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RESEARCH ARTICLE

A Novel Supplier-Managed Inventory Order Assignment Platform Enabled by Blockchain Technology

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ABSTRACT Supplier Managed Inventory (SMI) can be considered an enabler for supply chain coordination in which the supplier takes over the customer's inventory to optimize the supply chain. However, the successful implementation of SMI is centered on the high level of trust, accurate data transfer, and efficient interaction between parties. This requires the sharing of information through supply chain stakeholders which face resistance and challenges due to the fear that this information will be revealed to its competitors and transparency of data. This paper has investigated the application of Blockchain technology and its potential for successful SMI implementation. The paper has proposed a Blockchain framework for the coordination of suppliers and customers. The framework includes a mathematical model for multiple supplier-customer order fulfillment which is embedded in the blockchain framework. The paper has demonstrated case studies to evaluate the performance of the proposed model with literature discussing the details of its blockchain framework.

INDEX TERMS Supplier managed inventory (SMI), blockchain technology (BC), order assignment, supply chain management (SCM).

I. INTRODUCTION

Supply chain management refers to the processes involved in the supply of raw materials or organizational components that a company requires during the production of a product, as well as the delivery of those products and services to customers. It is also responsible for facilitating the transfer of orders and services among the various stakeholders involved [1], [2]. The modern supply chain is characterized by a variety of complex factors that can negatively affect its efficiency and effectiveness. These factors include a lack of transparency, volatility, disruptions, delays, manipulation, theft, and uncertainties. To achieve cost efficiency in the supply chain, effective inventory management is essential for balancing supply and demand. To address these challenges, several policies and strategies have been developed, including Quick Response (QR), Collaborative Planning, Forecasting, and Replenishment (CPFR), and Just-in-Time (JIT). Among these, supplier-managed inventory (SMI) stands out as one of the most crucial aspects of inventory management [3], [4]. SMI is a strategy in which the supplier assumes responsibility for managing the customer's inventory, aiming to optimize the supply chain. This approach offers numerous benefits to various stakeholders involved in the supply chain [3]. Indeed, SMI has the potential to reduce inventory costs and enhance cooperation and coordination between suppliers and customers. This, in turn, leads to improved accuracy and efficiency within the supply chain [5], [6], [7]. The efficient flow of information ensures the success of SMI performance. Therefore, the supplier needs a platform that must be created through the supplier to be able to access the customer's data so that he can use the right information to optimize his inventory [3]. There are additional challenges that hinder the success of SMI. One of these challenges is the struggle to establish trust among the various participants involved. Even when some information is exchanged, actors within the

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supply chain might be reluctant to share detailed information due to concerns about revealing valuable insights to their competitors. Data transparency, centralization of data centers, and information traceability are crucial considerations for stakeholders [8]. Blockchain technology is recognized for its potential to revolutionize the SMI process and has attracted the attention of researchers and companies in the field of inventory management and supply networks [5], [9]. Blockchain technology has the potential to replace traditional systems such as CPFR, QR, and JIT practices across the supply chain [10]. This technology creates a platform for all business partners to effectively coordinate and communicate with each other in a decentralized network [11], [12]. There is a limited amount of existing research on supply chain collaboration models that specifically explore the impact of blockchain technology on the supply chain. The primary objective of this paper is to propose a solution based on blockchain technology that can enhance the SMI model within the supply chain. The main contributions of this study can be summarized as follows:

- Blockchain- supplier managed inventory (Block-SMI) distributed platform
- A consensus mechanism for the order replenishment in supplier-managed inventory strategy
- An effective solving mathematical model based on blockchain technology in supplier-managed inventory.

II. LITERATURE REVIEW AND RELATED RESEARCH STUDIES

In this section, the concept of integration between supplier-managed inventory (SMI) and blockchain technology (BC) is discussed. Therefore, this section focuses on two issues:

A. Importance of supplier-managed inventory.
B. Blockchain-based supplier-managed inventory.

A. IMPORTANCE OF SUPPLIER-MANAGED INVENTORY

In the 1980s, customers encountered challenges in effectively managing their inventory, which led to the recognition of a collaborative approach known as SMI. Under this approach, the supplier assumes responsibility for managing the customer's inventory levels. Consequently, the customer's warehouse inventory data is shared with the supplier, facilitating the delegation of inventory operations to the supplier. The SMI mechanism also entails the establishment of a direct agreement between the supplier and the customer. These agreements can encompass various aspects, such as the extent of participation, logistics collaboration, and terms related to production and distribution. Such agreements play a vital role in fostering cooperation among the involved parties. [13]. It also helps to reduce the cost of transportation among members, so that the supplier can reduce the frequency by holding inventory until the capacity requirement is met [7], [14]. Some authors have used SMI for coordination and cooperation in the supply chain and as a driver for supplier selection [8].

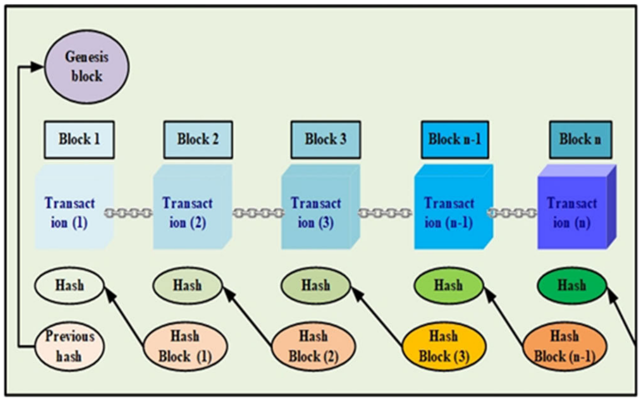

FIGURE 1. Blockchain architecture.

B. BLOCKCHAIN-BASED SUPPLIER-MANAGED INVENTORY

An efficient replenishment strategy, such as SMI, by eliminating the need for traditional orders, creates an effective platform for information exchange. SMI operations are usually carried out by centralized network administrators, who are often SMI service providers [15]. However, the adoption of blockchain technology in SMI processes removes the need for service providers, leading to minimal human involvement and decreased transaction costs. For the first time, Satoshi Nakamoto introduced blockchain technology in 2008 and used blockchain as a platform to decrypt bitcoins [16]. A blockchain is a decentralized distributed ledger or information structure that can hold any information, such as transactions and records, which are simulated and shared between members of a network. This has created a new peer-to-peer communication platform that is, secure and reliable [17] as shown in FIGURE 1 in the form of a blockchain architecture.

