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Blockchain-Based Supply Chain Finance Management Methods and Systems

Xiepeng XU[1], Zhuochi Lin[2]

[1]R&D Management Department, Cloud Based (Jiangxi) Big Data Development Co., Ltd., Nanchang, China
Email: *Xuxiepeng[at]jxdata.com*

[2]R&D Management Department, Jiangxi Lianjiaoyun Registration and Settlement Center Co., Ltd. Nanchang, China
Email: near11[at]yeah.net

Abstract: ***In view of the core pain points of traditional supply chain finance, such as financing difficulties for secondary and above suppliers, opaque transaction information, and difficulty in confirming accounts receivable of small and medium-sized enterprises, this study proposes a blockchain-based supply chain finance management method and system. The system builds a consortium chain network composed of core enterprise nodes, factoring company nodes, supplier nodes, upstream enterprise nodes and information notary nodes, relying on blockchain core technologies such as distributed ledgers and smart contracts to realize the whole process management of credit line issuance, digital bill issuance, circulation endorsement, maturity redemption and discounting. As the core carrier, digital bills have the characteristics of splitting, circulation and discounting, realizing the cross-level transmission of core enterprise credit; The distributed architecture and information notarization mechanism of the consortium chain ensure that transaction information is transparent, traceable, and cannot be tampered with, effectively reducing information asymmetry and transaction risks. Through multi-node collaboration and automated processes, the system not only alleviates the financing pressure of small and medium-sized enterprises, optimizes the efficiency of supply chain capital flow, but also enhances supply chain synergy and the competitiveness of core enterprises, providing practical solutions for the digital transformation of supply chain finance.***

Keywords: Blockchain, Supply Chain Finance, Alliance Chain, Digital Bills, Financing Services

1. Introduction

1.1. Research background

In the context of global economic integration and deepening industrial division of labor, the supply chain is a key link connecting core enterprises, upstream and downstream suppliers and financial institutions, and its stable operation and efficient coordination are crucial to industrial development. As an innovative financial service model relying on core enterprise credit, integrated logistics, capital flow and information flow, supply chain finance aims to provide customized financing solutions for enterprises in all links of the supply chain, especially small, medium and micro enterprises, so as to optimize the allocation of industrial funds and enhance the overall competitiveness of the supply chain. In recent years, with the continuous increase in the proportion of small, medium and micro enterprises in the supply chain, their financing needs have become increasingly urgent, but the traditional supply chain finance model has gradually exposed many deep-seated problems in the actual promotion process, which seriously restricts the full release of its service efficiency.

The traditional supply chain finance model takes core enterprises as the core credit core, and financial institutions mainly provide financing services for their upstream and downstream enterprises based on the credit qualifications and operating strength of core enterprises. However, small, medium and micro enterprises in the supply chain are often numerous, scattered, limited in scale and lack of standardized financial information, and financial institutions are limited by manpower, material resources and information collection costs, making it difficult to conduct accurate risk assessment for such enterprises. At the same time, core enterprises usually only establish direct business dealings with first-level distributors or first-level suppliers and sign formal contracts, and second-level and above suppliers cannot effectively prove the legality and authenticity of their claims due to the lack of direct cooperative relations with core enterprises, resulting in financial institutions being difficult to provide financing support to them, forming the dilemma of "difficult and expensive financing" for small and medium-sized enterprises at the end of the supply chain.

Opaque transaction information and lack of credibility are another core bottleneck faced by traditional supply chain finance. Although core enterprises have strong market competitiveness and credit qualifications, they are often limited by their own financial technology level and are often difficult to achieve effective integration, sharing and verification of transaction information throughout the supply chain. The procurement contracts, transaction invoices, logistics vouchers and other information in each link of the supply chain are mostly stored in the internal systems of each enterprise, and the phenomenon of information islands is prominent, resulting in financial institutions being unable to fully grasp the true situation of supply chain transactions. In addition, the risk of forgery of transaction information and the problem of authenticity verification further exacerbate the information asymmetry between financial institutions and enterprises, making financial institutions too cautious in the loan approval process, and the approval process is lengthy and inefficient, which seriously affects the turnover speed of supply chain funds.

The difficulty of confirming accounts receivable also restricts the development of traditional supply chain finance. The core logic of supply chain finance is to carry out financing services based on accounts receivable in the context of real trade, and

the ownership confirmation of accounts receivable is a prerequisite for financing issuance. In the traditional model, core enterprises occupy a strong position in the supply chain, and upstream and downstream small and medium-sized enterprises are often in a passive state in cooperation with core enterprises. At the same time, due to the lack of unified information recording and traceability mechanisms, it is difficult for financial institutions to verify the authenticity, completeness and transferability of accounts receivable, which not only increases the credit risk of financial institutions, but also makes it difficult for small and medium-sized enterprises to convert accounts receivable into high-quality assets that can be financed, further exacerbating their capital turnover pressure.

As a disruptive technology that has risen rapidly in recent years, blockchain technology provides a new technical path to solve the pain points of traditional supply chain finance with its core features such as distributed ledger, tamper-proof, transparent traceability, consensus mechanism and smart contracts. The distributed ledger ensures that all parties involved in the supply chain have consistent transaction records, avoiding the possibility of information tampering and unilateral manipulation. Immutability and transparent traceability make the transaction information traceable, verifiable throughout the process, and effectively improve the credibility of the transaction information. Smart contracts can automate the execution of transaction processes, reducing manual intervention and operational risks. The deep integration of blockchain technology and supply chain finance and the construction of a blockchain-based supply chain finance management system are expected to break the information barriers of the traditional model, realize the cross-level transmission of core enterprise credit, solve the financing problems of small and medium-sized enterprises, opaque transaction information and difficulties in confirming accounts receivable, and promote the development of supply chain finance in a more efficient, safe and inclusive direction. In this context, this study proposes a blockchain-based supply chain finance management method and system, aiming to provide practical solutions for the digital transformation of supply chain finance.

