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Secure Identification, Traceability and Real-Time Tracking of Agricultural Food Supply During Transportation Using Internet of Things

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ABSTRACT Food supply chain process comprises crops collection, processing of food, shipping & delivery to the whole seller in the market. Harvested foods decompose from the moment they are harvested due to attacks from enzymes, oxidation, and microorganisms. These include bacteria, mold, yeast, moisture, temperature, and chemical reaction. The spoilage of fresh food has increased over time due to the multistage slow food supply chain process. The identification, traceability, and real-time tracking of goods in supply chains have always been a challenge. The advent of the Internet of Things and cloud computing has brought a new approach to the food supply chain process for better cooperation among supply chain partners. The supply chain management (SCM) benefit greatly through automation based on key technologies of IoT, Radio Frequency Identification (RFID), and Wireless Sensor Networks (WSN). These technologies collect the data relevant to the food supply chain system, such as identifying tag-possessed objects or individuals and sensing capabilities of the surrounding environment. However, the collected data can be tempered or modified by attackers to provide false information about environmental conditions. They can destroy or damage the product due to false identification of dynamic environmental conditions. Furthermore, the current automation systems in industry-based retail logistics and SCM do not provide efficient solutions for monitoring the quality of perishable products with integrated solutions. This research aims to develop a secure monitoring and reporting system based on IoT to update the quality of the perishables along with the SCM with a focus on transportation without any human intervention.

INDEX TERMS Supply chain management (SCM), Internet of Things (IoT), real-time tracking, business management, smart transportation, secure supply chain management.

I. INTRODUCTION

In Supply Chain Management (SCM) of goods, the safe and complete delivery of perishable items from source to destination is viably essential due to today's modern business needs (e.g., agriculture landscape, business units, or consumers) [1]. Currently, SCM is a complex network of nodes (supply chain objects such as agriculture units, factories, human resources, etc.) and edges (business relations measured in terms of supply time, cost, distance, and strength of relations between producers and consumers) [2]. The manual SCM with human intervention is tedious, time-consuming, insure, costly, and does not guarantee the safe and complete delivery of items from source to destination [3].

In this era of the industrial revolution, when the industry is producing a myriad of products at a very high rate to meet the needs of its consumers, the conventional SCM techniques are quite vulnerable to insecure delivery during the entire course of SCM [4]. Besides, the natural disasters like floods, earthquakes, rains, exceptionally hot or humid climate) [5], epidemics [6], local or regional geographical conditions [7], political policies [8], society norms [9], and even attitudes of SCM stakeholders [10] badly impact the delivery of valuable goods to destinations. These challenges and associated risk factors require SCM stakeholders including agriculture forms, producers, companies, consumers, and

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third-party mediators, to mitigate the risk to build resilient, cost-effective, and adaptive solutions to cater to the needs of modern SCM [11]. The computational solutions for transportation in SCM have been proven useful since they can identify the shipment through effective tracking mechanisms [12]. Recently, the internet of things (IoT), cloud computing, and Blockchain technology have gained popularity in terms of devising smart solutions for the management of the delivery of perishable goods [13]. These technologies have much helped in digitizing the whole SCM process from producers to consumers. With these advancements, the SCM processes' stakeholders have better connectivity and communication to monitor the delivery process at each stage of the producer-consumer supply chain process [14]. The supply chain nodes can provide visibility of transactions, transparency, agile mobility, and SCM adaptability concerning current business needs and goals [15]. Besides, the trustworthy and secure SCM bestows satisfaction and convenience has resulted in rapid business opportunities at both producer and consumer sides [16].

Establishing trust between producer and consumer for the supply of agriculture and other food items is essentially required in the whole SCM process [17]. The reliability of SCM lies in recorded or stored information of shipment transactions at different nodes (instances or shipment points). The security of shipment log files is always very important to keep the transactions' information secure and trusted [18]. The current centralized systems (e.g., cloud storage) being the third party do not insight a completely safe and transparent understanding although they claim to provide secure access to stored data of transactions to all SCM stakeholders. Based on the issues and challenges of contemporary SCM mechanisms given in [19], [20], the questions arise; (1) what should be the architecture of SCM so that the Agri-food goods could be shipped promptly, (2) how to meet the expectations and requirements of SCM stakeholders in an agile manner while maintaining the real-time tracking and safety of goods from being spoiled, (3) how to develop the trust of producer-consumer in secure access to shipment log files from being tampered by third parties.

To resolve the mentioned challenges, this paper proposes a Blockchain-based SCM architecture with a focus on the secure identification, traceability, and real-time tracking of agricultural food supply during transportation using IoT and Blockchain.

The rest of the paper is organized as follows. Section 2 presents a critical analysis of recent works related to cervical cancer identification. Section 3 elaborates on the methodology in this work. Results are presented in Section 4, and the paper is concluded in Section 5.

II. RELATED WORK

The modern SCM is quite challenging and complex for several reasons, e.g., geographically distributed nodes, adaptability of stakeholders towards technology, trust-deeds between producer, consumer, third-party agents, and regional political and social scenarios in addition to natural disasters and unfavorable circumstances. However, with the advancement of IoT technology, sensor devices are being installed to aid the information collected at different points for better decision-making. The inherent nature of IoT makes it insecure to use it in the SCM process in its original form. Here comes the power of Blockchain technology to address most of the security requirements of IoT-based SCM.

The recent advances in Blockchain technology have significantly given a trusted channel to SCM stakeholders in the context of distributed and peer-to-peer communication [21]. The Blockchain ledger comes up with an agreed unanimity of most of the peers in the Blockchain networks invariant in nature and glimpses full transparency [22]. As a pitfall, the centralized storage of log files and related access requires stakeholders to be connected to centralized storage. Simultaneously, in the case of Blockchain, the peer-level connectivity makes it sufficient for the sensing devices to be connected in peer networks for efficient and reliable traceability of SCM items. The contemporary SCM mechanism's issues and challenges can be signified with an advanced SCM Blockchain architecture so that the Agri-food goods could be shipped on time [23]. Besides, SCM stakeholders' expectations could be satisfied rapidly without compromising the safety of goods with real-time tracking, and the producer-consumer trust to access the shipment data could be strengthened [24]. Table 1 below presents an insight into recent advances and applications of modern technology utilized in the context of SCM however, secure architecture for transportation especially with a focus on traceability and real-time tracking of the goods is not discussed in detail.

Table 1 presents an overview of supply chain management frameworks. We can summarize that IoT and Blockchain-based solutions have been adopted for a secure and sustainable solution as compared to conventional SCM mechanism. We can notice a few such published works that contained the agriculture or food supply chain issues. Moreover, each published study comes up with its limitations under its customized solution. We have proposed a framework that can be equally scaled or generalized for other different types of transactions/shipments.

III. METHODOLOGY

Supply chain management owns substantial worth in all business aspects. The conventional SCM methods are inefficient, sluggish, and do not keep pace with the modern revolutionary business needs. This study proposes a reliable, auditable, and trackable SCM framework that ensures transaction integrity, immutability, and transparency in the entire course of shipments of perishable products. The system provides a coherent digital representation of valuable assets to all stakeholders, from raw material suppliers to end-users or consumers. In the proposed Blockchain-based SCM, each of the stakeholders joins as Blockchain node to make Blockchain transactions as well as participate in keeping Blockchain up to date. On joining the Blockchain, each node is given a public/private

TABLE 1. An overview of existing research on SCM adopting IoT and Blockchain technologies.

