Digital Business 5 (2025) 100128

Contents lists available at ScienceDirect

Digital Business

journal homepage: www.elsevier.com/locate/digbus

A blockchain-driven business model for supplier selection and order allocation leveraging smart contracts in supply chains

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ARTICLE INFO

Keywords:
Supply chain management
Supplier selection
Order allocation
Blockchain applications
Smart contract

ABSTRACT

Supply chain operations have tended to become more complex, thus placing significant pressure on one of the most critical processes: supplier selection and order allocation (SSOA). This process involves a focal company selecting suppliers and allocating orders to obtain required materials. Achieving effective SSOA processes is challenged by (1) reliance on centralized governance and (2) ensuring effective contract management. While so called "smart contracts" could address these challenges, design knowledge about such technology — particularly in the SSOA context — is underexplored in the literature. In this paper we design a smart contract for SSOA in supply chains. We conducted a design science research study and developed three core artifacts: (1) a mathematical description of SSOA; (2) a system model of actor interactions; and (3) SSOA-relevant algorithms. Utilizing the Ethereum blockchain, we demonstrated and tested our smart contracts through scenario analysis. We found that our design is feasible and highly likely to address centralization and effectiveness challenges in SSOA. This paper contributes to the literature by demonstrating how smart contract design focusing on SSOA can further enhance blockchain-driven business models. In addition, we offer prescriptive knowledge on developing smart contracts for SSOA in supply chains.

1. Introduction

A supply chain (SC) consists of various enterprises coordinating the flow of materials, information, and financing to fulfill final customer demand at the lowest possible cost. The most effective SCs feature proficient management of supplier selection and order allocation (SSOA) (kumar, Rao, & Rao, 2018). SSOA involves a focal partner which selects suppliers and allocates orders to source materials to be delivered on time, in the correct quantities, and at appropriate prices (Naqvi & Amin, 2021). Current literature indicates that SSOA faces two primary challenges: (1) reliance on centralized governance; and (2) the need to ensure effective contract management.

Centralized governance makes SC systems vulnerable to problems such as process disruptions (Ashraf & Ali, 2023; Esmaeili-Najafabadi, Nezhad, Pourmohammadi, Honarvar, & Vahdatzad, 2019b; Rezaei, Aghsami, & Rabbani, 2021) and features transparency and trust issues (El Maouchi, Ersoy, Erkin, et al., 2018). This makes SSOA systems vulnerable to technical and financial challenges (Eddine, Saikouk, & Berrado, 2019; Kovach, Swink, & Rodriguez, 2023). Effective contract management is a further key challenge in SSOA (Zhao, Pan, & Song, 2018). These challenges include sub-optimal communication and collaboration between stakeholders (Dong & Yuan, 2025), difficulties ensuring regular monitoring of supplier performance (Aouadni, Aouadni, & Rebaï, 2019), delays in responding to operational issues (Scott, Ho, Dey, & Talluri, 2015), and ensuring compliance with obligations (Esmaeili-Najafabadi, Fallah Nezhad, Pourmohammadi, Honarvar, & Vahdatzad, 2019a). A recent survey showed that most companies faced financial losses and missed opportunities due to inefficiencies in contract management. Hence, 92% of organizations were found to be considering significant changes in their approach to SSOA (Knox, Fortescue-Webb, & Bruch, 2021). These challenges significantly impact the overall contract management process. For instance, studies by Oboloo (2023) on contract management discuss the importance

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https://doi.org/10.1016/j.digbus.2025.100128
Received 5 October 2024; Received in revised form 3 May 2025; Accepted 5 May 2025
Available online 16 June 2025

of effective communication and collaboration between stakeholders. Success leads to improved operational efficiency and risk reduction.

Blockchains are distributed systems through with transactions can be made and logged consistently and unchangeably by network members. Blockchain-driven business models (Marikyan, Papagiannidis, Rana, & Ranjan, 2022; Morkunas, Paschen, & Boon, 2019), particularly those featuring smart contracts (i.e, electronic protocols designed to automatically facilitate, validate, and execute contract provisions among stakeholders in decentralized systems) have significant potential to address aforementioned challenges (Di Vaio & Varriale, 2020). For instance, the decentralized and transparent nature of smart contracts effectively mitigate challenges related to centralized governance (Hanafizadeh & Alipour, 2024). At the same time, the ability of smart contracts to be self-executing may resolve contract management issues (Rathnayake, Wedawatta, & Tezel, 2022). Although the current literature features prescriptive knowledge on the development of smart contracts for SCs, it does not yet consider the SSOA setting. *This paper aims to design a blockchain-based smart contract for SSOA in SCs.* Specifically, we ask the following questions:

1. How can SSOA be mathematically represented to align with smart contracts, especially when they are required to determine the allocation of orders to each supplier?
2. What system model of actor interaction is used in an SSOA-based smart contract?
3. What algorithms are required to execute transactions in an SSOA-based smart contract?

We conduct a design science research study, with the design process comprising four phases. First, we define the problem notation. Second, we design the system model. Third, we demonstrate the application of blockchain. Finally, we evaluate our artifact using a test scenario. Our findings indicate the *feasibility* of the proposed smart contract, which would embed mathematical descriptions for determining order allocations to suppliers and incorporating six key algorithms. In so doing, we contribute to the blockchain-driven business model literature. Specifically, we reveal how smart contracts enhance blockchain-based business models in SCs (i.e., to create value) by potentially resolving the centralization and effective contract management challenges of SSOA. Furthermore, as one of the first to design smart contracts for SSOA, we provide prescriptive knowledge for this unexplored setting.

The main contributions of this work are summarized as follows:

- This paper aims to enhance blockchain-driven SC business models by leveraging smart contracts for SSOA. With the integration of blockchain-based smart contracts into SSOA, we are taking a pioneering path towards more decentralized and efficient SCs. We do this by addressing key challenges such as those concerning centralized governance and effective contract management.
- This paper provides a novel mathematical formula for determining the supplier selection and allocation of orders to each supplier, aligning with smart contracts. Additionally, we present algorithms to effectively implement these allocations in a smart contract, thus automating key processes, such as order placement, supplier selection, allocation, data interchange, and financial settlement.
- Based on a test scenario analysis conducted on the Ethereum blockchain, we have demonstrated the feasibility of our smart contracts addressing the centralization and efficient contract management in SSOA.

2. Literature review

Contract governed SCs help organizations to deliver quality goods and services efficiently. The objective of a contract can be to reduce the financial and operational risk inherent in SCs, including by sharing risks among multiple stakeholders.

A review of the SC contracts literature shows that much research in this area examines revenue sharing (RS) contracts. The subsequent sections delineate a thorough examination of contracts within SCs.

2.1. A brief review of contracts in two-echelon SCs

Panda (2014) investigated a manufacturer-retailer SC operating under a RS contract. The findings highlighted that adherence to corporate social responsibility principles by the retailer and manufacturer could enhance the SC's effectiveness. Bai, Chen, and Xu (2017) studied a sustainable manufacturer-retailer SC of perishable items, featuring government regulations for controlling carbon emissions. RS and two-part tariff contracts were proposed as the means for achieving system coordination. The study revealed that cooperation among SC members could boost profits and reduce carbon emissions. Xie, Liang, Liu, and Ieromonachou (2017) examined decentralized and centralized closed-loop dual-channel manufacturer-retailer models. The model identified the optimal values for advertising investment, wholesale prices, and offline/online prices under RS contracts. Cai, Zhong, Shang, and Huang (2017) looked at a manufacturer-retailer SC operated under an option contract, noting the unique combination of an option contract with a vendor-managed contract for effective inventory control. The key finding was the efficacy of the option contract in SC coordination. Yang, Shan, and Jin (2017) focused on a decentralized manufacturer-retailer SC with uncertain demand, using perfect and relative capacity cost-sharing contracts in which the retailer shares the capacity cost with the manufacturer. The study found that the capacity level threshold was critical for both the manufacturer and retailer when assessing the appeal of perfect or relative cost-sharing. Raza (2018) addressed the coordination and adherence to social responsibility challenges in a two-level SC consisting of a single supplier and retailer. Mathematical models were developed to determine the optimal price, inventory, and social responsibility investment levels. Taleizadeh, Moshtagh, and Moon (2018) investigated coordination methods for a dual-channel SC, considering a mix of cooperative advertising and two-part tariff contracts. They analyzed both single-channel SCs with dual-recycling, and dual-channel SCs with dual-recycling scenarios. They concluded that the latter was more advantageous for the manufacturer and resulted in higher product quality. Heydari, Govindan, and Sadeghi (2018) created a reverse SC model, featuring a manufacturer and retailer in centralized and decentralized scenarios under an RS contract. The study showed that a greater degree of significant uncertainty in the manufacturer's capacity levels led to smaller rewards being offered by the retailer to customers. Aslani and Heydari (2019) explored a green manufacturer-retailer SC, with them proposing a novel contract. This related to the transportation system linking SC members, with the goal of ensuring simultaneous SC profit with environmental considerations. The findings indicated that this contract could significantly contribute to SC coordination and profit enhancement for its members. Hong and Guo (2019) investigated a green manufacturer-retailer SC, with particular consideration for environmental considerations. The findings indicated that while different contracts might reduce the profits earned by each SC member, these members could leverage the environmental advantages of incorporating green practices into the SC.