Furthermore, the inherent features of blockchain, such as its ability to maintain records and employ cryptographic techniques, contribute to enhancing data security, data integrity, and the immutability of stored transactions [18]. As a result, blockchain technology reinforces the fundamental principles of SMI, which include data sharing, transparency, and traceability. By leveraging blockchain, data visibility and product traceability are improved, as sales levels and customer inventory information become transparent to all stakeholders within a private and permissioned network [19]. As a result, providing this information to suppliers promptly enables them to accurately assess product demand by continuously monitoring inventory levels [20]. Hence, employing a blockchain solution integrated with decentralized applications can establish an SMI system that dynamically meets customer demand [12]. As shown in TABLE 1, in recent years, there has been a significant increase in the number of researchers exploring the application of blockchain

TABLE 1. Recent research studies on blockchain technology applications in the vendor-managed inventory.

Ref.	Main Idea	Multi supplier – Multi customer	Mathematical model	blockchain
[12]	Blockchain-based VMI	×	×	Smart contract and data security
[21]	Blockchain for decentralized collaboration.	✓	×	VMI
[22]	VMI relationships based on blockchain	×	×	VMI and Smart contract
[8]	Blockchain between vendor and the buyer.	✓	×	Smart contract
[11]	Blockchain-based IT system in supply chain	×	×	supply and demand information
[23]	Blockchain-based inventory sharing	×	×	Ethereum smart contracts
[24]	Blockchain for transparency, data integrity	×	×	transparency, data integrity
[25]	Blockchain-based pharmaceutical supply chain system (PSCM)	×	×	pharmaceutical SCM
[26]	a specified architecture in cloud manufacturing based on blockchain	×	uncertain	order assignment
[27]	everything as a service (XaaS) based on blockchain	×	uncertain	order assignment
[17]	Blockchain to security and scalability	×	×	security and scalability of the cloud manufacturing (CMfg)
[28]	blockchain in the SCM context	×	×	blockchain–SCM integration
This paper	Improve the order assignment based on blockchain technology.	✓	Uncertain - genetic algorithm	optimal order in SMI

technology to Supplier Managed Inventory (SMI) and order assignments. However, much of the existing literature primarily focuses on establishing trust among the different components of an SMI strategy or presenting an architectural framework for implementing blockchain in SMI. This paper aims to bridge this gap in the literature by proposing a consensus mechanism that addresses optimization problems, including order assignment and matching requests within supplier-managed inventory. Additionally, the paper will also provide an architecture for implementing the proposed solution.

Extensive research has been conducted to address the challenging nature of order assignment problems in supplier-managed inventory, which are classified as NP-hard. The goal has been to discover optimal or nearly optimal solutions by utilizing metaheuristic algorithms, as discussed in [29]. These algorithms offer effective approaches for exploring large solution spaces and have shown promise in overcoming the computational complexity associated with NP-hard problems. However, this research faces challenges such as local optimal traps and slow convergence. To address these issues, blockchain technology provides a solution by enabling service matching agents to interact in a decentralized environment, thereby addressing the problems of supply chain collaboration. So this study is one of the first attempts to apply blockchain technology to the order assignment and matching request process in a supplier-managed inventory strategy. In most research studies, supplier-managed inventory has been approached from a centralized perspective, with one central management entity overseeing the inventory management process. However, Block-SMI proposes a decentralized approach, where multiple solvers work in parallel to solve sub-problems, and the results are recorded in the blockchain ledger. The use of blockchain as a distributed model in supply chain management is a relatively new area of research, and there are still relatively few studies that have explored its potential. However, there is growing interest in the use of blockchain to improve supply chain efficiency and transparency, and we can expect to see more research in this area in the future. By leveraging the benefits of blockchain, such as decentralization, immutability, and transparency, Block-SMI represents a promising solution for the supplier-managed inventory problem, which can improve supply chain efficiency and reduce costs.

III. BLOCK-SMI DISTRIBUTED PLATFORM

A. PROBLEM STATEMENT

The SMI strategy creates an efficient platform for exchanging information between parties by eliminating traditional ordering methods. SMI service providers, acting as administrators in a centralized network, carry out the process. To achieve effective managed inventory, certain requirements must be met, including sharing information, establishing mutual trust, integrating systems, and fostering long-term cooperation [8]. However, the high number of participants, distribution channels complex processes, and the lack of trust of the parties make SMI implementation difficult and prevent its acceptance. According to the literature review, it has been identified that the SMI problem, which falls under the category of NP-hard problems, can be transformed into an order assignment problem. NP-hard problems are known to be the most difficult optimization problems in combinatorial domains, and finding an efficient solution for them is a challenging task. Currently, there is no polynomial time algorithm that can solve NP-hard problems with certainty. In fact, in the worst-case scenario, algorithms attempting to solve NP-hard problems may experience exponential execution times, making them computationally demanding and time-consuming. As a result, the efficiency of solving NP-hard problems decreases significantly as the problem size increases. Evolutionary algorithms, such as genetic algorithms, particle swarm optimization algorithms (PSO), artificial bee colony algorithms (ABC), and ant colony algorithms (AC), among others, have been explored as potential solutions for matching requests in SMI. Evolutionary algorithms, unlike precise methods, do not offer a guarantee of achieving the optimal solution. However, they offer a heuristic approach that can efficiently search for near-optimal solutions by iteratively evolving a population of candidate solutions. These algorithms leverage concepts inspired by natural evolution and swarm intelligence to explore the solution space and converge toward satisfactory solutions. However, they can find a reasonably good solution in a reasonable amount of time, which makes them suitable for addressing the computational complexity of NP-hard problems like SMI [26]. The utilization of blockchain technology in implementing SMI offers several advantages, including the elimination of service providers, resulting in reduced transaction costs and improved ordering rates. One way to achieve this is through the use of Ethereum blockchain technology, which employs smart contracts to execute verified transactions with predefined conditions. Smart contracts enable auto-mated and transparent execution of transactions without the need for intermediaries, streamlining the ordering process and enhancing overall efficiency in SMI. [12], [21]. Therefore, blockchain technology reinforces the principles of managed inventory, which include data sharing, transparency, and traceability. This paper proposes a novel supplier-managed inventory model called Block-SMI, which is based on blockchain technology. Block-SMI is a customer-supplier collaboration architecture that utilizes blockchain technology to divide the main service integration problem into smaller sub-problems, each dealing with a smaller portion of the service/demand pool. Block-SMI aims to utilize the capabilities of blockchain technology to address the limitations of centralized approaches. Centralized approaches often struggle with large-scale problems and struggle to derive near-optimal solutions efficiently. By leveraging blockchain technology, Block-SMI seeks to overcome these challenges and achieve more efficient and effective solutions. Block-SMI operates under the same hypothesis as the supply chain collaboration model and seeks to address the challenges of scaling by utilizing the decentralized and distributed nature of blockchain technology.