Study	Weaknesses identified	Proposed solutions	State of the art technology adoption				Research outcomes
			IoT	Cloud	Blockchain	Others	
[25]	Unsatisfactory planning and management of goods' shipment through conventional SCM	Internet of Things (IoT) and Radio Frequency Identification (RFID) technologies	✓	×	×	✓	Signifies the adaptation of ICT technologies for a secure and smart supply chain management
[26]	The modern supply chain is non-proactive due to the tedious management of goods in traditional transit mechanisms	Proactive IoT based solution for smart management of goods	✓	×	×	×	IoT enabled supply chain management leverages the benefits of smart technologies in modern supply management
[27]	The complexity involved in globalization phenomenon and dynamic type markets that demands competitiveness under the scope of different supply chain managements	IoT based supply chain management by integrating pathogenic set with BWM and VIKOR methods	✓	×	×	×	Performance assessment of IoT based framework for SCM to remove ambiguity and uncertainty in conventional SCM
[28]	Issues of data management, data mining, privacy, security, and timely delivery of goods from source to destinations	IoT based solution involving RFID, barcodes, WSN, cloud computing, location-based services, and related networking, e.g., social and technology	✓	✓	×	✓	The impending applications of IoT in pharmaceutical SCM, including manufacturing and warehousing to SCM for enhancing productivity and quality
[29]	Limited efficiency and productivity of current supply chain management	IoT based conceptual framework on satisfying the enabling needs of industry 4.0 standards	✓	×	×	×	Enhance the performance and productivity of stakeholders of supply chain management
[30]	Competitive environment among supply chain managers cannot fill the gap with contemporary supply chain management principles	An aggregated IoT based solution for smart supply chain management	✓	×	×	×	Substantial positive impacts of IoT on SCM to cater to the needs and to bring a balance between the production of goods and their secure delivery using modern technology
[31]	Insecurity and tampering can be involved among stakeholders of current supply chain management	IoT and Blockchain for supply chain management of agricultural goods	✓	×	✓	×	SCM as an essential business process requires state of the art technology for better management of supply of Agri-items
[32]	Issues involved in the online trading of goods including security and satisfaction of buyers and sellers	IoT based technology for smart management of online transactions between producers and consumers	✓	×	×	×	Agile supply chain management for e-commerce systems
[33]	Unsatisfactory planning and management of items shipment through conventional SCM	Internet of Things (IoT) and Radio Frequency Identification (RFID) technologies towards the digital economy	✓	×	×	✓	Signifies the adaptation of ICT technologies for a secure and smart supply chain management
[34]	The complexity of SCM networks consisting of suppliers, third-party vendors, consumers, trade centers, warehouses, and supply stations	An Integrative solution based on Blockchain and IoT for Supply Chain Management to smartly combine the recent technology components	✓	×	✓	×	The impending applications of IoT for SCM, including manufacturing and warehousing to enhance productivity
[35]	Current SCM is inefficient and non-productive since it does not meet the recent requirements of SCM stakeholders for timely and secure transactions	Employment of state of recent technologies including IoT, cloud computing, RFID, and Blockchain for smart supply chain management	✓	×	✓	✓	Significant impacts of IoT and related technologies on SCM to cater to the needs of industry for secure delivery of items

TABLE 1. *(Continued.)* **An overview of existing research on SCM adopting IoT and Blockchain technologies.**

[24]	Current SCM systems underperform related to tracking of goods in shipment and don't provide the required security	IoT centric application for building a cooperative operating environment among business people	✓	×	✓	×	IoT and Blockchain-based applications to build distributed-ledger system for supporting shipment facilities among stakeholders
[36]	Current SCM is unsustainable in the context of scrap metal management (collection, processing, recycling, and shipment)	Sensors based IoT solution deployed to shops floors bins having capability of real-time monitoring	✓	×	×	×	Industry 4.0 standards require agile programs for secure and efficient transactions of materials and products
[37]	The conventional insecure mobile connectivity for larger areas having a high cost and device complexity are major pitfalls	Mobile IoT based solution for supply chain management through commercial explorations	✓	×	×	×	Exploration of mobile IoT perspective on supply chain operations for new insights and possibilities
[38]	The traditional SCM systems underperform in the context of privacy, scalability, security, and specifically to cater to the needs of different business networks' complexities	IoT based technology for smart management of transactions between producers and consumers ensuring the security and privacy	✓	×	×	✓	The deployment of mechanisms to get benefits of security, confidentially, privacy, integrity, and authentication
[39]	Inefficient customers' satisfaction and transactions cost management are significant challenges in current supply chain management systems	IoT based solution as a decision-making tool involving fuzzy-analytic hierarchical process for an assortment of leading 3PL provision	✓	×	×	✓	Building a tendency for better logistics activities that could contribute to a sustainable IoT-based agriculture SCM
[40]	Current technology for supply chain management is underperforming for complex supply chain networks	5G enabled supply chain management solution	✓	×	×	✓	Employing 5G technology in the management of the supply of goods can offer an excellent solution for complex supply networks
[41]	Current local supply chain management in Indonesia for the supply of chili is inefficient that waste time, money, and efforts of farmers and market dealers	An integrative solution based on Hyperledger Blockchain and IoT for better management of chili supply and delivery networks	✓	×	✓	×	Hyperledger Blockchain technology can add potential advantages to farmers and consumers by constructing a trusted distribution network
[42]	Collection, supply, and analysis of goods in SCM involve a larger set of stakeholders that require competent cutting edge technologies	A PERCEPTUS framework based on IoT involving semantic annotation to process complex events to predict disruptive events in heterogeneous data streams.	✓	×	×	✓	IoT-based framework bestows better SCM by validating datasets in semi-conductor manufacturing, providing accurate predictions of disruptive events compared to other SCM approaches.
[43]	The offline supply chain management systems don't express semantic annotation and monitoring; location identification and delays become tedious that require economic and computational investments.	An integrated solution based on microservice architecture for implementing semantic annotation of data feeds using online systems keeping the post-processing tasks, e.g., monitoring, goods' locations, and estimated delays	✓	✓	×	✓	Recent technologies like the Internet of Things and cloud computing broadens the spectrum from manufacturing to distribution in typical supply chain management (SCM) systems.
[44]	Supply Chain administration, keeping given current complex SCM networks, don't provide sustainable supply chain solutions to meet the antagonistic change in the customer needs	IoT, ERP, and Industry 4.0 require the potential benefits hidden in IoT embedded sustainable SCM solutions. The IoT based framework bestows readiness of SCM	✓	×	×	✓	The conceptual framework formulating five viable SCM perspectives, namely technology, business, collaboration, sustainable development, and management strategy, was developed.

TABLE 1. *(Continued.)* **An overview of existing research on SCM adopting IoT and Blockchain technologies.**

[45]	There are numerous challenges where supply chain partners are not fully connected and face issues in the supply of items to destinations in a cost-effective and timely manner.	An integrative system based on Blockchain and IoT provides immutable and secure transactions of perishable items during supply chain management, keeping in view the cost and delays.	✓	×	✓	×	Examined the limitations of the traditional IoT and Blockchain hybrid systems for a robust architectural framework design to overcome these limitations of current SCM systems.
[46]	There has been an increase in the number of items returned to retailers from customers. This has caused severe challenges to the growing need to efficiently managing backward goods in contemporary SCM.	A case study was demonstrated by employing IoT devices and sensors focusing on heterogeneous IoT networks in WEEE management.	✓	×	×	✓	The outcomes of this research pointed out the issues involving the reliability of complex and large-scale IoT systems.
[47]	There are several drawbacks associated with the typical supply chain management systems since they are inefficient in maintaining a trusted transaction ledger to satisfy many stakeholders' trust-based requirements in the traditional supply chain.	A solution based on DL-Tags to focus a privacy-preserving, decentralized, and verifiable measure during the entire product's lifecycle. The solution employed the distributed ledger technology (DLT) with Blockchain to cater to excellent communication between producer, consumer, and other SCM stakeholders.	✓	×	✓	✓	DLT tags management and cost analysis of all transaction logs using Blockchain technology so that the stakeholders could reach a consensus on the product's description.
[48]	The typical computer-based information systems cannot promptly monitor and manage assets' status and often lead to errors in working environments.	The IoT-based system with Near Field Communication (NFC) tags to exchange information for asset chain management to fulfill higher education institutions' needs.	✓	×	✓	✓	The IoT-based assets management can glimpse good governance of educational institutions addressing working environments' needs in real-time scenarios.
[49]	The traditional SCM systems underperform in the context of privacy, scalability, security, and specifically to cater to the needs of different business networks' complexities	IoT based technology for smart management of transactions between producers and consumers ensuring the security and privacy	✓	×	×	✓	The deployment of mechanisms to get benefits of security, confidentially, privacy, integrity, and authentication
[50]	The presented architecture is mostly for the decentralized system while IoT and Cloud-based systems are not supported by this study.	Blockchain & Smart contracts based architecture to support the researches for management of food sciences e.g., data search through blockchain can be done, providing tools to the different network research groups to make validations and contributes to the traceability, safety, and reliability of results	×	×	✓	✓	Smart contracts were used to define research protocols for subsequent data collection, automatic processing, and analysis, assuring that protocols were respected throughout the search chain and mapping the process efficiency.
[51]	The presented literature review to be further explored for the vulnerability of smart contracts, consensus algorithms, data security and data accessibility and integrity for sustainable traceability management	Blockchain-based IoT architecture is proposed to address traceability issues in food SCM	✓	×	✓	×	A study to contribute knowledge for better understanding of food traceability by using Blockchain technology
[52]	The proposed system is not suitable to work in environments where human interaction is not available or the integrity handling system is not intact already.	A blockchain-IoT-based food traceability system to integrate the blockchain, IoT, and fuzzy logic for traceability life management system for managing perishable food.	✓	✓	✓	×	The deployment of IoT-based framework, IoT – Blockchain-based mechanism, and fuzzy food quality evaluation for traceability for the complete food supply chain.

