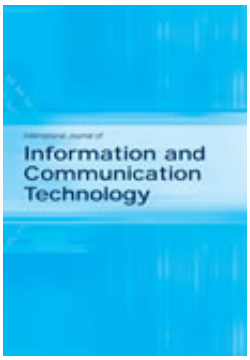

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Blockchain technology application and optimisation algorithm in enterprise supply chain management

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Abstract: Aiming at the issues of collaborative efficiency and trust crisis faced by supply chain management (SCM), this paper firstly design a blockchain-based SCM architecture, improve the blockchain smart contract, unite the election conditions of the Raft leader, set the election index rules, introduce preparatory candidates, and implement the division of subjects to authorise the legitimate subjects to be uploaded to the blockchain. Parameters such as chain owner costs and service credits are then materialised into a multi-business synergy model. Second, from the point of view of improving the efficiency of the genetic algorithm in generating the offspring buffer, the cross-variation part is parallelised, which greatly reduces the model solving time. Finally, the TOPSIS method is used to calculate the Euclidean distance and decide the ideal solution. Simulation results imply that the offered algorithm saves 16.37% of computation time and provides a new perspective for SCM.

Keywords: supply chain management; SCM; blockchain; raft algorithm; genetic algorithm; GA; TOPSIS method.

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Biographical notes: Zhihao Cao received his Master's degree at Chongqing University in 2022. He is currently a Lecturer in ChongQing College of Finance and Economics. His research interests are in blockchain, corporate governance and accounting information systems.

1 Introduction

Competition in the 21st century is no longer between individual enterprises, but between supply chains. The development of industrial internet has extended the structure of supply chain management (SCM) to industrial clusters, especially virtual clusters using the Internet as a technological tool. Such cooperation includes vertical cooperation between upstream and downstream segments, horizontal cooperation between similar segments, and diagonal cooperation across regions and industries. Supply chain structure tends to be loosely coupled but highly organised in a mesh structure (Gualandris et al.,

2021). In traditional SCM, collaborative operations are usually handled by the chain or chain-owning firms, and the process often faces a number of challenges, including information asymmetry (Bala, 2014), lack of real-time and flexibility, as well as significant consumption of computational resources and inefficiencies in the allocation of operations in a multi-enterprise environment (Melnyk et al., 2022). These issues not only affect the production efficiency, but also restrict the supply chain's ability to respond to rapid changes in the market. Therefore, it is necessary to study in depth an efficient and stable SCM strategy to enhance the competitiveness and market adaptability of the enterprise supply chain.

Prajapati et al. (2022) designed an IoT-embedded B2B SCM system, which integrates a mixed-integer nonlinear programming model inside the system to help the system to strictly control the costs in the supply chain production, and by using a global solver, it can be used to compute the optimal value of the costs in the supply chain, so as to achieve the minimisation of the overall costs of the supply chain. In Fierro et al. (2020), an innovative agent-based model is proposed to support the design and development of the CS2 supply chain simulator, allowing users to interact with each other through various simulation activities and facilitating data sharing and collaboration among different users. Zhu (2020) has achieved a high degree of integration between procurement and sales through the reorganisation and integration of e-commerce business, which not only optimises the management process, but also significantly reduces the intermediate links and effectively lowers the operating costs. Similarly, Huawei has also integrated the information and plans of production, procurement and other links by building an integrated management system based on cloud computing, forming a complete planning system to ensure the consistency and efficiency of the enterprise's operations (Luo et al., 2017).

The immutability, transparency, and traceability of blockchain technology provides a better and confidential mechanism for data transaction and maintenance, and also solves many problems in SCM and improves the operational efficiency of the supply chain. Du et al. (2020) reconstructed a supply chain financial management platform using blockchain technology to improve the security and efficiency of financing by optimising the mutual trust mechanism of enterprises. Varriale et al. (2021) analyse the supply chain in the context of 5G mobile edge computing and propose an authentication protocol based on blockchain and RFID, which saves computational costs between data communications. Nanda et al. (2023) designed a centralised collaborative management system for the medical and pharmaceutical supply chain with the help of blockchain technology. Rejeb et al. (2019) integrate IoT end devices with blockchain to automate data collection and uploading functions in the cold chain process. Ahmad et al. (2024) further investigated by integrating supply chain with blockchain and found that blockchain technology improves the availability of supply chain data and reduces the cost of data interactions. Sarfaraz et al. (2023) proposed an election supply chain based on the DPoS consensus mechanism, which promotes supply chain synergy.

Chen and Du (2024) designed an optimisation method for managing costs by analysing the domestic and international advantages of blockchain in cross-border supply chain and customs compliance and combining it with particle swarm optimisation (PSO) algorithm, but with high resource consumption. Zhang and Wang (2024) proposed to reconstruct the trust system of cross-border e-commerce using blockchain technology, which facilitates the further development of cross-border e-commerce by using ant

colony optimisation (ACO) algorithm in combination with multidimensional factors such as logistics tracking, quality control, and product traceability.

