Industry 4.0's Digital Supply Chain Technologies are built on the Internet of Things, Big Data, Blockchain, AI, and Digital Supply Chain, Twin Principles and their difficulties.

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Abstract - *Industry 4.0 represents the fourth industrial revolution and is the digital transformation of production and the smart industry markets. In the era of Industry 4.0, emerging technologies such as the Internet of Things (IoT), cloud computing, big data, Blockchain, 5G and digital twins have emerged rapidly. Most of them are used in supply chain management processes, leading to the growth of digital supply chains. The most used technology is IoT. The most common applications are technologies. combined with IoT, cloud computing and big data analytics. Blockchain is a developing technology, while digital offers Chain twins are an integrated technology that includes simulation. Therefore, this review focuses on these four critical technologies. (e.g. IoT, big data, blockchain, and digital supply chain twins) to explore their principles, applications, and potential challenges. in the digital supply chain. Additionally, this review also compares the difference between digital supply chains and smart supply. chains and explains their relationship.*

Key Words: Digital supply chain, smart supply chain, IoT, big data, blockchain and digital supply chain twins.

1.INTRODUCTION

Industry 4.0 is a time of truly popular content. It was first introduced in 2011 by a group of representatives from different sectors as part of an action to improve German competitiveness in manufacturing assiduity. Lately, the German civil government has stated that Assiduity 4.0 will be an integral part of the "High-Tech Strategy for Germany 2020". Assiduity 4.0 is the digital metamorphosis of artificial demands with smart manufacturing currently at the forefront. It represents the fourth artificial revolution in the chain of forces (SC), in logistics and in separate and process production. Assiduity 4.0 has been verified by numerous experimenters to provide similar benefits such as product stickiness, product diversification, quick response to requests, shorter delivery times, better capacity application, and others. In the era of Assiduity 4.0, emerging technologies such as the Internet of Things (IoT), pall computing, big data, blockchain, 5G, and digital halves have rapidly emerged. most of them are used in the operational processes of the force chain. Assiduity 4.0 represents an intelligent product network concept in which machines and products interact with each other without any mortal control. Industry 4.0 technology, according to Ivanov et al. (2019), opens up new manufacturing strategies based on highly customised assembly systems with flexible manufacturing process design. These strategies make use of cyber-physical system concepts. Cyber-physical systems make coherent judgements by integrating components of material and informational subsystems. Eventually, SCs developed into dynamically structured networks and systems. Digital SCs have become more prevalent recently due to cyber-physical systems. Academics and practitioners are paying attention to issues surrounding digital SC. Moreover, a large number of the technologies integrated and used in Industry 4.0 are applied to agricultural rather than the industrial sector. The following research questions are hence the focus of this review:

Point 1: Clearly define "digital supply chain" and explain how it differs from "intelligent supply chain";

Phase 2: List the essential elements of the digital supply chain, together with its guiding principles, existing uses, and potential obstacles.
in the supply chain associated with the agri-food industry.

1.1 Definition Of Digital And Smart Supply Chain

It states that a digital supply chain (DSC) is made up of technologies (such as software, hardware, and communication networks) that facilitate interactions across internationally scattered organisations and coordinate the operations of SC participants. These actions include purchasing, manufacturing, storing, transporting, and selling a product. A DSC is described as a smart, value-driven network that combines innovative ideas with novel technology and analytics to produce new income and commercial value for organisations.

In his conclusion, he defined DSC as an intelligent and ideal technological system that supports and synchronises the interaction between organisations that deliver more valuable, accessible, and affordable results that are consistently agile and effective. This system is based on big data analysis and excellent cooperation and communication for hardware, software, and digital networks. Additionally, Buyukozkan and Gocer said that DSC involves the use of several new technologies, including Internet of Things (IoT), cloud computing, and unmanned aerial vehicles (UAVs), to regulate SC operations.

It was mentioned that the term "smart" refers to any human-centered digital solutions that enhance SC process performance by combining networked and intelligent cooperation. Smart SC refers to the enhanced SC performance made possible by all human-centered digital technologies. Technical systems become intelligent and networked via the use of digital technology, as outlined by Khan and Keramati. Cyber-physical systems are designed systems that interact with one another to create the Internet of Things (IoT) and utilise analytics and big data to make intelligent, autonomous, local choices. Simultaneously, astute organisations rely on analogous digital technologies to facilitate system integration through partner connectivity to extended value networks.