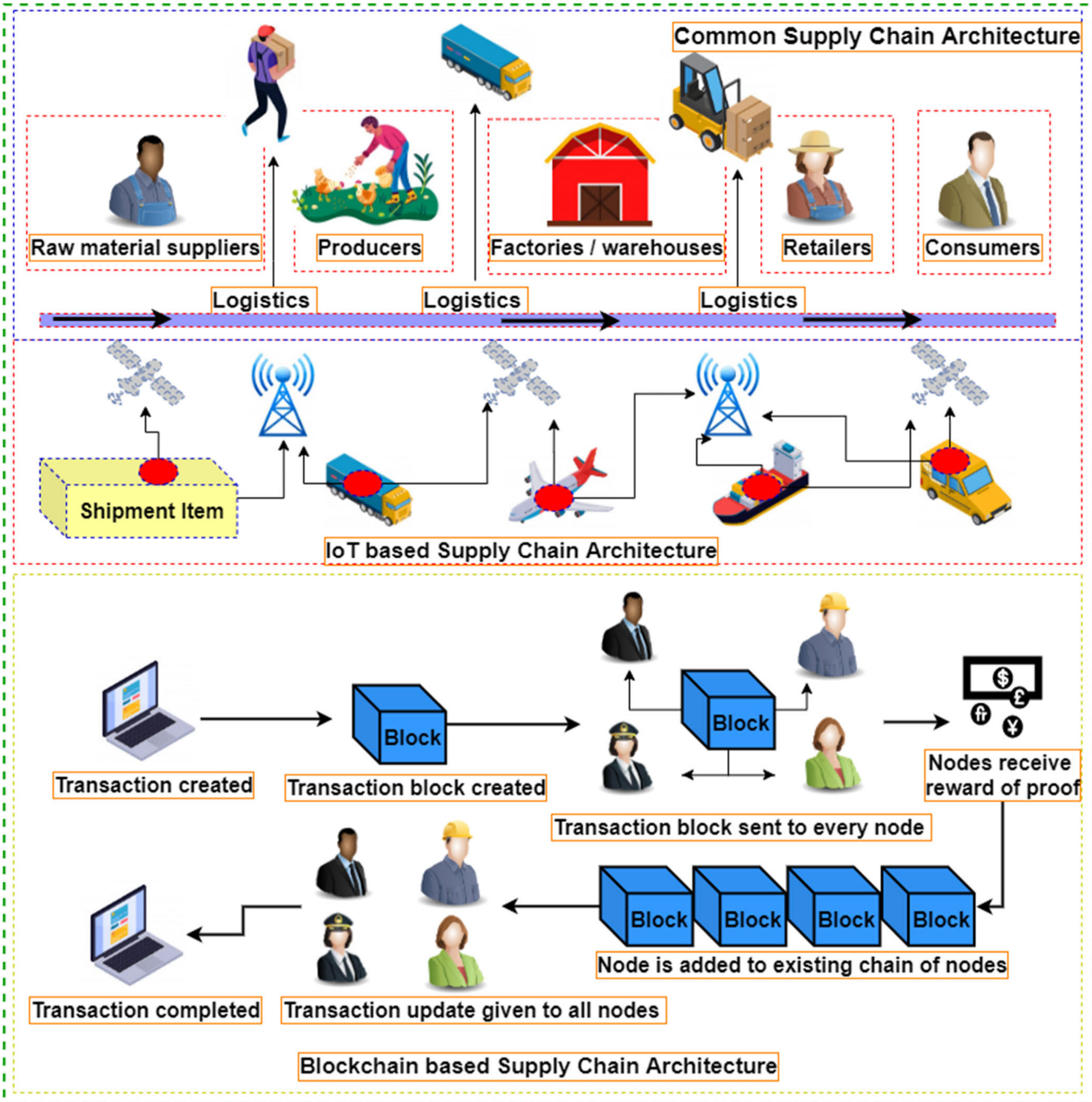

FIGURE 1. Conceptual framework of SCM adopting IoT and Blockchain technologies.

keypair to process secure cryptographic operations according to Blockchain architecture.

Figure 1 describes the conceptual framework of the proposed SCM system adopting IoT and Blockchain technologies. The proposed system leverages the recent IoT and Blockchain technologies to achieve the optimum and secure delivery of the SCM mechanism item. For instance, in a conventional SCM system, the raw material suppliers supply basic material to the manufacturer, e.g., factories, agricultural farms, and other industries. Such manufactures manufacture the products and ship to different places of the world employing traditional logistic procedures. Third-party business stakeholders later store the shipped products into warehouses that later supply the products to retailers or shopping markets where the consumers buy the items. The entire SCM mechanism involved in the old producer-consumer supply system lacks the fundamental aspects of security, trust, reliability, and integrity.

In the proposed SCM system, each shipment of items is digitally recorded and controlled. The individual shipment items adopt a unique digital identification tag that equips with navigation and communications sensors to track and trace the items during the life span of the entire delivery. In case the items are damaged or lost, the system can trace the location using GPS through communicating with a satellite. The location coordinates of individual items are transmitted through the communication channel to the tracking application. The system notifies the tracking application with the location coordinates. The local third-party representatives can then be contacted by providing them the exact locations of lost items. The digital code scanners installed at the entry and exit points of warehouses and shipment outlets can also notify the application of the updated status of items during the whole shipment process.

Besides, the proposed system integrates the Blockchain base framework to ensure quality control and comprehensive information sharing of digital transactions among SCM stakeholders in a secure way. The system provides a secure distributed ledger carrying numerous quality information, shipment information, and transaction information. The distributed ledger empowers the system for enhanced privacy protection through smart contracts.

In the proposed Blockchain-based SCM, each of the stakeholders (e.g., suppliers, producers, factories, logistics items retailers and consumers, etc.) joins as Blockchain node to make Blockchain transactions as well as participate in keeping Blockchain up to date. On joining the Blockchain, each node is given a public/private keypair to process secure cryptographic operations according to Blockchain architecture. The particular transaction is first created or generated by the system passed to all stakeholders who view and authenticate it. For authentication purposes, the transaction initiator signs the transaction with its private key which is further validated by each other processing node (stakeholder) with the public key of the initiator. Once the transaction is established on the network, the transaction block is added as a new block to the existing blocks in the Blockchain by using a suitable consensus mechanism. In the proposed architecture, it is recommended to use Proof of Supply Chain Share (PoSCS) as a consensus mechanism which is based on Proof of Stake (PoS) as proposed in [52]. The other popular consensus mechanism like Proof of Work (PoW) and PoS may not be suitable for food SCM due to the high demand for computational resources and wealth in the distributed network [52]. Each block in this chain keeps the hash address of the next neighbor. The last block in this data structure does not point to any other block. In creating and authenticating a new block, the previous block of the existing chain points to the newly created block.

