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Research on the Blockchain and IoT-based Supply Chain Finance Business Process Automation Model and Workflow Orchestration Algorithm

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Abstract: Traditional supply chain finance, while alleviating financing difficulties for small and medium-sized enterprises (SMEs), is still hindered by issues such as information silos, lack of trust, and fragmented business processes. These challenges result in low operational efficiency and high operational risks. To address these challenges, this paper aims to build an intelligent supply chain finance business automation framework that deeply integrates blockchain and IoT technologies. Blockchain technology, with its distributed ledger, immutability, and smart contract features, provides the underlying support for creating a trusted multi-party collaboration environment. Meanwhile, IoT technology enables real-time sensing and accurate traceability of physical asset states, integrating the four flows—business flow, logistics, information flow, and fund flow—into one, providing a reliable data foundation for digital risk control and decision-making. The core contribution of this paper is the proposal of an innovative business process automation model and dynamic workflow orchestration algorithm. First, by deconstructing typical business scenarios such as receivables financing and inventory pledge, complex financial activities are abstracted into standardized and configurable task units. Then, smart contracts are used to encode business rules and contract terms, enabling "machine trust"-based execution of key processes like automatic rights confirmation and settlement. To solve the coordination challenges of multi-party, multi-step business processes, this research designs an orchestration scheduling algorithm based on a workflow engine. This algorithm can dynamically optimize task execution paths and resource allocation strategies based on real-time IoT data and on-chain events, significantly improving the response speed and overall efficiency of complex business processes. Through comparative analysis and simulation experiments with typical platform cases, the proposed model demonstrates significant advantages in improving business processing efficiency, reducing credit risk, and lowering operational costs. Finally, this paper discusses the challenges faced in the practical application of this model, such as technology integration, performance scalability, and privacy protection, and looks forward to future research directions. It provides important theoretical references and practical paths for promoting the development of supply chain finance towards automation, intelligence, and ecosystem integration.

1. Introduction

In the current context of accelerating the construction of a new development paradigm and promoting the high-quality development of the real economy, supply chain finance has increasingly emerged as a key tool for promoting the deep integration of industrial and financial chains. It aims to leverage the credit of core enterprises to effectively alleviate the long-standing financing bottlenecks faced by small and medium-sized enterprises (SMEs) in the upstream and downstream of the supply chain. However, traditional supply chain finance models have always been constrained by inherent issues: the information systems of various supply chain participants are heterogeneous and independent, forming “data silos”; the high-quality credit of core enterprises is difficult to securely and credibly transmit to multi-level suppliers; at the same time, business processes are highly dependent on manual review and offline document circulation, leading to low efficiency and increased operational and moral risks, severely limiting their service effectiveness and risk management capabilities.

In recent years, the rapid development of cutting-edge technologies such as blockchain and the Internet of Things (IoT) has brought revolutionary opportunities to solve these challenges. Blockchain technology, as a distributed ledger technology, offers an ideal solution for building a multi-party collaborative and trusted supply chain finance infrastructure with its features of decentralization, immutability, traceability, and smart contract automation. Blockchain technology provides authenticity and integrity protection for key data such as transaction backgrounds, debts and liabilities, and becomes the cornerstone of trust for the non-destructive transmission of credit in the supply chain. The Internet of Things (IoT) technology acts as the ‘eyes’ and ‘nerves’ to perceive the physical world through sensors, RFID, GPS and other devices, realising real-time tracking of asset status and automatic data collection.

Although the integration value of "Blockchain + IoT" has become a consensus in the industry, and useful explorations have been made in the practices of certain industrial internet platforms, a key gap still exists in current research and practice: how to move beyond simple technological stacking and build an automated engine at the system level that can dynamically respond to business events, intelligently schedule resources from all parties, and ensure the efficient and reliable execution of processes. Current models mainly focus on the trusted storage of data, but there is a lack of in-depth theoretical research and algorithmic support in areas such as the fine-grained modeling of business processes, intelligent orchestration of task nodes, and automated collaboration across systems.