Smart SC is an adaptive organization capable of optimizing SC. It features intelligent reaction capabilities, process visualization, on-demand customization, and a powerful early warning system. A smart supply chain is defined by three characteristics: collaboration, transparency and visualization. Intelligent supply chains are systems that integrate intelligent management with information technology. To realize intelligent, connected and automated trade between enterprises, intelligent supply chain management or intelligent SC is a comprehensive and integrated management and technology system that combines Internet, technology and management theory, method and technology. current SC. In order to increase the operational efficiency of the SC, it is determined that the intelligent SC should be a system with more symmetrical information and real-time connections between SC members conveniently in information flow, logistics, capital flow, and other areas. The primary distinction between intelligent and conventional SCs is that the former use computer networks as the foundation for information transfer inside their systems. Every business has the ability to link its system to the intelligent SC information system, guaranteeing strong integration of the SC's information flow and information interchange. Consequently, since digital SC offers the technological component of SC, we understand that digital SC is the foundation of smart SC. Smart SC, on the other hand, emphasises the better advantages of digital application.

1.2 A Framework for an Intelligent Supply Chain

According to this definition, a smart supply chain integrates its partners, self-organises and automatically adjusts to changes in the environment, and makes wise decisions that maximise company objectives. A smart supply chain is described as a new kind of linked business system that goes beyond isolated, local, and single-company applications to include systematic smart implementations across the whole supply chain. It presents a multi-level smart SC framework by adhering to the notion of smart SC. The information communication technology (ICT), artificial intelligence (AI) & machine learning (ML), and other technologies are used to represent the various phases and scopes of SC management through four levels.

Level 0 consists of smart technologies, such as ICT, AI and ML, and other technologies, which serve as the foundation for smart supply chains. Big data, blockchain, cloud, IoT and 3D printing are included in ICT. Artificial intelligence, machine learning, optimization, etc. all are defined as AI&ML. Other technologies are advanced manufacturing, robotics, digital twin, intelligent transportation, drones, supply chain finance, banking 4.0, etc.

The first phase of the smart supply chain is called Level 1, and it uses ICT and AI to enhance one specific function—smart flow—in the supply chain, such as material, information, and finance, with smart drivers—pricing, inventory, transportation, facilities, and sourcing—to make smart decisions about strategy, tactics, and operations, such as smart logistics and intelligent inventory management systems. This level is characterised by optimisation, visibility, and real-time.

In order to implement intelligent choices at all levels (i.e., operational, tactical, or strategic) in all flows (i.e., material, information, money), Level 2 represents all supply chain partners connected. This smart SC level possesses self-organising, intelligent, and linked qualities. In reaction to changes in the surrounding environment and in the objectives of the company, they can reorganise and self-optimize the network. As a result, it is able to exhibit exceptional performance in every important area, such as sustainability, resilience, efficiency, and adaptability.

In order to match business strategy, facilitate the implementation of Industry 4.0, and ultimately achieve the economic, environmental, and social goals, SC supports Level 3 smart businesses, systems, and industries. Examples of these include smart automotive manufacturing under Industry 4.0, smart retailing, smart healthcare services, and even smart cities.

2. The digital supply chain involves several technologies, their use, and challenges.

Smart SC employs new technologies to improve quality, performance, and decision-making. It demonstrated the technologies used in the smart SC, such as big data analysis, Internet of Things (IoT), social media, user interface, robots, 3D printing, blockchain, augmented reality, GPS, RFID, simulation, cyber-physical system, cybersecurity system, and cloud computing. It evaluated the existing literature on ICT technologies under Industry 4.0 of smart SC management, and they advised that future researchers can investigate the connected concerns of smart SC using the relevant technology. Thus, we examine the fundamentals of important technologies for smart SC with IoT, big data & IoT, blockchain, and digital SC twins.

Kevin Ashton first used the phrase "Internet of Things" (IoT) in 1999 when he described how supply chains may be connected to the Internet via Radio-frequency Identification (RFID). The Internet of Things is a cohesive system of cloud computing, big data, and wireless sensor networks combined with intelligent interconnectivity. IoT refers to the process of connecting a network of "things" to the Internet or via it without the need for direct human interaction. Any device that has sensors or actuators that are individually controllable, networked, and available online might be considered a "thing." IoT is a technological paradigm that conceives of a huge network of equipment and gadgets that are digitally connected. It was explained that in order to successfully implement IoT-based goods and services, there are five categories in which IoT technologies fall: cloud computing, middleware, RFID, wireless sensor networks (WSN), and IoT apps.

