IoT in Supply Chain Management: An Overview

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***Abstract*—In today's digital era, businesses are increasingly adopting advanced technologies to optimize their supply chain processes. The adoption of technologies like the Internet of Things (IoT), AI, drones, and robotics is required. However, integrating these technologies into current supply chain processes has different issues and limitations. Although there are different studies that have been conducted in Digital Supply Chain Management (DSCM), there is still a noticeable need to focus on IoT-based supply chain management to enhance supply chain efficiency and decision-making capabilities. Consequently, this paper provides a review of the previous studies that were conducted on the IoT-based SCM. Also, a comparison between these studies that considers different factors, such as domain, technologies, dataset, hardware and software, and evaluation metrics, is provided. Furthermore, the paper examines the potential challenges and future trends in this field.**

***Keywords*—supply chain 4.0, smart supply chain, Internet of Things (IoT), blockchain, machine learning**

I. Introduction

Supply chain management begins with obtaining raw materials from vendors, manufacturing goods at the production facility, and then moving those goods—all while being closely monitored—to a retail location where final consumers can buy them. A Supply Chain (SC) is a collection of business-specific entities and processes (such as manufacturers, distributors, retailers, suppliers, and end users).As shown in Fig. 1, that are connected to control the flow of goods and services in order to satisfy demand and fulfill orders from customers. According to the Supply Chain Operation Reference (SCOR) model, the primary processes of SC are plan, source, make, deliver, return, and enable reuse after the end of the product life cycle (Pal, 2023).

Fig. 1. SCM processes.

The supply chains are spreading across the globe and are challenged by customer awareness. Nowadays, customers want on-time delivery along with product quality, price, and service. With this rapid development of supply chain, its complexity has increased and supply chain management has become the backbone of many industries (Kamat & Dalpati, 2021). There are many challenges faced by traditional supply chains, including vulnerability, high costs, uncertainty, and complexity. Intelligent supply chains are necessary to address these problems (Hu *et al.*, 2023). Traditional supply chains typically involve little to no data sharing and a linear relationship between suppliers and customers. For a considerable amount of time, the traditional supply chain model worked well; however, because information could not flow freely, the process was delayed and its visibility was restricted (Akinbola, 2023). Therefore, there is a need to explore the recent solutions that can be used to improve the process of the traditional supply chain. One of these solutions is integrating the traditional supply chain with smart technologies such as IoT, blockchain, and AI. This solution is called supply chain 4.0 (SCM 4.0), or Smart Supply Chain (SSC).

The SCM 4.0 which is called also Digital Supply Chain Management (DSCM) can be defined as integrating the traditional supply chain with different technologies such as IoT, cloud computing, big data, blockchain and Artificial Intelligent (AI) (Khan *et al.*, 2022). This integration can positively affect the traditional SC into improve performance and visibility of its process, enable real-time monitoring and provide demand forecasting (Akinbola, 2023). Due to the importance of this field, this paper will focus on IoT-based supply chain management.

The Internet of Things (IoT) is a scalable and user-friendly technology that uses the internet to transmit all pertinent data in real time throughout the supply chain. The end-to-end visibility of the supply chain becomes increasingly important as the network gets more complex and involves more and more parties (Akinbola, 2023). Finding the applications of IoT that can improve an organization's performance becomes crucial. Information sharing between an organization's supply chain partners is highly likely to occur. In order to compete in the global market, supply chain partners can share relevant information by using IoT (Kamat & Dalpati, 2021).

A wide range of stakeholders, including manufacturers, inspection departments, warehouses, carriers, and retailers, can share item-related data with one another through the Internet of Things. All parties involved in the SC now have access to information in real time. Real-time data can be obtained through the integration of sensors, barcodes,

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Radio Frequency Identification (RFID) tags, and communication protocols. With the aid of other identification technologies and Global Positioning Systems (GPS), IoT facilitates real-time tracking and tracing. Rapid advancements in wireless communication technologies and sensors in recent years have made it possible for IoT-based systems to be adopted, allowing for the monitoring of objects from any remote location with internet connectivity (Pal, 2023).

The gap or limitations found in the previous studies are that there is a lack of literature review for IoT-based SCM (Taj *et al.*, 2023). Therefore, this paper can be considered a starting point for researchers in the field of IoT-based SCM, to discuss the current state and future directions and gaps. The paper will explore the fields of Digital Supply Chain Management (DSCM) and the Internet of Things (IoT). Moreover, this paper provides a review of the related works in the field of IoT-based supply chain management in order to discuss their domain, the technologies, and the hardware and software used to implement such systems. In addition, there are potential challenges and future trends in this field.