According to the comprehensive analysis of the existing research, the existing SCM methods have the problems of collaborative efficiency, information traceability and trust crisis, therefore, this paper firstly designs the blockchain-based SCM architecture, including each participant in the supply chain and the third-party CA authentication organisation. Then improve the blockchain smart contract, combine the election conditions of Raft leaders, set the election index rules, and complete the blockchain-based Raft consensus optimisation. Introduce preparatory candidate roles and implement the division process for the subgroups of follower nodes, add the corresponding remote procedure call (RPC) messages to realise the reasonable verification of CA on the identity of the supply chain subjects, and authorise the subjects with legitimate authentication to be uploaded to the blockchain. On this basis, we dig deeper into the constraints of the blockchain, the master enterprise and the on-chain enterprises, and visualise the parameters such as the cost and service points of the master enterprise, the number of the on-chain enterprises and the stability of the blockchain into the collaborative management model of the supply chain. Second, from the point of view of improving the efficiency of the genetic algorithm (GA) in generating the offspring buffer, the cross-variation part is parallelised, which greatly reduces the model solving time. In addition, in order to solve the problem that the Pareto solutions cannot dominate each other, TOPSIS is adopted to calculate the Euclidean distance and decide the ideal solution. The experimental outcome imply that the CPU usage and memory usage of the offered method are controlled at 18.7% and 1.92GB, respectively, which greatly improves the efficiency of SCM.

2 Relevant technologies

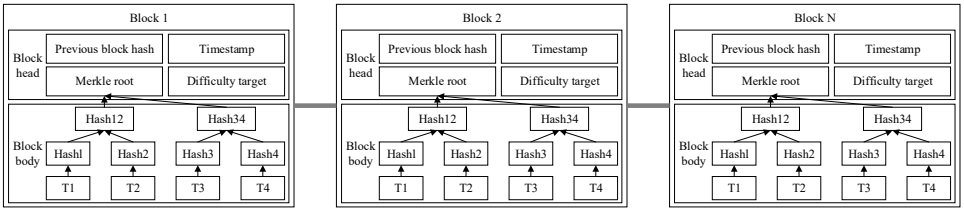
2.1 Blockchain basic concepts

The basic elements of blockchain contain transaction, block and chain (Yu et al., 2018). Transactions are used to record the changes that occur in the state of the ledger after the completion of each operation; blocks record the transactions and state results that occur over a period of time, which is a consensus on the current state of the ledger; and chains are used to represent the logging of the entire state. Blockchain technology records transactions through a distributed ledger without the need for a centralised institution to manage them, which meets the need for decentralised and flat structure in SCM (Zeng et al., 2020). Blockchain is a chained storage structure with blocks as the basic unit, as shown in Figure 1. Each chain is composed of multiple blocks, and each block consists of two parts: the block header and the block body (Bhutta et al., 2021).

The underlying architecture of blockchain has six layers, from bottom to top, which are data level, network level, consensus level, incentive level, contract level and application level (Al Ahmed et al., 2022). The data level encapsulates the underlying data blocks and basic data encryption algorithms. The network level has distributed network structure, data authentication and dissemination mechanisms. The consensus layer contains several consensus algorithms to help realise the packaging and chaining of transaction data. The incentive level mainly provides rewards to the nodes in the blockchain for participating in security verification. The contract layer encapsulates

algorithms, scripts, and smart contracts to provide programmable properties for the ledger. The application level contains various application scenarios and cases of blockchain.

Figure 1 Structure of the blockchain



2.2 Genetic algorithm

GA is a heuristic global optimisation algorithm that mimics the evolutionary process in nature by cyclically performing selection, crossover, and mutation operations to drive the entire population towards the optimal solution of a problem (Thede, 2004). Compared to PSO and ACO algorithms, GA is able to find the near-optimal or optimal solution of the problem in a shorter time (Kumbharana and Pandey, 2013).

1 Initialise the population. Generate initial individuals in the decision space of the optimisation problem as follows.

$$v_{i,1}^{j} = v_{\min}^{j} + rand\left(v_{\max}^{j} - v_{\min}^{j}\right) \tag{1}$$

where rand $\in$ [0, 1] is a uniformly distributed random number and $v_{\max}^{j}$ and $v_{\min}^{j}$ are upper and lower bounds on the value of the i^{th} decision variable.

2 Construct the fitness function. It since the individual consists of genes, the fitness function is defined as the cumulative value of the reward of all genes in the individual.

3 Selection operation: good individuals are selected from the old population with a certain probability to form a new population. The probability that individual i is selected is $p_i = F_i \Big/ \sum_{j=1}^{N} F_j$, where F_i is the adaptation value of individual i, N is the number of individuals in the population.

4 Crossover operation: Two individuals are randomly selected in a population and their chromosomes are exchanged to produce a new superior individual. The crossover operation between the l^{th} chromosome a_l and the k_{th} chromosome a_k at position j is as follows:

$$\begin{cases} a_{lj} = a_{lj}(1-b) + a_{kj}b \\ a_{kj} = a_{kj}(1-b) + a_{lj}b \end{cases} \tag{2}$$

5 Mutation operation: An individual is randomly selected in the population and a single point of mutation in the individual produces a new superior individual. The j^{th} gene a_{ij} of the i^{th} individual is mutated as follows:

$$\begin{cases} a_{ij} + (a_{ij} - a_{\max})\, g(f), & v \geq 0.5 \\ a_{ij} + (a_{\min} - a_{ij})\, g(f), & v < 0.5 \end{cases} \tag{3}$$