Nie and Du (2017) explored a two-level SC comprising a single supplier and two retailers. One of the retailers was unaware of the other's existence, whereas the other retailer was aware of the first. A wholesale price contract was implemented to coordinate this SC. Equilibrium solutions under various conditions were determined for the SC in question. Gao and You (2019) introduced a novel optimization framework for a single manufacturer and multi-retailer SC, employing the leader-follower Stackelberg game and two-stage stochastic programming. The study addressed decisions regarding transportation, pricing, inventory, and production for the SC. Taleizadeh and Rabie (2018) investigated a green SC involving two manufacturers and a single retailer. They examined cost-sharing and quantity-discount contracts in terms of the impact on profitability for the SC as a whole, and for each chain participant. The findings indicated that the quantity-discount contract was more advantageous than the cost-sharing contract for the retailer and one of the manufacturers.

Li, Chen, and Ai (2019) explored the effects of information sharing on cross-sales, considering both two-part tariff and wholesale contracts. They demonstrated that the two-part tariff contract performed more effectively under certain conditions. Raj, Jauhar, Ramkumar, and Pratap (2022) investigated ways to enhance the performance of payment transactions in a supplier-vendor SC involving a third-party logistics company responsible for shipping. They developed a blockchain-based smart contract to improve the productivity and traceability of all operations within the chain.

The research by Seifert, Zequeira, and Liao (2012) is noteworthy regarding three-level SC coordination. This study examined the effects of sub-coordination among SC members, including a supplier, a manufacturer, and a retailer. It was demonstrated that upstream sub-coordination is more effective than downstream sub-coordination when a price-only contract is used for coordination. Modak, Panda, Mishra, and Sana (2016) adopted an RS contract to coordinate a manufacturer-distributor-multiple retailers‘ SC, and found that this contract could create mutually beneficial outcomes for all SC members. Biswas, Gupta, Tiwari, and Talluri (2023) investigated the impacts of different contract mechanisms and their implementation sequence on members' profits in a three-echelon SC using dynamic game tools. They concluded that SC coordination also depends on the sequence of contracts implemented.

2.2. A review of blockchain-based smart contracts research

De Giovanni (2020) considered a supplier-retailer SC where the supplier provides an item to the retailer. This relationship determines the supplier's selling price and optimal order quantity. This research contributes to the development of a blockchain-based platform as an alternative to traditional online systems for reducing SC operational cost and risk. The security and visibility of the chain are enhanced when using such a platform. Additionally, the study analyzes the application of two smart contracts — wholesale and RS — for achieving better coordination of SC members. Baharmand and Comes (2019) explored the implementation of smart contracts in humanitarian SCs. They also discussed the organizational and environmental barriers to this implementation. Dietrich, Palm, and Louw (2020) provided a framework for improving the auditability and transparency of products in manufacturing systems using BT. Each product component can be tracked using a unique identification number generated by a blockchain-based smart contract. Chang, Chen, and Lu (2019) examined using a blockchain-based framework with smart contracts for re-engineering organizational processes, comparing the benefits of re-engineered processes with current ones. Hasan, AlHadhrami, AlDhaheri, Salah, and Jayaraman (2019) presented a design using blockchain tools for tracking shipment movement in SCs through smart containers, applying smart contract capabilities to this design. Additionally, various Internet of Things (IoT) sensors are employed in the containers to gather data necessary for tracking and managing movements. This chain automates payments between the sender and receiver using Ethereum smart contracts. In the research by Omar, Jayaraman, Salah, Debe, and Omar (2020), a supplier-retailer SC initially employs vendor-managed inventory as a control policy, with the supplier managing the retailer's inventory. This system reduces inventory holding and ordering costs in the chain. Then, a novel blockchain-based tool using smart contracts was proposed to enhance the traceability, security, and auditability of transactions and relevant data for the vendor-managed inventory system. Mao, Hao, Wang, and Li (2019) proposed a blockchain-based food trading system to address security and trust issues in online food trade transactions and to find a suitable portfolio for buyers. They also developed the initial steps of a smart contract for this purpose. A recent study ? discusses an optimal policy computing algorithm for smart contracts within the blockchain, applicable to assemble-to-order services. The system treats each order as associated with a demand that may require multiple services from different suppliers Dai (2022) simultaneously, and the corresponding arrival rate may be determined by blockchain history data, represented by a long-range stochastic process. To achieve this goal, they developed a blockchain-based decision-making system based on federated learning combined with an evolving convolutional neural network. Mokgomola, Telukdarie, Munien, Onkonkwo, and Vermeulen (2024) developed the framework of a blockchain-based smart contract for an agri-food SC. This system tries to guarantee the quality and safety of products in their origin. Yigit and Dag (2024) proposed the framework of a blockchain-based smart contract for a general SC. They discuss and propose the required functions for such a system, and describe its effects on SC processes. They also examine the effects of this system on SC reliability. Bhatia, Chaudhuri, Kayikci, and Treiblmaier (2024) examined the financial solutions in the SCs of four companies that utilized blockchain-based solutions for this purpose. They found that these types of solutions played central roles in mitigating costs, such as those related to transactions, negotiation, and contracting.

2.3. The role and challenges for contracts in supplier selection and order allocation

Supplier selection and order allocation (SSOA) are pivotal processes in SC management that directly impact the operational efficiency, cost-effectiveness, and resilience of SCs (Rao, Rao, et al., 2018). Numerous researchers are actively investigating supplier order allocation challenges. Their studies primarily focus on four key areas: the development of mathematical and optimization models for SSOA; the application of Multi-Criteria Decision-Making (MCDM) techniques; the emphasis on sustainable and green supplier selection (Dewi & Zagloel, 2023); and lastly, the enhancement of SSOA through the use of novel and advanced technologies and information systems (Scott et al., 2015).

Schleper, Blome, and Wuttke (2017) emphasize that well-structured contracts and agreements serve as a foundation for transparent and efficient supplier relationships, as well as enabling organizations to mitigate risks. Effective contract management facilitates the operationalization of these decisions, ensuring compliance, fostering trust, and enabling swift dispute resolution (Singh, 2024; Wass, 2017). Despite its significance, integrating effective contract management into SSOA is fraught with challenges (Lee & Moon, 2024).

The lack of effective communication and collaboration among stakeholders is identified as a principal challenge (Dong & Yuan, 2025). This challenge underscores the necessity for creating mechanisms and platforms that facilitate transparent, timely, and reciprocal exchanges of information. Such platforms are essential for aligning stakeholder expectations, facilitating consensus, and fostering a collaborative culture.

Moreover, the literature highlights challenges such as the regular monitoring of supplier performance (Aouadni et al., 2019), quickly responding to operational issues (Scott et al., 2015), and the assurance of compliance with contractual obligations (Esmaeili-Najafabadi et al., 2019a). The difficulty in consistently monitoring supplier performance demonstrates the need for comprehensive and robust systems to track, analyze, and report performance metrics against agreed benchmarks.