The rest of the paper is organized as follows: Section II presents the technologies used to enhance supply chain management. Section III presents the related works in IoT-based supply chain management. The discussion section provides the finding of the proposed paper. Finally, the conclusion and future work are presented.

II. Background

A. *Internet of Thing (IoT)*

The Internet of Things (IoT) can be defined as a network of physical objects that are embedded with a set of sensors and communication modules that allow them to exchange data with other devices and systems over the network. IoT serves as a bridge between the digital and physical worlds, interpreting and transmitting valuable data from the physical world and communicating it to the digital world to be used as the basis for numerous analysis and plans.

Real-time data collection is made possible by IoT technology, which is connected to allow users to access information at any time and from any location. Research on the application of IoT in supply chains has been ongoing for some time. Researchers have studied the impact of IoT on supply chains using survey-based analysis (Kamat & Dalpati, 2021).

Currently, the primary use of IoT in Supply Chain Management (SCM) is real-time object tracking. However, as sensor technologies advance, each object has the potential to be a passive device that can measure a wide range of variables, and there are countless ways to use the measured data in various SCM-focused business contexts (ZandiZand, 2023).The exchange of information is the most important component in achieving supply chain performance goals. In recent years, information sharing has come to be seen as a valuable resource. Sharing information leads to effective management of supply chain partners' performance. Suppliers make up the majority of the supply chain partners and are crucial to its operation (Kamat & Dalpati, 2021).

The digitization of supply chain procedures has made technologies like the Internet of Things (IoT) more crucial for businesses hoping to adopt and use Industry 4.0 innovations. The development of intelligent business models, logistics, transportation, and factory energy management are all strongly tied to the Internet of Things. Because its performance, defects, and consumption patterns are provided for the customer, the Internet of Things (IoT) is becoming more and more important in terms of the need to realize real-time information as well as the need to improve after-sale services through sensors existing inside its products, which are based on big data technology (Sharifpour *et al.*, 2022).

To incorporate IoT into supply chain management, four primary layers can be identified in an IoT system used in supply chain management as shown in Fig. 2:

- **A sensor layer** that unifies various "things" such as actuators, RFID tags, and sensors.
- **A networking layer** that facilitates information transfer via wired or wireless networks
- **A service layer** that unifies applications and services via middleware technology.
- **A user interface layer** that presents data to the user and enables user interaction with the system.

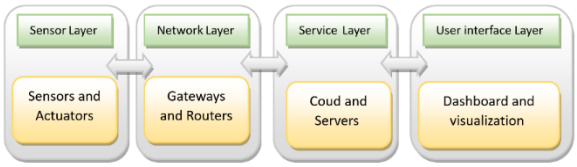

Fig. 2. IoT architecture layers.

B. *Blockchain*

Blockchain can be defined as a distributed, decentralized manual for smart contracts that facilitates supply chain automation, tracking, document management, payment apps, and other commercial activities. Blockchain technology allows documents to be replicated almost instantly among trading partners while maintaining document integrity. Blockchain gathers data from enterprise resource planning and makes it accessible to a network of documents that are shared among various businesses. The advantages of blockchain allow businesses to better understand their clients' needs and wants (Sharifpour *et al.*, 2022). Smart contracts are extremely important for the safe exchange of data between two parties. Smart contracts and blockchain technology enable lower operating costs, less human interaction, fewer middlemen, and better self-execution of data stored in the blockchain (Nanda *et al.*, 2023).

There are different kinds of blockchain networks that exist at the moment. The most popular one is ***public blockchain*** that has no limitations on who can access it. Sending transactions to it and acting as a validator, that is, taking part in the implementation of a consensus protocol, is open to anybody with an Internet connection. These networks typically provide financial rewards to

individuals who protect them and make use of proof-of-work algorithms. The **Ethereum** and **Bitcoin** public blockchains are two of the biggest and best-known examples of blockchain technology. In sectors like supply chain management or financial services, where numerous organizations must work together to achieve a common objective, ***consortium blockchains*** are frequently utilized. A consortium blockchain is A blockchain that blends aspects of public and private blockchains. Because fewer nodes are usually needed to validate transactions, consortium blockchains have the potential to be more effective and scalable than public blockchains. Furthermore, because consortium members collaborate to maintain the network, consortium blockchains have the potential to offer higher security and dependability than private blockchains. **Quorum** is one instance of a consortium blockchain (Chowdhury, 2019).

