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RESEARCH ARTICLE

An IoT and Blockchain-Based Secure and Transparent Supply Chain Management Framework in Smart Cities Using Optimal Queue Model

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ABSTRACT The process of controlling the flow of products and services from a company by encompassing each stage involved in transforming raw materials and parts into finished items, also delivering them to the final consumer is known as Supply Chain Management (SCM). The development of numerous smart city applications including smart grids, smart homes, smart supply chains, and smart healthcare has drawn attention to the Internet of Things (IoT). Nowadays, researchers are considering the smart healthcare system's role as a Public Emergency Service (PES) to treat patients promptly. A distributed smart fire brigade system receives little attention like PES to save lives and property from catastrophic fire damage. The conventional PES methods are created using a centralized method that needs a lot of processing power and doesn't offer timely services. The traditional systems developed for managing the supply chain have drawbacks like single-point failure issues, data integrity, transparency, and lack of trust. To alleviate the existing issues, in this paper, a Blockchain and IoT Enable Secure and Transparent Supply Chain Management framework is utilized for PES in the smart city environment. Further, two edge computing servers, like a service controller and an IoT controller are adapted. The local storage is handled by the service and IoT controller. Thus, it enhances the data processing speed of PES requests and PES fulfillment. The service controller utilizes the Optimal Queue Model to manage the PES requests based on the minimum service queue length. The efficiency of the network is improved by fine-tuning the parameters from the Queue model with the aid of a Revised Fitness-based Political Optimizer (RF-PO). The multi-objective constraints like queue length, utilization, actual arrival time, expected arrival time, and end-to-end delay are utilized for the efficient supply chain system. These stimulated results show the feasibility and effectiveness of the supply chain framework.

INDEX TERMS Supply chain management system, smart cities, the Internet of Things, blockchain, revised fitness-based political optimizer, optimal queue model.

I. INTRODUCTION

An efficient flow of goods and services in any business can be achieved by the SCM [1]. SCM can generate more profits by satisfying both stakeholders and customers by delivering

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the products at the correct time. Information technologies are becoming more and more important to physical logistics, and they can also serve as catalysts for new kinds of partnerships [2]. The management of an extended enterprise, procedures, and technology that create interdependence and a shared destiny are presented to businesses [3]. Supply Chain Finance (SCF) has become more popular due to the rapidly rising demand for corporate finance. To offer effective financial services, the downstream and upstream suppliers are managed by the supply chain [4]. Financing via security markets, commercial banks, and enterprises are the Small-Medium Enterprises (SMEs) financing methods. The workflows in the SCM are effectively handled by the information technology. With the help of information technology in SCM, reverse securitization and financing transactions are made simple [5].

IoT devices are the main equipment employed in the smart cities. To make life easier for people in smart cities, the data are collected and correct information is provided by the IoT devices [6]. Different kinds of applications are available to pass the information to the people in smart cities [7]. Smart traffic environment, smart agriculture, smart grid, smart supply chain, smart home automation, and smart healthcare are some of the smart city applications [8]. The need for IoT devices is rising daily. These devices generate enormous amounts of data to provide useful information [9]. But, managing that data becomes difficult. Vulnerability to attack, less transmission range, limited storage, and low computation power are some of the drawbacks of IoT devices. In recent days, some systems have been developed to handle the data and devices [10]. One of the methods useful for this purpose is cluster head. Yet, this approach also has some disadvantages like information processing, scalability, and vast data storage [11]. Some of the difficulties in a centralized system are data integrity, transparency, trust, and single point of failure. To resolve these issues, blockchain and edge computing servers are useful [12].

In blockchain, once a transaction is completed, new blocks will be added and it is immutable [13]. The predecessor block's hash value is presented in the blockchain along with the past transaction history. For a distributed manufacturing process, the cloud and blockchain methods are integrated [14]. Immutable archives and records are created by combining blockchain with cloud-based SCMs [15]. Reuse, recycling, disassembly process, assembly, production, and designing processes are achieved by integrating CM, SCM, and blockchain [16]. Some of the challenges of SCM are poor inventory management, non-compliance, poor customer experience, increasing risks, long production cycles, rising logistics costs, and delays in delivery [17]. Therefore, to raise the security and transparency of the SCM in smart cities, an IoT and blockchain-based model is proposed.

The main goals of the implemented Blockchain-based secure and transparent SCM framework in smart cities using optimal queue model are listed below:

- To present a Blockchain-enabled supply chain management framework to improve the transparency and security of supply chain processes in emergency systems at smart cities, and also provide a transparent and immutable record of all transactions and activities within the SCM, allowing for increased visibility and accountability.
- To suggest an RF-PO algorithm by improving the random parameter in the conventional PO algorithm. It is useful in progressing the functionality of the recommended model by optimizing parameters and aids in solving optimization problems by finding the most efficient solution given a set of conditions or constraints.
- To employ a queuing model for increasing the service quality of the supply chain management approach. From, this model, parameters like temperature threshold, smoke threshold, and humidity threshold are optimized to maximize, the difference between actual and expected arrival time. Further, this optimization is also beneficial in decreasing the end-to-end delay, actual arrival time, queue length, and utilization.
- To confirm the potential of the suggested blockchain-based supply chain management model, the attained results are analyzed with various optimization algorithms. Moreover, the existing technologies used in the field of managing supply chain systems are also considered.

The proposed model for handling the supply chain systems in smart cities is briefly described in the upcoming sections. The existing works implemented to manage the supply chain systems are discussed in Province II with their drawbacks and strengths. In province III, a brief introduction to supply chain management in smart cities is given. The blockchain Preliminaries are described in this section along with a detailed justification of the proposed model. In province IV, the proposed optimization approach to enhance the performance of the recommended model is provided. Province V describes the queuing model-based supply chain management system elaborately. The numerical findings are given in Province VI. The conclusion of the presented model is depicted in Province VII.

II. EXISTING WORKS

A. RELATED WORKS

In 2022, Wang and Wang [18] have provided a supply chain finance strategy to create an efficient framework for managing supply chain financing. Blockchain technology and supply chain financing were established based on theoretical research. In addition to the unique circumstances surrounding supply chain finance, an analysis was done on the supply chain's cash flow, risk control system, and management system. To significantly lower the risks that occur by each party involved in the supply chain financing, all parties optimize the supply chain finance risk control system while raising corporate efficiency and lowering expenses. For developing the growth of commercial banks, the shared data and blockchain-based IoT environments were very powerful.

In 2023, Matenga and Mpofu [19] have created Cloud Manufacturing (CM) platforms for supply chains that were sustainable. Servitization caused the CM systems to change from product-oriented to service-oriented approaches. Knowledge management was made possible by data traceability along the value chain and information through the interconnection of manufacturing inputs and processes in CM. SCM was used in the manufacturing of boxed flat sheet metal and then it was utilized as a part of railcar manufacturing. The methods used a whole product's lifecycle, from conception to End-of-Life (EOL), and determined the value of the product based on the capability of the product. In the railcar remanufacturing supply chain, order and part tracing was done using the Life Cycle Assessment (LCA) approach. This strategy concentrated on SCM and blockchain integration to optimize Product Lifecycle Management (PLM) for better traceability.

In 2009, Dotoli et al. [20] have suggested a supply chain, which was a network of autonomous logistics and manufacturing businesses that handled the crucial tasks involved in order fulfillment. They developed an efficient and flexible model based on first-order hybrid Petri Nets (PNs) that utilized first-order fluid approximation to characterize the information flow, financial, and material of supply chains at the operational level. The supply chain designer could able to select the appropriate facility production rates to maximize the selected objective function with the help of the suggested method. Using the state information of the derived state variable model, time-varying and linear discrete-time action was carried out to respond the unforeseen occurrences like supply disruptions or accidents in transportation facilities.

In 2022, Bhawana et al. [21] have created a PES framework for smart cities that was Blockchain-Enabled Secure, and Trusted (BEST). To prevent significant fire damage in smart homes, the BEST framework focused on offering a fire brigade service as a PES based on information from IoT devices. Additionally, an IoT controller, a service controller, and two edge computing servers were used in this work. To prevent misleading in the PES department, the IoT controller maintained an access control list that tracked registered IoT devices and IoT gateways. Based on the minimal service queue length, the service controller handled the PES requests using the queue model. Additionally, several smart contracts were created on the hyper ledger fabric platform to automatically activate a PES in the event of an unpredictable environment, like, when the smart homeowner was not present in the home. The suggested BEST framework's performance evaluation highlighted the advantages of making use of the smart contract logic and distributed environment.

In 2022, Guo et al. [22] have designed a framework for information management based on IoT and Blockchain Technology (BCT), which served as regulation to enhance the information transparency in SCF's business processes. Through the integration and coordination of trade flow, logistics, information flow, and capital flow in the supply chain, the BC4Regu could lower the operation cost of the entire supply chain. The contributions of the proposed model were: the technical design of BC4Regu, which included the reshaped SCF process, distributed ledger-based integrated data flow service, and Blockchain infrastructure. The second contribution was the proposal of a novel information management framework. The third one was applying BC4Regu to a range of scenarios and evaluating the efficiency of the model using the principal-agent model.

In 2021, Majdalawieh et al. [23] have proposed an IoT and blockchain-based framework to control and manage the operation of the processed poultry food supply chain industry by improving the quality and safety of food products supplied to final consumers. In this study, Ethereum smart contracts maintained the integrity of supply chain transactions while creating a tamper-proof, transparent, and dependable food supply chain structure. All participants inside the network were kept fully informed about transactions by the smart contract, which also regulated and managed the exchanges between the network's entities. The program's objectives were to detect and eradicate food contamination and adulteration. Also, to improve the supply chain's quality and safety for the food business, they increased legal accountability and transaction transparency. Therefore, this method increased the value of the brand and consumer trust.

In 2023, Yazdinejad et al. [24] have suggested machine learning and Bidirectional Encoder Representations from Transformers (BERT)-based threat detection modules to boost security and intelligence in blockchain-based Drug SCM. Pandemics might have a significant impact on several healthcare streams, including DSCM. Using DSCM to give medication to patients was a complicated procedure. In addition, DSCM faced several difficulties, such as fraud, counterfeiting, and medicine availability. Eradicating pharmaceutical fraud was crucial to provide equitable and safe access to medication, intelligence tactics, security, support, and services were required as it was a major problem in Cyber-Physical Systems (CPS). The findings of the evaluation demonstrated that the BERT-based recommended system ideally provided suitable substitute medications. The precision and accuracy of the suggested method for attack detection were higher than traditional methods.