Therefore, the core of this research is to build a supply chain finance business process automation model deeply integrated with blockchain and IoT and design corresponding workflow orchestration algorithms. This study will first deconstruct typical supply chain finance business scenarios to form a standardized task unit library. Then, using smart contracts as the carrier of business rules and IoT data as the input to trigger processes, a dynamic orchestration mechanism based on a workflow engine will be designed. This mechanism will automatically optimize task execution paths based on preset strategies and real-time status, accurately delivering instructions to the relevant business nodes (such as core enterprises, financial institutions, warehouses, etc.), ultimately forming a self-driving, traceable, and efficient business loop. Through this research, we aim to provide solid theoretical support and feasible technical paths to promote the evolution of supply chain finance towards higher levels of automation, intelligence, and ecosystem integration.

2. Related Research

At the technical foundation level, blockchain technology, due to its core advantages in building trust, ensuring data authenticity, and guaranteeing immutability, has been widely regarded as a key enabling technology to address the core pain points of supply chain finance (SCF). As Rijanto A [1] confirmed through multiple case studies, based on the Technology Acceptance Model (TAM), the data trustworthiness of blockchain (perceived usefulness) and the automated execution capabilities of smart contracts (perceived ease of use) are the key drivers for solving automation challenges in SCF processes such as accounts receivable and order financing. Furthermore, Zheng K [2] focused on the specific stage of credit investigation. In response to data silos and privacy issues in traditional credit systems, he proposed a blockchain-based credit investigation model. By improving the consensus mechanism, the model enables secure sharing and traceability of data, providing methodological support for building a trustworthy SCF credit system.

On the IoT side, its development has provided a solid foundation for digitizing information from the physical world within supply chains. Nofrialdi R [3] pointed out that the application of IoT has profoundly influenced work efficiency, individual behavior, and even the operation of entire supply chains. This highlights its immense potential in SCF for acquiring real-time, reliable asset data, such as inventory status.

However, the application of a single technology still has limitations. Blockchain excels at handling information and financial flows, but it requires trustworthy data inputs; IoT can capture physical-world data, but it must ensure that such data is directly integrated into trusted processes. As a result, research has shifted towards the integration of technologies and the orchestration of automated business processes. Tailor R K [4] envisioned the combination of Robotic Process Automation (RPA) with blockchain, which holds promise for achieving higher levels of automation in complex business processes, offering technical imagination for practical implementation. More importantly, when multiple technologies and services such as blockchain and IoT are integrated into a complex system, how to coordinate them in an orderly manner becomes a central challenge. In this regard, the research of Terracina A [5] on service orchestration algorithms is particularly inspiring. His innovative solutions for dynamic environments provide valuable algorithmic insights to ensure that complex tasks composed of multiple independent services can be completed reliably and in an orderly fashion [6].

In summary, existing research has demonstrated the independent value of blockchain and IoT in SCF and has begun exploring their integration and process automation [7]. Yet, no study has systematically proposed an integrated model that positions IoT as a trusted data source, blockchain as a trusted processing platform, and advanced workflow orchestration algorithms as the enabler of end-to-end automation in business processes [8].

3. Business Process Automation Model and Workflow Orchestration Algorithm Design

3.1. Overall Architecture and Key Component Design of the Automation Model

When constructing a blockchain and IoT-based supply chain finance business process automation model, the overall design is layered, modular, and event-driven. It aims to integrate business flow, logistics, information flow, and financial flow, breaking down complex financial operations into standardized task units [9]. By leveraging smart contracts and a workflow engine in tandem, the model achieves a closed-loop automation of "on-chain rules—off-chain execution," while ensuring dynamic orchestration and elastic scaling under the premise of privacy and compliance. Logically, the system can be divided into five layers: perception, data access, on-chain governance, orchestration execution, and operational risk control [10]. These layers are naturally interconnected through data and event interfaces.