C. Artificial Intelligence (AI)

Artificial Intelligence (AI) is the ability of a computer to identify patterns and make decisions based on available data and statistical models (Hassani *et al.*, 2020).

There are many different approaches to AI, but some of the most common include:

- **Machine learning**: In this method, computers are trained to learn from data without the need for explicit programming.
- **Natural Language Processing (NLP):** In this method, computers are trained to comprehend and produce human language.
- **Computer vision**: teaching computers to interpret and comprehend visual data.

Artificial Intelligence (AI) is used in the supply chain industry for a number of purposes, such as demand forecasting and capacity planning, which lowers overall operating costs. Artificial intelligence gathers information, analyzes trends in the data, and builds automated processes such as sorting and self-managing inventory systems. Using AI in the supply chain enhances optimization capabilities, which are necessary for precise capacity planning, reduced operating costs, increased output, and improved productivity while fostering a positive work environment. AI is also utilized in supply chain management to improve supply and purchasing management. An essential component of supply chain management is the make-or-buy choice, which primarily addresses whether to manufacture the product or service in-house or to contract out in order to maximize the company's resources and concentrate on its area of expertise (Akinbola, 2023).

III. Related Work

In this section, the related works that were conducted in the field of IoT-based supply chain management are presented and discussed.

Singh & Raza (2023) proposed a smart food chain management system (IBFS) framework by integrating IoT and blockchain technologies to control food inventory systems within a company. The paper focuses on the quality and safety of the goods delivered to final customers. They used IoT-sensors to collect the shipment's geolocation and temperature of the goods. The collected data has been recorded using a Message Queue Telemetry Transport (MQTT). In order to improve trust, reliability, and transparency, Ethereum-based Blockchain Technology (BCT) has been used to build two types of smart contracts: the first to deal with shipment and the second to deal with custody. The performance evaluation proves the effectiveness of the framework under various test conditions.

In a study conducted by (Ramanathan *et al.*, 2022), the integration and testing of digital technologies such as IoT sensors and big data analytics in the food supply chain are presented. The case study that discussed in this paper was a Yumchop foods, which is family-owned company for frozen food. The main objective of this paper is to use IoT-based supply chain management to reduce food waste and assure product quality within the company. To implement the alerting system, IoT sensors have been installed in cold containers and fridge freezers to monitor the temperature and humidity of frozen food. Each sensor has its own rule-based alerting algorithm using different threshold temperatures. The system was built into the REAMIT dashboard using the Amazon Simple Notification Service (SNS). The results show that the IoT-based real time monitoring system contributes mainly to reducing food waste and ensuring product quality.

(Nanda *et al.*, 2023) developed a Health Supply Chain (NAIBHSC) management system by combining IoT with blockchain technology to track and trace medical products. They used IoT-sensors to track the shipment's geolocation and control the temperature of the medicine. Moreover, smart contracts have been developed by using a solidity programming language in combination with Ethereum blockchain technology to avoid single entity problems, modifications, or damage attackers from attackers. The experimental results show that the NAIBHSC outperforms the existing blockchain-based approaches in terms of improving response time, reducing latency time, and increasing performance.

As shown by (Hu *et al.*, 2023) the proposed Vaccine Supply Chain (VSC) system combines three main technologies: IoT, blockchain, and machine learning to provide decision support for VSC management during the COVID-19 pandemic. The IoT sensor monitors the vaccine quality using real-time data. While blockchain is used to improve trust between stakeholders, on the other hand, machine learning techniques have been used to predict vaccine demand.

In a research study by Alzahrani & Asghar (2023), they established a supply chain risk prediction system for the logistics industry. Using a hybrid Deep Learning (DL) approach consisting of a Convolutional Neural Network (CNN) and a Bidirectional Gating Recurrent Unit (BiGRU), the proposed system has been built and tested on a dataset collected from Kaggle titled "US Supply Chain Information for COVID-19". The results show that the system performs very well, with high accuracy up to 94%.