The reliance on centralized systems and the prevalence of centralized solutions in SSOA have added more complexities. The existing literature highlights the challenges faced by centralized supplier ordering and allocation systems, for example: increased vulnerability to disruption (Esmaeili-Najafabadi et al., 2019b; Rezaei et al., 2021); difficulties in coordinating sustainability initiatives (Esmaeili-Najafabadi et al., 2019b); and a lack of consideration for the reliability of suppliers in the decision-making process (Rezaei et al., 2021). These challenges are due to the reliance on a single supplier or a small group of suppliers in centralized systems. This makes SCs more susceptible to disruptions caused by supplier failures, natural disasters, and other unforeseen events (Esmaeili-Najafabadi et al., 2019b; Katsaliaki, Galetsi, & Kumar, 2021). Moreover, centralized digital platforms inherently lack transparency and trust (El Maouchi et al., 2018) and are vulnerable to single points of failure, which can render entire networks inoperable (Khan, Alshahrani, & Jacquemod, 2023). Trust, traceability, and transparency in SC networks have been extensively studied, and the result shows their significant impacts on SC performance (Buell, Kim, & Tsay, 2017; Heese, 2007; Skilton & Robinson, 2009). However, more transparency in real-world applications is required (Difrancesco, Meena, & Kumar, 2023). The increasing globalization and focus on sustainability have further highlighted the need for greater transparency in SC networks (Awaysheh & Klassen, 2010; Brun, Karaosman, & Barresi, 2020). Furthermore, financial settlements such as delayed payments, disputes about payments (Kovach et al., 2023), and currency exchange risks (Eddine et al., 2019) can be significant challenges. BT has been identified as a tool for creating transparent, secure, and immutable contracts, facilitating real-time monitoring and enforcement of contractual obligations (Casey & Wong, 2017). The application of BT and smart contracts in SC management has been analyzed in several recent research projects (Bhatia et al., 2024; Di Vaio & Varriale, 2020; Kshetri, 2017; Queiroz & Wamba, 2019; Ying, Jia, & Du, 2018). It should be noted that BT has had a considerable impact on organizations' business models and SCs (Agi & Jha, 2022; Grünewald, Gürpinar, Culotta, & Guderian, 2024). While previous studies have highlighted the benefits of smart contracts and BT in SC management, they can also be valuable solutions for addressing the challenges in the centralized SSOA systems are used currently.

BT has the potential to revolutionize contract management in SSOA. Thanks to the immutable distributed ledger that records all transactions and interactions it enhances transparency in allocation processes. Smart contracts contribute to fairness by automating allocation based on predefined rules and offers. They also facilitate efficient coordination across SC participants by improving real-time communication between buyers and suppliers.

It is important to acknowledge that companies have encountered several challenges and obstacles in integrating BT. For instance, Kaur et al. (2022) explored the impediments to employing BT to enhance traceability and reduce transaction costs within Indian enterprises. Their research identified technological barriers as the foremost among various challenges in this domain.

SSOA can be regarded as either a single B2B business transaction or a series of transactions between buyers and suppliers. A review of previous research found no studies in which a blockchain-based smart contract had been developed for such B2B business models. This paper aims to enhance insights into how blockchain-driven SC business models can utilize smart contracts for SSOA. This paper introduces a blockchain-based smart contract system specifically designed for SSOA within SC management. The proposed system is designed to automate the allocation processes, data exchange, and financial transactions. It will also deploy algorithms that facilitate the coordination of interactions between SC stakeholders.

3. Problem description and notation

In the proposed model, we assume an SC includes an arbitrary number of suppliers, a buyer, and a final end customer who demands a single product. The demand from the customer is communicated to the buyer, and subsequently the buyer makes an order to meet this demand with a variety of suppliers. The demand is assumed to be constant and is visible to all SC members due to the transactions being logged on blockchain-based infrastructure. The allocation of the whole order between different suppliers is achieved by designing a contract to regulate the relationships between the buyer and the suppliers. A smart contract automates interactions during the execution of the contract. The significant interactions of such a system are:

- Entrance of customer demand, with this demand data visible to all members of theSC
- An order made by the buyer to the suppliers based on the contract terms
- Sourcing and dispatching orders to the buyer by each supplier
- Enacting the financial settlement based on factors related to the shipments, such as quality and delivery time

Initially, the following information is communicated by the suppliers and is recorded in the decentralized system (e.g., blockchain), thus making it visible to all players of the SC:

- Sales price
- Maximum delivery delay time
- Defects of the order, expressed as a maximum percentage
- Ability to supply, expressed as a minimum and maximum

We assume that the buyer determines a minimum order size for each supplier in order to safeguard long-run cooperation between SC members. This assumption implies the possibility of long-term collaboration and increased trust among SC members. The buyer and suppliers provide their information into the decentralized system (e.g., blockchain) at roughly the same time, prompted by a smart contract. The order quantity assigned to each supplier is automatically determined based on the information provided by the suppliers, as well as three additional factors: price, delay, and defect rate. This level of interaction and transparency enhances the perception of fairness in order allocation. The buyer and suppliers take their interests into account when announcing, respectively, their minimum amount of ability to supply and minimum order lot size. This creates transparency for SC members and boosts meritocratic decision-making. The buyer tries to encourage the suppliers to reserve their capacity to meet the buyer's orders. For this reason, it is logical to assume that:

- If the maximum value of the addressed minimum values (i.e., the minimum amount of ability to supply by the supplier and the minimum amount of order lot size allocated to the supplier by the buyer) is less than a predetermined value (this value can be considered as an agreed value which can be considered as a coefficient of the whole order size), then this maximum value is considered to be the agreed minimum amount of supply;
- Otherwise, the predetermined value is considered to be the agreed minimum amount of supply.

Each supplier undertakes to deliver its orders to meet a specified maximum time delay, which the buyer accepts. This assumption is based on a realistic view, since, in the real world, orders may face delays due to a variety of reasons. Furthermore, the supplier undertakes to deliver its orders, taking account of defects expressed as a maximum percentage. Afterwards the buyer can choose to accept or not, based on a variety of real world factors. If there are any deviations from the given maximum values, a penalty can be levied on the supplier. Table 1 shows the notations of the model, including indices, parameters, and decision variables.

After the required data is entered by the SC members, initially, the agreed minimum amount of supply from supplier i is determined using the rule:

If $max(min\mathrm{QS}_i, min\mathrm{QB}_i) \le c_i\mathrm{Q}$

then $min\mathrm{Q}_i = max(min\mathrm{QS}_i, min\mathrm{QB}_i)$

else $min\mathrm{Q}_i = c_i\mathrm{Q}$

The allocated amount of order delivered to supplier i is determined by using the total score of each supplier, with respect to the given objectives, including total cost, total quantity of late delivered products, and total of defective products. The objectives are considered to be the criteria of a multiple-criteria decision-making model. Table 2 should be constructed, and each supplier's total score should be calculated using a simple additive weighting method (SAW). In this method, the given

Table 1
Table of notation.

Indices	
i	The index of suppliers, $i = 1, 2, 3, \dots, n$
j	The index of model objectives, $j = 1, 2, 3, \dots, n$
Parameters	
P_i	Price of the product given by supplier i
$min\mathrm{QS}_i$	Minimum amount of supply ability of supplier i
$max\mathrm{QS}_i$	Maximum amount of supply ability of supplier i
L_i	Maximum delay in delivery of supplier i
L'_i	Number of units of excess time delays in receiving the order from the supplier i
R_i	Maximum percentage of the order defects of supplier i
R'_i	Percentage of excess defects in the order received from the supplier i
$min\mathrm{QB}_i$	Minimum amount of ordering to supplier i by the buyer
$min\mathrm{Q}_i$	Agreed minimum amount of supply from supplier i
c_i	A coefficient of the whole order, which is used in obtaining the agreed minimum amount of supply from supplier i
S_i	Total score of supplier i with respect to the given objectives (or criteria)
Q	The customer demand or the buyers' order given to the suppliers
w_j	The weight of objective j; it is assumed that the total cost, total late delivered products and total defective products are the three objectives of the model.
Decision variable	
Q_i	The allocated amount of order to supplier i
Smart Contract variables	
bpk	Buyer's Public Key
cpk	Customer's Public Key
spk_i	Supplier i's Public Key
$order$	A boolean variable that shows the customer has placed an order

scores for each supplier (with respect to each criterion) are normalized and then multiplied by their corresponding weights. We provide a detailed description in the next section. It should be noted that since all three criteria are negative (i.e., the higher is the figure, the less is the desired outcome), the inverse values of Table 2 should be used when calculating the suppliers' total scores. The mathematical descriptions of how the allocated amount of order to each supplier is obtained are given in Appendix. After receiving the order from supplier i, if the delay in delivery is less than the maximum delay in delivery of supplier i and if the percentage of the order defect is less than the maximum percentage of the order defects of supplier i, then settlement takes places between the buyer and supplier i. The mathematical formula for the amount payable to each supplier is given in Appendix.

4. System design

This section initially outlines the primary tools implemented in the system design, as well as the protocols utilized in the desired system. Previously, orders and invoices were managed through paper-based methods, which were prone to errors and occasionally resulted in data loss. With the help of blockchain, the entire process is moved to a secure platform, with every authorized party able to access accurate and trusted records.