The proposed SCM framework is logically fragmented into the layered architecture. The first layer is equipped with sensors that collect real-time data at a low level. These sensors can sense the environment data e.g. the sensors installed at some agricultural form, factory of the warehouse that record the temperature, humidity and other parameters and notify the respective caretakers. The second layer involves the digital ledger that contains latest and agreed transaction information in context of data attributes, quality, logistics and relevant transaction information. The third layer ensures the privacy and security of individual transaction. Here, the digital contracts are signed distributed among all nodes in the defined network. Operationally, the authenticated contracts are stored in the blocks and appended to the Blockchain nodes. At the system hierarchy, different stakeholders that participate in the entire process, reside at the top later that encapsulates all the three layers.

Figure 2 presents the methodological framework of the proposed SCM. The shipment of items and the transaction's description involves a structured sequence of steps explained below,

- Let us assume that each shipment of items from one stockholder to another stakeholder (in the supply chain process) requires a standard description of items. For the sake of representation, let the shipment $\boldsymbol{S}$ contains N items defined as $\boldsymbol{S} = \{S_1, S_2, S_3, S_i\}$, $i <= N$. The individual items are the products that should be delivered from shipment point A to another point B.
- Since the proposed SCM, the system realizes each item as a perishable product that must preserve its originality by passing through various outlets. Mostly, in conventional SCM architecture, there is a high probability of loss or damage of items. To avoid such incidents and protect the products, it is viable to monitor shipment paths from source to destination. The proposed SCM architecture equips each item S_i with dedicated N_i and C_i navigation and communication sensors such that $i < N$. The sensors help to track the course of shipment and trace the particular items in case of damage or loss.
- The proposed SCM system provides a digital representation of individual transactions. The system creates a digital ledger that contains information about quality, transaction information, stakeholders' information, and other relevant information. Let us assume that the system creates a Blockchain transaction $\boldsymbol{BT}$ with j nodes such that $\boldsymbol{BT} = \{B_1, B_2, B_3, \ldots B_j\}$. Here each Bi represents an individual transaction block that hosts the data structure information. All the relevant stakeholders should authenticate each Bi once created.
- The system tracks each shipment item Si employing defined N_i and C_i navigation and communication channels (for $i < N$) and makes the relevant decision based on tracking. During the event of monitoring, if item Si is lost during shipment, the system notifies the lost and traces the lost item's location.
- The location coordinates of Si items are identified through Ni and Ci (for $i < N$).
- The system then creates and distributes (or redistributes in case of un-authentication) BTi Blockchain transaction among Bi defined nodes such that $i < N$.

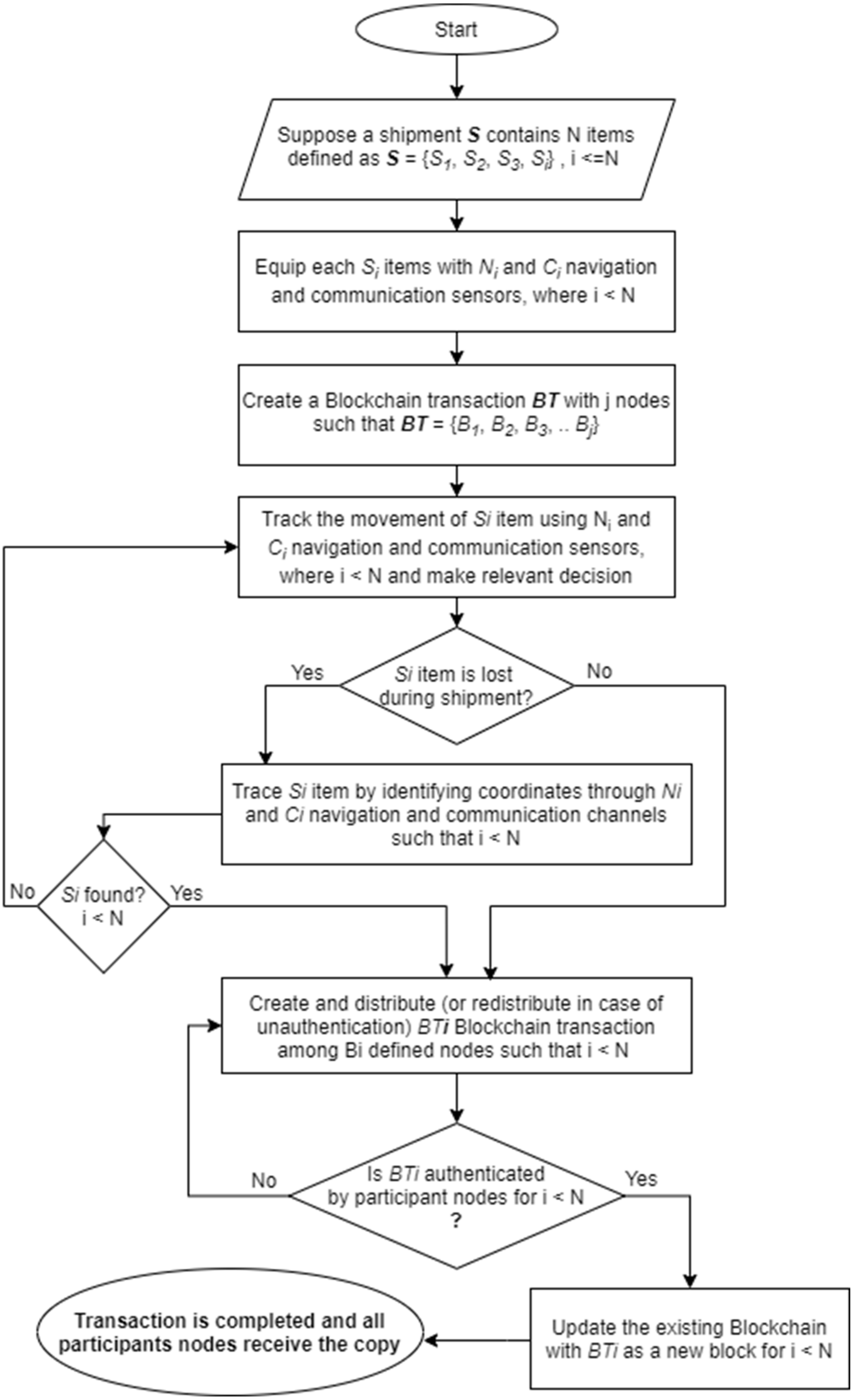

FIGURE 2. The proposed methodological framework of SCM.

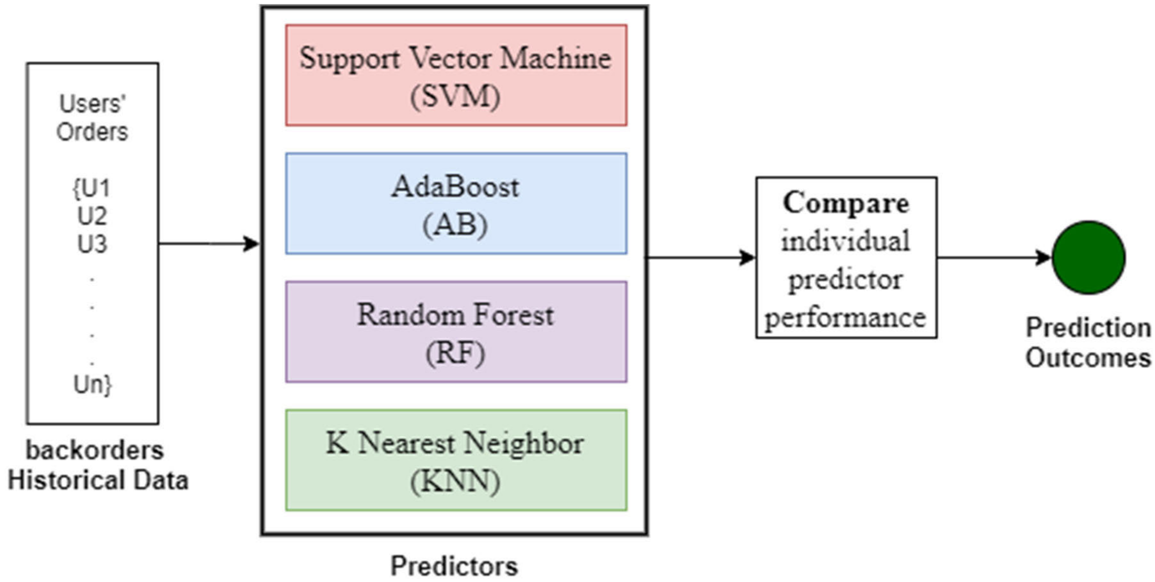

FIGURE 3. Machine learning-based architecture for prediction of customers' backorders.