2. Research Significance

2.1 Theoretical Significance

The theoretical significance of this study is mainly reflected in the following three aspects: First, it enriches the application research results of blockchain technology in the financial field. At present, the research on blockchain technology in the financial field mostly focuses on digital currency, cross-border payment and other scenarios, and the systematic research on the whole process management of supply chain finance is relatively insufficient. This study delves into the integration path of blockchain technology and supply chain finance, and designs the network architecture, transaction process and smart contract mechanism based on the consortium chain in detail, providing a theoretical reference and technical paradigm for the in-depth application of blockchain technology in the field of supply chain finance. Second, the credit transmission theory of supply chain finance has been improved. The credit transmission of traditional supply chain finance is centered on core enterprises, showing one-way and hierarchical characteristics, and the credit transmission efficiency is low and the scope is limited. The credit transmission model based on digital bills proposed in this study realizes the multi-directional and cross-level transmission of core enterprise credit in the blockchain network, expands the theoretical boundary of supply chain financial credit transmission, and provides new ideas for the innovation of credit transmission mechanism. Third, it complements the theoretical system of supply chain financial risk control. Traditional supply chain financial risk control mainly relies on core enterprise guarantees and offline due diligence, and the risk control method is single and the effect is limited. This study uses the characteristics of blockchain to construct a risk control system based on the whole process recording of transaction information and the automatic execution of smart contracts, which provides a new theoretical perspective and method support for supply chain financial risk control.

2.2 Practical significance

The practical significance of this study is mainly reflected in the following four aspects: First, it effectively alleviates the financing difficulties of small and medium-sized enterprises. Through the cross-level transmission of core enterprise credit and the flexible circulation of digital bills, secondary and above suppliers at the end of the supply chain can obtain financing support from factoring companies by holding legal and effective digital bills without directly establishing business relationships with core enterprises, broadening the financing channels of small and medium-sized enterprises, and reducing the financing threshold and financing costs. Second, improve the overall operation efficiency of the supply chain. The divisible and transferable characteristics of digital bills break the limitations of traditional commercial bills and accounts receivable that cannot be separated and difficult to circulate, so that the funds in all links of the supply chain can be quickly turnover, alleviate the short-term capital redemption pressure of core enterprises and the capital occupation problem of small and medium-sized enterprises, and improve the efficiency and anti-risk ability of the supply chain. Third, reduce the business risks and operating costs of financial institutions. The blockchain network realizes the trusted sharing and full traceability of transaction information, and financial institutions can easily verify the authenticity of transactions and the legality of creditor's rights, effectively reducing credit risks. At the same time, the automated execution of smart contracts reduces manual intervention, simplifies business processes, and reduces operational costs and human risks. Fourth, promote the digital transformation of the supply chain finance industry. The management methods and systems proposed in this study provide implementable digital solutions for the supply chain finance industry, which helps to promote the digital collaboration of financial institutions, core enterprises, suppliers and other parties, accelerate the standardization, standardization and intelligent development of the supply chain finance industry, and provide strong support for the digital transformation of the industry.

2.3 Research content and technical route

2.3.1. Research content

The main research content of this study includes the following four aspects: First, blockchain network architecture design. Clarify the network type, participating node composition and node access mechanism of the blockchain-based supply chain financial management system, design the functional positioning and permission allocation scheme of each node, build a consistent, safe and credible alliance chain network environment, and provide a technical foundation for the development of supply chain financial business. Second, the construction of supply chain financial management methods. Design in detail core business processes such as credit line issuance, digital bill issuance, circulation endorsement, maturity redemption and discounting, and clarify the operation specifications, data interaction standards and security guarantee mechanisms of each process. Focus on the splitting, circulation rules and smart contract implementation logic of digital bills to ensure the legality and effectiveness of creditor's rights transmission. Third, the development of supply chain financial management system. Based on the design of the blockchain network architecture and management method, a supply chain financial management system is developed including core enterprise node module, factoring company node module, supplier node module, upstream enterprise node module and information notary node module, so as to realize the collaborative linkage of each module function and the automatic processing of business processes. Fourth, system advantage verification and application prospect analysis. By analyzing the advantages of the system in credit transmission, information transparency, capital flow efficiency and risk control, and discussing the promotion value and application prospects of the system in combination with actual application scenarios, it provides a reference for the actual implementation and optimization and upgrading of the system.

2.3.2 Technical route

This study follows the technical route of "problem analysis-technology selection-scheme design-system construction-advantage verification": firstly, by sorting out the operation status of the traditional supply chain financial model, in-depth analysis of its financing difficulties, information opacity, rights confirmation difficulties and other problems, the core pain points and solution needs of the research are clarified; Secondly, based on the core characteristics of blockchain technology and combined with the business needs of supply chain finance, the alliance chain is selected as the network architecture type to determine the application mode of key technologies such as smart contracts and distributed ledgers. Thirdly, the supply chain financial network architecture based on the alliance chain is designed, and the whole process management method including credit, invoicing, circulation, redemption, discount and other links is constructed, and the functions and interaction logic of each node are clarified. Then, the supply chain financial management system is developed according to the design scheme to realize the integration of each module function and the automatic execution of business processes. Finally, through theoretical analysis and scenario simulation, the advantages of the system in solving the pain points of traditional supply chain finance are verified, and the application value and promotion prospect of the system are analyzed.

2.4 Relevant technical foundation

2.4.1 Core features and principles of blockchain technology

As a decentralized distributed ledger technology, the core design concept of blockchain technology is to realize the trusted storage, efficient sharing and non-tampering of data through multi-node collaborative maintenance, cryptography encryption and other mechanisms, providing fundamental solutions to problems such as lack of trust and information asymmetry in supply chain finance scenarios. The core characteristics of blockchain are mainly reflected in the following four aspects: First, distributed ledger characteristics. There is no central control node in the blockchain network, and each participating node has a complete copy of the ledger, and all transaction information is synchronously recorded in the ledger of each node. This distributed storage architecture ensures redundant backup of data, avoids the risk of data loss or tampering caused by the failure of a single node, and at the same time prevents any node from controlling transaction information alone, providing equal access rights to all participants in supply chain finance. In the supply chain finance scenario, core enterprises, factoring companies, suppliers, upstream enterprises and information notary nodes all hold consistent ledger data, ensuring the transparency and traceability of the transaction process. Second, immutability and cryptographic guarantees. Once the transaction information in the blockchain is recorded, the block hash value is generated through cryptographic algorithms, which are connected to the hash value of the previous block to form a chain structure. To tamper with the information of a block, it is necessary to modify not only the hash value of the block, but also to recalculate the hash value of all subsequent blocks, and to control more than half of the nodes in the network, which is technically extremely difficult and costly. This feature ensures the authenticity and completeness of the whole process information such as the issuance, circulation, endorsement, and redemption of digital bills in supply chain financial transactions, and provides solid technical support for the confirmation of accounts receivable. Third, the consensus mechanism. The consensus mechanism is the core technology for achieving data consistency among nodes in the blockchain network, and its purpose is to ensure that transaction information is recognized and recorded by all nodes in the distributed network. Aiming at the characteristics of the alliance chain in the supply chain financial scenario, this study adopts a consensus algorithm suitable for multi-party authorization participation, so that core enterprises, factoring companies, information notary nodes and other nodes that have undergone registration and review can quickly reach a consensus to ensure the efficient confirmation and validity of transactions. The existence of the consensus mechanism avoids transaction disputes, reduces the cost of trust, and provides a mechanism guarantee for the collaborative operation of all participants in supply chain finance. Fourth, smart contract automated execution. Smart contracts are programmable scripts deployed based on blockchain technology, capable of automatically executing transaction operations based on preset rules and conditions without manual intervention. In this study, the processes of splitting, circulation, discount triggering, and maturity redemption of