Blockchain

BT was initially realized to enable Bitcoin cryptocurrency (Nakamoto, 2008), with all modifications and transactions recorded on an append-only public ledger which is distributed across the nodes of a peer-to-peer network. Transactions generated at close time intervals are usually grouped into blocks. These blocks are sorted, and each is mathematically related to previous blocks which form a chain. The blockchain is generally a linked-list data structure created from these blocks. Blocks are created and added to the main chain by nodes known as miners. Miners add new blocks to the blockchain using consensus mechanisms like Proof of Work (PoW) and Proof of Stake (PoS) processes, thus ensuring the integrity and security of the data. Blockchains can be categorized into three main types: public-permissionless; public-permissioned; and consortium-based. Public blockchains, like Bitcoin and Ethereum, allow open participation and access. Permissioned blockchains restrict participation to authorized entities, although they remain read-accessible to anyone. Consortium blockchains are shared among multiple organizations, featuring a private ledger that is accessible to selected participants. For further details, the reader can refer to the work of Tanwar (2022). The strong recent growth of blockchain development highlights the potential for its use in various business contexts (Chong, Lim, Hua, Zheng, & Tan, 2019). This is particularly the case in SC management (Myerson, 2018), where it improves transparency, traceability, fairness, and trust. By using blockchain, businesses can build trust between stakeholders, attract more customers, and protect processes from a range of threats. A blockchain-driven business model uses BT to create decentralized, transparent, and secure systems for various business functions (Taherdoost & Madanchian, 2023; Upadhyay, 2024). From 11.4 billion US dollars in 2022 to 17.57 billion US dollars in 2023, blockchain-driven businesses are expected to record 469.49 billion US dollars in 2030 (Fortune, 2023).

Smart contract

Smart contracts, first introduced by Szabo (1994), are digital instructions that enforce agreements automatically among parties and thus eliminates the need for considerable levels of trust between each other. These contracts are stored and executed on a blockchain network, ensuring tamper-proof and immutable transactions. As each change is replicated across all network nodes, the state of the contract remains transparent and secure (Taherdoost, 2023). Smart contracts on platforms like Ethereum can execute universal programs (Hewa, Hu, Liyanage, Kanhare, & Ylianttila, 2021), triggered by specific events or conditions. They are written in high-level languages, compiled into bytecodes, and deployed with unique addresses on the network. Transaction fees, known as gas, vary based on the computational effort required. To ensure security and reliability, smart contracts undergo rigorous testing and adhere to evolving standards. For further details, the reader can refer to the works of Ante (2021), Hewa et al. (2021), Taherdoost (2023).

4.1. System model

We propose a public blockchain-based smart contract solution for an SC that includes an arbitrary number of suppliers, a buyer, and an end customer. Fig. 1 illustrates the proposed system model. The buyer shares the smart contract with suppliers to allocate the order amount to each supplier. The smart contract calculates the number of orders automatically and transparently, and all players can monitor all these rules and transactions. Financial settlement can also be made automatically through a smart contract. The main statements for the transparent calculation of each supplier's order size occur in a transaction on the blockchain platform. Some actions, such as order delivery (due to current technology limitations), depend on claims made by players'. For this reason, we assume all players will act with honesty on this system, but nevertheless we define a penalization mechanism to

Table 2
The scores for each supplier with respect to each criterion.

Suppliers \ Criteria	Total cost (with weight w_1)	Total late delivered products(with weight w_2)	Defective products (with weight w_3)
1	P_1	L_1	R_1
2	P_2	L_2	R_2
3	P_3	L_3	R_3
⋮	⋮	⋮	⋮
n	P_n	L_n	R_n

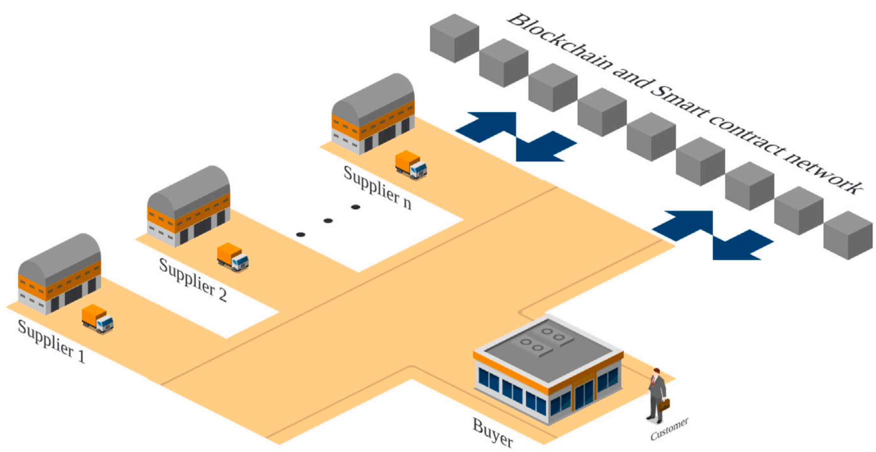


Fig. 1. System model and actors.

ward against malicious behavior. In the following section, we introduce the main players in the system.

Customer. The customer interacts with the buyer to place an order. Negotiations between the buyer and the customer are carried out off-chain. Then, the required amount of orders from a product is sent as a transaction in the smart contract. Based on the customer's and the buyer's off-chain agreement, the product cost can be deposited automatically to the smart contract's address during the order placement step or after receiving the goods.

Buyer. The buyer interacts with the customer and suppliers. The buyer receives the customer's order and tries to distribute the received orders among the suppliers in an optimal fashion. This step is called supplier order allocation. Buyers negotiate with suppliers off-chain and register agreed conditions and prices in a smart contract. The smart contract determines the optimal order allocation, based on these terms.

Supplier. After off-chain negotiations with the buyer, the registered suppliers submit their offers via a smart contract transaction. They are responsible for supplying the goods at a specific time according to the offers made.

Smart Contract. The smart contract stores all the relevant information about the agreement between the players, and helps to perform the protocol and the financial settlement correctly, with all these steps publicly verifiable.

In the following, we present the sequential phases of the proposed solution.

4.1.1. Setup

The buyer deploys the smart contract, featuring the weight factors (i.e., $w_1, w_2, \dots, w_m$ values) which determine the order size of each supplier, so that $\sum_{i=1}^{m} w_i = 1$. We have considered only three criteria: cost, time, and quantity ($m = 3$). Furthermore, α and β and the number of suppliers are required.

4.1.2. Registration

In this phase, the buyer sends the blockchain addresses (e.g., Ethereum addresses) of the customer and selected suppliers as input for a smart contract transaction. This step is the official start point of the contract. At the end of this phase, the buyer announces the end of the registration phase by sending a transaction. Algorithm 1 summarizes suppliers and customer registration.

Algorithm 1: Suppliers and customer registration

Input : $\mathsf{spk}_i, 1 \le i \le n$ as suppliers Public Key, cpk as customer Public Key and bpk as Buyer Public Key
Output: Smart contract state changed.

```
if buyer's Public Key == bpk && Registration phase then
    Register cpk
    Register spk_i, 1 ≤ i ≤ n
    Change registration phase
else
    Do not accept transaction
    Invalid bpk or invalid phase
end
```

4.1.3. Ordering

In this phase, the customer first announces the quantity of its demand Q and sends it as a transaction argument to the smart contract. Algorithm 2 summarizes customer order registration; then, each supplier i announces its product price i.e, P_i, maximum delay L_i, maximum percentage of the order defect R_i, minimum quantity to be supplied as $min\mathsf{QS}_i$, and maximum quantity to be supplied as $max\mathsf{QS}_i$. The suppliers have time to send a transaction and announce their conditions. When all suppliers have submitted their conditions, the ordering phase changes automatically. Algorithm 3 summarizes Suppliers' term announcement.

4.1.4. Allocation

After the suppliers announce their conditions, the buyer submits its terms. They determine $min\mathsf{QB}_i$ and c_i for each supplier i; then, the smart contract calculates $min\mathsf{Q}_i$ as the minimum amount of supply from supplier i. Algorithm 4 summarizes the buyer's term announcement. The smart contract calculates optimally the score, quantity, and price for each supplier, as well as the buyer's final price. Algorithm 5 shows how the calculations are performed. Once the price is determined, the

Algorithm 2: Customer order registration

Input : cpk as customer Public Key, Q

if *Customer's Public Key* == cpk *&&* *ordering phase* **then**
  Upload order quantity Q and price
  order = true
else
  Do not accept transaction
  Invalid cpk or Invalid phase
end

Algorithm 3: Suppliers term announcement

Input : spk_i, $1 \le i \le n$ as suppliers Public Key, $\{P_i, L_i, R_i, min\mathsf{QS}_i, max\mathsf{QS}_i\}$ as suppliers term

if *supplier ith Public Key* == spk_i *&& order==true && ordering phase* **then**
  Update supplier term list order with set $\{P_i, L_i, R_i, min\mathsf{QS}_i, max\mathsf{QS}_i\}$
  if *i == Number of registered suppliers* **then**
    Change ordering phase
  end
else
  Do not accept transaction
  Invalid spk_i or invalid phase
end

buyer transfers the money corresponding to the price in the smart contract. It should be noted that the smart contract deposits the money until the next phase.