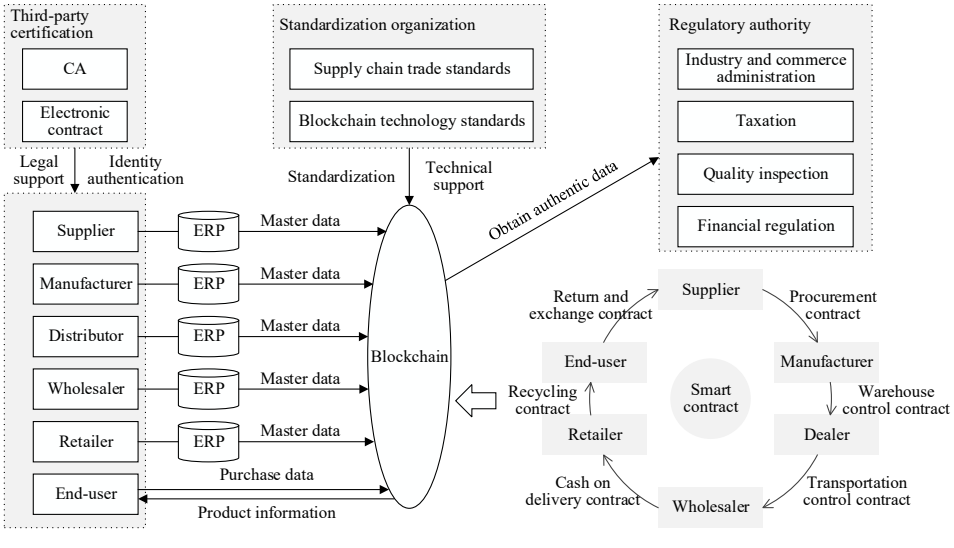
where $g(f) = R(1 - f / F_{\max})^2$ where $b_{\max}$ and $b_{\min}$ are the upper and lower bounds of b_{ij}, respectively; w is any number between [0, 1]; R is any number; f and $F_{\max}$ are the number of current iterations and the maximum number of iterations, respectively.

3 Preprocessing of a multimodal English corpus

3.1 Blockchain-based SCM architecture design

At present, most of the enterprises in the supply chain still rely on ERP for SCM, and each enterprise maintains its own ERP system, which is unable to realise the interconnection of information in the supply chain network. To this end, this paper uses blockchain to open up the ERP system between enterprises, improves the efficiency of SCM with improved consensus algorithm, and authorises the legitimate subjects to be on the chain to prevent the risk of default and establish a supply chain environment of mutual trust and win-win situation, as shown in Figure 2. The architecture consists of two elements: the first one is each participant in the supply chain, including suppliers, manufacturers, distributors, etc.; and the second one is a qualified third-party CA certification organisation, which provides legal support and guarantee for identity authentication and e-contract authentication.

Figure 2 Blockchain-based SCM architecture

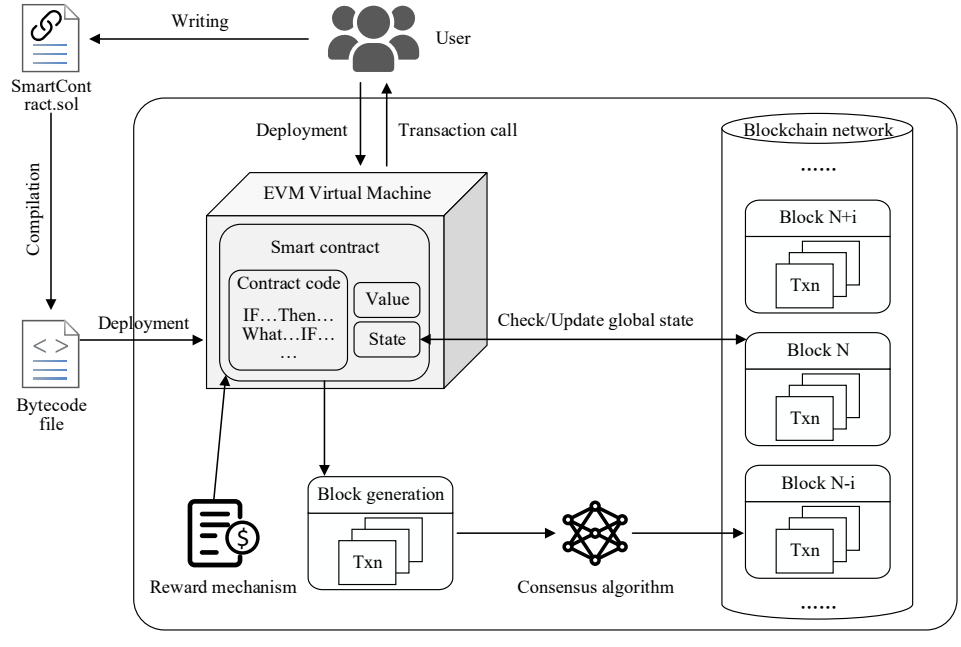


3.2 Blockchain smart contract

Designing an enterprise SCM architecture with blockchain is only the first step; smart contracts are the key to optimising enterprise SCM (Agrawal et al., 2023). Modern supply chains have numerous operations and smart contracts can be used at many points, the smart contract structure is shown in Figure 3. Assuming a blockchain network, $\dot{A}$ is the data encoding information within the contract, the identity function associated with this information is $F(\dot{A})$ and S is the target communication node of this information, the data communication behaviour from $\dot{A}$ to S can be defined as follows, where ξ is the authentication parameter of the data information under this contract.

$$D_{A\to S} = \frac{F(\dot{A})}{\sqrt{\xi\left(\dot{A}^2 + S^2\right)}} \tag{4}$$

Figure 3 Smart contract operation mechanism



Since a smart contract acts as a piece of code on the blockchain organisation in the communication network, it can be automatically executed once the communication data triggers a clause in the contract. By specifying $\hat{d}$ as the coded code elements within the blockchain, w as the contract clause trigger factor, $\vec{\psi}$ as the data communication vector defined by the triggered contract clause, and a as the trustworthiness parameter, and associating the consensus (4), the blockchain smart contract can be defined as follows:

$$G = \hat{d}\,\frac{(1-\omega)D_{A\to S}}{\vec{\psi}^{a-1}} \tag{5}$$

3.3 Election of leaders in the corporate supply chain

Leader election in blockchain environment is an important part of consensus algorithms. There are numerous consensus algorithms for blockchain, among which the Raft algorithm (Huang et al., 2019) uses three states, leader L, follower F, and candidate C, which reduces complexity. When L fails, the system needs to conduct L election to ensure the reliability and consistency of the data identity. Let w be the communication request coefficient within L node, σ be the communication request coefficient within F node, f be the communication log replication parameter, and $\hat{h}$ be the message definition term, and associate equation (5) with the definition of the Raft leader election in the blockchain environment as follows:

$$\sum_{\omega=1}^{+\infty} f \times (\hat{h}+1) \tag{6}$$

When a node starts up, it initialises itself to the follower state and waits for an authentication message from L. If no RPC authentication message is received from L within the election timeout period, the blockchain node will enter the candidate state and start the election.