digital bills are automatically processed through smart contracts. For example, when a digital bill expires, the smart contract can automatically detect the bill holding status and trigger the redemption operation of the core enterprise; When a supplier initiates a bill split request, the smart contract can complete the amount splitting and endorsement circulation according to preset rules, greatly improving transaction efficiency and reducing human error and moral hazard.

2.4.2 Alliance chain technical architecture and access mechanism

As an important branch of blockchain, the consortium chain is a semi-decentralized blockchain form between public and private chains, and its core feature is the restriction and controllability of participating nodes, which fully adapts to the requirements of qualification review, authority management and compliance of participants in supply chain finance scenarios.

In terms of network architecture, the consortium chain is composed of multiple authorized nodes, the number of nodes is a definite value, and each node has a clear identity and permission configuration. The supply chain financial alliance chain network constructed in this study includes core enterprise nodes, factoring company nodes, supplier nodes, upstream enterprise nodes and information notarization nodes, and each node needs to join the network by submitting the basic materials of the enterprise and completing the registration review. This access mechanism ensures the legitimacy and credibility of participating entities, preventing unrelated entities or malicious nodes from entering the network and interfering with the transaction order.

In terms of permission management, the consortium chain assigns different operational permissions according to the roles and responsibilities of each participating node. For example, the core enterprise node has the authority to issue digital bills, the factoring company node has the authority to issue and discount credit lines, the information notarization node has the authority to confirm and sign transaction information, and the supplier and upstream enterprise nodes have the authority to receive, circulate and apply for digital bills. This refined division of authority not only ensures that nodes can perform their duties normally, but also prevents overstepping their authority and ensures the security and orderliness of the network.

In terms of data sharing and privacy protection, Consortium Chain has achieved a "controllable and transparent" data sharing model. All transaction information is shared synchronously among authorized nodes, ensuring that all participants can obtain real and complete transaction data in real time, solving the problem of information silos in traditional supply chain finance. At the same time, the consortium chain can encrypt the sensitive information of nodes through privacy protection technology, and only open necessary transaction information to authorized nodes, which protects the commercial privacy of all participants while ensuring information transparency.

2.4.3 Digital bill technology system and functional characteristics

The core of the digital bill in this study is to combine the credit value of the core enterprise with the legal attributes of commercial paper and transform it into a digital asset that can be flexibly circulated, split and redeemed in the blockchain network, providing a core carrier for the digital transformation of supply chain finance.

The technical construction principle of digital bills is mainly based on the issuance mechanism of encrypted digital currency (token), and the credit value of core enterprises is replaced into the blockchain network by using the commercial paper pledge model. The core enterprise issues an electronic commercial acceptance bill to the factoring company as a collateral certificate, and the factoring company issues a credit line accordingly, and the core enterprise then issues a digital bill based on the credit line to realize the digital confirmation of accounts receivable. The whole life cycle of digital bills, including issuance, circulation, splitting, discounting, redemption and other links, is recorded and controlled through blockchain technology to ensure the authenticity, legality and immutability of creditor's rights.

Digital bills have multiple functional characteristics and can effectively solve the limitations of traditional commercial paper and accounts receivable: First, it is separable. Traditional commercial papers and accounts receivable are often difficult to separate during the transfer process, and cannot meet the needs of suppliers to pay for goods to multiple upstream enterprises. The digital bill supports arbitrary splitting according to the actual payment amount, and the supplier node can split a complete digital bill into multiple copies and transfer the endorsement to different upstream enterprise nodes, realizing the refined distribution of creditor's rights and greatly improving the efficiency of capital use. The second is transferability. Digital bills rely on the distributed architecture and smart contract mechanism of blockchain networks to support multi-level circulation endorsements. Supplier nodes can transfer digital bills to their own upstream enterprises (secondary suppliers), and secondary supplier nodes can further flow to third-level supplier nodes, so that the credit of core enterprises can be transmitted to small and medium-sized enterprises at the end of the supply chain across levels, solving the problem of financing difficulties for secondary and above suppliers in traditional supply chain finance. The third is adjustability and withdrawability. The account period of digital bills can be flexibly adjusted according to the actual needs of supply chain transactions to adapt to the capital turnover cycle of different enterprises. At the same time, digital bills have clear time attributes for withdrawal periods, and when the bills expire, the holding node can initiate a redemption application to the core enterprise node to realize the conversion of digital assets into cash. In addition, before the expiration of the bill, the holding node can also transfer the digital bill to the factoring company node to apply for discounting, withdraw funds in advance, and meet the short-term capital turnover needs; Fourth, credit recharge and value settlement functions. Digital bills support credit recharge according to encrypted digital currency technology, and core enterprises can flexibly adjust the issuance amount of digital bills according to their own credit lines and transaction needs. At the same time, digital bills can be used as the settlement value unit of transactions between various participants in the supply chain, and nodes in the chain can directly use digital bills as payment methods

to complete transaction settlement, and enterprises outside the chain can also participate in digital bill transactions by registering to join the alliance chain, expanding the service scope of supply chain finance.

2.4.4 Information notarization and transaction security technology

As an authoritative third-party node in the blockchain network, the core function of the information notary node is to confirm and sign transaction information, provide legal validity guarantee for supply chain financial transactions, and realize blockchain-based distributed ledger and cryptographic signature technology.

The technical operation mechanism of the information notarization node is that every time a transaction occurs, the transaction information will be sent to the core enterprise node, factoring company node, supplier node, upstream enterprise node and information notary node. The information notarization node reviews the authenticity and legality of transaction information, including verifying the consistency of transaction contracts, invoices and other supporting materials, and confirming the identity legitimacy and operational authority of both parties to the transaction. After passing the review, the information notary node uses its own digital certificate to sign the transaction information, which will be permanently recorded in the blockchain ledger and become a necessary condition for the transaction to take effect.