B. CONCEPTS OF BLOCK-SMI

Block-SMI is a peer-to-peer supplier-managed inventory platform between the supplier and the customer that can create and submit the suitable inventory to the customer in real time. The platform can be configured to process, manage, and control inventory where the blockchain peers are the solvers while the suppliers and customers are part of the platform. This section describes the introduced platform Block-SMI. A high-level abstract diagram of the platform is displayed in FIGURE 2. To demonstrate the main concepts of Block-SMI, the main blockchain elements in this platform are defined in the following sections.

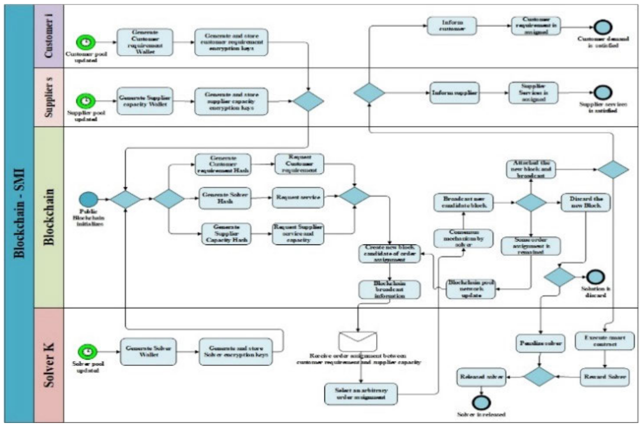

FIGURE 2. Business process-modeling notation (BPMN) for block-SMI.

C. ENCRYPTION MECHANISM

One of the main cores of blockchain technology is cryptography. The purpose of this science is to create rules that enable users to communicate with each other in an insecure environment while preserving the privacy and authenticity of their data. To ensure the integrity of data and the legitimacy of messages flowing in the network, authentication blockchain must use cryptographic techniques (such as hashing). The hash function refers to a mathematical algorithm and a series of numerical calculations that map different data into a bit string (of the same size) [26].

D. TRANSACTIONS AND BLOCKS DEFINITIONS

Blockchain is a distributed ledger technology that comprises a series of blocks inter-connected in chronological order. Each block contains a list of transactions recorded over a specific period. The initial block in a blockchain is known as the genesis block, and subsequent blocks are linked to their preceding blocks. This linkage is established by including the hash of the previous block in the new block. This ensures the immutability and integrity of the blockchain as any change in a previous block would result in a mismatched hash and disrupt the chain. This ensures that any tampering with the data in one block will be detected since it will change the hash value of that block and all subsequent blocks. In the case of Block-SMI, transactions refer to the amount of inventory that the supplier sends to the customer. These transactions are recorded in the blockchain, and they mainly focus on the details of order assignment and matching requests in supplier-managed inventory. The body section of each block in the blockchain carries a set of data about the transactions performed during a specific time slot, including the customer's demand, the supplier's inventory, and the cost of fulfilling the customer's demand. By recording these transactions in the blockchain, Block-SMI ensures the immutability and transparency of the supplier-managed inventory process, thereby improving supply chain efficiency and reducing costs. Equation (1) illustrates the public Blockchain (PBN) of Block-SMI. Specifically, the PBN consists of three sets of nodes: the supplier pool (SP), the customer pool (CP), and the solver pool (SoP). These nodes are updated at each iteration of the Block-SMI model.

$$\text{PBN} = (\text{SP, CP, SoP, Smart Contract,} \times \text{Consensus Method, Transaction.}) \tag{1}$$

There is a separate ID with a public key for the customer and the supplier, and there is also an ID for the solver. A transaction specifies how many orders are shipped from a supplier to a customer. The customer and the supplier sign through their public key, and most importantly, the customer signs with their demand amount, and the supplier signs with their available capacity. The capacity indicator is the same as the account number which shows whether the supplier has the capacity or not. Therefore, from these signatures, it can be understood that the block that is attached does not create a contradiction. To keep all transactions in the Block-SMI confidential, two types of cryptographic keys must be adopted. Public key or verifier and private key or secret. In the Block-SMI model, private keys (SKs) are generated by entities and utilized as signatures to access data. In contrast, public keys (VKs) serve as an authentication mechanism to grant access to data. In this process, a supplier creates both a private key and a corresponding public key. The supplier keeps the private key secure while sharing the public key with the customer. This enables the customer to authenticate and access the relevant data. The public blockchain generates its own unique public and private keys through hashing, as represented by Equation (2), to ensure the secure broadcasting of information. In the blockchain, every component, including the customer pool and the supplier pool, must generate its hash to uniquely identify itself within the Public Blockchain Network (PBN). This hash serves as a unique identifier for each component within the network as shown in Equations (3) and (4) (where I, S = customer and supplier pool sets, respectively). Each supplier and customer in the PBN is identified with their verification key.

$$PBN_{public} = \text{Hash}\left\langle PBN_{private}\right\rangle \tag{2}$$

$$CP_{i,p\ ublic} = \text{Hash}\ \left\langle CP_{i,private}\right\rangle \tag{3}$$

$$SP_{s,public} = \text{Hash}\ \left\langle SP_{s,private}\right\rangle \tag{4}$$

Once the network is encrypted, the customer pool (CP_i) and supplier pool (SP_s) submit their demand and supply data on the PBN, and make their confirmation keys publicly accessible so that all nodes can access this data synchronously. The data that must be included in the request packages consists of the following information: (1) for (CP_i): demand pool's ID, demand quantity, delivery time, price, budget encryption key, and so on (5); (2) for (SP_s): service pool's ID, capacity, budget, incentive/price, response time, encryption key, and other relevant information. (6).

$$CP_i\text{-Request} = \text{Hash}\ \langle ID_i, D\,T_i, D\,Q_i, P_i, B_i, \times C\,P_{i,public,.......}\rangle \tag{5}$$

$$SP_s - \text{Request} = Hash\ \langle ID_s, T\,C_s, C_s, P_s, B_s, R\,T_s, \times S\,P_{s,public,.......}\rangle \tag{6}$$

With the solver accessing the required data that includes the amount of customer demand and the amount of supplier capacity from a sub-problem. At this stage, the Solver provisions the smart contract, which refers to the mining operation, to match each customer's order with the most suitable supplier. The Solver is responsible for providing the necessary smart contract for this purpose. When the matching problem between the supplier's inventory and the customer's demand (SMD) and optimal order (OO) is finished, the resulting solution applies the hash function using the public keys of the suppliers and customers. Similarly, in the described process, the Solver attaches its verification key and the requested reward to the Block. This Block is then signed either by the supplier pool or the private key customer pool. This signing process ensures the authenticity and integrity of the information attached to the Block, and it helps establish trust within the Block-SMI platform. This ensures that the Solver's identity and the desired reward are associated with the Block in the blockchain network. The obtained transactions (transaction means the amount of inventory or order sent from the supplier to the customer) are placed in a block and encrypted. Then the created block is connected to the blockchain pool and broadcasted to be confirmed by the consensus mechanism. Therefore, when the transactions are placed in the block, the solver broadcasts the candidate block (7) to confirm the solution in the consensus mechanism in the blockchain network.