In the Raft consensus algorithm, a node can cast only one vote for a term number, i.e., the Raft algorithm allows the leader node to authenticate the data identity only once. By specifying v as the object index coefficient, j_1 as the election vector of L, j_2 as the voting vector of F, and θ as the readability coefficient of the voting information, the election indexing criterion of the Raft algorithm for data identity information can be defined as follows. If a node has a smaller tenure number than the other nodes, it will update its own tenure number to maintain consistency, thus improving authentication.

$$J = H \frac{\sum_{v \to \infty} w \times j_1}{j_2 \left| \theta^2 - 1 \right|^{-1}} \tag{7}$$

3.4 Supply chain subject identity consensus mechanism construction

In the enterprise SCM, in order to build a reasonable identity consensus mechanism, the Raft algorithm should also introduce a reserve candidate role (i.e., a reserve supplier) and add corresponding RPC messages according to the criteria of supplier subgroups, so as to realise a reasonable authentication of supply chain subjects' identities, as implied in Figure 4. Define K_1 and K_2 as non-overlapping supply chain subjects, l_1 as the candidate identity information corresponding to K_1, and l_2 as the candidate identity information corresponding to K_2. The conditions for the introduction of preparatory candidate roles between K_1 and K_2 are expressed as follows.

$$M_{1 \to 2} = \left| \Delta m \right| \times \frac{o_1 l_1 - o_2 l_2}{\vartheta^2 J} \tag{8}$$

where Δm is the communication transmission, o_1 is the identity candidate with K_1, o_2 is the identity candidate with K_1, and ϑ is the role identity definition parameter.

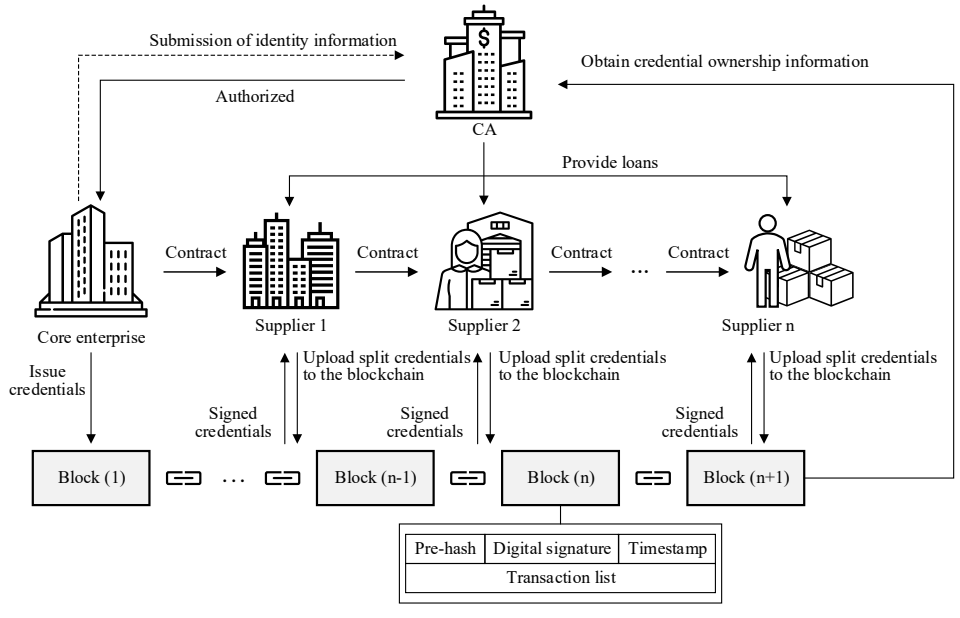
After the introduction of preparatory candidate roles, according to the idea of clustering algorithm, the supply chain subject will be divided into several subgroups, and

each subgroup organisation will carry out local consensus first, and then the subgroup organisation will transmit the consensus identity information uniformly, so as to facilitate the construction of a complete identity consensus mechanism. Providing that b_1, b_2, …, b_n is n F nodes and μ is the separation relationship between F nodes and ready candidate roles, the subject subgroup division formula is as follows.

$$V = v^2 \vec{C} \sqrt{\frac{\mu(b_1 + b_2 + \cdots + b_n)}{(n-1) \times M_{1 \to 2}}} \tag{9}$$

where v is the local consensus parameter and $\vec{C}$ is the clustering operation vector.