4.1.5. Delivery and settlement

If the supplier i delivers the orders successfully, and the buyer confirms delivery by sending a transaction, the money will transfer to supplier i account A_i based on $Price_i$. In the case that one supplier sends the order with a delay and the percentage of the order defect is higher than the value promised, the smart contract uses α and β as the penalty factors, with these values subtracted from the amount already calculated. Algorithm 6 demonstrates this procedure. It should be mentioned that in our scheme, we assume all parties are honest (as we discussed in Section 4.1.1 and that the buyer adds accurate information to the smart contract.

Algorithm 4: Minimum Q calculation

Input : $\{min\mathsf{QB}_i, \mathsf{c}_i\}_{1\le i \le n}$ as buyer term, bpk as buyer Public Key, List of suppliers term
Output: $min\mathsf{Q}_i$

if *Buyer's Public Key* == bpk *&& Allocation phase* **then**
  while $i \le n$ **do**
    if $Max(min\mathsf{QS}_i, min\mathsf{QB}_i) \le c_i\mathsf{Q}$ **then**
      $min\mathsf{Q}_i = Max(min\mathsf{QS}_i, min\mathsf{QB}_i)$
    else
      $min\mathsf{Q}_i = c_i\mathsf{Q}$
    end
    i++
  end
else
  Do not accept transaction
  Invalid bpk or invalid phase
end

Algorithm 5: Score, quantity and price calculation

Input : Buyer term list, bpk as buyer Public Key, List of suppliers term, minimum Q
Output: S_i,Q_i,Price

if *Buyer's Public Key* == bpk *&& Allocation phase* **then**
  while $i \le n$ **do**
    $\mathsf{S}_i = w_1 \frac{\mathsf{P}_i^{-1}}{\sum_{i=1}^n \mathsf{P}_i^{-1}} + w_2 \frac{\mathsf{L}_i^{-1}}{\sum_{i=1}^n \mathsf{L}_i^{-1}} + w_3 \frac{\mathsf{R}_i^{-1}}{\sum_{i=1}^n \mathsf{R}_i^{-1}}$
  end
  while $i \le n$ **do**
    $\mathsf{Q}_i = min\mathsf{Q}_i + \frac{\mathsf{S}_i}{\sum_{i=1}^n \mathsf{S}_i}(\mathsf{Q} - \sum_{i=1}^n min\mathsf{Q}_i)$
    $Price_i = \mathsf{P}_i \times \mathsf{Q}_i$
  end
  Price $= \sum_{i=1}^n Price_i$
else
  Do not accept transaction
  Invalid bpk or Invalid phase
end

Algorithm 6: Buyer complete payment

Input : bpk as buyer Public Key, Price, α and β as the penalties percents, L_i', R_i'

if *Buyer's Public Key* == bpk *&& Delivery and Settlement phase* **then**
  while $i \le n$ **do**
    A_i = Price $- \sum_{j=1, j\neq i}^n \mathsf{P}_j$
  end
  if *Supplier i deliver successfully && order is received&& delay is False* **then**
    Return A_i to supplier i
  end
  if *Suppliers deliver successfully && order is received&& delay is True* **then**
    Return $\mathsf{A}_i = \alpha.L_i' - \beta.R_i'.P_i\mathsf{Q}_i$ to supplier i
  else
  end
else
  Do not accept transaction
  Invalid bpk or invalid phase
end

4.1.6. Final step

After receiving all the goods and transferring the funds to the suppliers' blockchain accounts (e.g. Ethereum addresses), the smart contract's state changes to 'finished'. At this point, the buyer can destroy the contract. It should be noted that destroying a smart contract does not remove the previous transactions. Rather, the smart contract address will no longer be accessible, and all transactions will be archived on the blockchain. It is noteworthy that the contract can be destroyed once its status has changed and all payments have been completed. Due to this, we design the process with multiple states and check each algorithm carefully to ensure that the states are correct.

5. Implementation

In this section, we describe the implementation of the proof-of-concept (PoC) of the proposed blockchain-based system for supplier order allocation in SC management. Previous studies outlined important considerations when implementing a blockchain platform: purpose, accessibility, programming language, consensus mechanism, ecosystem, and maturity (Miyachi & Mackey, 2021). We have decided to use Ethereum for our PoC for the following reasons:

- Mature Ecosystem: Ethereum has a well-developed and mature ecosystem, including a robust and supportive community, extensive documentation, and numerous development tools that facilitate the creation and deployment of smart contracts.
- Active Development: Ethereum is continuously being improved and updated by a dedicated team of developers, ensuring that it remains at the forefront of BT.
- Private Test network: Ethereum's accessibility and open-source nature allow for the creation of private blockchains for testing purposes, which are not part of the public Ethereum network (mainnet) (Miyachi & Mackey, 2021).
- Acceptance in SC community: This has been reflected in the adoption of Ethereum by 23% of all SC projects using blockchain between 2010 and 2020, with Hyperledger (Androulaki et al., 2018) being the second most utilized blockchain at 21% (Vadgama & Tasca, 2021).
- Interoperability: For making further improvements, the interoperability of Ethereum is useful. Ethereum supports interoperability with other blockchains and technologies, making it a versatile choice for integrating various SC components.

Furthermore, our proposed solution can be implemented with permissioned blockchains and operated privately by stakeholders on a shared blockchain, whether with Ethereum or any other blockchain.

We have implemented the PoC in Solidity language by FixidityLib[1] library, with few changes. FixidityLib provides overflow-protected fixed-point arithmetic for Solidity. A limitation was that, according to Solidity documentation,[2] fixed-point numbers are not yet fully supported by Solidity. Thus, we had to use FixidityLib for our implementation. We deployed on the Kovan Testnet,[3] one of the Ethereum test networks. Table 3 described the functions implemented of the given Algorithms 1–5. The developed smart contract has been uploaded to the GitHub repository.[4] The sequences diagram of functions execution and the interactions among the players in the system are illustrated in Fig. 2. Each player in the system has an EOA[5]; thus, it can interact with the blockchain and smart contract.

In the beginning, the buyer deploys the smart contract on the Ethereum network and then registers customers and suppliers by calling the `addSupplierPublicKey()` and `customerRegister()` functions. This allows them to interact with the contract by their EOAs. When all suppliers and the customer are registered, the buyer finishes the registration phase by calling `endRegistration()` function; then, the customer submits its demand quantity using the `customerOrdering()` function in the smart contract. By calling `supplierStatement()` and `buyerStatement()` function, suppliers and the buyer state their conditions. The buyer can call the `payPriceCal()` function to determine each supplier's optimum order quantity and the transparent amount and price. `minQCalulation()` function is executed by `payPriceCal()` to determine the $min\mathrm{Q}_i$ value of each supplier i. After determining the amount to be given to each supplier, the buyer transfers the sum of these amounts to the smart contract account with a transaction by calling the `deposit()` function. Then, each supplier delivers the goods. After receiving the goods from the buyer, the buyer sends a transaction and calls the `delivery()` function. The `transfer()` function exists in the `delivery()` function. The `transfer()` function sends the price value determined in the previous steps to the relevant supplier account. In the case of one of the suppliers violating the declared defect percentage, or making an illegal delay, the buyer runs the `delayDelivery()` function and enters excess time delay and the percentage of excess defects. This function will automatically calculate and transfer the new payment price. Finally, the buyer can run `destroy()` function to destroy the smart contract.

Any address other than the buyer's address cannot call this function successfully, and its transaction will be reverted. Note that the destruction of the smart contract only makes its address inaccessible from that block onwards, but all previous information within the blockchain will remain immutable (see Table 5).