$$\text{Candidate block} = \text{Hash} \left\langle \left[\left[\left\{ \begin{array}{c|c} VK_{CP_i} & \left\langle VK_{SP_s} - SMD - OO - VK_{CP_i} \right\rangle \\ VK_{SP_s} & \langle singed\ by CP_i \text{ or } SP_s\rangle \\ & \left\langle VK_{S_k} Reward\right\rangle \end{array} \right\} \right] \right] \right\rangle \tag{7}$$

Since the first node was added to the blockchain pool, the block is attached without contradiction. When the block is attached, all capacities and demands are updated. When the solver (2) wants to attach its block, it does not know that the solver (1) has attached its block, which is the optimal solution. Therefore, solver (2) also connects and broadcasts its block in the blockchain pool. If the amount that solver (2) sends to the blockchain pool in its block is more than the client's demand, the blockchain returns that block, and solver (2) must solve the sub-problem again. Because the block that has connected the solver (2) to the blockchain made the answer possible, it must update the capacity and demand values (more details in scenario 2). A smart contract refers to a pre-defined set of terms established between a supplier and a customer. These contracts serve as agreements that govern the provision of supplier services to meet the specific needs of the customer within the blockchain. Smart contracts executed on a distributed ledger benefit from an encrypted and decentralized infrastructure, which enables the

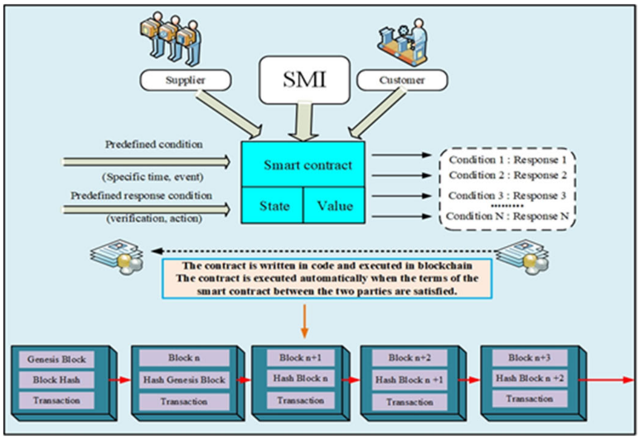

FIGURE 3. Operation mechanism of the smart contract between supplier and customer.

execution and recording of transactions. As a result, smart contracts in blockchain are commonly programmed using a procedural language. This procedural language allows for the specification of step-by-step instructions that define the logic and behavior of the smart contract when it is executed on the blockchain network. The use of procedural language ensures that the smart contract functions as intended and carries out the desired actions securely and transparently. When the customer submits his request to the supplier, he also provides information about the data, order cost and payment method, price, delivery time, and so on. Then the supplier negotiates with the customer to decide on these rules and turns them into these rules as a smart call. Deploy through the block in BCN. A smart contract between supplier and customer is shown in FIGURE 3.

E. MINING OPERATION

Mining is responsible for validating transactions in the blockchain. This function ensures the validity of all transactions in the blockchain and helps ensure that the recorded transactions are valid and without any tampering. Miners check the transactions in the block and confirm if they are correct. Miners are interested entities in solving a series of mathematical equations and puzzles. Block-SMI similarly utilizes this function: In the Blockchain context, the role of "Solvers" is replaced by the "miners" component. Miners can be individuals or large companies with sufficient computing power, responsible for solving the assigned order assignments, which involve determining the quantity of inventory to be sent from the supplier to the customer. Similar to other entities in the Peer-to-Peer Blockchain Network (PBN), Solvers (miners) are required to present their hash keys to connect to the Blockchain network. These hash keys serve as identification and verification mechanisms to ensure the integrity and security of the network as described in (8) (S = Solver set).

$$S_{k,p\ ublic} = Hash\left\langle S_{k,private}\right\rangle \tag{8}$$

F. CONSENSUS MECHANISM

The most important consensus algorithms in blockchain are Proof of Work (PoW), Proof of Stake (PoS) Algorithm, Proof of Burn (PoB), Proof of Capacity (PoC), Proof of Storage, Delegated Proof of Stake (DPoS), Proof of authority (POA) and Practical Byzantine Fault Tolerance (PBFT) [30] to ensure the security of the blockchain. Blockchain-based supplier-managed inventory platform, a specified proof of work mechanism is designed. In this mechanism, each solver can prove (PR) and attempt to solve a dedicated mathematical and cryptographic (PM) puzzle that is its set of order assignments through its optimization methods. Then the new block is created by the solver and distributed in the blockchain network for consensus. The consensus mechanism offered in the Blockchain-based supplier-managed inventory encourages solvers to better packages of order assignments. (9) depicts the PoW mechanism in Block-SMI:

$$Hash_x = Hash\langle PM, P\,R\rangle \tag{9}$$

This cryptographic hash function is summarized as follows (10), as shown at the bottom of the next page.

In the Block-SMI model, any changes in the supplier service information or customer demand result in changes in the hash of the block. In such cases, the new block cannot be connected to the previous block because the hash of the new block does not match the hashes of the previous blocks in the blockchain. This ensures the integrity and security of the data stored in the blockchain, as any attempt to modify the data would require changing the hashes of all subsequent blocks, which is computationally infeasible.

G. REWARD OR INCENTIVE MECHANISM

Solving a complicated mathematical problem, for instance, services composition in supplier-managed inventory brings its costs. Solvers must use their computing power to solve the given problem. Therefore, they need incentives or rewards to be able to confirm transactions. In the blockchain, a reward function is shared among all participants to encourage them to solve the cryptographic puzzle. Any solver who can combine the services between the customer and the supplier faster will receive the reward. In the Block-SMI platform reward has been defined as a function of objective function optimality of order assignment set as shown in FIGURE 4. As the solvers compete with each other to propose valid and optimal sets of order assignments, conflicts arise. They face a decision between continuing to improve the optimality of their proposed order assignments or stopping and announcing their sets of order assignments. The solver that emerges as the winner will receive a reward for their successful solution. The graph shows that solvers will be rewarded equally according to the capacity and computational power they have to solve the combination of services between the supplier and the customer.