It demonstrated the Internet of Things' four-layer design for the industrial framework. Information is generated using sensors and identification devices in the first layer; it is transmitted through network construction in the second; it is processed using management techniques in the third; and it is applied using an integrated application in the fourth. In order to include the variety of technologies, protocols, standards, etc. used, it is often observed in the literature that the layers of the Internet of Things architecture are divided into three categories: device, network, and application. Physical items (things) with the ability to connect to the Internet, sense or act, and automatically identify themselves make up the device layer. Using communication protocols, the network layer sends the data to a gateway (or proxy server) and subsequently the Internet (cloud). While information is kept and made available to the end user for processing and analysis at the application layer.

There are two data (or information) processes involved in the device layer's implementation. One is the data transmission process, in which a sensor measures a physical parameter, such as air temperature, and converts it into an analogue signal, such as electric voltage or current, which is then converted into a corresponding digital format by the interfacing circuit, known as an Analogue-to-Digital Converter (ADC). Next, the microcontroller, such as microprocessors or single-board computers, receives digital data from one or more sensors via ADC and transfers it to the transceiver, a wireless communication module that sends the data to a gateway. The other is the reception process. When the transceiver receives a signal, it is communicated to the microcontroller, where it is converted to an analogue signal by a Digital-to-Analogue Converter (DAC) or a digital signal by a Digital-to-Digital Converter, also known as the interfacing circuit, before being interpreted by the actuator and acting on the received signal.

During the network layer implementation phase, data is sent to an intermediary platform, the Internet (cloud), and then to the actuators that are being used. When data is transmitted to the intermediate platform, technologies such as Near Field Communication (NFC), WSN, RFID, and others are employed. The intermediate platform is often an internet gateway near the linked devices, which may contain a proxy server. Data is collected and processed on a regular basis to communicate information to the end user via the Internet via common protocols such as MQTT, HTML, or XMPP.

A user interface software program, data analytics, storage, and access to data via a suitable program Programming Interface (API) are among the significant services that are included in the application layer implementation procedures. For interoperability, the middleware platform is also provided to manage heterogeneous cloud data. Depending on the application and architecture, data storage can be cloud-based, meaning it can occur on one or more locally based servers with data saved in various databases. Data analytics can be accomplished by distributed computing, such as edge and fog computing, or cloud computing, which involves managing computer resources remotely to analyse data, frequently Big Data. IoT middleware solutions are particularly well-suited to address various IoT application issues, such as interoperability. IoT middleware systems use enablers, such as standardised APIs and protocols, to attempt and simplify complicated cloud connectivity that results from the heterogeneity of devices, communications, and networks.

The difficulties with supply chains based on IoT:

It was mentioned that managing software systems and the increasing cost of smart devices, particularly RFID, are two of the many financial and environmental obstacles that the IoT-based SC must overcome. It was mentioned that the food supply chain and industry are still in the very early stages of developing IoT integration with business operations. For instance, the cross-functional organisations in the food supply chain create granular data alignment when building an end-to-end digital thread from farm to consumer, making data exchange challenging. Developed countries process raw commodities that are often sourced from poor nations. It will be difficult to gather all the data needed for the acquisition procedure.

3. Internet of Things, cloud computing, and big data

According to Wikipedia, "big data" is described as "a fast-growing amount of data from various sources that presents a complex range of value-use, storage, and analysis issues to industrial organisations." International Data Corporation (IDC) defines five characteristics of big data: variety (V1), velocity (V2), volume (V3), veracity (V4), and value-adding (V5). Addo-Tenkorang and Helo also discussed some of the most widely used "big data" operational technologies, including as cloud computing, master database management systems, map-reduce, Apache Cassandra, Pentaho, and Apache Mahout.

He delved into the relationship between big data and cloud computing, where big data relies on cloud computing to perform effective analytical processes. Cloud computing analytics offers enormous data processing and storage options. Furthermore, by using parallel computing power to improve the efficiency of big data processing and acquisition, cloud computing virtual storage technology can efficiently manage and analyze huge volumes of data. He further stated that big data and IoT should be developed simultaneously due to their interconnection. In other words, the widespread adoption of IoT results in rapid growth in the volume of unstructured and semi-structured data. IoT Big Data is only useful if it is processed and evaluated to provide value.

The problems with big data and the Internet of Things:

It was stated that the data security elements of big data/IoT may be authenticated since data and information in general, and supply-chain management or industrial operations data in particular, are sensitive and secret. Furthermore, managing big data problems is difficult and time-consuming; effective data processing and analysis in an acceptable amount of time requires a sizable computer infrastructure. Cloud computing is also a solution to this issue. However, related research using cloud computing and big data in food safety is still in its early stages.

