability: A literature review*.
(24). Drago, E., Campardelli, R., Pettinato, M., & Perego, P. (2020). *Innovations in smart packaging concepts for food: An extensive review*. Foods, 9(11), 1628.
(25). EU. (2002). *Regulation (EC) No 178/2002…* Official Journal of the European Communities, 31, 1–24.
(26). Evren-Bolgun, K. (2023). *Alternative finance technique in the logistics sector:*

Blockchain. PressAcademia Procedia, 17(1), 6–20.
(27). Fatorachian, H., & Kazemi, H. (2021). *Impact of Industry 4.0 on supply chain performance*. Production Planning & Control, 32(1), 63–81.
(28). FDA. (2019). *Exploring the use of blockchain to improve supply chain transparency and traceability for pharmaceuticals*. https://www.fda.gov/
(29). Galvez, J. F., Mejuto, J. C., & Simal-Gandara, J. (2018). *Future challenges on the use of blockchain for food traceability*. Journal of the Science of Food and Agriculture, 98(9), 3499–3504.
(30). Gong, B., Li, F., & Chen, X. (2020). *Information transparency in agricultural supply chains: The blockchain solution*. Computers and Electronics in Agriculture, 178, 105668.
(31). Guerra, M. (2023). *An introduction to blockchain-based transformation in supply chains*. Journal of Supply Chain Innovation, 12(3), 44–58.
(32). Guenfoudi, M., El Ayadi, H., Maalel, A., & al. (2020). *La logistique 4.0 : une réalité*. Revue du contrôle, de la comptabilité et de l'audit, 4(2), 732–749.
(33). Guo, J., & Liang, C. (2016). *Blockchain application and outlook in the logistics industry*. Journal of Logistics Technology, 39(4), 14–18.
(34). Hald, K. S., & Kinra, A. (2019). *How the blockchain enables and constrains supply chain performance*. International Journal of Physical Distribution & Logistics Management, 49(4), 376–397.
(35). Hastig, G. M., & Sodhi, M. S. (2020). *Blockchain for supply chain traceability: Business requirements and critical success factors*. Production and Operations Management, 29(4), 935–954.
(36). Helo, P., & Hao, Y. (2022). *The role of IoT and blockchain in improving supply chain resilience*. Industrial Management & Data Systems, 122(2), 394–412.
(37). IBM. (2017). *IBM Food Trust: Blockchain for a new era of food transparency*. IBM Corporation.
(38). Ishikawa, A., Kato, S., & Kobayashi, T. (2021). *Smart contract governance: Challenges and perspectives*. Journal of Information Security, 12(2), 101–119.
(39). ISO. (2015). *ISO 9001:2015—Quality management systems—Requirements*. International Organization for Standardization.
(40). Jabbar, S., Ullah, F., Khalid, S., & al. (2017). *IoT-based smart logistics: A review of technologies, architectures, and future prospects*. IEEE Access, 5, 14411–14431.
(41). Jansen-Vullers, M. H., van Dorp, C. A., & Beulens, A. J. M. (2003). *Managing traceability information in manufacture*. International Journal of Information Management, 23(5), 395–413.
(42). Kamilaris, A., Fonts, A., & Prenafeta-Boldú, F. X. (2019). *The rise of blockchain technology in agriculture and food supply chains*. Trends in Food Science & Technology, 91, 640–652.
(43). Kamble, S., Gunasekaran, A., & Sharma, R. (2020). *Modeling the blockchain-enabled traceability in agriculture supply chain*. International Journal of Information Management, 52, 101967.
(44). Kamble, S., Xu, D., & Ghosh, J. (2022). *IoT and blockchain convergence for logistics: A review and future research agenda*. Transportation Research Part E: Logistics and Transportation Review, 159, 102631.
(45). Kim, H. M., & Laskowski, M. (2018). *Toward an ontology-driven blockchain design for supply-chain provenance*. Intelligent Systems in Accounting, Finance and Management, 25(1), 18–27.
(46). Kshetri, N. (2018). *1 Blockchain's roles in meeting key supply chain management objectives*. International Journal of Information Management, 39, 80–89.

(47). Kumar, A., Liu, R., & Shan, Z. (2020). *Is blockchain a silver bullet for supply chain management?* Decision Sciences, 51(4), 745–785.

(48). Lazzeri, J., & Fabbe-Costes, N. (2014). *La traçabilité totale des supply chains : Concept et modèle théorique de mise en œuvre*. Revue française de gestion industrielle, 33(1), 55–79.

(49). Lee, J., Bagheri, B., & Kao, H. A. (2015). *A cyber-physical systems architecture for Industry 4.0-based manufacturing systems*. Manufacturing Letters, 3, 18–23.

(50). Li, Z., Wu, H., King, B., & al. (2021). *IoT-based smart supply chain monitoring using blockchain*. Journal of Network and Computer Applications, 175, 102914.

(51). Lin, Y. T., Petri, I., & Rana, O. (2022). *A review of blockchain and IoT integration in supply chains*. Future Internet, 14(5), 138.

(52). Lucena, P., Binotto, E., Claudia, R., & al. (2018). *Blockchain-based traceability in the fruit supply chain*. Journal of Food Engineering, 256, 12–21.