The core value of information notary technology is to improve the legal validity and credibility of transactions. In traditional supply chain financial transactions, the verification of transaction information often relies on offline review, which is cumbersome and prone to disputes. The digital signature of the information notarization node has the characteristics of non-forgeability and non-repudiation, which can provide strong proof of the validity of the transaction and reduce the probability of transaction disputes. At the same time, the participation of information notarization nodes makes the transaction information form a pattern of "multi-party witness" in the blockchain network, which further strengthens the immutability and traceability of transaction information, and provides a reliable basis for the risk assessment of financial institutions and the supervision and inspection of regulatory authorities. In addition, transaction security technology also includes supporting technologies such as node identity authentication and data transmission encryption. Node identity authentication technology ensures that only legitimate nodes that have passed registration and audit can access the blockchain network to prevent the intrusion of malicious nodes. Data transmission encryption technology uses encryption algorithms to encrypt transaction information transmitted between nodes to prevent information from being stolen or tampered with during transmission, and comprehensively ensures the security of supply chain financial transactions.

3. Blockchain- based Supply Chain Financial Management Method

3.1 Blockchain network architecture design

The core design idea of the supply chain is to create a safe, credible, collaborative and efficient distributed collaboration environment by clarifying the participants, standardizing the access mechanism, and dividing the node authority, so as to provide underlying technical support for the whole process of supply chain finance business.

3.1.1. Network participation node composition

The participating nodes of the blockchain network cover the core entities in the supply chain financial ecosystem, including core enterprise nodes, factoring company nodes, supplier nodes, upstream enterprise nodes and information notarization nodes, and each node assumes specific responsibilities in the network to jointly complete the closed-loop processing of supply chain financial business: the core enterprise node, as the core hub of the supply chain, is the source of credit transmission, and is responsible for submitting mortgage proof information to obtain credit lines, issuing digital bills and executing maturity redemption operations; The factoring company node assumes the role of providing financial services, responsible for reviewing the mortgage certificate of the core enterprise, issuing credit lines, processing the digital bill discount application and completing the discount payment; Supplier nodes are direct partners of core enterprises, receive digital bills issued by core enterprises, split bills according to needs, and transfer them to upstream enterprises, or initiate discount applications. Upstream enterprise nodes include the direct upstream (secondary supplier) of the supplier and the deeper supply chain participants (such as tertiary suppliers, etc.), which receive the circulating digital bills, which can be held for maturity or early discounting, or can further circulate the bills; The information notarization node is served by an authoritative third-party institution such as a bank or a notary office, as a witness to the validity of the transaction, and is responsible for reviewing, confirming and signing all transaction information to ensure the legality and non-repudiation of the transaction.

3.1.2. Node access and permission management mechanism

All node entities who want to join the alliance chain need to submit complete basic enterprise materials (including business licenses, qualification certificates, business cooperation certificates, etc.), and only after being reviewed and approved by the network management can they obtain access rights and assign unique identifiers. This access mechanism ensures the legitimacy and credibility of the participants, and avoids the risk of malicious node intrusion and false transactions from the source.

In terms of permission management, refined permission allocation is implemented based on the role positioning of nodes: core enterprise nodes only have the authority to apply for credit, issue and redeem digital bills; The factoring company node has the authority to grant credit approval and issuance, discount review and payment; Suppliers and upstream enterprise nodes have the right to accept, circulate, split and discount digital bills. The information notary node has the authority to receive, review, and sign transaction information, but does not have the authority to operate bills or dispose of funds. Through permission isolation and role binding, it ensures that each node can only operate within the scope of authorization, ensuring the orderliness and security

of network operation.

3.1.3. Distributed ledger synchronization mechanism

Each node in the Consortium Chain network stores a complete blockchain ledger, which is synchronized and completely consistent in real time. When any node initiates a transaction (such as credit issuance, bill issuance, circulation endorsement, etc.), the transaction information will be broadcast to all participating nodes through the peer-to-peer network, and each node verifies the validity of the transaction according to the consensus algorithm. After verification, the transaction information will be packaged and written to a new block and linked to the blockchain main chain, and each node will update the local ledger synchronously. This distributed ledger mechanism ensures that transaction information cannot be tampered with and traceable throughout the process, and no node can modify the ledger data alone, providing a credible data storage foundation for supply chain finance business.

3.2. Core business process design

Based on the above-mentioned alliance chain network architecture, the core business process of the supply chain financial management method revolves around the whole life cycle of digital bills, including five key links: credit line issuance, digital bill issuance, bill circulation endorsement, maturity redemption and discount processing.

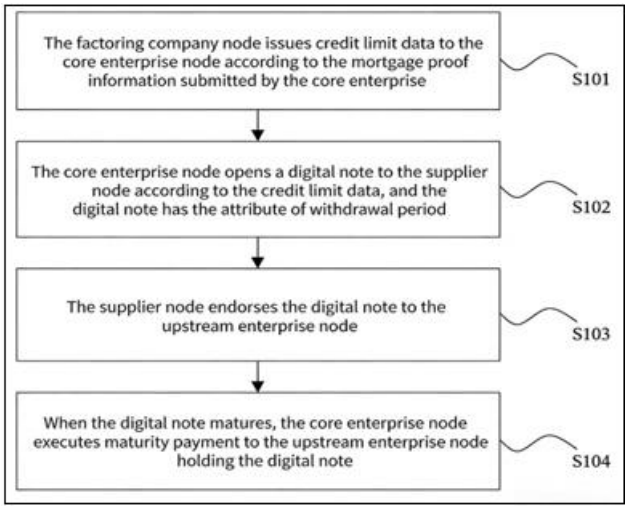

Figure 1: Flow chart of blockchain-based supply chain finance management method.

3.2.1. Credit line issuance process (S101)

The issuance of credit lines is the starting point of supply chain finance business, and its core is to convert the credit of core enterprises into credit resources that can be circulated in the network, and the specific process is as follows:

a) **Mortgage proof submission:** The core enterprise needs to submit legal and valid mortgage proof information to the factoring company node, and the core form is electronic commercial acceptance bills. The face value of the commercial bill must fully cover the credit line to be given to the core enterprise by the factoring company, and the maturity date of the commercial bill must be later than the maturity date of the digital bill subsequently issued by the core enterprise in the network to ensure the sufficiency and validity of the collateral assets;

b) **Credit Review and Line Issuance:** After receiving the mortgage certificate information, the factoring company node can verify the authenticity and legality of the commercial bill and the credit status of the core enterprise through a combination of automatic verification and manual review. After passing the review, the factoring company node issues the corresponding credit line data (also known as credit token limit data) to the core enterprise node, which is written to the blockchain ledger in real time as the basis for the core enterprise to issue digital bills.

c) **Quota record and publicity:** After the credit line data is generated, it will be synchronized to the ledger of all nodes in the network to realize the openness and transparency of credit information, facilitate each node to query the available credit line of the core enterprise, and provide reference for the subsequent receipt and circulation of digital bills.