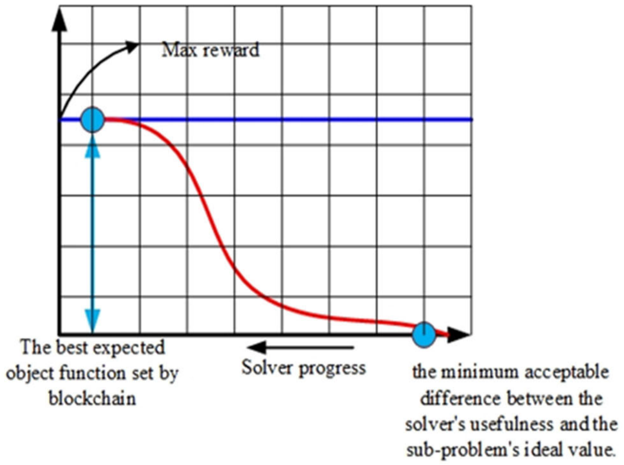

FIGURE 4. Reward schematic model for each solver (X-axis and Y-axis are solver gained object function and solver reward respectively).

IV. BLOCK-SMI MATHEMATICAL MODEL

In this section, a mathematical model has been formulated and developed. This model is divided into two parts: 1)TC_s (12); It is related to the total cost of the supplier, 2) TC_c (13); It is related to the total cost of the customer. First, the problem is solved in a centralized network using a genetic algorithm and provides the total cost value (TC_{sc}). Because of the increase in the number of suppliers, customers, and orders (orders), it does not give us a definite answer and it cannot be solved in Games software. Therefore, the genetic algorithm gives us a non-deterministic optimal solution and the solution time in a specific iteration. As mentioned in the previous section, first suppliers and customers register in blockchain networks. In the Block-SMI model, solvers choose a sub-problem from the pool of supplier capabilities and customer requirements once they have acquired the required data. Subsequently, they generate a smart contract to facilitate the matching of the customer's demand with appropriate suppliers. The smart contract is generated based on the data obtained and the requirements specified by the customer, and it is designed to ensure that the terms and conditions of the agreement are met by all parties involved in the transaction. A public and private key is created and encrypted for each. Each customer announces their orders/demands and suppliers their inventory capacity. After the operation of matching an order to a supplier by the solver, the candidate block is created and distributed in the blockchain network. In each block, a list is provided that includes the supplier, the customer supply plan, and the amount of stock that must be sent to the customer. Also, the values of cost, order, maintenance cost, etc. Therefore, a set of q^k_{xijs} is sent to the blockchain network. In the proposed Block-SMI solution, transactions are primarily focused on achieving optimal order fulfillment. This is achieved by matching the customer's requirements with the supplier's capabilities to ensure that the customer's expectations regarding material fulfillment are met. The objective is to find a suitable supplier that can effectively meet the customer's requirements once a match is made. By leveraging blockchain technology, Block-SMI aims to provide a decentralized and secure environment for facilitating such transactions, thereby streamlining the supplier-managed inventory process and improving supply chain efficiency. When solvers select a sub-problem, they attempt to solve the customer's demand based on the amount of inventory available from the suppliers. They propose the best service combination based on the overall cost of inventory between the supplier and the customer in the sub-problem. The solvers take into account various factors, including the availability of inventory, the cost of inventory, and the customer's demand, to propose an optimal solution that meets the customer's requirements while minimizing the overall cost of inventory for both the supplier and the customer. The decision variable on how to allocate the amount of inventory or orders sent from the proper supplier to the customer and also the total amount of inventory. q^k_{xijs} Attention indicates that order j for customer i is allocated to supplier s in the sub-problem x by Solver K and Q_j is the total amount of inventory.

Indexes:

i: customer

j: order

s: supplier

Parameters:

V_j : Space required to store a unit of j^{th} orders

C_j : Cost of production per unit of order j for the supplier

D_j : Demand of j^{th} order by all customers in T cycle

A_j : Cost of setting up the production of j^{th} orders for the supplier

h_j : cost of holding a unit of j^{th} orders in the store of the supplier

F_i : Capacity of the i^{th} customer store

B_i : Budget of the i^{th} customer in T cycle

F_s : Capacity of s^{th} supplier store

B_s : Budget of the s^{th} supplier in T cycle

h_{ijs} : cost of holding a unit of j^{th} orders in the store of the i^{th} customer by s^{th} supplier

c_{ijs} : The purchase price of each unit of j^{th} order by i^{th} customer from the s^{th} supplier

$$Blockk_x = Hash \left\langle \left\{ \begin{array}{c} VK_{CP_i} \\ VK_{SP_s} \\ Hash\ of\ the\ pivious\ Block_x - 1 \end{array} \middle| \begin{array}{c} \langle VK_{SP_s} - SMD - OO - VK_{CP_i} \rangle \\ \langle singed\ by\ CP_i \text{ or } SP_s \rangle \\ \langle VK_{S_k} Free \rangle \end{array} \right\} \right\rangle \tag{10}$$

a_{ijs} : The cost of ordering jth order for ith customer by sth supplier

d_{ij} : The amount of ith customer demand for jth order

t_{ijs} : The cost of transporting jth orders from the sth supplier to the ith customer

Scalars:

n: Number of replenishments in a production period

P: production rate for all orders

D: total demand

Objective Function:

$$TC_{sc} = TC_s + TC_c \tag{11}$$

$$TC_s = \sum_{j\in J} \frac{A_j D_j}{nQ_j} + \sum_{x\in X}\sum_{i\in I}\sum_{j\in J}\sum_{s\in S} \frac{a^k_{xijs} D_j}{Q_j} + \frac{1}{2P}\sum_{x\in X}\sum_{i\in I}\sum_{j\in J}\sum_{s\in S} h_j q^k_{xijs} \tag{12}$$

And

$$TC_c = \sum_{x\in X}\sum_{i\in I}\sum_{j\in J}\sum_{s\in S} \frac{t^k_{xijs}\times d_{ij}}{q^k_{ijs}} + \frac{n}{2}\sum_{x\in X}\sum_{i\in I}\sum_{j\in J}\sum_{s\in S} h^k_{xijs} q^k_{xijs} \times \left(1-\frac{D}{P}+\frac{D}{nP}\right) \tag{13}$$