In 2023, Qatbi and Rathinam [25] have suggested combining supply chain management with the IoT. This innovative approach used blockchain technology to solve stakeholders' problems about data privacy that impact the development of smart cities, smart buildings, and smart gadgets all around the world. The transportation of raw and finished products as well as the production process was handled by supply chain management. It was a cross-functional approach. To continue the supply chain management, manufacturers or customers must have faith in internal or external stakeholders. Blockchain technology was developed to enable supply chain management processes to be visible and traceable. The

TABLE 1. Features and Challenges of blockchain and IoT-enabled secure and transparent supply chain management framework.

Author [citation]	Methodology	Features	Challenges
Wang *et al*. [18]	Blockchain technology	• It increases the security and traceability of data shared across the business network.	• Blockchains are high energy dependence and the integration process is complicated.
Matenga *et al*. [19]	CM	• This method provides real-time information to everyone along the supply chain.	• In CM data security and privacy threats occur. • CM is based on internet services, so interruption can occur for any reason.
Dotoli *et al*. [20]	PN	• PN makes it easier to understand the overall functionality of the system. • It can automatically compute system invariant from the net syntax.	• PN are inherently complex, which limits their use in complex systems.
Bhawana *et al*. [21]	BEST	• It is a decentralized structure, which improves the security and privacy of the network.	• High cost of implementation and inefficient in the mining process. • This method needs a high level of security through a private key.
Guo *et al*. [22]	BCT	• The security of the system is improved because each node within the blockchain has transaction copies.	• Lacks of distributed computer systems and network security disruption are the main issues.
Majdalawieh *et al*. [23]	IoT-based device	• It improves the speed and accuracy of the supply chain process. • It provides live monitoring and tracking automatically.	• IoT technology consumes a large amount of energy. • Initial costs and ongoing maintenance costs are also high.
Yazdinejad *et al*. [24]	DSCM and BERT	• Highly efficient. • This method provides better demand forecasts and reduces medication errors.	• This method prevents the supply chain from being reliable and responsive. • Lack of visibility
Qatbi and G. Rathinam [25]	IoT	• IoT-based technique improves the resource management efficiency of the network.	• Lack of encryption and data overloading are the main issues.

process entailed building a blockchain inside a blockchain to protect the integrity and security of sensitive data, including traceability and maintainability of the supply chain while managing the manufacturing costs.

In 2023, Ahmad Reegu et al. [31] have planned to create an interoperable blockchain-based Electronic Health Record (EHR) platform. The suggested framework could allow safer ways of exchanging medical data in the health care sector, as well as permanence, safety, and access by users over stored documents, eliminating the requirement for centrally storage. This work contributed to a better understanding of the potential uses of blockchain technology in EHR environments and proposed an extensible blockchain-based EHR framework that could satisfy the needs of several national and international EHR standards. In general, this work offered significant effects on the healthcare sector because it could enhance the secure exchange and preservation of electronic health records while protecting the secrecy, confidentiality, and authenticity of medical data.

In 2023, Dziyauddin et al. [32] have comprehended the challenges that exist in IoT and how they may be addressed using the Blockchain idea. The IoT has been categorized as an industry changer because it involves a multitude of intelligent gadgets with computing, sensors, and actuator capabilities. Incorporating social media ideas into the IoT in today's culture has resulted in the development of an innovative idea known as social IoT. The IoT deals mainly with the connection of different smart devices. Because of the absence of basic safety options, every aspect of IoT infrastructure was subject to privacy and security threats.

In 2022, Ahmad Reegu et al. [33] have investigated the network layer safety flaws associated with IoT. It also investigated and assessed existing network-layer security issues and dangers, in addition to mitigating and preventative measures solutions.

B. PROBLEM STATEMENT

Managing a supply chain management system requires time, money, and human resources. If not implemented properly, there is a service redundancy, and missed deadlines. It is difficult to track the movement of goods and services across a global supply chain and this will lead to delays and inefficiencies. Hence, a blockchain-enabled secured and trusted framework is implemented to handle SCM in a smart city environment. The pros and cons of existing SCM models are elaborated in Table 1. Blockchain technology [18] increases the security and traceability of data shared across the business network. But, blockchains are high energy-dependent and the integration process is complicated. CM [19] provides real-time information to everyone along the supply chain. Yet, data security and privacy threats occur and it is based on internet services, so interruption can occur for any reason. PN [20] makes it easier to understand the overall performance of the system and can automatically compute the system invariant from the net syntax. But, they are inherently complex, which limits their use in complex systems. BEST [21] is a decentralized structure, which improves the security as well as privacy of the network. Still, high cost of implementation and is inefficient in the mining process and this method needs a high level of security through a private key. BCT [22] security of the system is improved because each node within the blockchain has transaction copies. But, lack of distributed computer systems and network security disruption are the main issues. IoT-based device [23] improves the speed and accuracy of the supply chain process and provides live monitoring and tracking automatically. Yet, IoT technology consumes a large amount of energy, and initial costs and ongoing maintenance costs are also high. BERT [24] provides better demand forecasts and reduces the medication error. However, it prevents the supply chain from being reliable and responsive. IoT [25] technique improves the resource management efficiency of the network. Still, encryption and data overloading are the main issues. To overcome the existing challenges, we developed an effectual blockchain-based secure, and transparent SCM framework.

While IoT-based blockchain-enabled supply chain management systems offer numerous advantages, there are a few potential disadvantages to consider: As the number of IoT devices and transactions increases, the scalability of the blockchain network may become a challenge. The system needs to handle a large volume of data and transactions efficiently. The developed model can help manage and prioritize data transactions to enhance the system's scalability. Additionally, implementing and maintaining a traditional IoT-based blockchain system can be costly, especially for small and medium-sized businesses. The expenses include IoT device deployment, blockchain infrastructure, and ongoing maintenance. In the recommended model, the RF-PO algorithm can help optimize resource allocation and decision-making, leading to cost reductions in supply chain operations. Moreover, ensuring compatibility and interoperability between different IoT devices and blockchain networks can be complex in the existing models. Standardization efforts are ongoing, but it may still pose a challenge in the implementation of IoT-based blockchain systems. Optimizing the parameters can facilitate interoperability by standardizing data formats and communication protocols. So, the developed model optimizes the parameters like the threshold of temperature smoke, and humidity to tackle the issues. This allows for seamless integration of different IoT devices and ensures compatibility across blockchain networks.

Moreover, the individual process of the blockchain and IoT lacks network security, requires more cost in the traditional models, and cannot be appropriate for offering effective privacy to the data. But the developed integrated IoT and blockchain-based system addresses the challenges of, cost, data privacy, and interoperability through the implementation of the optimization algorithm. It optimizes scalability, reduces costs, enhances data privacy and security, and promotes interoperability among different IoT devices and blockchain networks.

TABLE 2. Attributes details of the developed blockchain and IoT-enabled secure and transparent supply chain management framework.

Attributes	Values
Sub-areas in a smart city	7
Smart homes in each sub-area	50
IoT Controllers	7
Service Controller	1
PES departments	7
PES provider in each PES department 1	10
Maximum service queue length of each PES department	10
b	0.5
γ	0.014
Th^{α} , Th^{β} , Th^{β}	60^0, 120ppm, 65%
Distance $D_{i,j}$ between the i^{th} smart home and j^{th} PES department	5 to 50km
Time duration $T_{i,j}$ for j^{th} PES department in high traffic to reach i^{th} smart home	15 to 30 min
Time interval T	24 hr
The average speed of j^{th} PES department	50 to 60 km/h

III. AN INTRODUCTION TO SECURE AND TRANSPARENT SUPPLY CHAIN MANAGEMENT USING BLOCKCHAIN-BASED OPTIMAL QUEUE MODEL

A. ATTRIBUTES DETAILS

The following are the attributed aids in developing the IoT and Blockchain-based SCM system. The developed model can be completed by initializing these parameters in Table 2.

B. SUPPLY CHAIN MANAGEMENT IN SMART CITIES-BRIEF INTRODUCTION

IoT is the main component that is employed in the smart cities. To improve the lives of people living in smart cities, these IoT devices gather and transfer useful information to them. Smart city applications like smart traffic environment, smart agriculture, smart grid, smart supply chain, smart home automation, and smart healthcare are utilized to share that information. The need for IoT devices is maximizing daily because of the smart city applications. To manage a greater number of IoT devices, data storage, scalability, fast computing, and high bandwidth, edge computing servers are utilized. To ensure the flow of business in urban areas, supply chain management systems are essential. Delivering, returning, and planning are some of the phases of the supply chain. During this business flow the necessary information is protected by the blockchain. The communication issues between the stakeholders and partners are resolved by enabling blockchain technology in supply chain management. Supply chain management covers the process of turning a raw material into a useful product. Consumers, retailers, distributors, manufacturers, and suppliers are the five entities in supply chain management. The products are transferred among each entity by paying a particular amount for each product.

Giving PES to residents of smart cities to shield them from dangerous situations is another crucial factor in SCM. The current PESs solely concentrate on the intelligent healthcare system to offer medications based on patient requests via the centralized system. But, more PESs are needed, like a smart fire brigade system that effectively manages service requests for a smart house from the fire department during an emergency. The smart home's IoT gadgets are set up to gather data about the environment and send it to the central processing unit for additional processing through an edge computing server. The fire department can retrieve fire brigade service requests through the centralized system and take appropriate action. The rapid production cycle is achieved with the help of managing the supply chain in smart cities. A pictorial view of blockchain-enabled supply chain management in smart cities is provided in Figure 1.