- We need to ensure that the floated *BTi* (all participant nodes over the network authenticate for $i < N$) transaction.
- When the nodes authenticate the transaction, the relevant transaction block is appended to the existing Blockchain (i.e., inserted *BTi* as a new block for $i < N$).
- Ultimately, the system notifies the successful completion of the transaction and forwards the copy of agreed-upon transaction information to all network nodes.

With the proposed SCM system, it is advantageous that the Blockchain ledger comes up with an agreed unanimity of most of the peers in the Blockchain networks invariant in nature and portraits complete transparency. Besides, the centralized storage of log files and related access requires stakeholders to be connected to centralized storage. Simultaneously, in the case of Blockchain, the peer-level connectivity makes it sufficient for the sensing devices to be connected in peer networks for efficient and reliable traceability of SCM items. The issues and challenges of the contemporary SCM mechanism are signified with the proposed SCM Blockchain architecture.

In a formal food supply chain management, despite the SCM mechanism is secure with Blockchain technology, still, the customers' orders are delayed or suspended to the non-receipt of orders in time. To reduce the backorders issues, and to find an enhanced solution for predicting the customers' backorders, further, we introduce here a machine learning-based architecture to predict the customers' backorders.

Figure 3 presents a machine learning-based architecture for the prediction of customers' backorders. The architecture performs the predictive modeling for backorder identification of the popular predictors, namely, AdaBoost (AB), Support Vector Machine (SVM), K-nearest neighbor (KNN), and Random Forest (RF). The architecture compares the performance of each predictor on a set of backorder historical data represented as backorder instances $\{\boldsymbol{U_1}, \boldsymbol{U_2}, \boldsymbol{U_3}, \boldsymbol{U_n}\}$. The study adopts the best prediction outcomes to find the optimal prediction accuracy of individual predictors.

IV. EXPERIMENTATION AND DISCUSSION

The proposed SCM system provides a digital representation of individual transactions. The system creates a digital ledger that contains information about quality, transaction information, stakeholders' information, and other relevant information. Besides, in the proposed SCM system, each shipment of items is digitally recorded and controlled. The individual shipment items adopt a unique digital identification tag that equips with navigation and communications sensors to track and trace the items during the life span of the entire delivery.

Figure 4 presents the experimentation framework of the proposed supply chain management system. At the implementation level, a data structure that represents the nodes is created. Each node in this structure contains the transaction information, including block identification number, hash code or address of next transaction block in the chain, quality information, data and time stamp, and other miscellaneous information required by all the parties involved in the supply chain cycle. For instance, first structure node B_1 points to the second transaction node B_2. Once we create a new node B_3, node B_2 adopts the hash address of B_3 and points to B_3. Let us suppose that B_6 is the last node in this list; at the moment, node B_6 owns a hash address, but it does not contain the hash address of the next node since the list does not contain the next node. Block B_6 will point to new

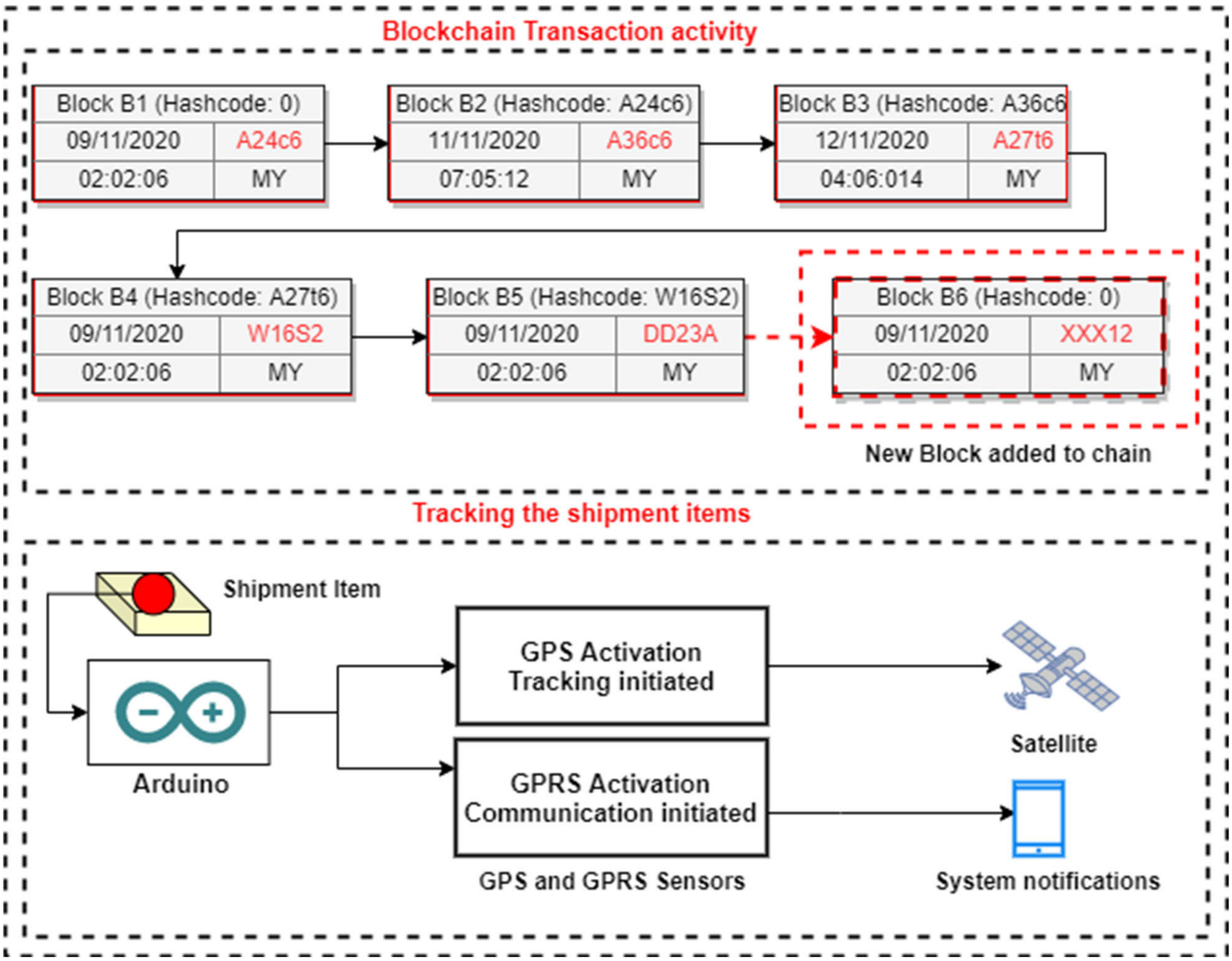

FIGURE 4. Experimentation framework of proposed SCM.

TABLE 2. Shipment of items using Blockchain.