Figure 4 Supply chain subject identity consensus mechanism



In the process of building the identity consensus mechanism, the request authentication message is initiated by the supply chain subjects, and as the number of subjects increases, the number of request authentication messages will also increase. Assuming Z is the authentication vector and ϕ is the message logging parameter, the message increase behaviour is shown below:

$$X^2 = \phi \dot{Z} \times \frac{(\varphi - 1)\tilde{q}\overline{E}}{V^2} \tag{10}$$

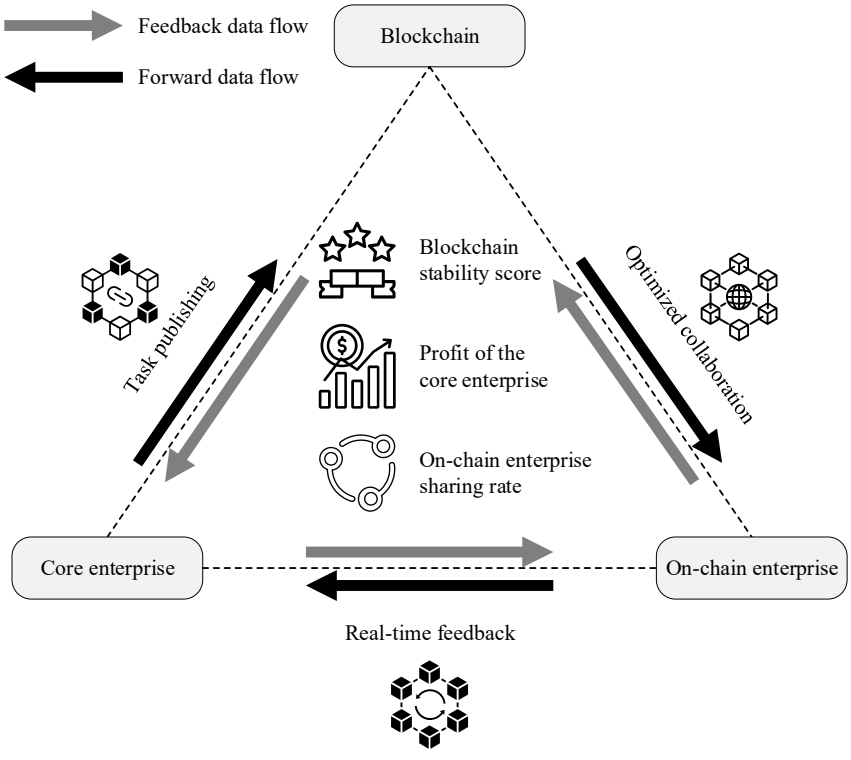
where φ is the increase operation threshold, $\tilde{q}$ is the broadcast vector of the message, and $\overline{E}$ is the unit broadcast average of the message. The reliability of subject authentication can be improved by the above consensus mechanism.

4 Blockchain technology application and optimisation algorithm in enterprise SCM

4.1 Integrated factor collaboration model for SCM on blockchain

After using the improved Raft algorithm to certify the legitimacy of supply chain subjects, the legitimate subjects are uploaded to the chain, and on the basis of fully analysing the relationship between the chain master enterprise and the chain enterprises, and comprehensively considering the cost of the chain master enterprise, the profit of the chain enterprises, and the stability of the blockchain and other factors, a parallel collaborative management scenario based on multi-objective GA for supply chain business is proposed. This scenario integrates the standards and features of blockchain into collaborative tasks, and realises the efficient and stable management of supply chain business through multi-target GA.

Figure 5 Blockchain-based SCM optimisation model



The objective of the designed model is to establish a business synergy model that takes into account factors such as order demand, production capacity, and supply capacity of the chain master enterprise, combined with the production capacity, logistics cost, and production cost of the enterprises in the chain, as shown in Figure 5.

In this model, the chain master enterprise, as the hub of the supply chain transaction, is responsible for order management and coordination, assigning each order task to the enterprises in the chain, investing capital to obtain production outsourcing services, and

considering the optimisation objective of minimising cost and completion time and maximising service quality for the chain master enterprise as shown in equation (11) to equation (13).

$$C_p = \sum_{l=1}^{L}\sum_{m=1}^{M_i}\sum_{n=1}^{N} C_a x_i + \sum_{l=1}^{L}\sum_{m=1}^{M_i} C_b + \sum_{l=1}^{L}\sum_{m=1}^{M_i} C_d \tag{11}$$

$$T_f = \sum_{l=1}^{L}\sum_{m=1}^{M_i}\sum_{n=1}^{N} T_a x_i + \sum_{l=1}^{L}\sum_{m=1}^{M_i} T_b + \sum_{l=1}^{L}\sum_{m=1}^{M_i} T_c \tag{12}$$

$$Q_s = \sum_{l=1}^{L}\sum_{m=1}^{M_i}\sum_{n=1}^{N} Q_i x_i \tag{13}$$

where C_p is production cost, T_f is completion time, Q_s is service quality, C_a is the service cost of the firms in the chain, C_b is logistics cost, C_d is warehousing cost, T_a is processing time, T_b is the time required for the logistics process, T_c is the time required for warehousing, and Q_i is the service quality credit. The above three optimisation objectives are normalised, and corresponding weights are assigned according to the focuses of different chain enterprises, so as to obtain the optimisation objective function of chain enterprises.

$$T_1 = \min\left(\alpha\frac{C_p - \min C}{\max C - \min C} + \beta\frac{T_f - \min T}{\max T - \min T} - \gamma\frac{Q_s - \min Q}{\max Q - \min Q}\right) \tag{14}$$

where α, β, and γ are cost weights, time weights, and quality weights, respectively.

In supply chain collaboration, chain companies maximise their benefits by maximising their participation in sub-task processing and optimising towards increasing the number of orders, as shown below.

$$T_2 = \min\left(\frac{1}{\sum_{l=1}^{L}\sum_{m=1}^{M_i} x_i}\right) \tag{15}$$

where $x_i = 1$ is the n-th firm to participate in the order task; $x_i = 0$ is the task is completed by other firms in the chain.