(53). Maaloul, A., Bouslimi, S., & Boudriga, N. (2022). *Secure IoT-based traceability architecture for supply chains*. Journal of Information Security and Applications, 66, 103123.

(54). Madhwal, Y., & Panfilov, P. (2017). *Blockchain and supply chain management: A new paradigm*. In Proceedings of the International Conference on Operations and Supply Chain Management (pp. 1–12).

(55). Mahmud, N., & Pradhan, S. (2021). *Blockchain-based identity and traceability frameworks for logistics*. IEEE Access, 9, 103122–103135.

(56). Marbouh, D., et al. (2020). *Blockchain for COVID-19 contact tracing: A review*. IEEE Access, 8, 182939–182966.

(57). Nakamoto, S. (2008). *Bitcoin: A peer-to-peer electronic cash system*. https://bitcoin.org/bitcoin.pdf

(58). Nasir, A. F. A., Majeed, A. P. A., Zakaria, M. A., & Razman, M. A. M. (2021). *Automatic identification and categorization zone of RFID reading in warehouse management systems*. Springer, 194–206.

(59). Olsen, P., & Borit, M. (2013). *How to define traceability*. Trends in Food Science & Technology, 29(2), 142–150.

(60). Paul, P., Aithal, P. S., & Saavedra, R. (2021). *Blockchain technology and its types: A short review*. International Journal of Applied Science and Engineering, 9(2), 189–200.

(61). Petrželová, B. (2023). *The proposal of key performance indicators management to achieve the defined financial objectives of the selected company*.

(62). Piccialli, F., Cuomo, S., Schiano di Cola, V., & al. (2019). *A machine learning approach for IoT cultural data*. Journal of Ambient Intelligence and Humanized Computing, 1–12.

(63). Pinchen Cui, P., Dixon, J., Guin, U., & al. (2019). *A blockchain-based framework for supply chain provenance*. IEEE Access, 7, 157113–157125.

(64). Pinto, G. P., & Prazeres, C. (2019). *Web of things data visualization: From devices to web via fog and cloud computing*. IEEE, 140–145.

(65). Rahma, H. N., & Hersugondo, H. (2022). *Impact of corporate social responsibility on economic value added: The role of the supply chain management environment at LQ45 Indonesia*. Jurnal Organisasi dan Manajemen, 18(2), 113–129.

(66). Salah, K., Nizamuddin, N., Jayaraman, R., & al. (2019). *Blockchain-based soybean traceability in agricultural supply chain*. IEEE Access, 7, 73295–73305.

(67). Sankaranarayanan, S., Manogaran, G., & Cao, Y. (2020). *Efficient traceability systems of steel products using blockchain-based industrial IoT*. IEEE Transactions on Industrial Informatics, 16(9), 6004–6012.

(68). Saikouk, T., & Spalanzani, A. (2016). *Review, typology and evaluation of traceability* *technologies: Case of the French forest supply chain*. Supply Chain Forum, 17(1), 39–53.

(69). Sharma, V., Kumar, A., Kumari, N., & Thakur, M. (2023). *Sustainable nanomaterials for the food industry: Current scenario and perspectives*. In Sustainable Nanomaterials for Biosystems Engineering (pp. 447–491). Apple Academic Press.

(70). Sigfox. (2018). *Sigfox and Louis Vuitton: Luggage tracking solution*. https://www.sigfox.com/en/news/sigfox-and-louis-vuitton-partner-innovative-luggage-tracker

(71). Swan, M. (2015). *Blockchain: Blueprint for a new economy*. O'Reilly Media.

(72). Takubo, T., Nakamura, T., Sugiyama, R., & Ueno, A. (2023). *Multifunctional shelf and magnetic marker for stock and disposal tasks in convenience stores*. Journal of Robotics and Mechatronics, 35(1), 18–29.

(73). Tamayo Giraldo, S. (2011). *Exploitation des informations de traçabilité pour l'optimisation des choix en production et en logistique* (Doctoral dissertation). Université Paul Verlaine – Metz.

(74). Thebault, P. (2013). *La conception à l'ère de l'Internet des Objets*. Thèse ParisTech.

(75). Vidigal, T. P., Prodanov, W., & Rocha, C. (2023). *When technical solutions are not enough: Using software concepts to analyse challenges at delivery processes between mixed-signal IC team members*. IEEE Transactions on Engineering Management.

(76). Wang, S., Li, D., Zhang, Y., & Chen, J. (2019). *Smart contract-based product traceability system in the supply chain scenario*. IEEE Access, 7, 115122–115133.

(77). Wen, Q., Gao, Y., Chen, Z., & al. (2019). *A blockchain-based data sharing scheme in the supply chain by IIoT*. IEEE, 695–700.

(78). Westerkamp, M., Victor, F., & Küpper, A. (2018). *Blockchain-based supply chain traceability: Token recipes model manufacturing processes*. IEEE, 1595–1602.

(79). Yong, B., Shen, J., Liu, X., & al. (2020). *An intelligent blockchain-based system for safe vaccine supply and supervision*. International Journal of Information Management, 52, 102024.

(80). Zhang, A., & Li, J. (2021). *Application of blockchain and IoT in cold chain logistics monitoring*. Journal of Cleaner Production, 315, 128217

(81). Zhou, W., Piramuthu, S., & al. (2020). *IoT and blockchain for improved supply chain transparency*. Decision Support Systems, 136, 113348.