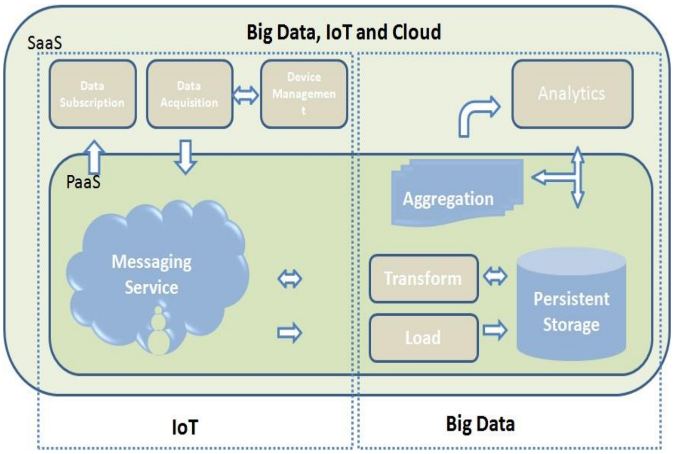

Fig -1: Functionality of Big Data, IoT, and Cloud

4. Blockchain

Blockchain technology has shown promise in the bitcoin space since its launch in 2008. The decentralised digital ledger technology of blockchain is well-known for doing away with the necessity for a reliable middleman in transactional processes. Blockchain is essentially a shared database of documents that are kept up to date by all group members in "blocks" that are immutable. It will always be available in the future. Therefore, it has been stated that blockchain technology offers various qualities including a decentralised ledger, smart contract, consensus, provenance, immutable, and transparency to preserve trust and transparency in a collaborative setting like the supply chain ecosystem. Distributed ledger technology enables different entities to connect to one another in a peer-to-peer network without the use of middlemen. Consensus refers to when all parties engaged in a transaction agree on its execution. The immutability (the impossibility of any individual to change a transaction on the distributed ledger) is by far its most important characteristic. Because all transactions are recorded on a distributed ledger and made public to all network nodes or stakeholders, a provenance component can provide the ability to follow the whole history of each transaction. A smart contract is a computer program that, under certain conditions, may be run and contains the logic of a contract between two or more parties.

Blockchain technology may be used in the food supply chain by digitally recording information such as food production data, origin, storage and transportation temperature, expiry date, and so on in a database, allowing for speedy detection of an epidemic or the authenticity of food. Blockchain technology may be used to keep track of and monitor food goods in order to enforce food safety and integrity protocols, boosting supply chain visibility and responsibility. The most prominent examples are Walmart and IBM. The practical application of blockchain in food safety tracking is highlighted. It should also be emphasised that when blockchain technology is extensively deployed, standardisation of the protocols used in blockchain is vital because of appropriate smart contracts for data sharing, blockchain with strong algorithms suited for data privacy and integration through artificial intelligence designed for data immutability.

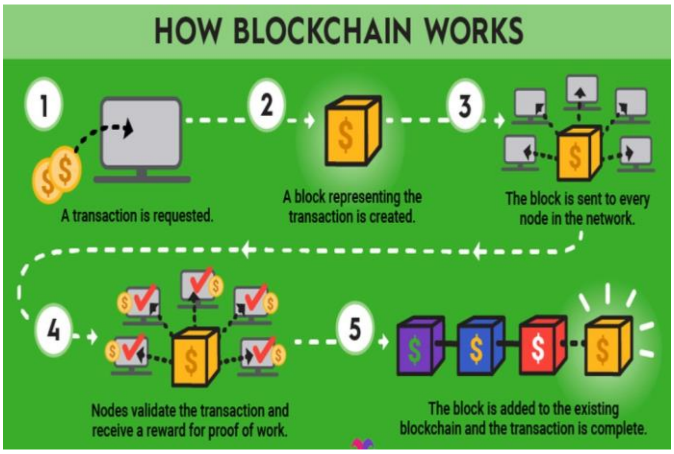

Fig -2: How Blockchain Works

5. Twin Digital Supply Chain

It was mentioned that a digital twin uses disruptive technology to combine real and virtual systems. A virtual model and thorough description of the system used to comprehend performance metrics, optimise workflows, and successfully boost value-added activities is called a "digital twin." A digital twin is a simulation-based digital replica of a physical system that works with design systems and optimises them for increased efficiency. Based on the information gathered, the digital twin may replicate the production environment and assist the owner in selecting the best course of action for greater productivity, accuracy, and economies of scale. With remarkable accuracy and agility, a digital twin can manage manufacturing operations in response to shifting market demands. It was mentioned that separate, customised applications have been developed using digital twin frameworks taking into account one or more production sites. They are yet unable to create a digital twin as the system's primary technological component, though. To put it briefly, the concept of virtual equivalents of physical items is the basis for the importance of digital twins in the manufacturing business.