C. BLOCKCHAIN PRELIMINARIES

Blockchain is an append-only data structure that replaces the centralized system by maintaining immutable transactions among unknown and untrusted parties in the form of a distributed ledger. The financial application that allows people to move digital assets from one place to another in minutes has made the Bitcoin blockchain well-known. The users of the Bitcoin blockchain are linked together in a peer-to-peer network, and they sign transactions using a pair of private and public keys. This gets rid of the middleman's job of validating the transaction on the Bitcoin blockchain. Blockchain technology has distinct features including smart contracts, transparency, immutability, consensus protocol, and distributed ledger. With the help of private and public keys, anyone can join the blockchain network.

The most well-known private blockchain systems are Hyperledger Indy, HyperledgerBesu, and Fabric. Popular public blockchain networks include Quorum, Litecoin, R3 Corda, Ethereum, and so on. These two blockchain systems are utilized for creating smart city apps and implementing financial applications.

1) BLOCK

Blockchain is composed of numerous blocks. In each block, a body and a header are presented. Transaction information is stored in the block body. Genesis is the first block's name in the blockchain. It has information like smart contract logic address, consensus protocol, and validator. A cryptographic hash function is formed by connecting all the blocks present after the genesis block.

2) SMART CONTRACT

A self-implementable code written between two organizations like an agreement is known as a smart contract. It helps to store information without any third-party app intervention. The smart contracts are not changeable after it is employed in blockchain. Based on some conditions it automatically executes.

D. PROPOSED BLOCKCHAIN-ENABLED SUPPLY CHAIN MANAGEMENT SYSTEM

The prior technologies used for managing supply chain networks are vulnerable to cyber-attacks. So, a secured blockchain technique is needed. Due to the usage of untrusted hardware, the integrity of the supply chain is highly affected. Lack of real-time information, poor traceability, and fragmentation are some of the issues in the existing supply chain management approaches. The request processing time of the traditional methods used in the field of supply chain management is high. Storage is also the biggest issue in managing requests, so the usage of an efficient storage mechanism will be beneficial for handling more amounts of requests and storage. Interchangeability and information compatibility are also two issues that need to be solved in the supply chain management frameworks. Moreover, giving priority to the requests that are raised first should be given more importance. Most of the existing systems lack security and integrity. Resolving or responding to the requests takes more time in traditional techniques due to more amounts of requests. Therefore, an efficient technique to offer high security and transparency is developed. The diagrammatic view of the proposed blockchain-enabled supply chain management system is visualized in Figure 2.

A blockchain and IoT-enabled supply chain management approach is proposed to improve the security and transparency of the supply chain. Blockchain is employed to handle the data storage. Data processing and the PES requests are managed by the service controller. A queuing model is utilized by the service controller to fulfill the PES requirements. To fulfill those requests effectively within a short period, smart cities are divided into small sub-areas. Each sub-area consisted of a limited number of smart homes employed with IoTs. This SCM framework is further enhanced by optimizing the parameters in the queue model such as temperature threshold, smoke threshold, and humidity threshold to improve the difference between actual and expected arrival time. Also, it is beneficial for decreasing the end-to-end delay, actual arrival time, queue length, and utilization. This parameter optimization in the queue model is done via the proposed RF-PO algorithm. By employing this queue model, the PES request that is raised first is given more priority than the last received request. This helps to increase the transparency of the supply chain. The outcomes of the developed mechanism are correlated with various techniques

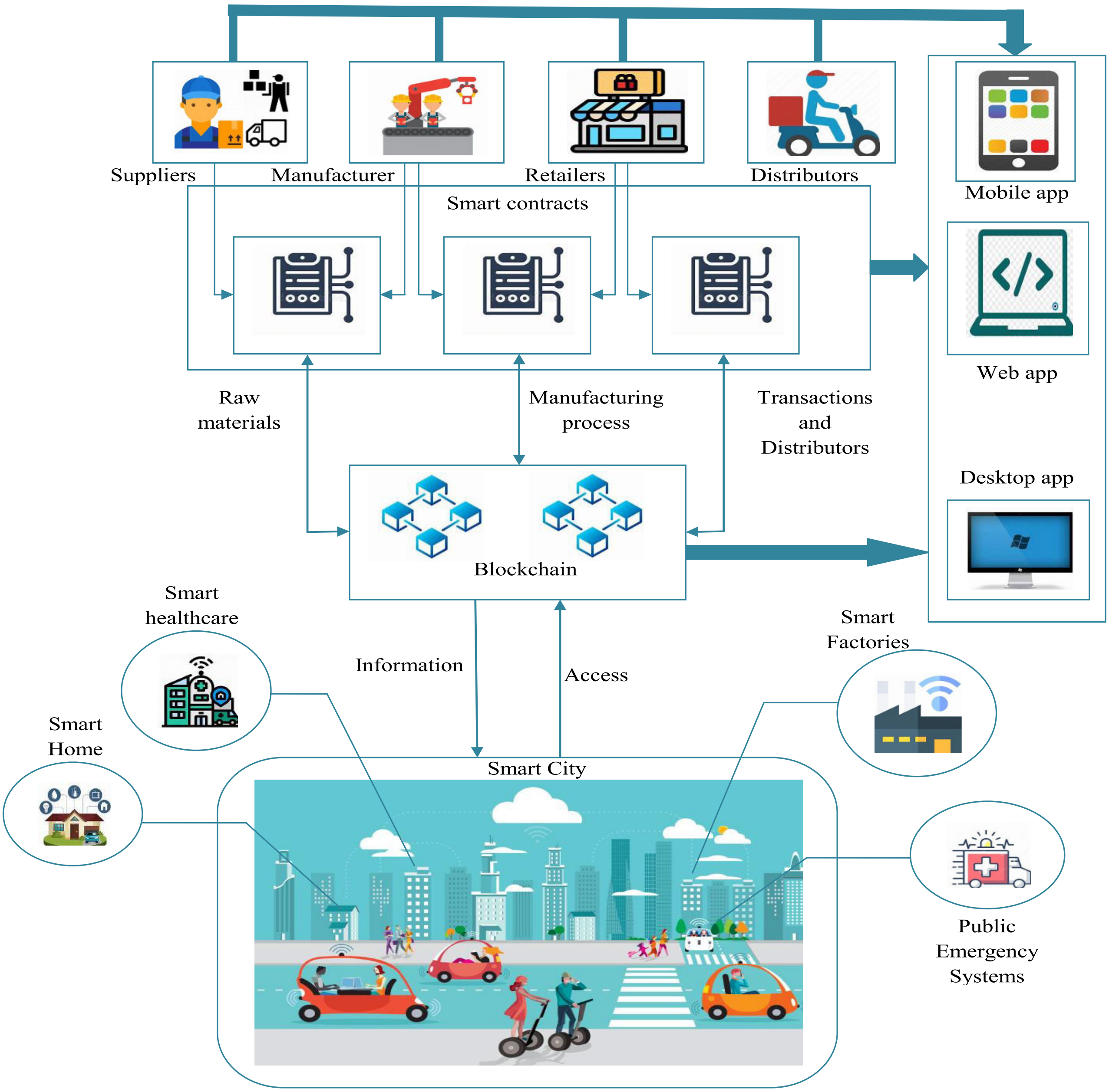

FIGURE 1. **Pictorial view of blockchain-enabled supply chain management in smart cities.**

that are used to improve the supply chain processes and algorithms.

One popular blockchain platform for supply chain management is Hyperledger Fabric. It allows for the development of secure and transparent supply chain solutions. It offers features like permission access, encryption, and privacy controls, making it an ideal choice for implementing the RF-PO. In terms of the consensus algorithm integrated into the RF-PO, it depends on the specific implementation and requirements of the SCM system. It ensures the security of the SCM system by validating and agreeing upon the order of transactions. By achieving consensus among network participants, the system ensures that only legitimate and authorized transactions are added to the blockchain, enhancing the security and integrity of the supply chain data. By combining the RF-PO with a Hyperledger Fabric blockchain platform, the proposed blockchain-enabled secure and transparent SCM system can provide enhanced security, transparency, and efficiency for supply chain operations.

E. IOT DATA COLLECTION AND SHARING RELATED PRIVACY CONSIDERATIONS

When it comes to the collection and sharing of IoT data within the supply chain, privacy considerations are crucial. IoT devices in the supply chain can gather a vast amount of data,