Item ID	Block ID	Short Hash Code	Blocks pointing to hash of next blocks	List Structure
I_1	B_1	BT22D	2AXB9	B_1
I_2	B_2	2AXB9	7CTT4	$B_1 \rightarrow B_2$
I_3	B_3	7CTT4	JO76A	$B_1 \rightarrow B_2 \rightarrow B_3$
I_4	B_4	JO76A	MH2T	$B_1 \rightarrow B_2 \rightarrow B_3 \rightarrow B_4$
I_5	B_5	MH2T	B2B3S	$B=B_1 \rightarrow B_2 \rightarrow B_3 \rightarrow B_4 \rightarrow B_5$
I_6	B_6	B2B3S	D25Y1	$B \rightarrow B_6$
I_7	B_7	D25Y1	AA7N2	$B \rightarrow B_6 \rightarrow B_7$
I_8	B_8	AA7N2	41FE9	$B \rightarrow B_6 \rightarrow B_7 \rightarrow B_8$
I_9	B_9	41FE9	SS2W1	$B \rightarrow B_6 \rightarrow B_7 \rightarrow B_8 \rightarrow B_9$
I_{10}	B_{10}	SS2W1	0	$B \rightarrow B_6 \rightarrow B_7 \rightarrow B_8 \rightarrow B_9 \rightarrow B_{10}$

block B_7 when the system creates the new block after having all stakeholders' mutual agreement in the chain.

In case of tracking the items in this shipment, GPS and GPRS sensors are equipped to the item. The location coordinates of the shipment item are recorded, and in case of loss of the item, the tracer locates the last location of the item and helps the relevant units trace the lost item.

Table 2 describes the implementation scenario of Blockchain transactions. The shipment items are assigned identification numbers. Each shipment item is associated with unique block identification numbers. The hash code pointer of the data structure for block B_1 points to the hash address of second block B_2. Similarly, the pointer of block B_2 points to the hash code of block B_3 and so on. The last block in the set of blocks does not point to any next block. Each block is added to the existing list of blocks once all the stakeholders authenticate and approve the particular transaction. Once agreed, the new block is linked with the prevailing list.

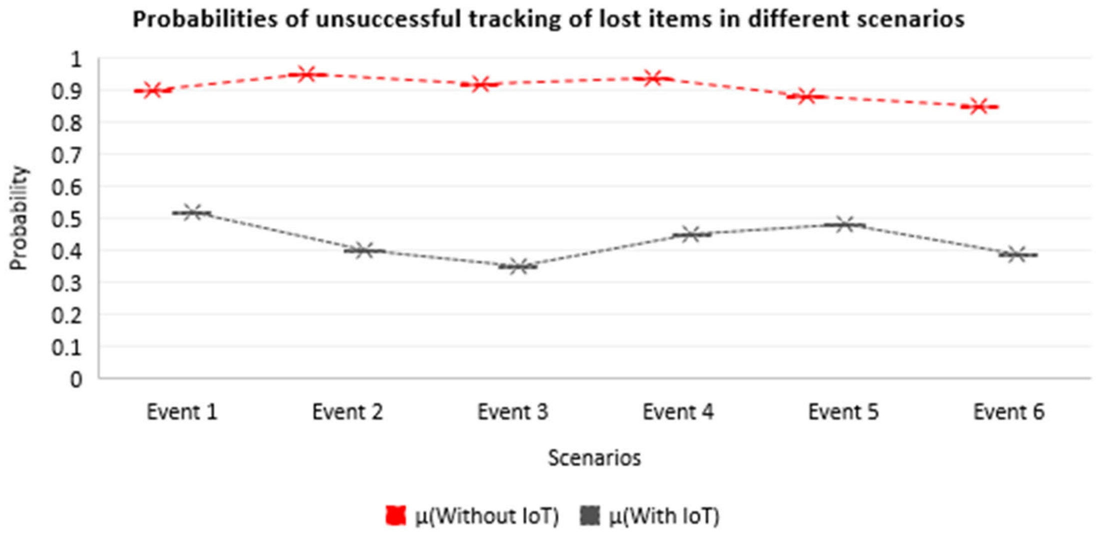

FIGURE 5. Probabilities of unsuccessful tracking with conventional and IoT based scenario.

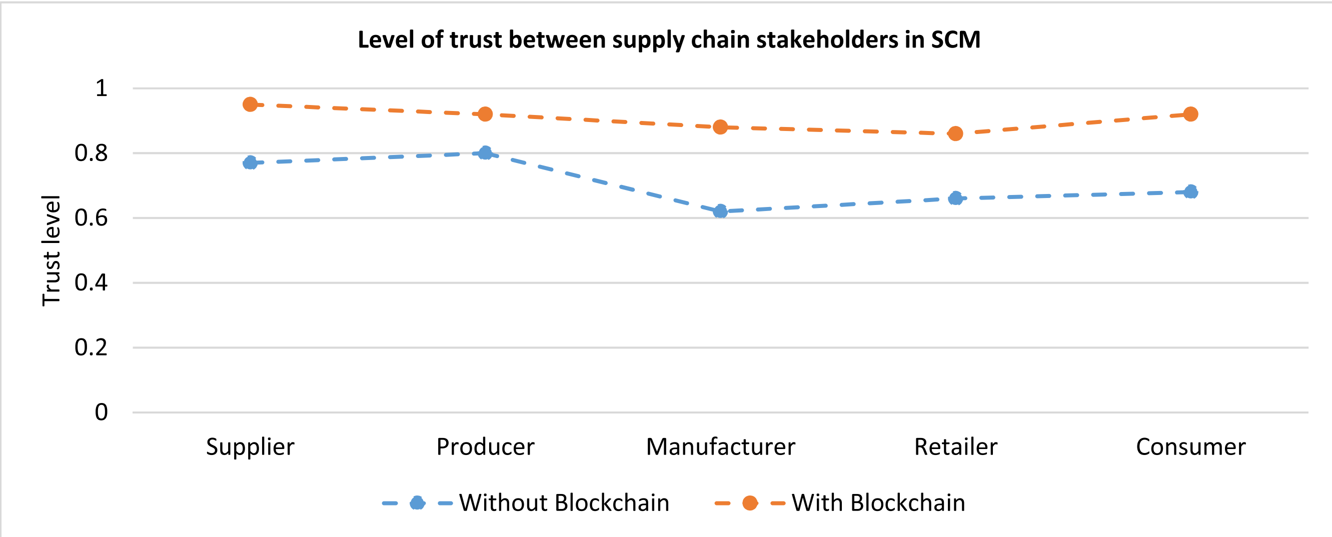

FIGURE 6. Trust level between different stakeholders in supply chain in both scenarios.

Figure 5 is a representation of probabilities of unsuccessful tracking with conventional and IoT-based scenarios. The mean probability of unsuccessful tracking with traditional human intervention methods is relatively high at different events [9]–[27]. There is a subtle difference between the two measurements. The navigation and communication channels empower the system for instant tracking of shipment items. Careful mentoring of items during shipment is the main objective of any successful supply chain management system that is significantly achieved using IoT deployed devices. The IoT-based SCM provides coherent and real-time shipment information to managers. Besides, the environmental conditions, e.g., temperature, humidity, pressure, and other similar parameters, can be remotely sensed from the logistic vehicles. The managers could also predict the date and time of shipment from source to destination, passing through various stopovers. Conclusively, efficient resource management is achieved by employing IoT in shipments.

Figure 6 depicts the level of trust between stakeholders in SCM involving Blockchain implementation (survey-based approach). It can be noticed that secure transaction is done through the Blockchain mechanism develop a significant level of trust in the whole SCM system [9]–[27]. Strong security threats can be observed in the traditional SCM mechanisms. Since the Blockchain bestows encrypted transactions and ledgers, this outperforms the conventional banking transactions where the parties have to wait for days to process the transactions least securely. Besides, adopting this