Therefore:

$$minTC_{sc} = \sum_{j\in J}\frac{A_j D_j}{nQ_j} + \sum_{x\in X}\sum_{i\in I}\sum_{j\in J}\sum_{s\in S} \times \frac{a^k_{xijs} D_j}{Q_j} + \frac{1}{2P}\sum_{x\in X}\sum_{i\in I}\sum_{j\in J}\sum_{s\in S} \times h_j q^k_{xijs} + \sum_{x\in X}\sum_{i\in I}\sum_{j\in J}\sum_{s\in S} \times \frac{t^k_{xijs}\times d_{ij}}{q^k_{ijs}} + \frac{n}{2}\sum_{x\in X}\sum_{i\in I}\sum_{j\in J}\sum_{s\in S} \times h^k_{xijs} q^k_{xijs}\left(1-\frac{D}{P}+\frac{D}{nP}\right) \quad \forall k\in K \tag{14}$$

$$\sum_{x\in X}\sum_{j\in J} V_j q^k_{xijs} \le F(s) \quad \forall i\in I, \forall s\in S, \forall k\in K \tag{15}$$

$$n\sum_{x\in X}\sum_{j\in J} C^k_{xijs} q^k_{xijs} \le B(s) \quad \forall i\in I, \forall s\in S, \forall k\in K \tag{16}$$

$$\sum_{x\in X}\sum_{j\in J} V_j\left[n\times q^k_{xijs} - (n-1)\frac{d_{ij}\times Q_j\times n}{P}\right] \le F(i)\ \forall i\in I, \quad \forall s\in S, \forall k\in K \tag{17}$$

$$n\sum_{x\in X}\sum_{j\in J} C^k_{xijs} q^k_{xijs} \le B(i) \quad \forall i\in I, \forall s\in S, \forall k\in K \tag{18}$$

$$Q_j = \sum_{i\in I} q^k_{xijs} \forall x\in X, \quad \forall j\in J, \forall s\in S, \forall k\in K \tag{19}$$

$$D = \sum_{i\in I}\sum_{j\in J} d_{ij} \tag{20}$$

$$q^k_{xijs}, Q_j \ge 0 \tag{21}$$

The objective function of Block-SMI aims to minimize the overall inventory cost within the entire supply chain management. This cost includes the expenses borne by both the supplier and the customer. This objective function is evaluated by all solvers and customers, and it is used to guide the matching process of customer demand with suitable suppliers. The aim is to find an optimal solution that minimizes the overall inventory cost while meeting the customer's requirements and ensuring that the supplier's capabilities are utilized effectively. By minimizing the total inventory cost, Block-SMI aims to reduce the overall cost of supply chain management and improve efficiency. Since the budget and warehouse capacity of suppliers and customers may be limited for inventory, two budget and warehouse capacity limits have been considered for each of them, which are introduced in formulas 14 to 18. (19) Shows the direction of balancing the model and ensures that the total amount of inventory is equal to the total amount of inventory that the supplier s^{th} has allocated to the customer i^{th} by the solver x^{th}. (21) The total demand rate D must be equal to the sum of all the requests sent to the customer i^{th}. (20) is a positive variable.

A. NUMERICAL EXAMPLE

To validate and assess the effectiveness of Block-SMI in the order assignment and matching request model, the paper presented a mid-scale problem based on supplier-managed inventory. This problem scenario involved multiple customers, orders, and suppliers. Specifically, the example utilized 50 customers, 4 orders, and 50 suppliers. Each order was randomly assigned to all suppliers within the system using MATLAB®'s Randi Function. This example allowed for the evaluation and analysis of the Block-SMI platform's performance and capabilities in handling a realistic and representative problem scenario. In Block-SMI, since the sub-problems are solved in parallel, all suppliers have the opportunity to supply the customer's demands. However, even though all suppliers have similar capabilities, different customers may have varying costs and processing times due to internal processes and management decisions of the suppliers. Furthermore, suppliers may have capacity constraints, and the only factor considered in matching service and demand is the cost of supplying inventory/customer demand and the allocated demand processing time. To solve the supplier-managed inventory problem efficiently, the solution space is decomposed into three different sub-problems based on the total number of suppliers, customers, and orders. This decomposition enables the solvers to focus on smaller and more manageable sub-problems, which can be solved efficiently using evolutionary algorithms. The sample codes developed for centralized and Blockchain-based models can be accessed via following shared repository link: http://doi.org/10.6084/m9.figshare.23608206.

To extract the best order assignment for each customer by the supplier, Block-SMI uses a cost function based on the cost of supplying inventory/demand for the customer. Suppliers are selected based on their capacity and the cost of providing

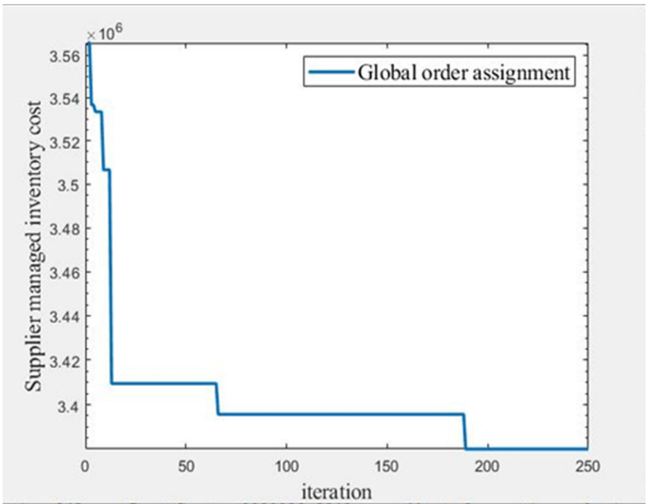

FIGURE 5. Evolution curve of supplier-managed inventory cost in centralized model.

inventory/demand for the customer. Block-SMI is utilized to address the order assignment problem between the supplier and the customer by identifying the supplier that can fulfill the customer's demand at the lowest cost. Once the solver obtains the sub-problem, they initialize the smart contract to address the task of matching supply and demand specifically for that sub-problem. To evaluate the effectiveness of Block-SMI, several scenarios have been conducted. These scenarios involve comparing the proposed method with a centralized mechanism that is commonly employed to handle similar types of problems. By comparing the performance and outcomes of Block-SMI with the centralized approach, the study aims to assess the advantages and benefits of utilizing the decentralized blockchain-based solution.

The characteristics of Block-SMI are further described and analyzed, and the results demonstrate that Block-SMI is an effective solution for supplier-managed inventory problems, especially for large-scale scenarios.

B. SCENARIO 1: CENTRALIZED MANAGEMENT

In the first scenario, the problem is solved centrally so that customers and suppliers are in a centralized network and operate independently. Customers and suppliers have to match each other, and the problem is solved only once. Therefore, with the increase of suppliers and customers, the decision to match between suppliers becomes very difficult takes a lot of time, and is not practical. Moreover, in supplier-managed inventory problems, customers may not be patient enough to wait for central authorities (such as planning managers) to come up with a solution as to which supplier can meet their demands. As the number of customers and suppliers increases, central management may not be able to provide an optimal solution promptly, causing customers to lose business and incur high costs. Therefore, the central organization may only have a few days to provide its final result. In the proposed Block-SMI solution, the genetic algorithm is used to find an optimal solution for the supplier-managed inventory problem. However, as the size of the problem increases (i.e., more customers, suppliers, and orders), the server may not be able to provide the optimal solution in time. In the implemented scenario, the genetic algorithm was run for 250 iterations, and the obtained objective function (supplier-managed inventory) in the final iteration of the algorithm was 3380223.8843. The solution was obtained in a solving time of 30 minutes, as shown in FIGURE 5.