3.2.2. Digital bill issuance process (S102)

Digital bills (also known as "cloud bills") are digital accounts receivable certificates issued based on the credit line of core enterprises, and their issuance process aims to realize the digital confirmation of accounts receivable, and the specific steps are as follows:

a) **Preparation and material upload:** After obtaining the credit line, the core enterprise node uploads offline transaction contracts, invoices and other supporting materials to the blockchain network according to the real trade background with the supplier, and clarifies key information such as transaction objects, amounts, and payment terms.

b) **Amount confirmation and electronic signature:** The core enterprise node determines the issuance amount of digital bills according to the amount agreed in the transaction contract and its own available credit line. At the same time, access to the electronic signature system, core enterprises and suppliers sign the "Payment Commitment Letter" online to clarify the creditor's rights and debts corresponding to the digital bill and ensure the legal validity of the bill;

c) **Bill generation and ledger records:** The core enterprise node triggers the generation of digital bills through smart contracts, and the bill information includes key attributes such as bill number, issuing entity, receiving entity, amount, withdrawal account period, and maturity date. After the digital bill is generated, it is automatically written to the blockchain ledger and synchronized to all nodes, and the transaction information is irreversible and cannot be tampered with, so as to realize the digital confirmation of accounts receivable.

d) **Receipt and confirmation of bills.** The supplier node receives the digital bill information synchronized by the blockchain network in real time, and completes the receiving operation after confirming that it is correct, and the confirmation behavior is also recorded in the ledger, forming a complete transaction closed loop.

The core feature of digital bills lies in their flexibility and functionality, in accordance with the technical specifications of encrypted digital currency, supporting credit recharge, amount splitting, account period adjustment, circulation and withdrawal, which can not only be used as a settlement unit

for transactions in the supply chain, but also provide a financing carrier for enterprises.

3.2.3. Endorsement process for digital bill circulation (S103)

The circulation endorsement of digital bills is a key link in realizing the cross-level transmission of credit of core enterprises, and supports suppliers to transfer bills to upstream enterprises to settle payments, the specific process is as follows:

a) **Circulation decision-making and splitting operations:** After receiving the digital bill, the supplier node can decide whether to circulate the bill according to its own settlement needs with the upstream enterprise. If the number of upstream enterprise nodes is multiple, the supplier node can split the digital bill and split a complete bill into multiple sub-bills of different amounts according to the amount to be paid to each upstream enterprise.
b) **Endorsement initiation and information submission:** The supplier node selects the target upstream enterprise node, initiates the bill circulation endorsement application, and submits the bill number, target node identification, circulation amount and other information. If it is a circulation after splitting, the application for endorsement of sub-bills will be initiated to the corresponding upstream enterprise nodes.
c) **Endorsement confirmation and ledger update:** After receiving the endorsement application, the upstream enterprise node verifies the authenticity of the transaction background and completes the acceptance operation after confirming that it is correct. At this time, the smart contract automatically updates the information of the holder of the bill, transfers the ownership of the bill from the supplier node to the upstream enterprise node, and writes the endorsement transaction information to the blockchain ledger and synchronizes it to all nodes.
d) **Multi-level circulation support:** After receiving the bill, the upstream enterprise node can further endorse its circulation to its own upstream enterprises (such as third-level supplier nodes) before the expiration of the bill according to its own business needs, and so on, so as to realize the in-depth transmission of core enterprise credit at all levels of the supply chain, so that the end small and medium-sized enterprises can also obtain legal and effective debt certificates.

3.2.4. Digital bill maturity and redemption process (S104)

Maturity redemption is the end of the life cycle of digital bills, ensuring that companies holding bills can collect payments on time, as follows:

a) **Redemption trigger and information verification:** When the digital bill reaches the agreed maturity date, the smart contract in the blockchain network automatically triggers the redemption process, verifies the current holding entity, amount, maturity date and other key information of the bill, and confirms the validity of the bill.
b) **Redemption execution and fund transfer:** According to the trigger instructions of the smart contract, the core enterprise node performs redemption operations to the current holder of the bill (which may be a supplier node, an upstream enterprise node, or a third-level or above supplier node), and transfers the corresponding amount of funds to the designated account of the holding enterprise.
c) **Bill cancellation and ledger records:** After the redemption is completed, the smart contract automatically marks the digital bill as "redeemed" and cancels it, and the relevant redemption information (including the redemption entity, receiving entity, amount, time, etc.) is written to the blockchain ledger and synchronized to all nodes to form a complete redemption record, which is convenient for subsequent traceability and auditing.
d) **Special scene processing:** If the digital bill is held by the factoring company node at maturity (that is, the enterprise has transferred the bill through discount), the core enterprise node will perform redemption operations to the factoring company node to ensure the security of the factoring company's assets.

3.2.5. Digital bill discounting expansion process

In order to meet the short-term capital turnover needs of enterprises, the method supports the discount operation of digital bills before maturity, and the specific process is as follows:

a) **Discount application initiated:** Before the expiration of the digital bill, if the supplier node or upstream enterprise node needs to withdraw funds, it can transfer its digital bill to the factoring company node, initiate a discount application, and submit the bill number, discount amount, collection account and other information;
b) **Discount review and discount calculation:** After receiving the discount application, the node of the factoring company will query the blockchain ledger to verify the authenticity, legality and current status of the bill, and calculate the discount amount according to the remaining maturity date of the bill, market interest rate and other factors.
c) **Discount payment and bill transfer:** After deducting the interest discount, the factoring company node will transfer the remaining discount amount to the designated account of the applicant enterprise to complete the loan loan. At the same time, the smart contract automatically updates the information of the bill holder, transfers the ownership of the bill to the factoring company node, and writes the discount transaction information to the ledger and synchronizes it to all nodes.
d) **Joint and several liability guarantees:** In the process of discounting, the core enterprise and the factoring company bear joint and several liability guarantees for the discount loan, and if the core enterprise fails to pay on time when the bill matures, the factoring company has the right to recover from the core enterprise to ensure that the risk of the discount business is controllable.