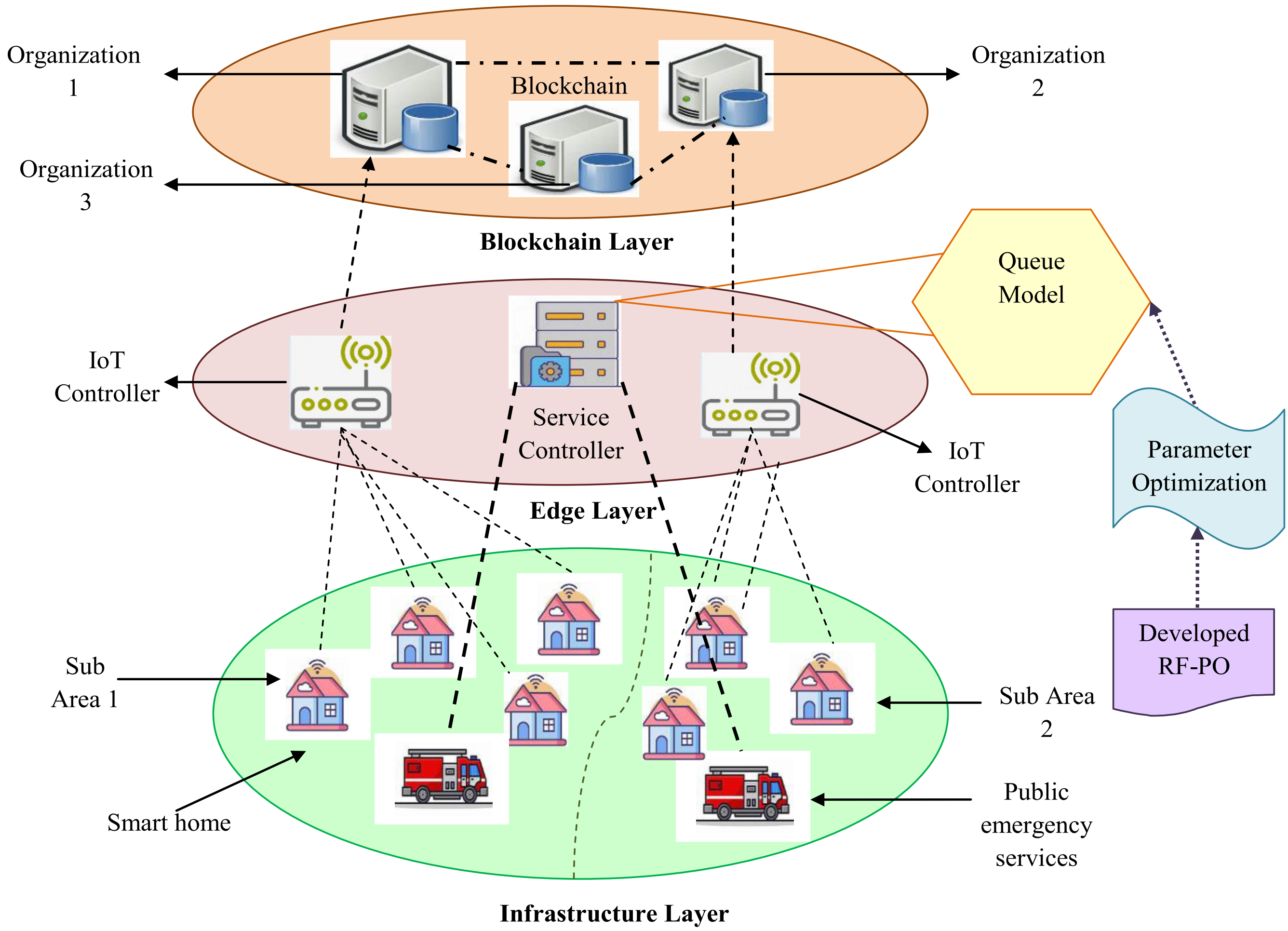

FIGURE 2. Diagrammatic view of the proposed blockchain-enabled supply chain management system.

including location, temperature, and product information. To ensure privacy, it's important to take the following considerations into account.

- ❖ ***Data Minimization***: Collect only the necessary data to fulfill the intended purpose and avoid collecting sensitive or personally identifiable information unless necessary. This helps minimize the privacy risks associated with data collection.
- ❖ ***Consent and Transparency***: Obtain explicit consent from individuals whose data is being collected and ensure transparency about how the data will be used and shared. Clear communication helps to build trust and maintain privacy.
- ❖ ***Data Security***: Implement robust security measures to protect IoT data from unauthorized access, breaches, or tampering. This includes encryption, secure storage, and regular updates to address vulnerabilities.
- ❖ ***Anonymization and Aggregation***: Prioritize anonymization and aggregation of data whenever possible to protect individual privacy. By removing personally identifiable information and aggregating data, it becomes harder to identify specific individuals or track their activities.
- ❖ ***Data Retention***: Establish clear policies regarding the retention of IoT data. Only retain data for as long as necessary and securely dispose of it when it is no longer needed. This helps minimize the risk of unauthorized access or misuse.

By considering these privacy considerations, companies can ensure that the collection and sharing of IoT data within the supply chain align with privacy regulations and protect the rights of individuals involved. The blockchain-based framework, along with RF-PO and optimal queue model, can contribute to data privacy and confidentiality in the following ways.

- ❖ ***Distributed Ledger***: The decentralized nature of the blockchain, combined with optimization algorithms, helps maintain data privacy. By distributing copies of the ledger across multiple nodes, it becomes harder for unauthorized individuals to access or manipulate the data without consensus from the network.

- ***Access Controls***: RF-PO can be employed to determine access controls within the blockchain framework. These algorithms can assign permissions and roles to participants, ensuring that only authorized individuals can view or interact with specific data.
- ***Optimal Queue Model***: The optimal queue model can help streamline and prioritize data transactions within the blockchain network. By optimizing the queue, it becomes easier to manage and control data access, reducing the risk of unauthorized access or data breaches.
- ***Smart Contracts***: Smart contracts, combined with RF-PO, can enforce data privacy and confidentiality. These contracts can define conditions for accessing or sharing data, ensuring that only authorized parties can engage with the data stored on the blockchain.

By incorporating RF-PO and the optimal queue model into the blockchain-based framework in the SCM, data privacy and confidentiality can be enhanced. These techniques work together to secure data, control access, and prioritize transactions, providing a robust environment for protecting sensitive information.

IV. EFFICIENT OPTIMIZATION STRATEGY FOR OPTIMAL TUNING OF PARAMETERS FROM QUEUE MODEL

A. CONVENTIONAL PO

Different processes of politics are mathematically modeled in the PO [26] algorithm. Parliamentary affairs, inter-party elections, election campaigns, party switching, and constituency allocation are the various levels of politics. In this algorithm, the population is divided into two categories i) constituencies and ii) political parties. Based on the constituency winner and party leader, the position of the members will change.

To win, each candidate uses their goodwill. Similarly, for forming a government, all the parties try to increase the number of seats in the parliament. In PO, the position of the candidate is upgraded based on the goodwill of the candidate. The fitness function is evaluated by the total votes of the candidate. The candidate's solution is the election process. Politics has four major phases; they are given in the following:

- Teamwork between the selected members to develop the government.
- Improvement of candidate behavior for the election process.
- Collaboration between different parties.
- Campaign for the election process.

At first, the total population E is allocated. Then, it is divided into a number of political parties. Likewise, a numbers of members are presented in each party. After dividing political parties, a potential solution is calculated. These stages are described in Eq. (1)-Eq. (3).

$$E = \{E_1, E_2, E_3, \ldots.., E_a\} \tag{1}$$

$$E_l = \left\{s_l^1, s_l^2, s_l^3, \ldots.., s_l^a\right\} \tag{2}$$

$$s_l^m = \left\{s_{l,1}^m, s_{l,2}^m, s_{l,3}^m, \ldots.., s_{l,v}^m\right\}^G \tag{3}$$

Here, the input variables are termed as v. The potential solution is indicated as s_l^m. Below Eq. (4) and Eq. (5) provides the constituency allocation process.

$$U = \{u_1, u_2, u_3, \ldots.., u_a\} \tag{4}$$

$$U_m = \left\{s_1^m, s_2^m, s_3^m, \ldots.., s_a^m\right\} \tag{5}$$

The party leader is the one who has high fitness value. The party leader s_l^* selection process is given in Eq. (6) and Eq. (7).

$$t = \arg\min_{1\le m\le a} f\left(s_l^*\right), \quad \forall l \in \{1, \ldots., a\} \tag{6}$$

$$s_l^* = s_l^t \tag{7}$$

All the party leaders are defined by Eq. (8).

$$E^* = \left\{s_l^*, s_l^*, s_l^*, \ldots.., s_a^*\right\} \tag{8}$$

The winning members for going to the parliament are estimated using below Eq. (9).

$$U^* = \left\{u_l^*, u_l^*, u_l^*, \ldots.., u_a^*\right\} \tag{9}$$

The campaign procedure is described in Eq. (10) and Eq. (11).

$$s_{l,h}^m(g+1) = \begin{cases} k^* + w\left(k^* - s_{l,h}^m(g)\right), & \begin{array}{l} if\ s_{l,h}^m(g-1) \\ \le s_{l,h}^m(g) \le k^* or\ s_{l,h}^m(g-1) \\ \ge s_{l,h}^m(g) \ge k^* \end{array} \\ k^* + (2w-1)\left|k^* - s_{l,h}^m(g)\right|, & \begin{array}{l} if\ s_{l,h}^m(g-1) \\ \le k^* \le s_{l,h}^m(g)\ or\ s_{l,h}^m(g-1) \\ \ge s_{l,h}^m(g) \ge k^* \ge s_{l,h}^m(g) \end{array} \\ k^* + (2w-1)\left|k^* - s_{l,h}^m(g-1)\right|, & \begin{array}{l} if\ k^* \le s_{l,h}^m(g-1) \\ \le s_{l,h}^m(g)\ or\ k^* \ge s_{l,h}^m(g-1) \\ \ge s_{l,h}^m(g) \end{array} \end{cases} \tag{10}$$

$$s_{l,h}^m(g+1) = \begin{cases} k^* + (2w-1)\left|k^* - s_{l,h}^m(g)\right|, & \begin{array}{l} if\ s_{l,h}^m(g-1) \\ \le s_{l,h}^m(g) \le k^* or\ s_{l,h}^m(g-1) \ge \\ s_{l,h}^m(g) \ge k^* \end{array} \\ s_{l,h}^m(g-1) + w\left(\begin{array}{l} s_{l,h}^m(g) \\ -s_{l,h}^m(g-1) \end{array}\right), & \begin{array}{l} if\ s_{l,h}^m(g-1) \\ \le k^* \le s_{l,h}^m(g)\ or\ s_{l,h}^m(g-1) \\ \ge s_{l,h}^m(g) \ge k^* \ge s_{l,h}^m(g) \end{array} \\ k^* + (2w-1)\left|k^* - s_{l,h}^m(g-1)\right|, & \begin{array}{l} if\ k^* \le s_{l,h}^m(g-1) \\ \le s_{l,h}^m(g)\ or\ k^* \ge s_{l,h}^m(g-1) \\ \ge s_{l,h}^m(g) \end{array} \end{cases} \tag{11}$$

In the above expressions, the first position of the party leader is stated as k^*. A random integer is indicated as w and it is updated using the new concept given in Eq. (14). After the campaign stage, the party-switching stage is executed. The swapping between party leaders is given in Eq. (12) and Eq. (13).

$$t = \arg\min_{1\leq l\leq a} f\left(s_l^m\right) \tag{12}$$

$$u_m^* = s_t^m \tag{13}$$

Finally, the government is formed after the election. The fitness value is improved by updating the parliamentarians u_l^m. The potential solutions are also updated about the position of parliamentarians. The winning party is indicated as l. The pseudocode of the traditional PO algorithm is shown in Algorithm 1.