As demonstrated in Jagtap *et al.* (2019), IoT and image processing approaches are used to monitor potato waste in food manufacturing. The paper focuses on measuring the amount of waste and indicating the reasons for waste in real-time. They used a specially positioned camera to capture images of potatoes and a digital load to measure their weight. The Convolutional Neural Network (CNN) was used to determine a potential reason for the potato waste. The system achieves a training accuracy of 94.06%, a validation accuracy of 85%, and a test accuracy of 83.3% after parameter tuning.

In a case study conducted by Alanazi *et al.* (2022), construction road projects often rely on supplier data, whereas the cost, quantity, quality, and transportation duration are difficult to predict. Therefore, they introduced a solution for smart cost optimization using an IoT-powered framework that can achieve up to 40% material cost savings.

Ktari *et al.* (2022) demonstrated a solution for an agricultural lightweight embedded blockchain system related to olive oil industry challenges in Tunisia. Since they often face main problems related to the traceability of the production process to guarantee the origin of the food at all times, the proposed system used multi-sensor IoT to track the process from the farmer through the oil mill, the transporter, and the quality controller to the customer. Moreover, two types of blockchain have been used: Ethereum and Quorum, to guarantee the origin of the food.

IV. Discussion

As mentioned previously, it is obvious that there is a lack of studies conducted in the field of IoT-based supply chain management. This can be a motivation for the researcher to provide more effort and time to conduct studies in this field. As presented in Table I, it is shown that the related studies are focused on the application domains of the food supply chain (Ktari *et al.*, 2022; Ramanathan *et al.*, 2022; Singh & Raza, 2023), medical and healthcare care supply chain (Hu *et al.*, 2023; Nanda *et al.*, 2023), logistics(Alzahrani & Asghar, 2023), and construction (Alanazi *et al.*, 2022). However, it is obvious that there are not enough studies in the field of industry. Also, there is a need to investigate the real-world implementation of SCM 4.0 in industry, as mentioned by Bentaher & Rajaa (2022).

Furthermore, most of the presented IoT-based supply chain management systems integrate different technologies, such as AI and blockchain, to improve performance. The blockchain used in (Benčić *et al.*, 2019; Cui *et al.*, 2019; Hu *et al.*, 2023; Ktari *et al.*, 2022; Lin *et al.*, 2019; Maiti *et al.*, 2019; Nanda *et al.*, 2023; Singh & Raza, 2023) plays a crucial role in ensuring the security and transparency of transactions. The blockchain methods that are used Ethereum and Quorum. In addition, these studies (Bentaher & Rajaa, 2022; Hu *et al.*, 2023) used machine learning methods such as RNN, LSTM and GRU or deep learning methods such as CNN in demand forecasting.

Moreover, one of the main components of IoT-based SCM is the sensors, which are responsible for collecting real-time data on various parameters such as temperature, geolocation, and product information. This enhances visibility throughout the supply chain. The hardware used in the presented systems are a camera sensor, RFID tags (Abdel-Basset *et al.*, 2018; Fan, 2019; Sangeetha, 2018; Zhou & Piramuthu, 2018), a temperature sensor, a humidity sensor, and GPS sensors. On the other hand, the protocols that are used for the transfer of data in IoT are MQTT (Singh & Raza, 2023), which is more efficient for IoT applications than the HTTP protocol used in Nanda *et al.* (2023).

In addition, there are different challenges in the implementation of IoT in SCM. There is no clear roadmap (Bentaher & Rajaa, 2022) for implementing IoT in SCM 4.0, starting with collecting data from sensors, managing the supply chain process in each phase, updating real time information, visualizing data, and providing dashboards for decision makers.

Therefore, there is a need to provide a study that discusses the key points of designing and implementing an IoT-based SCM system that can be used as a platform for any research.

V. Conclusion and Future Works

Digital supply chain management, coupled with IoT technologies, presents numerous opportunities for organizations to optimize their supply chain operations. This review paper has provided insights into the advantages, challenges, and future trends in this rapidly evolving field. By embracing DSCM and leveraging the power of IoT, businesses can enhance their competitiveness, customer satisfaction, and overall efficiency in the dynamic global marketplace.

The integration of IoT and blockchain technologies in supply chain management demonstrates significant potential for addressing various challenges and improving overall efficiency across different industries. The integration of IoT provides real-time data, while blockchain ensures security, transparency, and decentralized control.