3.2.6. Transaction notarization and security process

In order to further improve the security and legal validity of transactions, the network introduces information notary nodes to participate in all transaction processes, and the specific mechanism is as follows:

a) **Transaction information synchronization:** Each transaction (including credit issuance, bill issuance, circulation endorsement, redemption, discounting, etc.) will be synchronously sent to the core enterprise node, factoring company node, supplier node, upstream enterprise node and information notary node to ensure that the notary node can obtain complete transaction data.
b) **Notarization review and signature:** After receiving the

transaction information, the information notary node reviews the authenticity, legality, and compliance of the transaction, and verifies the consistency of transaction materials (such as contracts, invoices, electronic signatures, etc.). After passing the review, the information notary node uses its own digital certificate to sign the transaction information, which is a necessary condition for the transaction to take effect.

c) **Effective confirmation and record:** Only transactions that have been signed and confirmed by the information notarization node can be officially effective and written to the blockchain ledger. The signature information is bound to the transaction data and stored to ensure the non-repudiation of the transaction and provide authoritative evidence for possible dispute resolution in the future.

3.3 Key guarantee mechanism for method implementation

3.3.1 Consensus mechanism guarantee

The Consortium Chain network adopts a consensus algorithm suitable for multi-party authorization to ensure rapid confirmation and unanimous recognition of transaction information by each node. When the transaction is initiated, key nodes such as core enterprises, factoring companies, and information notarization participate in the consensus voting, and only when the preset consensus threshold is reached can the transaction be confirmed and written to the ledger, avoiding the risk of a single node manipulating the transaction and ensuring the fairness and effectiveness of the transaction.

3.3.2 Data security

Cryptography technology is used to protect transaction data in an all-round way, including data transmission encryption, storage encryption and digital signature verification. The transaction information transmitted between nodes is encrypted through encryption algorithms to prevent information from being stolen or tampered with. Ledger data is stored using hash encryption technology to ensure data integrity. All transaction participants are authenticated by digital signatures to prevent identity forgery and overstepping their authority.

3.3.3 Traceability and audit guarantees

The blockchain ledger records the whole life cycle information of digital bills from issuance, circulation, discount to redemption, and each transaction link has clear timestamps, participants, operation content and other records, forming an immutable audit trajectory. Each node can query relevant transaction records according to their authority to realize the full traceability of transactions, which is convenient for risk investigation of financial institutions, supervision and inspection by regulatory authorities, and internal audits of enterprises.

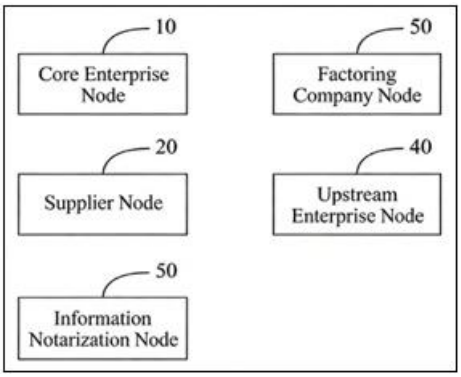

Figure 2: Schematic diagram of the structure of the blockchain-based supply chain financial management system

4. Blockchain-based supply chain financial management system

4.1 Overall system architecture design

The blockchain-based supply chain financial management system is supported by the alliance chain as the underlying technology and adopts a distributed architecture design to realize the collaborative operation of multiple entities such as core enterprises, factoring companies, suppliers, upstream enterprises and information notary institutions. The overall architecture of the system is divided into three levels: the underlying technical layer, the core function layer and the user interaction layer, and each level performs its own duties and progresses layer by layer to jointly ensure the efficient and safe development of supply chain financial business.

4.1.1. Underlying technical layer

The underlying technical layer is the basic support for system operation, covering the core technology of the consortium chain, cryptography technology, smart contract engine and data storage module, providing a trusted and secure technical environment for the upper-layer business:

1) The core module of the consortium chain: is responsible for maintaining the core functions of the blockchain network, such as node management, peer-to-peer communication, and consensus mechanism execution, to ensure the consistency and synchronization of ledger data of each node;
2) Cryptography module: Integrates digital signatures, hash encryption, data transmission encryption, and other technologies to ensure the authenticity, integrity, and confidentiality of transaction information, including node identity authentication, transaction data encryption, block hash generation, and other functions.
3) Smart contract engine: responsible for the deployment, parsing, and execution of smart contracts, supporting automated business processes such as digital bill splitting, circulation, discount triggering, and maturity redemption, and completing preset operations without manual intervention.
4) Distributed ledger storage module: Distributed database technology is used to realize multi-node redundant storage of transaction information, ensuring that data cannot be tampered with and traceable throughout the process, and supports efficient data query and retrieval.

4.1.2. Core functional layer

The core functional layer is the core business processing module of the system, focusing on the whole life cycle of digital bills, integrating five core functional modules: credit line management, digital bill management, transaction circulation management, redemption discount management and information notarization management, to achieve the whole process coverage of supply chain financial business:

1) Credit line management module: handle the submission and review of mortgage certificates of core enterprises, and the issuance, inquiry, and change of credit lines;
2) Digital bill management module: responsible for the issuance, splitting, cancellation and other operations of digital bills, and maintaining the whole life cycle information of bills;
3) Transaction circulation management module: support the circulation endorsement, receipt confirmation and other services of digital bills, and record the trajectory of bill ownership changes;
4) Redemption and discount management module: handle digital bill maturity payment, discount application, review, fund transfer and other businesses;
5) Information notarization management module: Realize the functions of receiving, reviewing, and confirming transaction information to ensure the legality and validity of transactions.

4.1.3 User interaction layer

The user interaction layer provides personalized operation entrances and interactive interfaces for each participant, and supports different nodes to carry out business operations according to their own permissions, including five user ports: core enterprise side, factoring company side, supplier side, upstream enterprise side and information notarization side: each port provides basic functions such as account registration, login, permission management, business operation, data query, and report export; The interface design follows the principle of simplicity and ease of use, and customizes the display of core functional modules according to the business needs of each node to ensure convenient and efficient operation.