Algorithm 1 PO

```
Initialize the number of total iterations G_M, switching
rate μ_M, party members, political parties, and
constituencies
Assign the value of E as given in Eq. (1)-Eq. (5)
Estimate the fitness value s_l^m
Estimate the total leaders E* in each party using Eq. (7)
Evaluate the constituency winners U* in Eq. (9)
g = 1;
E (G − 1) = E
f (E (G − 1)) = f (E)
μ = μ_M
while g ≤ G_M
    E_temp = E
    f (E_temp) = f (E)
    For each E_l ∈ E do
        For each E_l^m ∈ E_l do
            E_l^m = election campaingn
        end
    end
    Switching between parties E, μ
    Store the fitness values
    Estimate the total leaders E* in each party using Eq.
    (7)
    Evaluate the constituency winners U* in Eq. (9)
    E (G − 1) = E_temp
    f (E (G − 1)) = f (E_temp)
    μ = μ − μ_M / G_M
    g = g + 1
End
```

B. PROPOSED RF-PO

The RF-PO algorithm is proposed to enhance the performance of the queue model employed in the supply chain management framework by optimizing parameters from the queuing model. The optimized parameters are temperature threshold, smoke threshold, and humidity threshold. This optimization reduces the end-to-end delay, actual arrival time, queue length, and utilization, and also increases the difference between actual and expected arrival time. PO algorithm can help political parties and organizations make data-driven decisions by analyzing large amounts of information and identifying patterns and trends. It can assist in developing effective campaign strategies by analyzing voter behavior, demographics, and sentiment analysis from social media, allowing parties to target specific voter groups more accurately. Analyzing voter preferences and behavior can help political parties tailor their messages and policies to resonate with voters, increasing voter engagement and participation. For these benefits, we have chosen the traditional PO for performing the optimization process in the designed approach. But it heavily relies on data, which can be biased or incomplete. This bias can lead to skewed results and reinforce existing inequalities or biases in the political system. The use of personal data for PO raises concerns about privacy and data protection. There is a risk of misuse or unauthorized access to sensitive information. Thus, these drawbacks are rectified in the proposed RF-PO algorithm by upgrading the random value in the existing PO algorithm. To upgrade the random parameter, best fitness, and worst fitness values are taken into account in the suggested RF-PO. This procedure is provided in Eq. (14).

$$w = \frac{UG}{\sqrt{(UG\hat{}2 + FR\hat{}2)}} \tag{14}$$

In Eq. (14), the worst fitness score is mentioned as, and the best fitness score is stated as. The term is the random variable. Hence, the time complexity and more amounts of parameter problems are resolved by the investigated RF-PO algorithm. In addition, better optimal solutions are attained even though there is party-switching processes are done. Algorithm 2 presents the pseudocode of the proposed RF-PO algorithm.

Algorithm 2 Conventional PO

```
Initialize the number of total iterations G_M, switching
rate μ_M, party members, political parties, and
constituencies
Assign the value of E as given in Eq. (1)-Eq. (5)
Estimate the fitness value s_l^m
Estimate the total leaders E* in each party using Eq. (7)
Evaluate the constituency winners U* in Eq. (9)
while g ≤ G_M
    For each E_l ∈ E do
        For each E_l^m ∈ E_l do
            E_l^m = election campaingn
        end
    end
    Update the value of the random number w using Eq.
    (14)
    Switching between parties E, μ
    Store the fitness values
    Estimate the total leaders E* in each party using Eq.
    (7)
    Evaluate the constituency winners U* in Eq. (9)
End while
```

V. QUEUE MODEL-BASED SUPPLY CHAIN MANAGEMENT SYSTEM WITH MULTI-OBJECTIVE FUNCTION

A. QUEUEING MODEL

The queuing model [30] has three levels and it is a series-parallel network. The queuing model is defined as $Q/Q/1$ for the entire service-providing node. An exponential distribution parameter is employed to perform the service providing. First-In/First-Out (FIFO) is the basic concept for the queuing models. In addition to an exponential distribution, a demand point d is assigned to define the need for different commodities. The demand for the services is equal to the demand for the distribution centers η_c as mentioned in Eq. (15).

$$\eta_c = \sum_d \eta_d x_{cd} \quad \forall c \in C \tag{15}$$

The need for logistics centers is defined by the below Eq. (16).

$$\eta_c = \sum_d \eta_d x_{cd} = \sum_c \sum_d \eta_d x_{bc} x_{cd} \quad \forall b \in B \tag{16}$$

The demand size and demand occurrence are the two indices used for estimating commodity demands. A random variable W is assigned to define the need for a single commodity and its density function is denoted by the term $f_w(W)$. Another random integer X along with the density function $f_x(X)$ is defined to indicate the demand size. The random parameters W and X are independent of one another and it is defined in Eq. (17)-Eq. (19).

$$f_w(w) = \begin{cases} \psi h^{-\psi w}, & w \geq 0 \\ 0, & w < 0 \end{cases} \tag{17}$$

$$f_x(X) = \begin{cases} \dfrac{1}{j-i}, & i < x < j \\ 0, & otherwise \end{cases} \tag{18}$$

$$H(J) = H(WX) = H(W)\,H(X) = \frac{i+j}{2\psi} \tag{19}$$

Demand for multi-commodities is computed via Eq. (20).

$$H\left(J_d^s\right) = \frac{i_d^s + j_d^s}{2\psi_d^s} \tag{20}$$

The demand for s type commodities is described in Eq. (21).

$$\eta_d^s = \frac{1}{H\left(J_d^s\right)} = \frac{2\psi_d^s}{i_d^s + j_d^s} \tag{21}$$

$$\omega = \frac{\eta_d^s}{\lambda_d} = \frac{1}{\lambda_d H\left(J_d^s\right)} = \frac{2\psi_d^s}{i_d^s + j_d^s} \tag{22}$$

The queuing model using indices $Q/Q/1$ is defined using below Eq. (23)-Eq. (28).

$$f_{ra}(a) = (\lambda - \mu)\, e^{-(\lambda-\mu)a} \tag{23}$$

$$f_{RA}(a) = N(RA \leq a) = \int_{0dt=1-e^{-(\lambda-\mu)a}}^{a(\lambda-\mu)e^{-(\lambda-\mu)a}} \tag{24}$$

$$RA = G(RA) = \int_0^\infty f_{ra}(a)\, adt = \int_0^\infty (\lambda-\mu)\, e^{-(\lambda-\mu)a} dt = \frac{1}{\lambda-\eta} \tag{25}$$

$$RA_y = RA - \frac{1}{\lambda} = \frac{\eta}{\lambda(\lambda-\eta)} \tag{26}$$

$$RL = \eta RA = \frac{\eta}{\lambda-\eta} \tag{27}$$

$$RL_y = \eta RA_y = \frac{\eta^2}{\lambda(\lambda-\eta)} \tag{28}$$

The response time of the model is calculated using Eq. (29).

$$\begin{aligned} MinLA = &\sum_s \sum_b \frac{1}{\eta_b - \sum_c \sum_d \frac{2\psi_d^s}{i_d^s + j_d^s} x_{bc}^s x_{cd}^s} \\ &+ \sum_s \sum_c \frac{1}{\eta_c - \sum_d \frac{2\psi_d^s}{i_d^s + j_d^s} x_{cd}^s} + \sum_s \sum_d \frac{1}{\eta_d - \frac{2\psi_d^s}{i_d^s + j_d^s}} \\ &+ \sum_s \sum_c \sum_d AL_{bc}^s x_{bc}^s + \sum_s \sum_c \sum_d AL_{cd}^s x_{cd}^s \end{aligned} \tag{29}$$

The illustration of the queue model is depicted in the below Figure. 3.

B. PROPOSED QUEUE MODEL-BASED SUPPLY CHAIN MANAGEMENT

The important information criteria related to the supply chain are analyzed by the queuing model. The probabilities of delay and response time are calculated with the help of queuing models. This helps in managing an effective supply chain process. Therefore, a queuing model is employed in this work to implement an efficient supply chain management framework with high security and transparency. From this queuing model, the parameters are optimized to improve the efficacy of the supply chain. The adaption of the queuing model in the proposed work helps to decrease the waiting time by rectifying the requests based on the received time. Here, the smart city is divided into small sub-areas. The requests received from each area are managed by the appropriate PES departments. The overall efficacy of the supply chain framework is enhanced by reducing the workload with the help of the queue model. Productivity is highly enlarged using the queue model in the supply chain.

More data are collected and processed within a less amount of time without any storage issues. With the help of secure hashing methods in blockchain, the data are secured and transparency is maintained in the supply chain. Any information exchange happening in the blockchain is secured without any cyber-attacks.

The developed blockchain-based SCM framework with a queuing model eliminates the tampering and information leakage problems. It involves analyzing various factors such as arrival rates, service rates, and queue lengths to determine the most efficient configuration for minimizing wait times and maximizing customer satisfaction. By using a queue model, SCM can better manage the flow of goods and

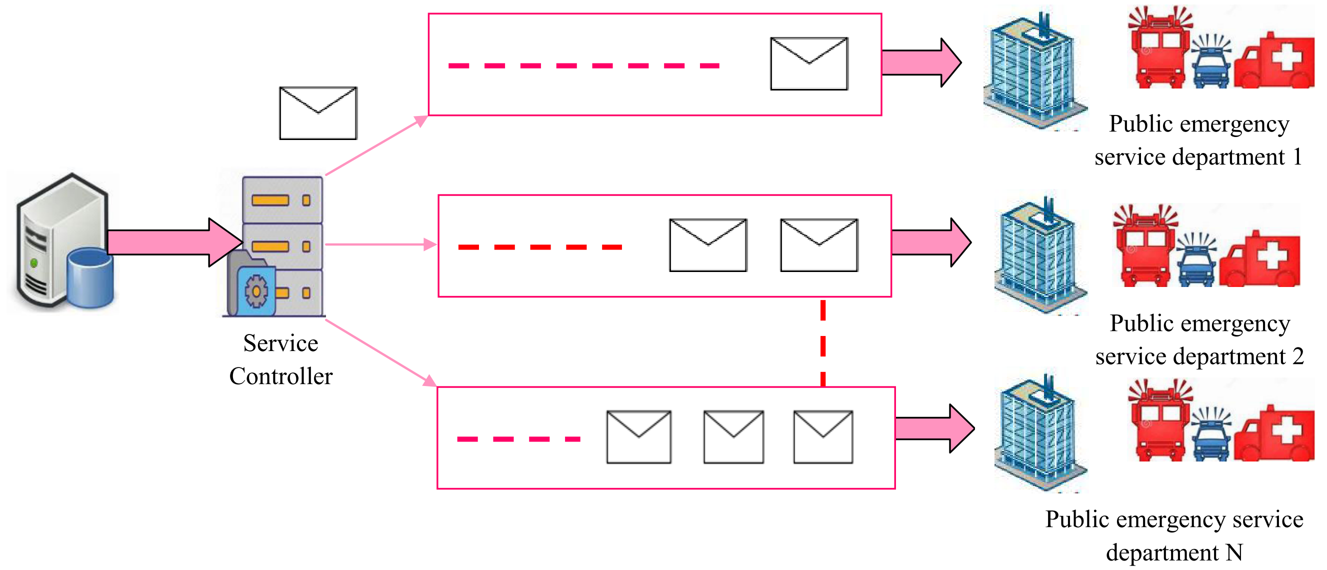

FIGURE 3. Illustration of queue model.

services, reducing bottlenecks and optimizing the overall efficiency of the supply chain. It helps in minimizing lead times by identifying potential delays or congestion points in the supply chain. This allows for timely actions to be taken to mitigate these issues and ensure smoother operations. The queue model enables better inventory management by providing insights into demand patterns, order quantities, and reorder points. This helps in reducing excess inventory and minimizing stockouts.