Subsequently, by optimising the accumulation of trust points and taking the stable point gain as the strategy to improve the stability of the blockchain, the nodes with higher point gain are ensured to be given priority in the order allocation, and the blockchain stability objective function is as follows.

$$T_3 = \min\left(\frac{1}{\sum_{l=1}^{L}\sum_{m=1}^{M_i}\sum_{n=1}^{N} S_i}\right) \tag{16}$$

where S_i is the contribution of the on-chain enterprise to the stable operation of the blockchain. The more stable the history, the higher the points.

Constraints in the model include the cost expectation constraint $C_p < \max C_p$, the time expectation constraint $T_f < \max T_f$, and the processing constraint $E_s \geqslant T_a + T_c$, that is, the

maximum serviceable time of the enterprise is not less than the sum of the actual processing time T_a and the storage time T_c.

4.2 Parallel optimisation of SCM based on multi-objective GA

In this paper, the coding efficiency of GA is improved from the perspective of the efficiency of generating offspring according to the characteristics of SCM, which greatly improves the solution speed. An improved multi-objective genetic algorithm (BCEMGA) is utilised to find the optimal solution of the objective function, and the specific steps are as follows:

1 Initialise the parent population: generate a population that satisfies each constraint. Transform the cost, completion time, and historical service quality of the chain's children into the enterprise matrix dataset, and transform the stable integral returns of the blockchain into an interpolatable three-dimensional surface. Create parent cache *ZONP* according to the function encoding result.

2 For a given individual i in W_i, first compute the set W_i of dominant individuals and the number $w(i)$ of individuals that dominate it. Individuals are then sorted non-dominantly according to $w(i)$. Assume that the number of individuals in *ZONP* is N. Denote $P = \{p_1, p_2, \ldots, p_N\}$ by *ZONP*. Calculate the Euclidean distance between the nearest individuals p_a and p_b of individual p_i in the target space, and weight and sum the distances according to the number of objective functions to obtain the congestion value of p_i.

3 Determine the parameters of crossover variation: evaluate the amount of parallel cycles by the number of crossovers N_C and the number of variations M_C, set the maximum number of parallel cycles N_P, calculate the crossover and variation cycles in parallel, and then filter the optimal offspring by non-dominated sorting to form the offspring cache.

4 Determine whether the maximum number of iterations is greater than the maximum number of iterations, if so, go to step (5); if not, return to step (2).

5 After optimisation the Pareto solution set is obtained and the unique optimal solution is decided using technique for order preference by similarity to ideal solution (TOPSIS).

TOPSIS provides decision makers with an intuitive and easy-to-understand evaluation by calculating the similarity between alternative scenarios and ideal and negative ideal solutions. Assume that there are x alternative scenarios, each with y evaluation indicators. Normalise the raw data X to Z.

$$Z_{il} = \frac{X_{il} - \min X_l}{\max X_l - \min X_l} \tag{17}$$

where X_l and $\max X_l$ are the minimum and maximum values of indicator l in all alternative scenarios, respectively. After normalising the data, the ideal solution A^* and the negative ideal solution A^- are determined as shown in equation (18).

$$\begin{cases} A_l^* = \max Z_{il} \\ A_l^- = \min Z_{il} \end{cases} \tag{18}$$

The Euclidean distances D_i^* and D_i^- between scene i and A^* and A^- are calculated as follows.

$$\begin{cases} D_i^* = \sqrt{\sum_{l=1}^{y} \left(Z_{il} - A_l^*\right)^2} \\ D_i^- = \sqrt{\sum_{l=1}^{y} \left(Z_{il} - A_l^-\right)^2} \end{cases} \tag{19}$$

The similarity of scenario i to the ideal and negative ideal solutions is calculated as follows.

$$\begin{cases} C_i^* = \dfrac{D_i^*}{D_i^- + D_i^*} \\ C_i^- = \dfrac{D_i^-}{D_i^- + D_i^*} \end{cases} \tag{20}$$

Based on the similarity of the scenarios with the ideal and negative ideal solutions, the composite score $Score_i$ is calculated, and the highest score is determined as the optimal solution for C_p, T_f, and Q, thus obtaining the optimisation of the SCM efficiency.

$$V_i = \frac{C_i^-}{C_i^- + C_i^*} \tag{21}$$

5 Experimental results and analyses

In this paper, a multi-node blockchain simulation environment is constructed, and HYPERLEDGERFABRIC is used as the underlying blockchain platform, and a coalition chain network consisting of five peer nodes (each configured with 8-core CPU, 16 GB RAM, and 500 GB SSD) and three orderer nodes is built. Use solidty language to write smart contracts, deploy the contracts into the blockchain network with the help of Truffle framework to ensure the security and accuracy of the data on the chain, set in the experiment the number of chain master enterprises on the blockchain is 1, the number of enterprises on the chain is 12, the stability of enterprises on the chain 5, 6 and 8 is higher, and the stability of enterprise 7 on the chain is lower. To study the computational efficiency improvement effect of the proposed method in different supply chain scenarios, this paper sets up eight main computational scenarios, as shown in Table 1.

To verify the effectiveness of BCEMGA, the S1-S4 and S5-S8 scenarios are each run 10 times and the average running time is counted, and the results are shown in Figure 6. The computational efficiency of S5–S8 with parallel design is significantly improved, at least 5.19% of that of S8, which is due to the fact that S8 is a dual-objective optimisation that consumes less computational resources. The largest improvement is S7, which is 16.37%, indicating that the parallel-designed BCEMGA has a significant computational

efficiency improvement. It can be expected that the parallel approach will save a lot of computation time when the number of enterprises and tasks in the chain is higher.