C. SCENARIO 2: BLOCK-SMI MECHANISM

In this suggested scenario, a configuration similar to scenario 1 is proposed. Within the blockchain network, a set of sub-problems and solvers are registered to address these sub-problems. Each sub-problem consists of distinct elements such as customers, orders, and suppliers. Importantly, there is no overlap between any pair of sub-problems, ensuring that each sub-problem is handled separately and independently within the Block-SMI platform. This approach enables efficient and parallel processing of sub-problems, promoting scalability and effective utilization of solver resources within the blockchain network. This approach allows for a decentralized and efficient allocation of solvers to address individual sub-problems, promoting scalability and parallel processing within the blockchain network. Ensuring that sub-problems remain distinct and non-overlapping, facilitates a more organized and manageable execution of solver assignments within the system. Solvers start to solve the sub-problems and the solver who can solve the order assignment and match the customer's requirement to the supplier in the shortest time wins and is announced in the blockchain network. In Block-SMI, reducing the solving time is the most important factor in solving the order assignment problem. Therefore, the solution that is reached may not necessarily be the global optimum, but it can still be a good solution that avoids the local optimum. However, the required time for finding the solution can be very long, leading to dissatisfied customers who may leave the system. Therefore, it is essential to balance the solution quality and the solving time to ensure customer satisfaction and system efficiency. FIGURE 6 shows the graph of supplier capacity-customer demand matching pair under solvers a, b, and c with different values.

V. DISCUSSIONS AND MANAGERIAL INSIGHTS

As illustrated in former sections, this paper has proposed a framework to enable supplier and customer interaction in the form of a blockchain-based SMI model. In the first step, the proposed framework enables multi-supplier, multi-customer stakeholders' interaction while securing competitive advantages for stakeholders when sharing their business information in the framework. Moreover, the framework enables the third stakeholder actors known as solvers to deal with the NP-hard problem of order replenishment assignment. The decentralized mechanisms supported by blockchain technology enable the solvers to match the supplier's replenishment capabilities for customers and receive

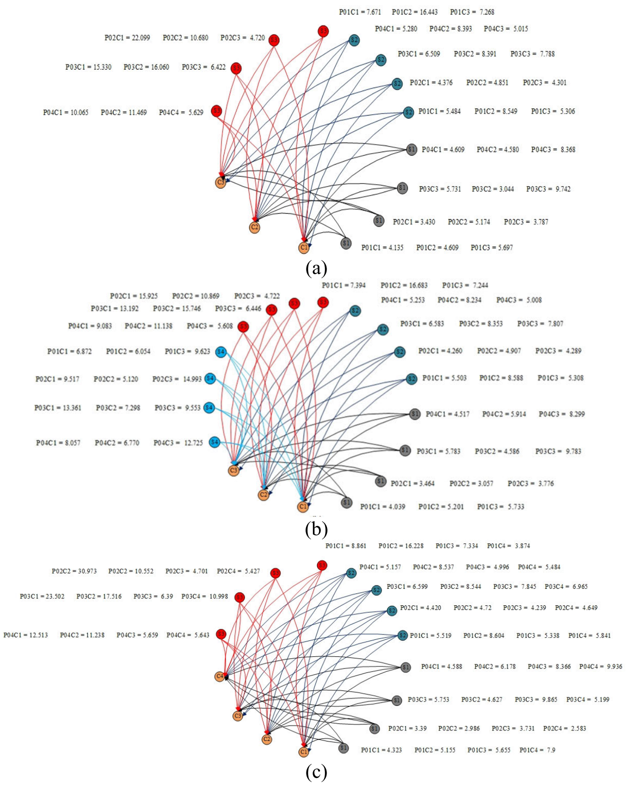

FIGURE 6. The graph of supplier capacity-customer demand matching pair under solver A, B, C with different value (S: supplier, C: customer, P: part; I: customer, J: PART, S: supplier).

their contributions for the assignment optimality inside the ecosystem.

From the point of view of managerial insights, the application of Blockchain technology enables the platform for managing the solvers' contribution to the assignment of supplies to customers as new service provider business models. From the point of view of business model competency, solvers as assignment service providers must increase their competencies for better performance in solving their sub-problems. As a Solver uses more time to proceed with its algorithm and get a better answer to increase its reward, other solvers may announce their solutions with overlap sooner. This causes persuades the solvers to restart the sub-problem formation.

VI. CONCLUSION

This paper has focused on the context of Supplier Managed Inventory (SMI) for enabling more efficient frameworks for the management of customer inventory over the cloud solution by the community of suppliers. While the proposed framework enables the sharing of information through supply chain stakeholders, it ensures the security fulfillment of the competitive advantage of each party with blockchain capabilities. Moreover, the framework has established a new business model for assignment service providers known as solvers. Within this framework, information regarding customer requirements and supplier capabilities is shared among the participants. Different solvers can select the sub-problems and try to solve them and offer a near to optimum assignment policy. The framework applies a reward policy mechanism to both promote the near to optimum assignment for solvers and also benefit them from the yielded optimality with the blockchain token model. Finally, the proposed frameworks enable the detection of possible conflicts among the solvers for overlapping sub-problems and avoid the announcement of in-feasible assignments regarding supplier capabilities and customers. The results show that the yielded optimality of consolidated sub-problems is better from the point of view of solving time and resulting from optimality. Further research studies for elaborating the token model mechanism to ensure the traceability and tracking of the order replenishment policies are strongly encouraged.

REFERENCES

[1] F. Xiong, R. Xiao, W. Ren, R. Zheng, and J. Jiang, "A key protection scheme based on secret sharing for blockchain-based construction supply chain system," *IEEE Access*, vol. 7, pp. 126773–126786, 2019.

[2] M. H. Hugos, *Essentials of Supply Chain Management*. Hoboken, NJ, USA: Wiley, 2018.

[3] A. Angulo, H. Nachtmann, and M. A. Waller, "Supply chain information sharing in a vendor managed inventory partnership," *J. Bus. Logistics*, vol. 25, no. 1, pp. 101–120, Mar. 2004.

[4] D. Wang, Z. Wang, B. Zhang, and L. Zhu, "Vendor-managed inventory supply chain coordination based on commitment-penalty contracts with bilateral asymmetric information," *Enterprise Inf. Syst.*, vol. 16, no. 3, pp. 508–525, Mar. 2022.