Relevance to SCM in smart cities and the effectiveness of resource allocation and task scheduling within the supply chain: In smart cities, where there is a high volume of goods and services being exchanged, efficient resource allocation and task scheduling are crucial for the smooth operation of the supply chain. The optimal queue model plays a significant role in achieving this efficiency and effectiveness. By applying the optimal queue model, supply chain managers can make informed decisions about resource allocation and task scheduling. They can analyze the flow of goods, services, and information within the supply chain network to identify bottlenecks and optimize the allocation of resources. This helps in reducing waiting times, minimizing idle resources, and improving overall productivity. Furthermore, the optimal queue model enables supply chain managers to optimize task scheduling. By considering factors such as processing times, deadlines, and dependencies, they can schedule tasks in a way that maximizes efficiency and minimizes delays. This ensures that resources are utilized effectively and tasks are completed promptly, leading to improved customer satisfaction and operational performance. In summary, the optimal queue model contributes to the efficiency and effectiveness of resource allocation and task scheduling within the supply chain. It helps in minimizing waiting times, optimizing resource utilization, and improving overall productivity. By implementing this model, the proposed framework for supply chain management in smart cities can enhance operational performance and provide a better understanding of how to achieve efficient resource allocation and task scheduling. The proposed queue model-based supply chain management is shown in Figure 4.

C. DESCRIPTION OF MULTI-OBJECTIVE FUNCTION

The implemented RF-PO-Queue-based secure and transparent supply chain management framework in smart cities helps minimize the actual arrival time and queue length. This helps reduce the waiting time of the persons who raised the request. Moreover, maximizing the difference in time and resource utilization helps to improve the planning process, and service levels and saves cost. The multi-objective function of the developed secure and transparent supply chain management model is given in Eq. (30).

$$jh = \underset{\{TT\mu, HT\eta, ST\lambda\}}{\arg\min} \left(\frac{1}{U + EA} + QL + AL + ED \right) \tag{30}$$

Here, the end-to-end delay is indicated as ED, actual arrival time is specified as AL. The term QL denotes the queue length. The difference between actual and expected arrival time is referred to EA and the utilization is represented as U. Humidity threshold is characterized as $HT\eta$ and it lies in the interval of $[50-75]$. The smoke threshold that is present in the range of $[100-150]$ is given as $ST\lambda$. The term $TT\mu$ denotes the temperature threshold that is present in-between $[25-65]$. The formula for estimating the queue length is given in Eq. (31).

$$QL = \eta AL \tag{31}$$

In Eq. (31), the waiting time is represented as A. The arrival time and the length of the queue are denoted as η and QL,

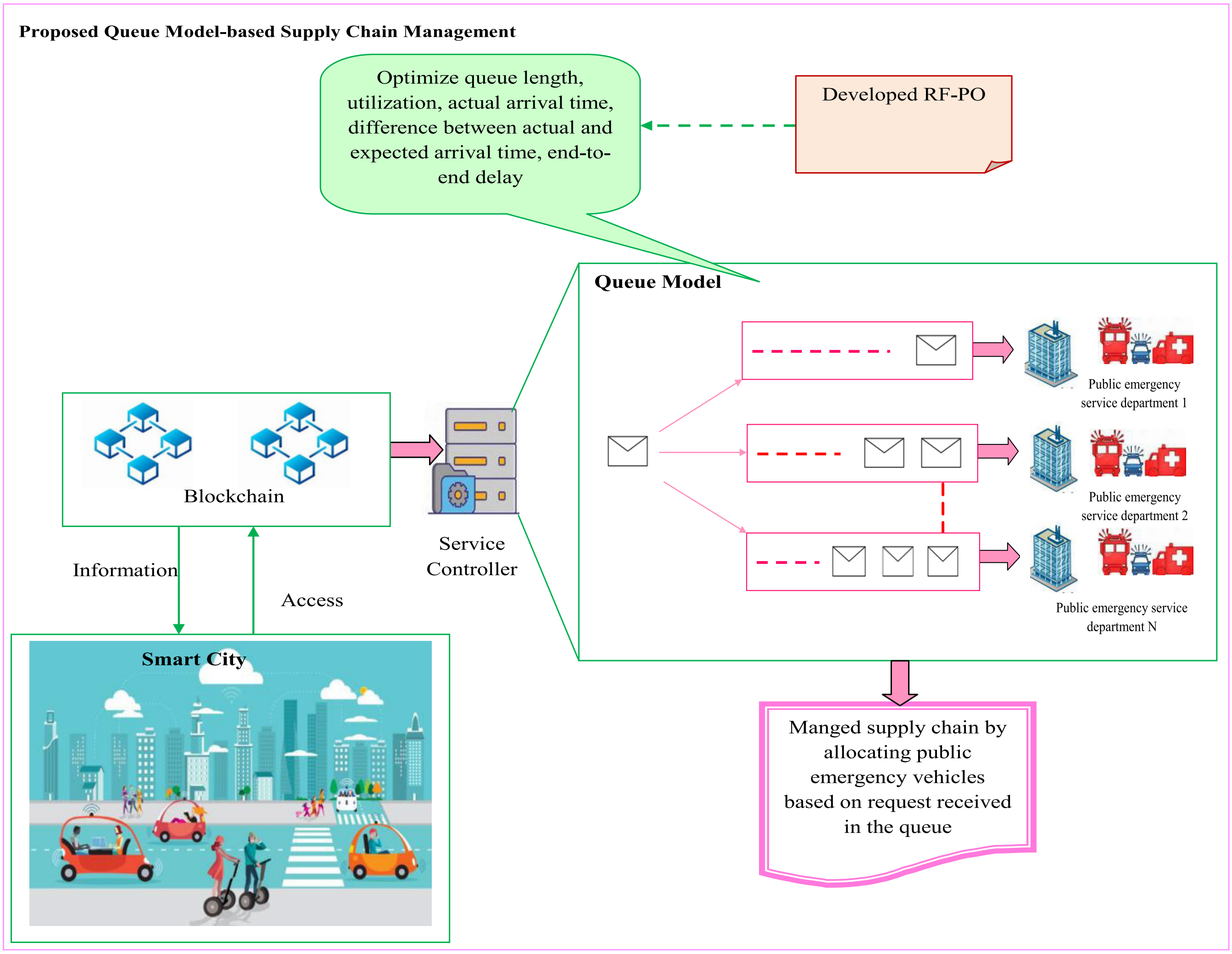

FIGURE 4. Proposed queue model-based supply chain management.

correspondingly. Arrival time in the queue is calculated by Eq. (32).

$$AL = \frac{1}{\eta \times 4.1} \tag{32}$$

Below Eq. (33) gives the calculation for delay in the queue model.

$$ED = \frac{1}{(\lambda - \eta)} \tag{33}$$

Here, the total number of requests is mentioned as λ. The estimation of utilization in the queue model is given in Eq. (34).

$$U = \frac{\eta}{\lambda} \tag{34}$$

The difference between actual and expected arrival time is computed via Eq. (35).

$$EA = \frac{\eta}{\lambda} * \frac{1}{(\lambda - \eta)} \tag{35}$$

The ability of the queue model to provide the best service within a certain amount of time is estimated by the above calculations.

VI. RESULTS AND DISCUSSIONS

A. EXPERIMENTAL CONFIGURATION

The designed Blockchain-enabled secure and transparent supply chain management for smart cities was implemented in Python. To execute this model, chromosome length was assigned as 3, and population and iteration count were allocated as 10 and 50. Other technologies and optimization approaches used for the supply chain process in smart cities were used to evaluate the effectiveness of the proposed architecture. For this purpose, the existing techniques including Blockchain technology [1], CM [2], PN [3], and BEST [4] were considered. Algorithms such as Mine Blast Optimization (MBO) [27], Archimedes Optimization Algorithm (AOA) [28], Artificial Gorilla Troops Optimizer (AGTO) [29], and PO [26] were contemplated to examine the proposed algorithm.