Table 1 Different supply chain scenarios

Scenario	*α, β, γ*	*Optimisation type*	*Distribution type*
S1	0.4, 0.4, 0.2	Triple aim	Chain master enterprises
S2	0.4, 0.2, 0.4	Triple aim	Differentiated needs exist
S3	0.4, 0.4, 0.2	No optimisation	Random allocation
S4	0.4, 0.4, 0.2	No optimisation	Highest corporate service points
S5	0.4, 0.4, 0.2	Triple aim	Chain master enterprises
S6	0.2, 0.4, 0.4	Triple aim	Differentiated needs exist
S7	0.4, 0.2, 0.4	Triple aim	Balancing the interests of all
S8	0.4. 0.4, 0.2	double target	Chain owners are the leading companies

Figure 6 Computational efficiency improvement effect of BCEMGA (see online version for colours)

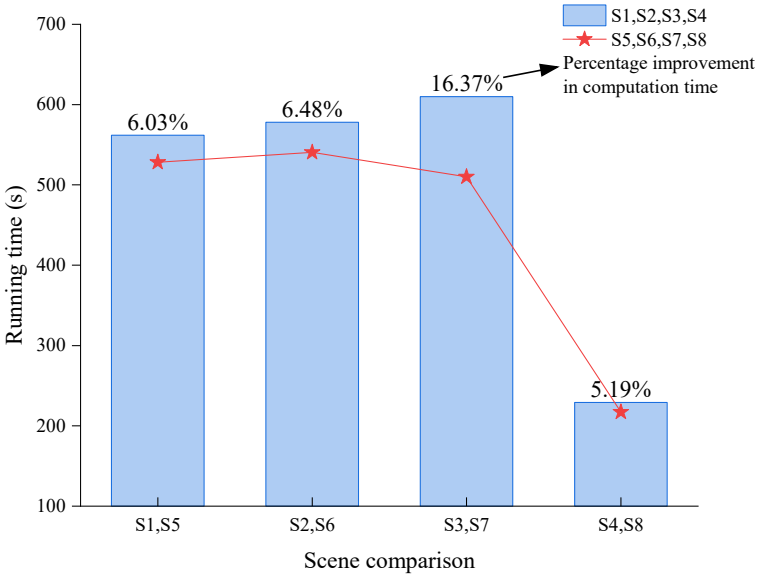
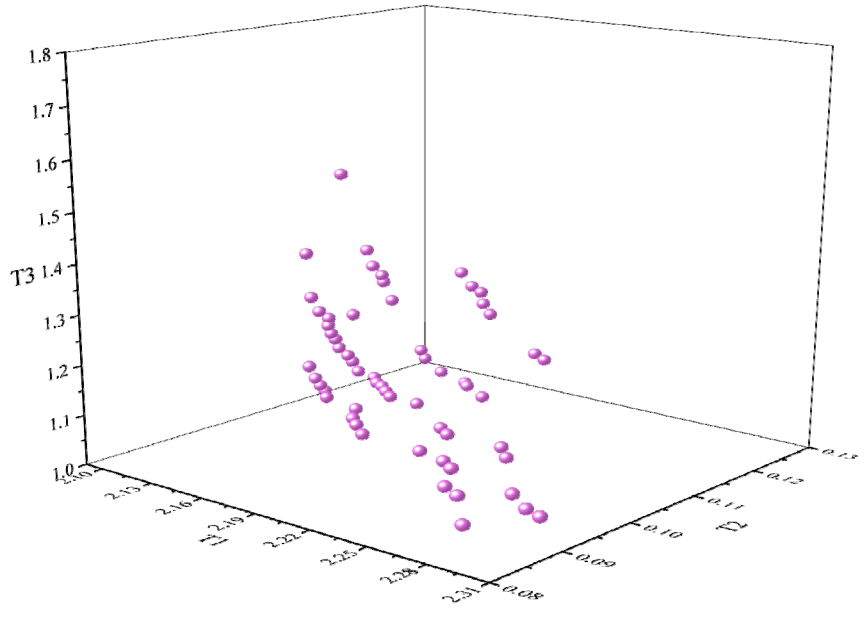
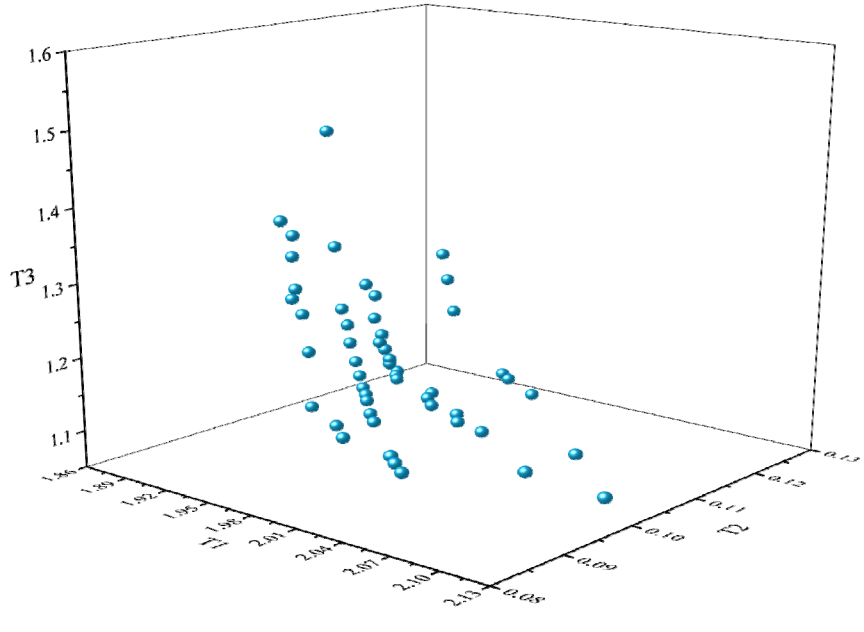