6. Test scenario

We tested our PoC implementation and carried out performance evaluations in multiple scenarios. We utilized the Remix IDE[6] to implement and test scenarios. Remix IDE is an open-source web and desktop application that provides an environment for deploying smart contracts, interacting with them, testing, and monitoring the details of each transaction. Here, we have designed a numerical example. We consider an SC to include a customer, a single buyer, and three suppliers. Table 4 provides the values for the suppliers' parameters. The values for other parameters are considered $\mathrm{Q} = 1000$, $w_1 = 0.5$, $w_2 = 0.25$, $w_3 = 0.25$, $\alpha = 5000$, and $\beta = 2$. The addressed SC is tested for the smart contract functionality. As the smart contract's owner in the registration phase, the buyer has to register the EOAs of suppliers and the customer. In the ordering phase, the customer issues his order by sending a transaction. Any EOAs other than four registered EOAs do not have permission to participate in the smart contract process. For example, an EOA other than the registered EOA for the customer cannot run the `customerOrdering()` function to issue an order. Then, suppliers send their conditions as a transaction to the network, based on what is given in Table 4. Suppliers cannot submit a transaction until the order has been issued. The buyer states each supplier's terms according to the supplier's conditions. All players can access all suppliers' details and the buyer conditions by calling public state variables `supplierTermsLists()` and `buyerTermsIds()` based on suppliers ID. State variables are values permanently stored in a contract storage system. Furthermore, all players can find each supplier ID by searching the suppliers' EOAs, calling `suppliesrIds()`. Now the buyer can run `payPriceCal()` function so that smart contract starts calculating Q_i and $Price_i = P_i * \mathrm{Q}_i$. After this is run, all participants can see each supplier's order amount by calling state variable `supplierQuantity()` with ID of Supplier and call `payPrice()` to see $Price_i$. Fig. 4 shows the result of the `supplierQuantity()` when a supplier ID is entered. Furthermore, in Fig. 3, the price to be paid to each supplier is shown, thus adding to transparency.

The buyer then calls the public state variable `payFee` to be informed of the total sum of prices payable. It then sets this value as `msg.value` and runs the `deposit()` function. The `deposit()` function checks that this value is equal to `payFee`; in this case, it adds this amount to the smart contract account. Once the money is added to the smart contract account, the buyer can no longer spend it. It can only be sent automatically to the supplier's account after delivery. Therefore, suppliers prepare the order and send it after preparation. The smart contract guarantees that the payment will be made automatically if they adhere to the contract's provisions. In the case of delivery on-time and with less than the specified percentage of defects, the buyer runs `delivery()` function. The money is then sent from the smart contract account to the supplier's EOA. Otherwise, `delayDelivery()` function is run by the buyer and receives L'_i and R'_i as the inputs for

[1] https://github.com/CementDAO/Fixidity
[2] https://docs.soliditylang.org/en/latest/types.html#fixed-point-numbers
[3] https://kovan-testnet.github.io/website/
[4] https://github.com/ashkanemami/Blockchain-based-supplier-order-allocation
[5] Externally owned account: This account type in Ethereum is controlled by a public/private key pair.
[6] https://remix.ethereum.org/

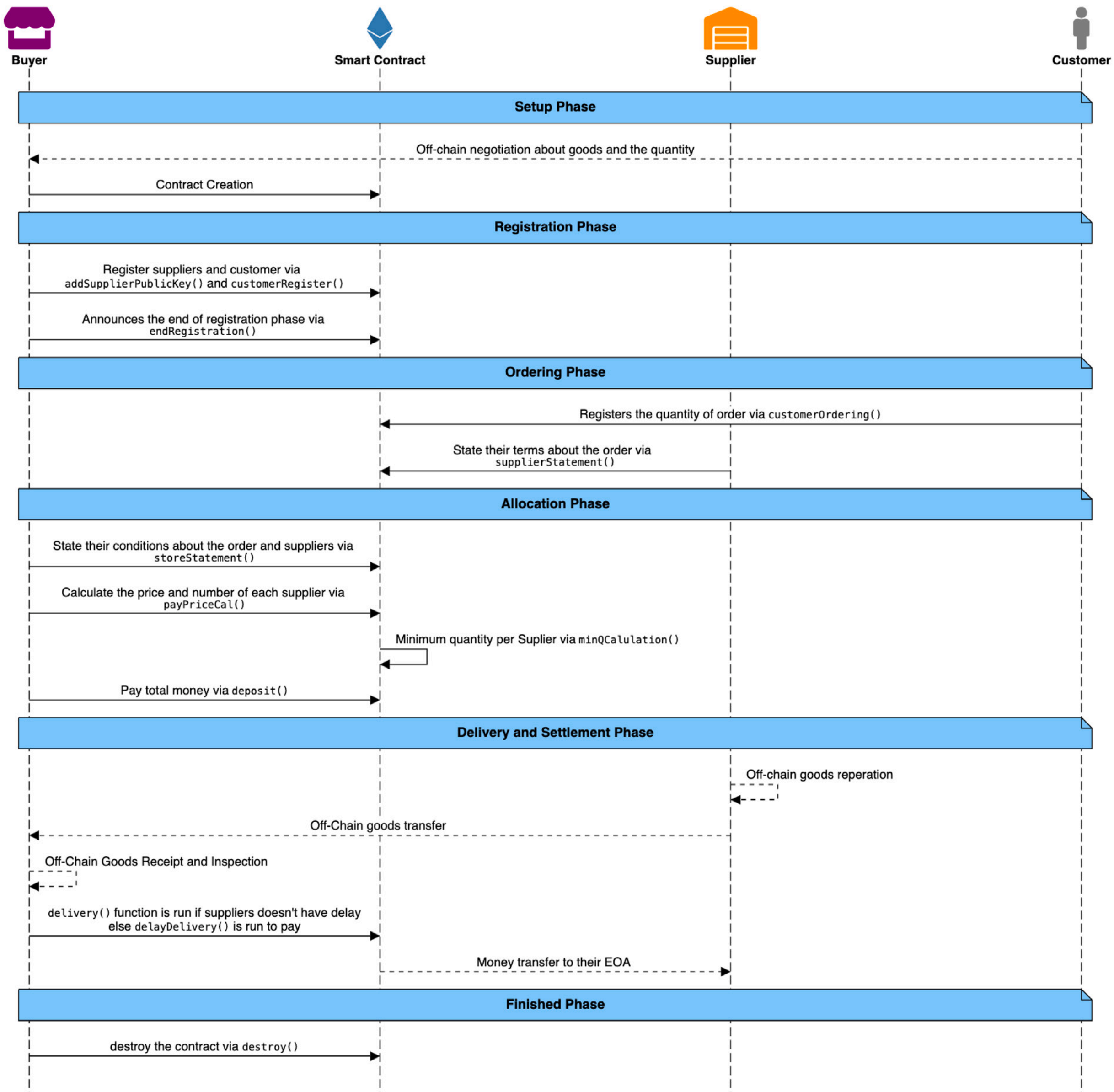
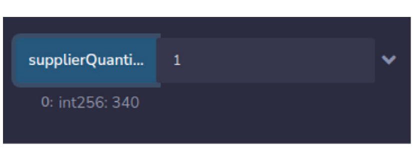
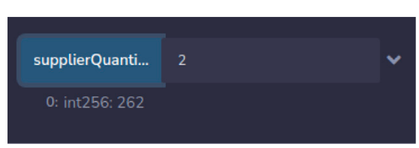


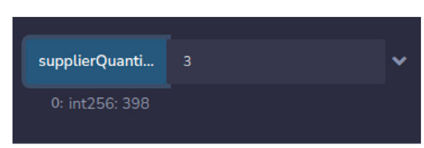
Fig. 2. Message sequence diagram among the players.



(a) The amount for supplier with $i = 1$

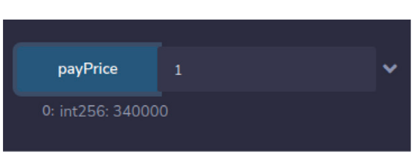


(b) The amount for supplier with $i = 2$

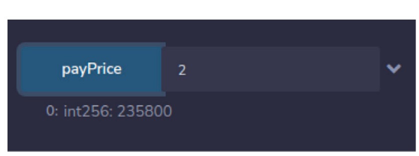


(c) The amount for supplier with $i = 3$

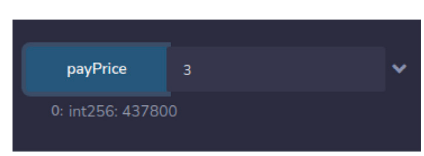
Fig. 3. The amount of order given to each supplier.



(a) $Price_1 = P_1 * Q_1$



(b) $Price_2 = P_2 * Q_2$



(c) $Price_3 = P_3 * Q_3$

Fig. 4. The price that the buyer must pay to each supplier.

Table 3
Description of the functions implemented in the auction smart contract.