In the perception layer [11], IoT terminals and edge gateways continuously collect events such as inventory, transportation, and delivery [12]. They perform filtering, signing, and caching on the edge side to ensure data is not lost and can be traced and synchronized during network fluctuations[13].The data access layer is responsible for device connection, message forwarding and protocol conversion, and through trusted preprocessing and predicator[14], the off-chain data is selectively uplinked or triggered with events, thus balancing efficiency and privacy while safeguarding the input of smart contracts[15].

The on-chain governance layer is based on the permission chain to achieve identity management, data deposit and contract execution. The relevant business rules are solidified on the chain, and the confirmation of rights and settlement can be completed automatically when the conditions are triggered, thus realising ‘machine trust’. In parallel, the orchestration execution layer relies on components such as the workflow engine, task unit library, plan template library, dynamic scheduler, and event listener to map smart contracts or IoT events to executable workflows. Instructions are issued to each node, dynamically adjusting paths and parallelism based on real-time resources, on-chain status, and optimization strategies. This enables efficient scheduling in multi-party business environments.

Within this architecture, functional modules collaborate closely. The edge gateway not only handles data signing, anomaly detection, and on-chain packaging but also cooperates with the digital asset and certificate management modules to assign unique digital identifiers to physical goods and debts, managing their lifecycle. The smart contract library encodes business rules and exposes events to the workflow engine, while the plan template library and task unit library break down typical business processes into standard nodes, allowing the workflow to assemble and rearrange automatically. The workflow engine and scheduler then generate and execute BPMN workflow files, with the event bus and oracles ensuring reliable communication between on-chain and off-chain components. The identity and access control system, based on PKI or DID, provides minimal privilege access and auditable calls, while the risk control engine integrates on-chain transactions and IoT data to compute credit limits and drive credit approval or financing suspension.

The end-to-end execution process involves IoT devices collecting critical events, which are signed by the gateway and submitted as summaries to the evidence repository. The oracle either on-chains the summary or triggers smart contract events. The workflow engine listens for these events, generates and deploys workflow instances, issues instructions to each node, verifies receipts, and, once conditions are met, automatically completes fund settlement and ledger recording. In case of anomalies, a compensation process is triggered and evaluated by the risk control module, forming a self-driven, traceable, and highly efficient business loop.

The overall design adheres to the principles of modularity, event-driven architecture, and eventual consistency. On-chain storage and off-chain evidence alignment support regulatory traceability. Privacy protection and compliance are ensured through summary-based on-chaining, access control, and encryption strategies, safeguarding data security. Key paths, such as the oracle and workflow executor, are deployed redundantly with automatic rollback strategies to ensure high availability and fault tolerance. Through the effective combination of the above architecture and components, the supply chain finance process not only achieves a higher degree of automation and intelligence, but also lays a stable operational foundation for the subsequent dynamic workflow orchestration algorithms and provides the necessary data support. This makes the whole system in the face of complex and changing business environment, can still maintain efficient operation, trustworthy and has good scalability.

3.2. Core Mechanism of the Dynamic Workflow Orchestration Algorithm

In supply chain finance, an environment involving multiple parties, complex resource types and the need to respond quickly to business changes, the goal of the dynamic workflow orchestration algorithm is to be able to generate and flexibly adjust the task execution plan in real time, to minimise processing delays and costs while enhancing the overall efficiency of the process under the premise of meeting compliance and risk control requirements. The algorithm models the entire workflow as a dynamically adjustable directed graph structure. Each node in the graph represents a standardised task unit, and the lines between the nodes indicate the dependencies between tasks. The system operation state is jointly determined by a variety of information, including events occurring in the chain, real-time data transmitted back from IoT devices, available resources, and the current state of each participant. Based on this model, the algorithm establishes a set of operation mechanisms that can be dynamically adaptive, covering key aspects such as event sensing, task instantiation, constraint checking, scheduling optimisation, real-time adjustment and risk linkage.