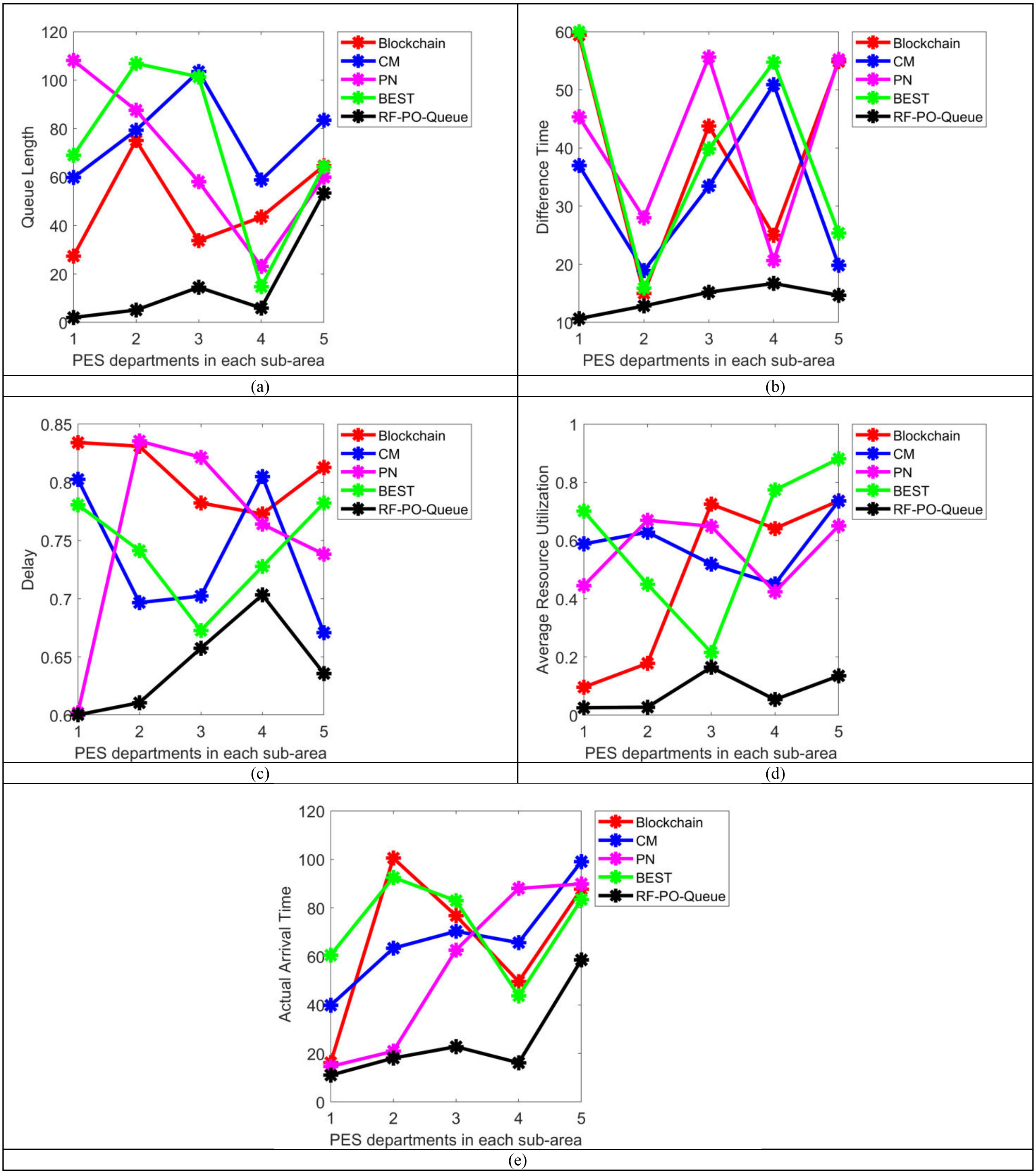

FIGURE 5. Performance validation of the proposed blockchain-enabled supply chain management framework in smart cities over existing techniques through a) Queue length, b) Difference time, c) Delay, d) Average resource utilization, and e) Actual arrival time.

B. PERFORMANCE VALIDATION AMONG DIFFERENT METHODS

The proposed RF-PO-Queue-based secure and transparent supply chain management framework in smart cities is correlated with other techniques used for the supply chain systems in smart cities. Figure 5 represents the analysis of developed RF-PO-Queue among other techniques concerning PES departments in each sub-area. The resource utilization of the implemented RF-PO-Queue is 75.67%, 73.52%, 64%, and 10% minimized than blockchain technology, CM, PN and

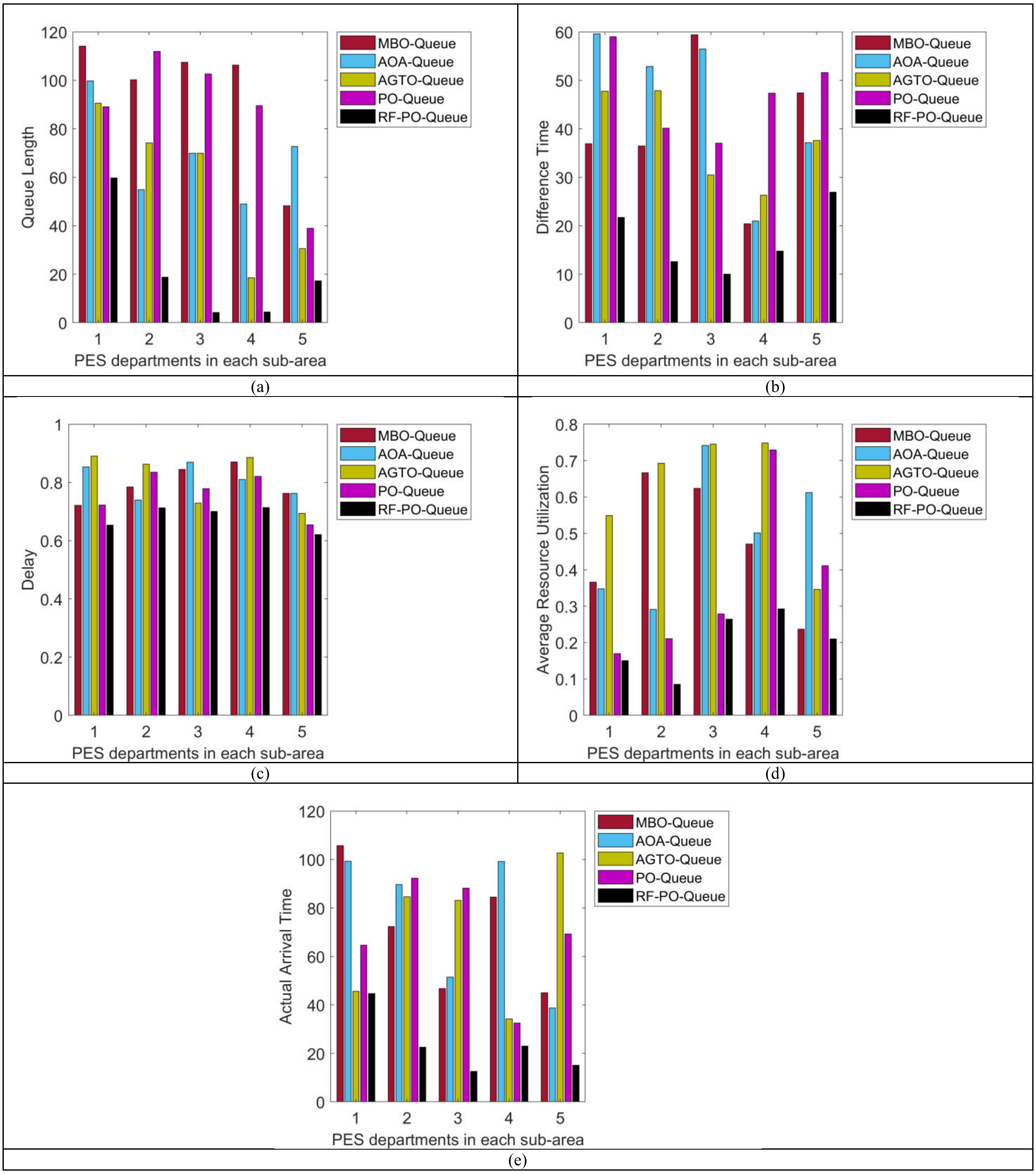

FIGURE 6. Performance estimation of the established blockchain-enabled supply chain management framework in smart cities among existing heuristic approaches through a) Queue length, b) Difference time, c) Delay, d) Average resource utilization, and e) Actual arrival time.

BEST at 2nd sub-area. Hence, the resource utilization of the implemented RF-PO-Queue is better than other models without any resource wastage.

C. PERFORMANCE VERIFICATION AMONG VARIOUS ALGORITHMS

The performance of the developed RF-PO-Queue-based secure and transparent supply chain management framework in smart cities is evaluated and the graphical results are given in Figure 6. The delay of the recommended RF-PO-Queue is 20.45%, 22.2%, 4.10%, and 9.09% minimized than MBO-Queue, AOA-Queue, AGTO-Queue, and PO-Queue at a sub-area of 5. When considering Figure 5 (a), the developed model offered effective performance, and the poor performance is given from the MBO-Queue model. Similarly, comparing all the graphs, the developed model