A digital force chain twin is used for advanced force chain modelling that is based on real-time predictive analytics and can provide relevant corrective steps to improve force chain optimisation. A thorough literature analysis revealed that a digital force chain twin is a critical component of complex force chains because it allows for dynamic allocation, aggregation, and integration of production resources. A "digital force chain twin" is another term for a clone of a virtual force chain made up of hundreds of real-world means, such as storages, fulfilment centres, and force locations. Regarding digital supply chain twins, was found that there was no agreement in the literature. The literature's definition of the digital supply chain twin varies according to its intended use. Thus, it is suggested to provide a conceptual explanation for the digital supply chain twin. A digital dynamic simulation model of a real-world logistics system with the features of a long-term, timely, bidirectional data link to that system is known as a digital supply chain twin or logistics twin. Prescriptive, predictive, and diagnostic techniques are made possible by the digital supply chain twin, which enhances logistical performance across the customer order.

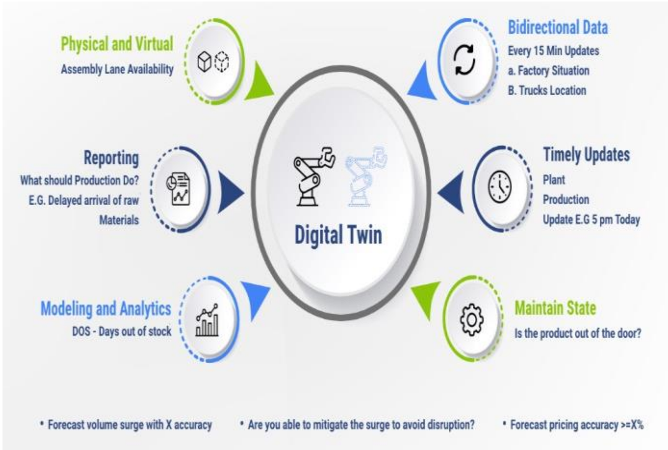

Fig -3: Twin Digital Supply Chain

Digital supply chain twin challenges:

The digital twin has a great deal of promise for tracking and tracing items to enhance efficiency and quality. Nonetheless, a number of issues, such as excessive idle time and energy waste, need to be resolved. Unstructured data sources, cybersecurity, IP protection, and the product life cycle are the obstacles to creating an effective digital supply chain twin.

5. Smart Manufacturing (AI-driven Decision-making)

AI helps manufacturers optimize production processes, manage resources, and make faster, data-driven decisions:

- **Supply Chain Optimization:** AI-powered systems forecast demand, optimize inventory management, and streamline logistics.
- **Real-Time Quality Control:** AI algorithms analyze production data in real time to ensure product quality and consistency.
- **Process Automation:** AI automates decision-making in tasks like production scheduling, process control, and order management.

In summary, AI is integral to the success of Industry 4.0 by driving automation, improving efficiency, enabling data-driven decision-making, and creating smarter, more adaptable systems across industries. It's revolutionizing how manufacturing, logistics, and supply chains operate on a global scale.

6. Conclusion

In order to address research question 1 (RQ1), the study provides a thorough analysis of the digital supply chain, concentrating on its definition and interactions with the smart supply chain. focusses on four essential elements of the digital supply chain:

• Big data, blockchain, Internet of Things (IoT), and digital supply chain twin

The evaluation looks into the underlying ideas of these technologies, as well as the application scenarios and related difficulties, in order to answer research question 2 (RQ2). Below is a quick rundown of the outcomes:

In digital supply chains, the Internet of Things (IoT) is the most widely used technology. To optimise data flow, it is frequently combined with big data analytics and cloud computing.
Smart contracts are noted as a key topic for further investigation, while blockchain is acknowledged as an emerging technology.

A complete technology that is primarily used to simulate and analyse different strategic scenarios is called a digital supply chain twin.

A number of other technologies are also highlighted, indicating the possibility for more study in the context of Industry 4.0, including robots, drones, 3D printing, virtual reality, and cyber-physical systems.

The assessment concludes that the problems related to these technologies vary as they advance and the range of applications they may be used for increases. As a result, research on these issues is still necessary.

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