4.2 Functional design of the core module of the system

4.2.1. Core enterprise node module

The core enterprise node module is the core module of credit initiation and redemption execution in the system, and its main functions revolve around credit application, digital bill issuance and maturity redemption, including:

1) Mortgage certificate management: Support core enterprises to upload mortgage certification materials such as electronic commercial acceptance bills, fill in key information such as mortgage amount and maturity date, and query the progress of material review;
2) Credit line query: Real-time display of the available credit limit, used line, remaining line and other information of the core enterprise in the system, and support the submission of credit line change application;
3) Digital bill issuance: Based on the real trade background, support core enterprises to upload transaction contracts, invoices and other supporting materials, enter the bill amount, withdrawal period, receiving supplier node and other information, and initiate the application for digital bill issuance. The system automatically verifies the adequacy of the credit line, and after completing the signing of the "Payment Commitment Letter" through the electronic signature system, it generates a digital bill and writes it to the blockchain ledger.
4) Bill Management Center: Support core enterprises to query the status (uncirculated, in circulation, redeemed, discounted, etc.), circulation trajectory, maturity date and other information of all digital bills issued by themselves, which is convenient for core enterprises to carry out supply chain capital planning;
5) After the core enterprise confirms the redemption of the funds, the system completes the transfer of funds to the bill holding node, and updates the bill status to "redeemed", and the relevant redemption information is synchronized to the ledger of all nodes.

4.2.2 Factoring company node module

The node module of the factoring company is responsible for the provision of financial services and risk control, and the core revolves around credit review, discount processing and fund management, and the specific functions include:

1) Mortgage certificate review: Accept the mortgage certificate information submitted by the core enterprise, support the combination of automatic verification and manual review, verify the authenticity, legality and credit status of the core enterprise of the electronic commercial acceptance bill, and generate review opinions;
2) Credit line issuance: After passing the review, the corresponding credit line data is issued to the core enterprise nodes according to the amount of the mortgage certificate, and the data is synchronized to the blockchain network in real time, and the credit issuance log is recorded.
3) Discount application processing: Receive discount applications submitted by supplier nodes or upstream enterprise nodes, query the authenticity, validity and remaining maturity date of digital bills, calculate the discount amount and generate a discount plan.
4) Transfer of discounted funds: After passing the review, deduct the discount amount, transfer the remaining funds to the designated account of the applicant enterprise, and update the holder of the digital bill as the factoring company node, and write the relevant discount transaction information into the blockchain ledger.
5) Capital and risk control: Real-time monitoring of the use of credit lines, the issuance of discounted funds and the recovery of maturity redemption, generating a risk warning form, and initiating a recovery process for overdue bills.

4.2.3 Supplier node module

The supplier node module is the core module of digital bill receipt and circulation, which supports suppliers to receive bills, split, circulate and apply for discounts, and the specific functions include:

1) Bill receipt confirmation: receive digital bill notifications issued by core enterprise nodes in real time, view bill amount, account period, maturity date and other information, complete the receipt operation after verification, and update the bill holding status in the system;
2) Digital bill splitting: When it is necessary to pay to

multiple upstream enterprises, the supplier node is supported to enter the identification of each upstream enterprise node and the corresponding payment amount to initiate the bill splitting application. The system automatically completes the bill splitting through the smart contract and generates multiple sub-bills to ensure that the sum of the sub-bills is the same as the original bill.

3) Bill circulation endorsement: Select the target upstream enterprise node, initiate the bill circulation endorsement application, and after submission, the system will transfer the bill ownership to the target node, synchronously update the bill holding information in the ledger of each node, and support viewing the bill circulation record.
4) Discount application initiation: Before the expiration of the digital bill, if there is a need for capital turnover, you can initiate a discount application to the factoring company node, upload relevant supporting materials, enter the collection account information, and check the progress of the discount application review.
5) Bill query management: Support supplier nodes to query the status, circulation trajectory, maturity date and other information of all digital bills held by themselves, which is convenient for fund planning and management.

4.2.4 Upstream enterprise node module

The upstream enterprise node module supports the operation of receiving bills, circulating bills and applying for discounts at the end of the supply chain, and realizes the cross-level transmission of core enterprise credit, including specific functions:

1) Bill receipt and confirmation: receive digital bills circulated by supplier nodes, view bill amount, account period, maturity date and other information, verify the authenticity of the transaction background and complete the receipt, and update the bill holding status in the system;
2) Secondary circulation of bills: Support upstream enterprise nodes to further transfer the received digital bills to their own upstream enterprises (such as third-level supplier nodes), initiate circulation endorsement applications, and realize the in-depth transmission of credit;
3) Discount application and inquiry: Before the expiration of the bill, you can initiate a discount application to the factoring company node to inquire about the progress of the application and the calculation result of the discount amount;
4) Maturity and redemption query: When the bill expires, the system automatically triggers the redemption process of the core enterprise, and the upstream enterprise nodes can query the redemption progress in real time, check the arrival of funds, and receive the redemption completion notification;
5) Bill ledger management: Automatically record all bill-related operations such as enterprise receipt, circulation, discounting, and redemption, generate bill ledgers, and support export and printing, which is convenient for enterprise financial accounting and auditing.

4.2.5 Information notarization node module

The core function of the information notary node module is to review and confirm the signature of all transaction information to ensure the legality and non-repudiation of transactions, including:

1) **Transaction information reception:** receive detailed information of all transactions (credit issuance, bill issuance, circulation endorsement, discounting, redemption, etc.) in the system in real time, including transaction entity, transaction amount, transaction time, supporting materials, etc.;
2) **Transaction review and verification:** review the authenticity, legality, and compliance of transaction information, verify the consistency of transaction contracts, invoices, electronic signatures, and other materials, and confirm the legality and operational authority of transaction entities;
3) **Digital signature confirmation:** After passing the review, the information notary node uses its own digital certificate to sign the transaction information, which is a necessary condition for the transaction to take effect, and the signature information is bound to the transaction data and stored in the blockchain ledger.
4) **Notarization record query:** Support notary institutions to query all notarized transaction records, generate notarized statements, and provide authoritative evidence support for subsequent dispute resolution;
5) **Abnormal transaction warning:** Provide early warning of abnormal situations such as false transactions and unauthorized operations found during the audit process, and provide timely feedback to relevant nodes and system administrators to prevent transaction risks.

4.3 System data interaction and synchronization mechanism

4.3.1 Data interaction process

The data interaction between nodes and modules in the system is implemented based on the blockchain peer-to-peer network, following the standardized process of "initiation-verification-signing-synchronization-recording":

a) **Transaction initiation:** A node (such as a core enterprise node) initiates a business operation (such as opening a digital bill), generates transaction data, signs it, and broadcasts it to all participating nodes through the peer-to-peer network.
b) **Data verification:** Each receiving node (such as a factoring company node and an information notary node) verifies the authenticity and legitimacy of the transaction data and the authority of the initiating node.
c) **Notarization signature:** After the information notarization node completes the review, the transaction data is signed and confirmed.
d) **Consensus reached:** Each node votes to confirm the validity of the transaction according to the consensus algorithm, and the transaction takes effect after reaching the preset consensus threshold.
e) **Data synchronization and recording:** The effective transaction data is packaged and written to a new block, linked to the blockchain main chain, and each node updates the local ledger synchronously to ensure that the data of all nodes is consistent.