Phase	Function	Input	Output	Access	Description
Registration	`addSupplierPublicKey()`	Supplier Address	–	Buyer	Buyer registers suppliers
	`customerRegister()`	Customer Address	–	Buyer	Buyer registers customer
	`endRegistration()`	–	–	Buyer	Buyer declares the end of this phase
Ordering	`customerOrdering()`	The Quantity	–	Customer	Customer declares the Quantity of the order
	`supplierStatement()`	Supplier Conditions	–	Suppliers	suppliers declares their conditions
Allocation	`buyerStatement()`	Buyer Conditions	–	Buyer	Buyer declares its term per supplier
	`payPriceCal()`	–	–	Buyer	Each supplier quantity amount and its price
	`deposit()`	–	–	Buyer	Buyer pays total of the suppliers' price.
Delivery and Settlement	`delivery()`	–	–	Buyer	Transfer money of each supplier to their Ethereum accounts
	`delayDelivery()`	Delay Conditions	–	Buyer	Delay days and defects percentages and address of supplier as inputs and calculates new price to be given to supplier
Finished	`destroy()`	–	–	Buyer	Buyer can destroy the contract after receiving goods and settlement.

Fig. 5. The result of running `delayDelivery()` function in blockchain explorer.

Table 4
The values of the contract parameters of suppliers.

i	1	2	3
P_i	1000 wei	900 wei	1100 wei
L_i	2 days	5 days	1 days
R_i	2%	4%	1%
L'_i	3 days	0	0
R'_i	2%	0	0
$min\mathrm{QS}_i$	200 unit	100 unit	400 unit
$max\mathrm{QS}_i$	600 unit	800 unit	900 unit
$min\mathrm{QB}_i$	250 unit	150 unit	100 unit
c_i	0.2	0.2	0.2

calculating the penalty and new payment. The `delayDelivery()` function uses Eq. (2), considering α and β coefficients are entered when the smart contract is deployed. This calculates the new payment in a fuly transparent fashion, and the new amount is transferred to the supplier's account. Fig. 5 shows a transaction in blockchain explorer[7] related to `delayDelivery()` function, which is run by the buyer for the payment of supplier one. One can see the new payment calculated based on details of the delay mentioned in Table 4. This is then transferred to Supplier 1 EOA instead of the amount specified in Fig. 4(a). Note that in this scenario, we used wei[8] for payments. Ether has many names for different sub-units. These sub-units can be used regarding the payment volume of each scenario. Furthermore, a cost exists for deploying a smart contract; the function runs and each transaction that users initiate. We summarized the cost in Table 5.

7. Discussion

7.1. Theoretical contribution

This paper intends to provide further insight into how blockchain-driven SC business models can be enhanced by using smart contracts for SSOA. Currently, blockchain-driven business models in SCs are examined across three key literature streams: value creation; value delivery; and value capture (cf. Teece (2010)). Considering the first stream, blockchain-driven business models create value by, for example, preventing fake and counterfeit products (Mackey & Nayyar, 2017), improving product safety and quality (Tseng, Liao, Chong, & Liao, 2018), and decreasing the use of illegal production methods (Cole, Stevenson, & Aitken, 2019). This is because blockchain — as discussed in the second stream of literature — improves value delivery by ensuring traceability and transparency of product delivery to customers (Lim, Li, Wang, & Tseng, 2021). Finally, the third stream explores how blockchain can enhance mechanisms such as pricing strategies (Agrawal, Angelis, Khilji, Kalaiarasan, & Wiktorsson, 2023) and mechanisms to ensure the long-term sustainability of blockchain adoption (e.g., Chin, Shi, Singh, Agbanyo, and Ferraris (2022), Miatton (2020)). The SSOA context, however, is often overlooked in the SC process (see, for example, the review by Dutta, Choi, Somani, and Butala (2020), Lim et al. (2021), Pournader, Shi, Seuring, and Koh (2020)). This appears to be a significant omission because without SSOA, SC processes cannot function effectively (kumar et al., 2018). Thus, by introducing a smart contract for SSOA in a defined buyer–supplier SC scenario, we extend the existing literature by illustrating how blockchain enhances value creation and delivery in SCs by mitigating centralized governance and helping to effective contract management challenges. Although we do not claim to build a theory, the proposed paper implicitly contributes to the progression towards Type V theory development (i.e., theory for design and action) (see Gregor (2006)). Specifically, we provide the "how" through the proposed mathematical expression and algorithms, which can inform the development of smart contracts in SSOA. This contribution addresses an underexplored area. Most existing blockchain discussions in operational applications focus on behavioral aspects, such as adoption, rather than going deeper into the design properties of smart contracts. Furthermore, our design is unique as it addresses coordination and operational analytics—areas rarely covered in existing Type V theories. Most studies focus instead on themes such as (1) information sharing, (2) traceability, or (3) adaptability (see the review by Hanafizadeh and Alipour (2024)).

Our second contribution is to provide prescriptive knowledge on developing smart contracts for SSOA in SCs. In the problem space, we provide a mathematical representation aimed at optimizing SSOA

[7] https://etherscan.io/

[8] The smallest possible denomination of ether (ETH) as One ether = 10^{18} wei.

Table 5
Costs of the contract functionalities.

Functionality	Tx's	Gas	Fee (ETH)	Fee (USD)	Caller
`Contract creation`	1	4, 738, 127	0.011	44	Buyer
`addSupplierPublicKey()`	1	188 008	0.00047	1.88	Buyer
`customerRegister()`	1	48 544	0.00012	0.54	Buyer
`endRegistration()`	1	49 323	0.00011	0.45	Buyer
`customerOrdering()`	1	74 854	0.00018	0.81	Customer
`supplierStatement()`	1	175 484	0.00042	1.89	Suppliers
`buyerStatement()`	1	225 635	0.0005	2.25	Buyer
`payPriceCal()`	1	974 532	0.0024	10.8	Buyer
`deposit()`	1	33 757	0.00008	0.32	Buyer
`delayDelivery()`	1	102 425	0.00025	1	Buyer
`delivery()`	1	64 659	0.00017	0.68	Buyer
`destroy()`	1	30 765	0.00007	0.28	Buyer
`suppliesrIds`	0	–	free	free	anyone
`supplierTermsLists`	0	–	free	free	anyone
`buyerTermsIds`	0	–	free	free	anyone
`payFee`	0	–	free	free	anyone
`payPrice`	0	–	free	free	anyone
`SupplierQuentity`	0	–	free	free	anyone

for blockchain environments. To the best of our knowledge, this approach has yet to be considered elsewhere in the literature. We have designed a logical value that is computationally efficient within a blockchain environment. Future research can build upon this formula to further enhance SSOA optimization. In the solution space, we propose novel algorithms for decentralized supplier order allocation and financial settlement within a given SC system. This is achieved through a smart contract which provides decentralized automation, transparency, traceability, integrity, availability across the decentralized network. A transparent digital ledger automates communication, collaboration, financial settlement and data sharing among stakeholders, effectively addressing long-standing issues such as a lack of shared visibility, manual errors, and payment disputes. The evaluation of this implementation provides valuable insights into the potential of decentralized technologies to overcome the limitations of traditional centralized approaches.

The third contribution is that international researchers can implement platforms of this type for global SCs with geographic dispersion. Many SCs are geographically dispersed due to objectives such as risk mitigation, cost reduction, and environmental harm reduction. Sustainable SCs adhere to the three dimensions mentioned above. To address these dimensions, the proposed solution ensures accurate and timely supplier payments, while offering secure cross-border transactions to mitigate currency risks. Additionally, by utilizing blockchain technology (BT), our solution automates and optimizes ordering, thus reducing paperwork and manual errors, and thereby contributing to cost reduction and environmental harm mitigation. Our proposed solution shares similarities with Maersk's TradeLens platform (Jovanovic, Kostić, Sebastian, & Sedej, 2022), developed in collaboration with IBM. It digitizes and streamlines the documentation process in international trade, resulting in reduced paperwork, enhanced transparency, and improved efficiency (Difrancesco et al., 2023). Furthermore, Walmart has implemented blockchain to automate and optimize ordering processes, further reducing paperwork and manual errors (Difrancesco et al., 2023).

The fourth contribution is that we believe our proposed solution can lead to cost reductions in SSOA. According to Xia, Li, and He (2023), real-time order tracking has allowed all parties to access information about orders seven days earlier than the previous system, which increases delivery schedule accuracy by 10%. Additionally, previous studies by Omar et al. (2020), Wang, Li, Zhang, and Chen (2019) have utilized smart contracts to address similar issues in SCs and conducted thorough testing and analysis. The findings demonstrated that implementing Ethereum smart contracts could lead to cost savings and increased stakeholder profits. Our proposed solution incorporates real-time order tracking, enabling all parties to access information about orders promptly. Therefore, we can conclude that our solution also contributes to cost reductions.