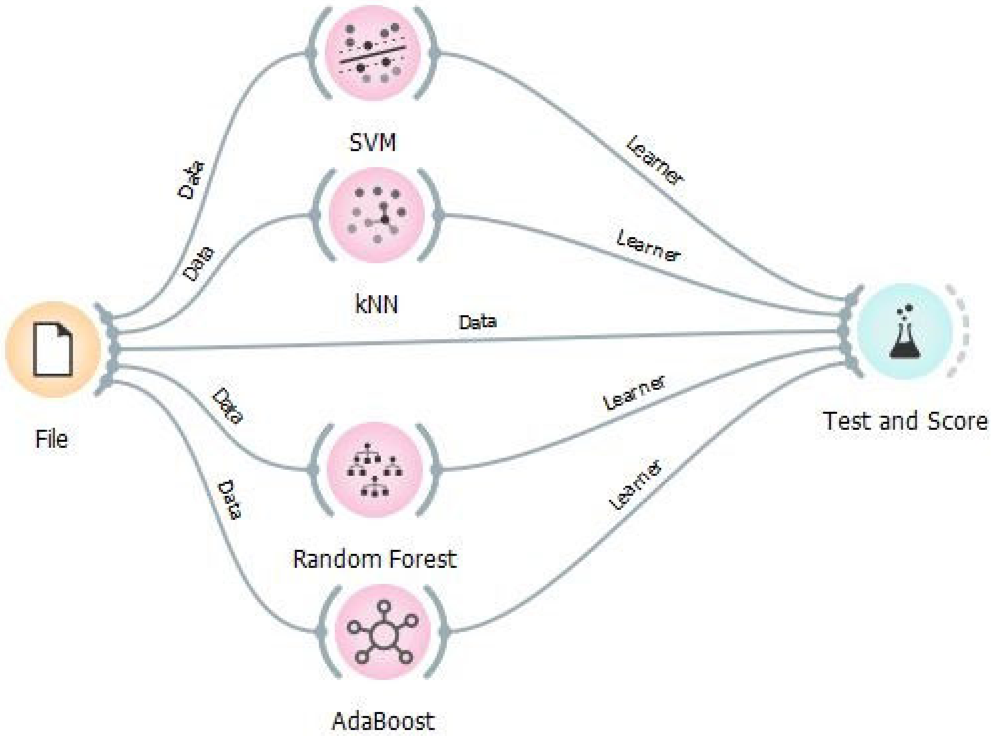

FIGURE 7. SCM backorder prediction with machine learning algorithms.

technology strength the traceability mitigates the huge cost of maintainability and quality issues. It is worth mentioning that it will take some time for the people involved in the traditional SCM mechanism to switch to the proposed system. It is due to existing collaboration and relationships between different parties. Commonly, the producers, warehouse owners, manufacturers, and logistic managers do not favor advertising the private information, e.g., such as demand, supply, quality, pricing, margins, commissions, and other similar details. In a competitive environment, and to maximize the gains from products, it is still tough for the stockholders to make available private information publicly accessible in the new SCM system. Perhaps, as a starting point, the limited number of stakeholders, having an existing mutual trust, can be a useful initiative to migrate from traditional supply chain management to the proposed IoT and Blockchain-based framework.

Further, we implement the proposed idea to predict the backorder cases employing the potential features of Support Vector Machine (SVM), K-Nearest Neighbors, Random Forest (RM), and AdaBoost algorithms. The backorder scenario is an open optimization problem in supply chain management. The significant handling of backorders is highly impactful to all the stakeholders in the entire supply chain process, particularly to the companies or suppliers. The customers' trust and binding with the business are significantly related to the proper management of customers' backorders. We present here an enhanced machine learning model that significantly predicts the backorders employing the machine learning algorithms,

Figure 7 describes a backorder prediction model leveraging the potentials of Support Vector Machine (SVM), K-Nearest Neighbors, Random Forest (RM), and AdaBoost algorithms. Different machine learning algorithms' characteristics differ according to the nature of data, e.g., biasness, overfitting, over-sampling and under-sampling, imbalance classes, outliers, missing values, and other noisy data. We implement this prediction using algorithms that work in such different scenarios. This analysis's outcomes helped to choose the right machine learning algorithms for a significant prediction of the backorders. Other backorder SCM datasets are publically available on Kaggle. We have preprocessed and simulated data with 10, 000 instances, having 22 features. This data contained an imbalanced class problem having 112 positives and 9888 negative instances. We applied SMOTE algorithm to establish a balance between the class labels. With SMOTE, we achieved 7168 positive instances and 9888 negative instances.

For the performance evaluation of different classifiers, we adopted the performance evaluation metrics, namely area under the curve, prediction accuracy, F1-score, precision, and recall.

Figure 8 presents the confusion matrix outcome of four machine learning algorithms. The SVM algorithm correctly classifies 85.8% of all orders; the KNN algorithm classifies 99.7% instances while Random Forest and AdaBoost

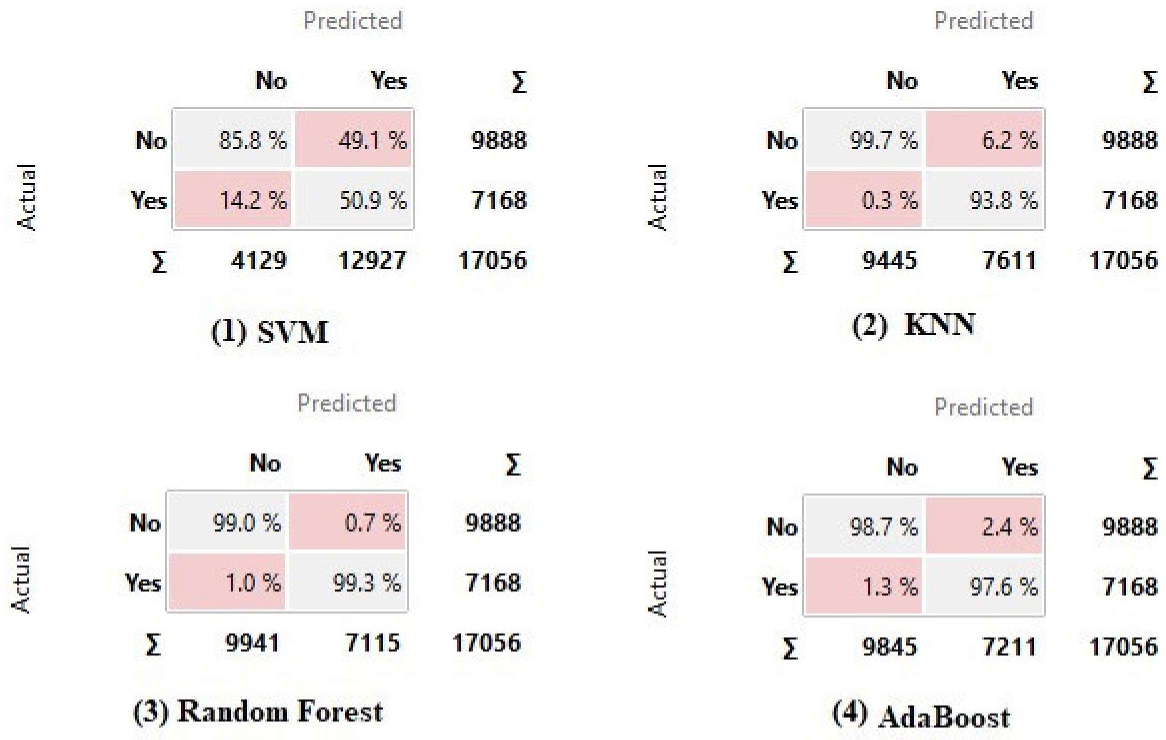

FIGURE 8. Confusion matrix of machine learning algorithms.