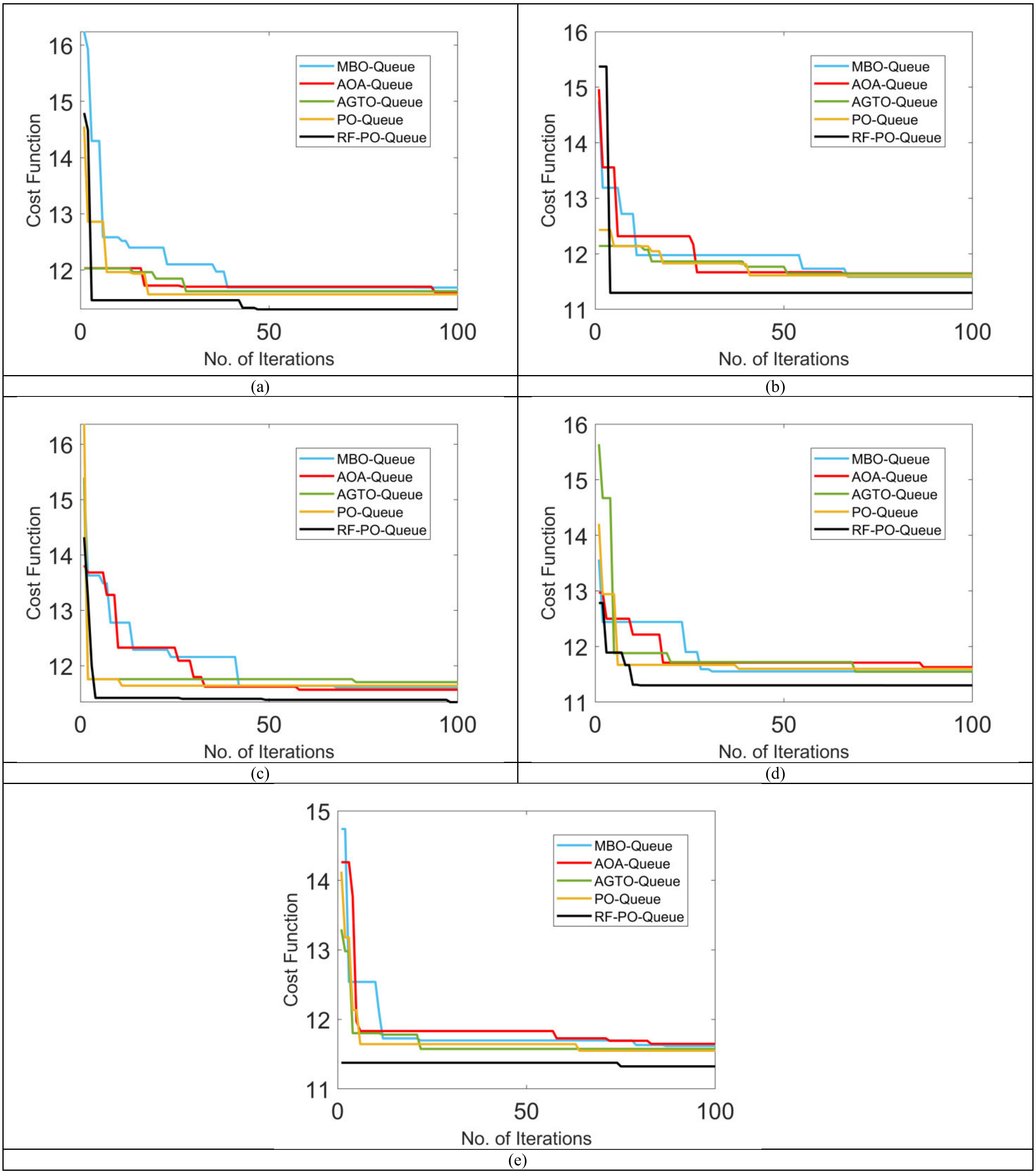

FIGURE 7. **Cost function inquisition of the implied blockchain-enabled supply chain management framework in smart cities over different algorithms.**

proves the superior analysis to others. Hence, the results showcased that the delay of the investigated model is less than other existing algorithms. The developed model provides a transparent and immutable record of all transactions and activities within the supply chain, allowing for increased visibility and accountability.

D. COST FUNCTION EVALUATION

The cost function results of the introduced RF-PO-Queue-based secure and transparent supply chain management framework in smart cities are verified by varying the total number of iterations. The convergence results of the executed RF-PO-Queue are shown in Figure 7. In Figure 7 (b), the

TABLE 3. Statistical observation results of the implemented blockchain-enabled supply chain management framework in smart cities among other algorithms.

Statistical Report					
TERMS	MBO-Queue [27]	AOA-Queue [28]	AGTO-Queue [29]	PO-Queue [26]	RF-PO-Queue
PES departments in sub-area: 1					
BEST	11.689	11.605	11.623	11.569	11.301
WORST	16.239	12.033	12.029	14.555	14.794
MEAN	12.051	11.752	11.714	11.705	11.434
MEDIAN	11.691	11.705	11.623	11.569	11.301
STANDARD DEVIATION	0.77075	0.12608	0.15603	0.41462	0.46757
PES departments in sub-area: 2					
BEST	11.584	11.648	11.643	11.597	11.298
WORST	14.748	14.965	12.141	12.431	15.371
MEAN	11.932	11.904	11.78	11.755	11.42
MEDIAN	11.976	11.668	11.705	11.612	11.298
STANDARD DEVIATION	0.48186	0.53416	0.16966	0.22553	0.69837
PES departments in sub-area: 3					
BEST	11.604	11.568	11.705	11.642	11.344
WORST	15.328	13.814	15.399	16.362	14.32
MEAN	12.008	11.911	11.78	11.699	11.451
MEDIAN	11.638	11.624	11.759	11.642	11.386
STANDARD DEVIATION	0.63284	0.59484	0.36638	0.47214	0.34838
PES departments in sub-area: 4					
BEST	11.552	11.629	11.547	11.6	11.301
WORST	13.565	12.971	15.639	14.206	12.783
MEAN	11.783	11.82	11.816	11.702	11.368
MEDIAN	11.552	11.71	11.72	11.6	11.302
STANDARD DEVIATION	0.40942	0.29259	0.65036	0.36386	0.24508
PES departments in sub-area: 5					
BEST	11.617	11.648	11.575	11.549	11.324
WORST	14.74	14.261	13.295	14.126	11.376
MEAN	11.815	11.863	11.659	11.674	11.362
MEDIAN	11.697	11.832	11.575	11.644	11.376
STANDARD DEVIATION	0.48273	0.47514	0.26674	0.34208	0.023065

cost function of the implied RF-PO-Queue is 7.37%, 3.41%, 4.23% and 1.73% superior to MBO-Queue, AOA-Queue, AGTO-Queue, and PO-Queue, correspondingly. Thus, the experimental findings proved the capacity of the developed RF-PO-Queue model. The developed model eliminates the need for transaction costs and administrative expenses associated with traditional SCM.

E. STATISTICAL OBSERVATION RESULTS AMONG OTHER ALGORITHMS

The statistical results of the designed RF-PO-Queue-based secure and transparent supply chain management framework in smart cities are given in Table 3. At PES departments in sub-area 3, the mean value attained by the RF-PO-Queue is 4.63%, 3.86%, 2.79%, and 2.11% more efficient than MBO-Queue, AOA-Queue, AGTO-Queue, and PO-Queue. Therefore, the efficacy of the proposed RF-PO-Queue-based secure and transparent supply chain management framework is higher than traditional algorithms and by automating the processes through smart contracts, blockchain eliminates the need for intermediaries, reducing manual errors, and delays, leading to faster and more efficient operations.

F. DISCUSSION

In industries with stringent regulations, such as food and pharmaceuticals, compliance with data protection, product traceability, and supply chain sustainability are of utmost importance. The developed IoT and Blockchain-Based SCM with the assistance of RF-PO address these compliance considerations in the following ways:

1) DATA PROTECTION

The blockchain technology used in the model ensures data integrity and immutability, making it suitable for meeting data protection requirements. By storing data in a decentralized and transparent manner, the developed model enhances security and reduces the risk of data tampering or unauthorized access.

2) PRODUCT TRACEABILITY

Traceability is a critical aspect of supply chain management, especially in industries where safety and quality are paramount. The blockchain-based developed model enables end-to-end product traceability by recording every transaction and movement of goods on the blockchain. This allows for real-time visibility and verification of product origins, ensuring compliance with regulatory requirements.

3) SUPPLY CHAIN SUSTAINABILITY

Sustainability is increasingly important in SCM, as companies strive to reduce their environmental impact and ensure ethical practices. The developed blockchain-based model can facilitate sustainability efforts by providing transparency and accountability throughout the supply chain. It allows for the tracking of sustainability metrics, such as carbon emissions or fair-trade certifications, ensuring compliance with sustainability standards.

By integrating blockchain technology into the supply chain, the proposed model aligns with regulatory requirements and standards in industries with strict regulations. It enables enhanced data protection, product traceability, and supply chain sustainability, helping companies meet compliance obligations while fostering trust and transparency in their operations.

G. CASE STUDY

This section is devoted to analyzing the solution canvas designed for the use case,

The decision provider is the e-commerce food chain seller [34], particularly its supply chain and management of warehouses, which must nurture and support the usage of Blockchain-based technology.

The Blockchain-based solution's consumers are the parties described in the preceding part, namely the manufacturer, storage executives, distributor/carrier, and the consumer. Certifiers and auditing firms, who inspect norms, might also be called users. They are looking for reliable data on the technique used for manufacturing and provenance to award certifications (for example, organic and bio labels).

In terms of decision-maker-user connections, warehouse managers work with producers to gather specific information while optimizing and planning inbound flows. As previously said, in this approach, Blockchain might improve the visibility of the entire network of producers and warehouses on inbound operations and inventory status.

Furthermore, the distributor/carrier works with warehouse staff to schedule time slots and distribute inbound products gathered from manufacturers. The solution could be executed through a pilot project sponsored by an e-commerce food store that picks a group of suppliers and distributors/carriers that are prepared to use Blockchain technology. The pilot project embodies an implementation and choice pathway, as it permitted to adoption of the software on a smaller scope showing the increase in the view of incoming handles and gaining insight into predicting the future purchases of goods, in addition to decreasing refunds and documents expenses to verify its return on expenditure.

VII. CONCLUSION

A blockchain and IoT-enabled supply chain management approach was proposed to improve the security and transparency of the supply chain management systems in smart cities. To rectify the storage issues as well as to secure the data, Blockchain technology was employed. In addition, a service controller was placed to process the data and manage the PES requests. A queuing model was utilized by the service controller to fulfill the PES requirements. This SCM framework was further enhanced by the developed RF-PO algorithm. This algorithm helped optimize the parameters from the queue model such as temperature threshold, smoke threshold, and humidity threshold to reduce the end-to-end delay, actual arrival time, queue length, and utilization. Also, it improved the difference between actual and expected arrival times. The queue model was employed to process the PES request which was raised first from each sub-area in the smart cities. The investigated RF-PO-Queue model helps to increase the transparency and security of the supply chain system in smart cities. The outcomes of the developed mechanism were correlated with various techniques and heuristic algorithms. The queue length of the recommended RF-PO-Queue was 90.9%, 94.04%, 93.50%, and 92.18% minimized than blockchain technology, CM, PN, and BEST in the 4th sub-area in Figure 5. Thus, the ability to improve the security and transparency of the recommended RF-PO-Queue model was higher than prior supply chain management techniques. The developed model had several potential future directions for research and development in IoT and blockchain-enabled SCM frameworks. One direction was to focus on enhancing interoperability between IoT devices and blockchain platforms. This would enable seamless integration and communication between different devices and systems within the supply chain network, leading to improved data accuracy and transparency. Another area of research was scalability. As the number of IoT devices and transactions within the supply chain increases, it became crucial to develop scalable blockchain solutions that could handle the growing volume of data and transactions without compromising performance.

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