7.2. Managerial implications

Industry practitioners can consider adapting or extending their blockchain-driven business model in buyer–supplier SCs by incorporating smart contracts, particularly in SSOA. Our first objective in this study was to highlight the challenges associated with traditional, centralized approaches, including communication, collaboration, performance monitoring, and compliance assurance. We discussed how effective contract management is critical to SSOA within a buyer–supplier strategic partnership.

Our design demonstrates how smart contract-based SSOA can add value by addressing centralization and contract management challenges. From a business-to-business perspective, reliable SCs foster long-term cooperation among members. The proposed solution aims to better facilitate supplier compliance with contractual terms by leveraging various attributes of blockchain and smart contract technologies. Specifically, automatic monitoring and real-time reporting of suppliers' adherence to agreed obligations (e.g., delivery times, quality standards) on an immutable shared ledger can promote compliance transparency throughout the supply network.

Our design knowledge also offers valuable guidance for developers to design and implement smart contracts on their SC networks. First, our mathematical formula provides (Appendix) a foundation for optimizing SSOA in smart contracts, which can be extended by incorporating additional variables beyond late delivery or product defects. Second, our system model offers practitioners a practical solution for identifying key participants and interactions within their SC networks. It enables them to design tailored smart contracts that address specific operational needs. Finally, our proposed algorithms offer practitioners precise, step-by-step approaches for coding smart contracts, which can also be customized to suit their specific contexts.

As a result, industry practitioners can raise customer satisfaction in SC by increasing transparency or by making SC more reliable by promoting long-term cooperation among members.

7.3. Limitations and future research

In this subsection, we discuss the limitations related to our (1) research approach and (2) the nature of the artifact. *Considering the research approach,* similar to other early-stage design science research studies (e.g., Mettler and Winter (2016)), we did not directly test our artifact with human participants. Instead, we focused on evaluating its technical efficacy in a controlled setting through simulation (Venable, Pries-Heje, & Baskerville, 2016). This approach is, nonetheless, justified as it provides an initial step to demonstrate the feasibility of our artifact and its significant potential to contribute to blockchain-driven business models in SCs. Future research can test our artifact in more naturalistic settings and involve human participants to validate its efficacy in addressing centralization and contract management challenges in SSOA. For example, this could be achieved by implementing the artifact in a case study and empirically analyzing its impacts.

Regarding the nature of the artifact, future research should address three key areas: privacy, goods control, and transaction costs. First, we utilized a public blockchain to address transparency issues among SC participants. As a result, all information about buyers and suppliers is publicly recorded on the blockchain, allowing partners with access to the blockchain to view and monitor every transaction. This creates a tension between transparency and privacy. Future research should build on our work to address this tension, for instance, by integrating smart contracts with cryptographic techniques such as homomorphic encryption, zero-knowledge proofs (de Haro-Olmo, Varela-Vaca, & Álvarez-Bermejo, 2020; Feng, He, Zeadally, Khan, & Kumar, 2019), or off-chain computations like trusted execution environments (Wang, Zhao, & Wang, 2020). In addition, future research could examine the possibilities of Layer 2 (L2) solutions being used for private or permissioned applications (Dabbagh, Choo, Beheshti, Tahir, & Safa, 2021).

Second, in this work, we do not have any mechanism to control the goods' quality on-chain because of technology limitations. After receiving the orders, we trust the buyer's claims about the defect percentage of goods. In future work, IoT sensors can be utilized to measure the quality of specific goods in certain SCs (cf. Hasan et al. (2019)). Adding IoT sensors for defect percentage measurement can be part of future work. This requires the use of a concept called an Oracle. Using oracles (Park, Kim, Kim, & Ryou, 2020) to feed outside data to smart contracts has also grown over the past few years (Moudoud, Cherkaoui, & Khoukhi, 2019). However, these technologies still face challenges (Hassan, Makhdoom, Iqbal, Ahmad, & Raza, 2023). As a future selection, oracles could be used in the proposed system in conjunction with IoT sensors to feed sensitive information to the proposed smart contract and assess its performance.

Finally, the proposed solution is more transparent if stakeholders use a public blockchain instead of a permissioned blockchain. However, smart contracts have rising transaction costs (for instance, Ether in the proposed PoC). Fees are incurred by users for each function that they execute and every transaction they initiate. The cost of submitting a transaction can vary significantly due to fluctuations (like Ether in our case) relative to currencies like the dollar. There can be a conflict between transparency and price. Stakeholders may, however, consider using public blockchains like Tron (2018), Solana (2018), and EOS (2017), which may offer a lower price, but there can be no assurance that the price will remain the same in the future given the proposed reason.

Despite these limitations, our work already makes significant contributions to the literature (see Section 7.1). Future studies can build on this foundation to further enhance our proposed smart contracts.

8. Conclusions

This paper examines the critical role of effective contract management and centralized governance in SSOA within SC management. A design science research study was conducted in order to examine limitations associated with traditional centralized governance. It also looked at challenges associated with effective contract management in SSOA, such as collaboration and performance monitoring. In our study, we examined the potential of blockchain-driven business models to revolutionize these issues by fostering transparency, immutability, and automation. To address these challenges, we developed a novel mathematical framework for allocating orders among suppliers and calculating penalty costs in the case of late deliveries or product defects. As a next step, we developed the system model of actors' interaction in a decentralized network like blockchain. We did this by defining the roles and responsibilities of the SC members, who are each capable of monitoring every interaction in the proposed system. In order to automate this process, we designed a smart contract to implement the proposed allocation formula. After identifying the actors who interact with each other, we developed algorithms which would manage interactions with the smart contract, including methods for submitting, verifying, and recording transactions. Eventually, the required algorithms were developed to take account of numerous features; registering SC players in the smart contract; submitting customer orders (as the buyer is required to order from suppliers based on this value); share their ability to supply transparently based on price, time, and defect percentage,;determining the minimum amount of supply each supplier must provide; calculating the quantity and price for each supplier in transparent fashion; and completing payments after goods are received. As a proof of concept, the proposed algorithms are implemented as an Ethereum smart contract, available on GitHub.

Using test scenario analysis on the Ethereum blockchain, we evaluated the proposed smart contract and confirmed its *feasibility*. Thus we potentially address the centralization and efficient contract management challenges in SSOA. We show that focusing on smart contract design for SSOA can enhance blockchain-driven business models in SC. To assist developers in developing and implementing smart contracts within their SC networks, we provided prescriptive guidance. By integrating blockchain-based smart contracts into SSOA, we are pioneering a path towards more decentralized and efficient SCs.

CRediT authorship contribution statement

Ashkan Emami: Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Conceptualization. **Mehdi Seifbarghy:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Formal analysis, Conceptualization. **Antragama Ewa Abbas:** Writing – original draft, Validation, Methodology, Investigation. **Wichai Chattinnawat:** Writing – review & editing, Project administration. **Nezir Aydin:** Writing – review & editing, Supervision.

Ethics approval

Not applicable, because this article does not contain any studies with human or animal subjects.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This research was funded [in whole / in part] by the Luxembourg National Research Fund (FNR), grant reference NCER22/IS/16570468/NCER-FT and the Ministry of Finance of Luxembourg through the FutureFinTech National Centre of Excellence in Research & Innovation. For the purpose of open access, and in fulfillment of the obligations arising from the grant agreement, the author has applied a Creative Commons Attribution 4.0 International (CC BY 4.0) license to any Author Accepted Manuscript version arising from this submission.

Appendix

Considering the parameters of $min\mathrm{Q}_i$, S_i and Q, the allocated amount of order to supplier i, i.e. Q_i can be calculated as in:

$$\mathrm{Q}_i = min\mathrm{Q}_i + \frac{\mathrm{S}_i}{\sum_{i=1}^{n} \mathrm{S}_i}(\mathrm{Q} - \sum_{i=1}^{n} min\mathrm{Q}_i) \quad (1)$$

In the given equation, the first term is the agreed minimum amount of supply from the supplier. The second term gives the supplier's quota i from the remaining order to its relative score. It should be noted that if Q_i is greater than the maximum amount of ability to supply of supplier i (i.e. $max\mathrm{QS}_i$), then $\mathrm{Q}_i = max\mathrm{QS}_i$ and the additional amount is assigned to other suppliers.

On the payable amount to each supplier, the buyer pays $P_i\mathrm{Q}_i$ to supplier i. Considering α and β as the penalties for one unit time delay in delivery and for one percent additional defect in the order, the amount payable to supplier i, is equal to:

$$P_i\mathrm{Q}_i - \alpha.L'_i - \beta.R'_i.P_i\mathrm{Q}_i \quad (2)$$

Data availability

We shared the implementation code of our solution through an anonymous GitHub repository for double-blind review purposes.

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