4.3.2 Data synchronization guarantee

a) **Real-time synchronization mechanism:** Once the transaction information takes effect, it is immediately

synchronized to all nodes through the peer-to-peer network to ensure the real-time consistency of ledger data at each node.

b) **Conflict resolution mechanism:** If the node data is inconsistent due to network delays and other reasons, the system will automatically synchronize the longest and most effective blockchain data according to the consensus algorithm and the principle of the longest blockchain chain, and correct the local ledger.

c) **Data verification mechanism:** Each node regularly verifies the local ledger data with the ledger data of other nodes in the network, and automatically triggers synchronous updates when discrepancies are found to ensure data accuracy.

4.4 System safety and performance design

4.4.1 System Security Design

a) **Identity security:** Use digital certificates and cryptographic signature technology to authenticate the identity of each node to ensure that only legitimate nodes can access the system and carry out operations to prevent identity forgery.

b) **Data security:** encryption algorithms are used to encrypt transaction data transmission, and hash encryption and distributed storage are used for storage to ensure that data is not stolen or tampered with.

c) **Permission security:** Role-based access control (RBAC) mechanism assigns refined operation permissions to each node, prevents unauthorized operations, and ensures the orderly use of system functions.

d) **Smart Contract Security:** Conduct security audits and vulnerability detection of smart contracts to prevent security risks caused by contract vulnerabilities and ensure that contracts are executed securely according to preset rules.

4.4.2 System Performance Design

a) **High concurrency processing:** Adopts distributed architecture and load balancing technology to support multiple nodes to initiate transactions simultaneously, improve the system's concurrency processing capabilities, and meet the high-frequency transaction needs of supply chain finance business.

b) **Efficient consensus algorithm:** Choose an efficient consensus algorithm suitable for the consortium chain to shorten the transaction confirmation time and ensure that the transaction takes effect quickly.

c) **Data query optimization:** Establish an indexing mechanism, optimize the ledger data query logic, support rapid retrieval and traceability of transaction information, and improve user operation experience.

d) **Scalability design:** The system adopts a modular architecture to support new node types and expand business functions to adapt to the future development needs of supply chain finance business.

5. Conclusions

Based on the core characteristics of blockchain technology, such as distributed ledger, non-tampering, and smart contracts, this study designs and constructs a complete blockchain-based supply chain finance management method and system, which provides a practical solution for the digital transformation of supply chain finance. Through a comprehensive study of system architecture, business processes, core functions and application value, the following main conclusions are drawn.

First, blockchain technology provides fundamental technical support for solving the pain points of traditional supply chain finance. The core contradiction of traditional supply chain finance stems from information asymmetry, obstruction of credit transmission and insufficient credibility of transactions, while the distributed ledger of blockchain realizes the synchronous sharing and traceability of transaction information at all nodes, the alliance chain architecture ensures the legitimacy and controllability of participants, smart contracts realize the automated execution of business processes, and digital bills become the carrier of cross-level credit transmission of core enterprises. The in-depth application of these technical features has fundamentally solved the problems of information islands, credit rupture and transaction risks, and laid a solid foundation for the innovation and development of supply chain finance.

Second, the constructed supply chain finance management method realizes the optimization of the whole process of business processes. The five core processes of credit line issuance, digital bill issuance, circulation endorsement, maturity redemption and discount processing are designed in this study, forming a closed-loop management of the whole life cycle of digital bills. Through the digital transformation and cross-level transmission of core enterprise credit, small and medium-sized enterprises at the end of the supply chain have obtained equal financing opportunities; The divisible and circulating characteristics of digital bills improve the efficiency of capital turnover; The participation of information notary nodes and the implementation of consensus mechanisms ensure the legitimacy and security of transactions. This method breaks the hierarchical limitations and process barriers of traditional supply chain finance, and realizes the collaborative optimization of credit transmission, information sharing and capital flow.

Third, the developed supply chain financial management system has complete functions and practical feasibility. The system adopts a three-level architecture of "underlying technology layer-core function layer-user interaction layer", integrating five core modules: core enterprise nodes, factoring company nodes, supplier nodes, upstream enterprise nodes and information notarization nodes, and realizes the full functional coverage of credit management, bill management, circulation management, redemption and discount management and information notarization management. Through refined permission allocation, all-round security design and efficient data synchronization mechanism, the system ensures the collaborative operation of all participants and the security and compliance of the business, and has strong practical implementation capabilities.

Fourth, the application of systems and methods brings multiple values to the participants of supply chain finance and the industrial ecology. for small and medium-sized enterprises, they have obtained convenient and low-cost financing channels, which has alleviated the pressure of

capital turnover; For core enterprises, supply chain management has been optimized, industrial cohesion and competitiveness have been enhanced; For factoring companies, it expands business scenarios and reduces credit risks and operating costs; For the entire supply chain and industrial ecology, it has improved the efficiency and collaborative level of capital allocation, and promoted the digital and standardized development of supply chain finance.

Finally, although this study constructs a complete blockchain-based supply chain financial management method and system, there are still certain limitations: first, the practical application effect of the system needs to be further verified in large-scale real scenarios, and the differences in business characteristics of supply chains in different industries may put forward higher requirements for system adaptability. second, the cross-platform mutual recognition and standardization system of digital bills has not yet been fully established, which may affect the cross-industry promotion of the system; Third, there is still room for optimization of complex scenario adaptation and security audit of smart contracts.

In the future, the research can be further deepened from the following directions: first, strengthen the optimization of the industry adaptability of the system, customize the business process and functional modules according to the business characteristics of the supply chain of different industries, and improve the universality of the system; second, promote the standardization of digital bills, establish a cross-platform mutual recognition mechanism, and promote the interconnection of supply chain financial ecology; The third is to deepen the application of smart contracts, introduce artificial intelligence and big data technology, realize advanced functions such as risk warning and dynamic credit, and improve the intelligence level of the system. Fourth, explore the integration and application of blockchain technology and other emerging technologies, such as Internet of Things technology for logistics information traceability and big data technology for credit evaluation, further enrich the service scenarios and risk control methods of supply chain finance, and promote the development of supply chain finance in a more efficient, intelligent and inclusive direction.

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