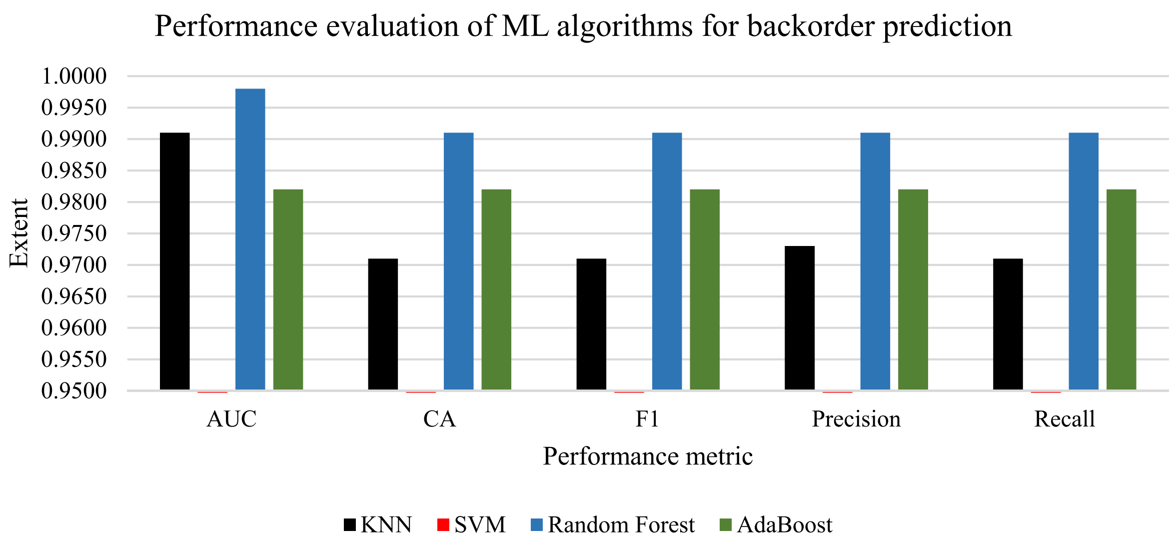

FIGURE 9. Performance evaluation of machine learning algorithms for backorder prediction.

could classify 99.0% and 98.7%, respectively. Further, we can investigate the performance in terms of evaluation measures, namely, the area under the curve, prediction accuracy, F1-score, precision, and recall as shown in figure 9.

We can find the performance metrics of SVM, KNN, Random Forest, and AdaBoost algorithms. In terms of area under the curve, Random Forest achieves the greatest extent of 0.998 compared to KNN having 0.991. The Random Forest's classification accuracy was recorded highest at 0.995, contrary to AdaBoost having an accuracy of 0.980. The F1-score of Random Forest also remained significant as compared to other algorithms. The SVM performed the least in this comparison. The precision and recall of AdaBoost remained less than the Random Forest but higher than the KNN algorithm.

Table 3 shows that KNN outperforms the SVM by 1.000. Besides, Random Forest achieves a significant extent of area under the curve, i.e., 0.998 as compared to KNN, and the AdaBoost underperformed than KNN by a factor of 0.000.

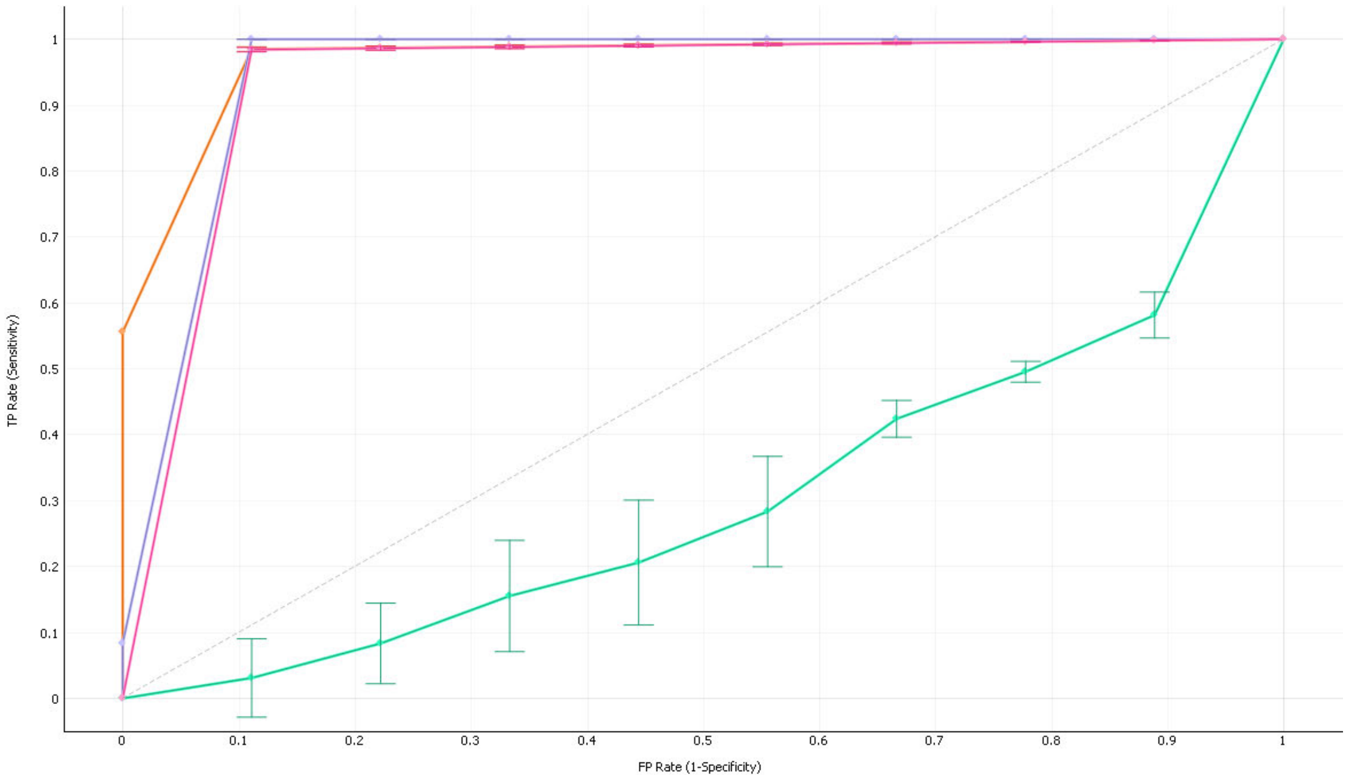

FIGURE 10. Receiver Operating Characteristic (ROC) curve analysis of machine learning algorithms for backorder prediction.

TABLE 3. Comparison of different models in term of the area under the curve.

Model	KNN	SVM	Random Forest	AdaBoost
KNN		1.000	0.000	1.000
SVM	0.000		0.000	0.000
Random Forest	1.000	1.000		1.000
AdaBoost	0.000	1.000	0.000	

Figure 10 presents the ROC curve analysis of SVM, KNN, Random Forest, and AdaBoost algorithms. We plot the true positive rate along the y-axis and the false positive rate along the x-axis. The Random Forest algorithm outperforms the other three algorithms. On a porotype sample of 10, 000 instances (becomes 17, 056 instances with an application of SMOTE), we can find that Random Forest is resilient compared to different algorithms. This algorithm can effectively deal with the missing data, data inconsistencies, and outliers in addition to the overfitting problems that usually arise in decision tree classification. The prediction of backorder can primarily help solve the business issues and achieve the business goals by enhancing profit.

V. CONCLUSION

This study proposed a reliable, auditable, and trackable SCM framework that ensured transaction integrity, immutability, and transparency in the entire course of shipments of perishable products.

The proposed system bestowed secure monitoring and reporting based on IoT and Blockchain frameworks to override the conventional supply chain management mechanisms that are economically and computationally expensive. The system empowered the stakeholders to update the quality of the perishables preserving the privacy and security aspects without any human intervention. It provided a digital representation of individual transactions. The framework created a digital ledger that contained information about quality, transaction information, stakeholders' information, and other relevant information. Besides, each particular shipment of items was digitally recorded and controlled. The individual shipment items adopted a unique digital identification tag equipped with navigation and communications sensors to track and trace the items during the life span of the entire delivery. Besides, aligned with the proposed idea, this study predicted the backorder cases employing the potential features of Support Vector Machine (SVM), K-Nearest Neighbors, Random Forest (RM), and AdaBoost algorithms. The scope of this study is contained in the agriculture food supply chain management, but it can be generalized or scaled for other types of shipments. Moreover, this study simulated the existing backorder data of customers. This study realizes the need to upgrade the existing data or generate new data in particular for the secure supply chain management. Besides, this study did not cover the aspects of disaster management, fault tolerance, and equipment failure, etc.

CONFLICT OF INTEREST

The authors have no conflict of interest in this research.

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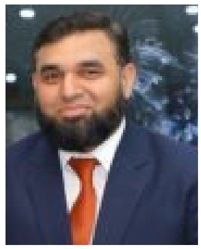

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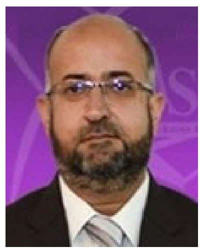

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