[5] K. Govindan, "Vendor-managed inventory: A review based on dimensions," *Int. J. Prod. Res.*, vol. 51, no. 13, pp. 3808–3835, Jul. 2013.

[6] Y. A. Hidayat, I. D. Anna, and A. Khrisnadewi, "The application of vendor managed inventory in the supply chain inventory model with probabilistic demand," in *Proc. IEEE Int. Conf. Ind. Eng. Eng. Manage.*, Dec. 2011, pp. 252–256.

[7] K. Sari, "Exploring the benefits of vendor managed inventory," *Int. J. Phys. Distrib. Logistics Manage.*, vol. 37, no. 7, pp. 529–545, Aug. 2007.

[8] T. Dasaklis and F. Casino, "Improving vendor-managed inventory strategy based on Internet of Things (IoT) applications and blockchain technology," in *Proc. IEEE Int. Conf. Blockchain Cryptocurrency (ICBC)*, May 2019, pp. 50–55.

[9] P. Gonczol, P. Katsikouli, L. Herskind, and N. Dragoni, "Blockchain implementations and use cases for supply chains—A survey," *IEEE Access*, vol. 8, pp. 11856–11871, 2020.

[10] H. Juma, K. Shaalan, and I. Kamel, "A survey on using blockchain in trade supply chain solutions," *IEEE Access*, vol. 7, pp. 184115–184132, 2019.

[11] T. Guggenberger, A. Schweizer, and N. Urbach, "Improving interorganizational information sharing for vendor managed inventory: Toward a decentralized information hub using blockchain technology," *IEEE Trans. Eng. Manag.*, vol. 67, no. 4, pp. 1074–1085, Nov. 2020.

[12] I. A. Omar, R. Jayaraman, K. Salah, M. Debe, and M. Omar, "Enhancing vendor managed inventory supply chain operations using blockchain smart contracts," *IEEE Access*, vol. 8, pp. 182704–182719, 2020.

[13] A. Mateen, A. K. Chatterjee, and S. Mitra, "VMI for single-vendor multi-retailer supply chains under stochastic demand," *Comput. Ind. Eng.*, vol. 79, pp. 95–102, Jan. 2015.

[14] A. Sainathan and H. Groenevelt, "Vendor managed inventory contracts—Coordinating the supply chain while looking from the vendor's perspective," *Eur. J. Oper. Res.*, vol. 272, no. 1, pp. 249–260, Jan. 2019.

[15] M. Murray, "Small business supply chain: Vendor managed inventory (VMI)," Balance Small Bus., 2018, vol. 5. Accessed: May 20, 2020. [Online]. Available: https://www.liveabout.com/vendor-managed-inventory-vmi-2221270

[16] S. Nakamoto, "Bitcoin: A peer-to-peer electronic cash system," *Decentralized Bus. Rev.*, p. 21260, 2008. Accessed: Oct. 15, 2020. [Online]. Available: https://bitcoin.org/bitcoin.pdf

[17] Z. Li, A. V. Barenji, and G. Q. Huang, "Toward a blockchain cloud manufacturing system as a peer to peer distributed network platform," *Robot. Comput.-Integr. Manuf.*, vol. 54, pp. 133–144, Dec. 2018.

[18] W. Gao, W. G. Hatcher, and W. Yu, "A survey of blockchain: Techniques, applications, and challenges," in *Proc. 27th Int. Conf. Comput. Commun. Netw. (ICCCN)*, Jul. 2018, pp. 1–11.

[19] S. Wang, D. Li, Y. Zhang, and J. Chen, "Smart contract-based product traceability system in the supply chain scenario," *IEEE Access*, vol. 7, pp. 115122–115133, 2019.

[20] F. Casino, T. K. Dasaklis, and C. Patsakis, "Enhanced vendor-managed inventory through blockchain," in *Proc. 4th South-East Eur. Design Autom., Comput. Eng., Comput. Netw. Social Media Conf. (SEEDA-CECNSM)*, Sep. 2019, pp. 1–8.

[21] E. Ahmadi, R. Khaturia, P. Sahraei, M. Niyayesh, and O. F. Valilai, "Using blockchain technology to extend the vendor managed inventory for sustainability," *J. Construct. Mater.*, vol. 3, no. 1, pp. 1–5, Dec. 2021.

[22] J. Kolb, J. Hornung, F. Kraft, and A. Winkelmann, "Industrial application of blockchain technology—Erasing the weaknesses of vendor managed inventory," in *Proc. 26th Eur. Conf. Inf. Syst. (ECIS)*. Portsmouth, U.K.: Beyond Digitization—Facets Socio-Technical Change, Jun. 2018. [Online]. Available: https://aisel.aisnet.org/ecis2018/

[23] I. A. Omar, R. Jayaraman, M. S. Debe, H. R. Hasan, K. Salah, and M. Omar, "Supply chain inventory sharing using Ethereum blockchain and smart contracts," *IEEE Access*, vol. 10, pp. 2345–2356, 2022.

[24] M. Hasan and B. Starly, "Decentralized cloud manufacturing-as-a-service (CMaaS) platform architecture with configurable digital assets," *J. Manuf. Syst.*, vol. 56, pp. 157–174, Jul. 2020.

[25] S. K. Dwivedi, R. Amin, and S. Vollala, "Blockchain based secured information sharing protocol in supply chain management system with key distribution mechanism," *J. Inf. Secur. Appl.*, vol. 54, Oct. 2020, Art. no. 102554.

[26] E. Aghamohammadzadeh and O. Fatahi Valilai, "A novel cloud manufacturing service composition platform enabled by blockchain technology," *Int. J. Prod. Res.*, vol. 58, no. 17, pp. 5280–5298, Sep. 2020.

[27] S.-A. Radmanesh, A. Haji, and O. Fatahi Valilai, "Blockchain-based cloud manufacturing platforms: A novel idea for service composition in XaaS paradigm," *PeerJ Comput. Sci.*, vol. 7, p. e743, Dec. 2021.

[28] M. M. Queiroz, R. Telles, and S. H. Bonilla, "Blockchain and supply chain management integration: A systematic review of the literature," *Supply Chain Manag., Int. J.*, vol. 25, no. 2, pp. 241–254, Aug. 2019.

[29] M. Akbari Kaasgari, D. M. Imani, and M. Mahmoodjanloo, "Optimizing a vendor managed inventory (VMI) supply chain for perishable products by considering discount: Two calibrated meta-heuristic algorithms," *Comput. Ind. Eng.*, vol. 103, pp. 227–241, Jan. 2017.

[30] Y. Li, L. Qiao, and Z. Lv, "An optimized Byzantine fault tolerance algorithm for consortium blockchain," *Peer-Peer Netw. Appl.*, vol. 14, no. 5, pp. 2826–2839, Sep. 2021.

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