Figure 7 shows the Pareto frontiers of S5 and S7 scenarios, and both scenarios show good convergence, which is in line with the triangular spatial distribution characteristics of the optimal solution of multi-objective optimisation, among which T_1 and T_3 show obvious contradiction, which proves the effectiveness of the blockchain multi-factor balancing mechanism proposed in this paper. In addition, the objective function T_2 is discrete in the solution space, resulting in a Pareto solution set that exhibits a striped characteristic, and there is no obvious regularity in the striped solution set as T_2 increases, which may be due to the intuitive uncertainty caused by the difference in α, β, γ.

Figure 7 Pareto frontiers of (a) S5 and (b) S7 scenarios (see online version for colours)



(a)



(b)

In addition to analysing the optimisation performance of BCEMGA, this paper also compares BCEMGA with SCPSO method (Chen and Du, 2024) and DSACO method (Zhang and Wang, 2024) for experiments, and evaluates the metrics chosen as throughput (TPS), CPU occupancy (U_{CPU}), memory usage, and disk usage (U_{disk}). TPS represents the

number of transactions processed per second by the system and is used to measure the processing power of the system, as shown in equation (22), where N_{TS} represents the total number of transactions and $Time_{total}$ represents the total time (s). CPU usage reflects CPU usage, as shown in formula (23), where $Time_{CPU}$ is the total CPU time. Memory usage indicates the amount of memory currently used by the system. Memory usage indicates the amount of memory currently used by the system. Disk usage indicates the storage space used on a disk. U_{disk} indicates the proportion of disk space occupied, as shown in formula (24), where S_{disk} is the used disk space, and N_{disk} is the total disk space.

$$TPS = \frac{N_{TS}}{Time_{total}} \tag{22}$$

$$U_{CPU} = \left(\frac{Time_{CPU}}{Time_{total}} \right) \times 100\% \tag{23}$$

$$U_{disk} = \left(\frac{S_{disk}}{N_{disk}} \right) \times 100\% \tag{24}$$

As shown in Table 2, in the throughput test, the average transaction processing capacity of SCPSO, DSACO, and BCEMGA reaches 524.7 TPS, 586.9 TPS, and 632.5 TPS, respectively, and BCEMGA shows good linear scaling characteristics with the increase of concurrent requests. In terms of resource consumption, the underlying blockchain architecture and smart contract design adopted by the platform optimise the utilisation efficiency of computing, storage and network resources, and the CPU occupancy rate and memory usage of BCEMGA are controlled at 18.7% and 1.92 GB, respectively, which are 19.1% and 48.67% lower than SCPSO, and 16.2% lower than DSACO, 29.69% compared with DSACO. Comparing the disk usage again, the disk usage of SCPSO, DSACO, and BCEMGA are 30.9 GB, 22.5 GB, and 18.7 GB, respectively.

Table 2 SCM performance metrics comparison

Method	*SCPSO*	*DSACO*	*BCEMGA*
Throughput (TPS)	524.7	586.9	698.2
CPU usage (%)	41.5	38.6	22.4
Memory usage (GB)	2.63	1.92	1.35
Disk usage (GB)	30.9	22.5	18.7

BCEMGA not only optimises the consensus algorithm in the blockchain, but also achieves multi-objective optimisation by taking into account the cost of the chain owner, the profit of the enterprises on the chain, and the stability of the blockchain, which greatly improves the management efficiency of the supply chain. In summary, the method has the technical foundation and performance advantages to support large-scale supply chain application scenarios, and provides a strong guarantee for promoting supply chain digital transformation and collaborative optimisation.

6 Conclusions

To cope with the issues of collaborative efficiency, information traceability and trust crisis in SCM, this paper applies blockchain algorithms to SCM and achieves the optimisation of the overall management efficiency of SCM. Firstly, this paper designs the blockchain-based SCM architecture, improve the blockchain smart contract, combine the election conditions of Raft leaders, set the election index rules, and complete the blockchain-based Raft consensus optimisation. Introduce preparatory candidate roles and implement the division process for the subgroups of follower nodes, and add the corresponding RPC messages to realise the CA's reasonable verification of the supply chain subjects' identities, and authorise the subjects with legitimate identities to be uploaded to the chain. Then, this paper digs deeper into the constraints of the blockchain, the master enterprise and the on-chain enterprises, and visualise the parameters of the master enterprise's cost and service points, the number of on-chain enterprises' participation and the stability of the blockchain into a multi-level and multi-business collaboration model. Secondly, from the perspective of improving the efficiency of the GA in generating the offspring buffer, the cross-variance part is parallelised to greatly reduce the model solution time; moreover, in order to solve the problem that the Pareto solutions cannot dominate each other, TOPSIS is used to compute the Euclidean distance and make decisions on the ideal solutions. The experimental results show that the throughput of the proposed method reaches 698.2 TPS, and the CPU occupancy rate is controlled at 18.7%, which not only reduces the computation consumption but also significantly improves the throughput, and realises efficient SCM. Although the method proposed in this study performs well in specific scenarios, its adaptability to different blockchain architectures and business logics has not been fully verified. In addition, the current algorithms are mainly designed for static or semi-static tasking problems, and for highly dynamic tasking scenarios, the response speed and accuracy of the proposed methods may need to be further optimised.

Declarations

All authors declare that they have no conflicts of interest.

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