The findings from these related works contribute to a growing body of knowledge that can guide future research and practical implementations in this filed. The future works that can be considered are:

- Conducting different studies on IoT-based SCM in the industry field.
- Providing a detailed study for designing and implementing an IoT-based SCM can be considered a roadmap for future work in this field. It should take into consideration the required hardware, the network capabilities to provide real-time data, and
- Providing a generic framework for IoT-based SCM systems that use blockchain to enhance security and machine learning and deep learning methods for predictive analytics, defect detection, and demand forecasting. Also, it is recommended to have a decentralized data handling framework.

TABLE I. IoT BASED SUPPLY CHAIN MANAGEMENT SYSTEM

Ref.	Domain	Objectives	Techniques/ Methods	Dataset	SW/HW tools	Evaluation metrics/tools
(Singh & Raza, 2023)	Food	Smart Food Chain Management System (IBFS) to regulate the food inventory systems in the organization focusing on the safety and nature of the items conveyed to the end consumers.	• Blockchain, • Internet of Things (IoT)	• Temperature of the goods • Shipment's geolocation	• IoT-sensors • Raspberry PIs, • Message Queue Telemetry Transport (MQTT) broker. • Geth, a Web-based IDE • Remix • Ganache the Ethereum-based BCT • Solidity, C++, JavaScript, and Python	• Gas Cost of transaction • Gas Cost of execution with smart contract function
(Nanda *et al.*, 2023)	Healthcare	Health Supply Chain (NAIBHSC) approach. provides decentralized tracking and tracing of the medical product, avoids counterfeit drugs, and provides the status of the products during the shipment process between manufacturers to end-user	• Blockchain, • Internet of Things (IoT)	• Temperature of the goods • Shipment's geolocation	• RFID tags • sensors • activators • HTTP server • Remix IDE • Ethereum blockchain platform • Solidity, HTML, CSS, JavaScript • PostgreSQL2 database • Bi-objective mathematical model	• Transaction response time • Transaction latency • Caliper tool
(Hu *et al.*, 2023)	Healthcare	Vaccine Supply Chain (VSC), an intelligent VSC management system, efficiently manages the VSC affected by the COVID-19 pandemic and prioritizes three key issues: vaccine quality, demand forecasting, and stakeholder trust.	• Blockchain, • Internet of Things (IoT) • Machine learning	• Vaccine information • Temperature	• RFID tags • IoT sensors • Inter Planetary File System (IPFS).	• Mean absolute error • Root mean square error • Mean absolute percentage error
(Alzahrani & Asghar, 2023)	Logistics sector	To accurately forecast supply chain risks in the logistics industry	• Internet of Things (IoT) • Machine learning • Deep learning	• Kaggle, US Supply Chain Information for COVID-19	_	• Accuracy • Precision • Recall • F1-score
(Ramanathan *et al.*, 2022)	Food	reducing food waste in a frozen food manufacturer in the UK and assure product quality	• IoT sensors • Big Data	• Temperature • Humidity	• ELT Lite logger sensors • Digital temperature sensor • Amazon Simple Notification Service (SNS) • REAMIT dashboard.	• Reduce food waste
(Ktari *et al.*, 2022)	Food	A general approach for managing the olive oil supply chain. The system track the olive oil manufacturing process from the farmer, through the oil mill, the transporter and the quality controller to the customer.	• Blockchain, • Internet of Things (IoT)	• Olive varieties • Time • Quantity • Agriculture areas • Water temperature • Humidity • Salinity • Soil PH • Location • Oil temperature • Oil color • etc.	• Sensors • GPS • Raspberry PI • Arduino • Quorum • Ethereum • Ganache • Truffle • MetaMask • Flatter.	–
(Jagtap *et al.*, 2019)	Food	an automated and real-time system based on the Internet of Things (IoT) concepts is proposed to measure the overall amount of waste as well as the reasons for waste generation in real-time within the potato processing industry	Deep learning CNN	Image potato	• camera • Bluetooth hardware • Keras library Python	Accuracy
(Alanazi *et al.*, 2022)	Construction	Conducted material logistics optimization models for road projects	• Internet of Things (IoT) • OD, BC, MSW, and CSM	• GPS coordinates, • Material prices, • Demand, capacities	• IoT-sensors	Cost savings

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

HA conducted the research; HA analyzed the data; HA wrote the paper; MA worked on supervision and reviewing; all authors had approved the final version.

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