When a task is triggered and instantiated, the algorithm continuously acquires on-chain transaction records and IoT reporting information through the event bus and the prediction machine, so as to transform the triggering conditions into specific executable tasks. Each task instance carries necessary meta-information, such as execution roles, input and output requirements, required resources, priorities, and handling strategies in case of exceptions. Part of this information comes from a library of pre-defined task units, while the other part is dynamically updated based on real-time data and smart contract conditions to ensure that the task is both executable and meets compliance requirements. The instantiated tasks need to go through a layered constraint validation: firstly, mandatory screening by the on-chain contract and compliance rules, and then pre-validation at the semantic level by the rules engine, which includes checking whether the external interface is available, whether the status of the guarantee credentials is valid, and whether the necessary physical evidence signatures are complete, and so on. Only tasks that pass the validation will enter the pool of tasks to be scheduled, a mechanism that helps reduce subsequent compensation costs and compliance risks.

In the task scheduling and optimisation phase, the algorithm needs to strike a balance between real-time response and global optimum. For short-lived high-priority events, lightweight heuristic scheduling methods are used to ensure fast response; for tasks that can be processed in batches, the optimiser is invoked periodically to rebalance task allocation, parallelism and resource usage. Scheduling objectives typically combine risk exposure, transaction cost, and processing time in a weighted manner, and support dynamic adjustment of weights as the business changes. The algorithm also uses a rolling time domain policy for dynamic decision updating. When new on-chain events or IoT anomalies occur, tasks can be locally rescheduled, split or merged; for operations that have already been executed and cannot be rolled back, a preset compensation process is triggered, and the contract and the off-chain actuator collaborate to complete the rollback or compensation processing. In the key submission nodes, the system adopts a hybrid strategy to ensure the consistency of on-chain and off-chain operations, and the final consistency can be achieved even under network fluctuation or concurrency conditions. Risk perception and risk control measures are implemented throughout the scheduling process. The algorithm continuously extracts key indicators from on-chain history, IoT behavioural characteristics and external credit data, and transforms them into dynamic constraints or penalty terms to be incorporated into the objective function. Once an abnormal pattern is detected, the system will prioritise the degradation or suspension of the relevant tasks and automatically switch to manual intervention for approval, effectively controlling credit risk while maintaining business continuity. To continuously improve system performance, the algorithm also introduces an online learning module based on simulation and historical backtesting to gradually optimise strategy parameters. Each scheduling and adjustment decision is fully documented with decision basis, input snapshots and related chain evidence for subsequent regulatory audits and model improvements. The system has built-in multiple fault-tolerance mechanisms, such as task timeout retry, scheduler master and backup switching, and multi-source data validation, to ensure that the business process can still continue to move forward in the event of high concurrency or partial node failure. Through event-driven instantiation, layered validation, hybrid scheduling strategies, online reconfiguration and compensation, and deep integration with risk control, the dynamic workflow orchestration algorithm realizes real-time, adaptive, and auditable orchestration of supply chain finance processes. This not only enhances process responsiveness and resource utilization efficiency but also lays the groundwork for cross-chain collaboration and large-scale deployment.

4. Model Validation and Performance Analysis

4.1. Case Scenario Simulation and Model Implementation

To verify the feasibility and effectiveness of the constructed automation model and dynamic orchestration algorithm in real-world business scenarios, this study selected representative supply chain finance business cases and implemented an end-to-end prototype in a simulation environment. The validation objectives include evaluating the reduction in processing delay and manual intervention due to process automation, testing the adaptability of the orchestration algorithm under multi-event concurrency and abnormal conditions, and assessing the improvements in risk control and auditability achieved through on-chain and off-chain collaboration.

The focus of the scenarios is on two typical business types: one is receivables financing backed by the credit of core enterprises, covering stages such as application initiation, credit verification, rights confirmation, and loan settlement; the other is inventory pledge financing, including stages such as warehouse confirmation, warehouse receipt on-chain, transportation monitoring, and fund transfer triggered by conditions. A typical workflow for this business model is shown in Figure 1. Each scenario is designed with several abnormal sub-cases, such as missing physical evidence, sensor anomalies, or network partitioning, to test the effectiveness of the compensation mechanism and fault-tolerance strategies.

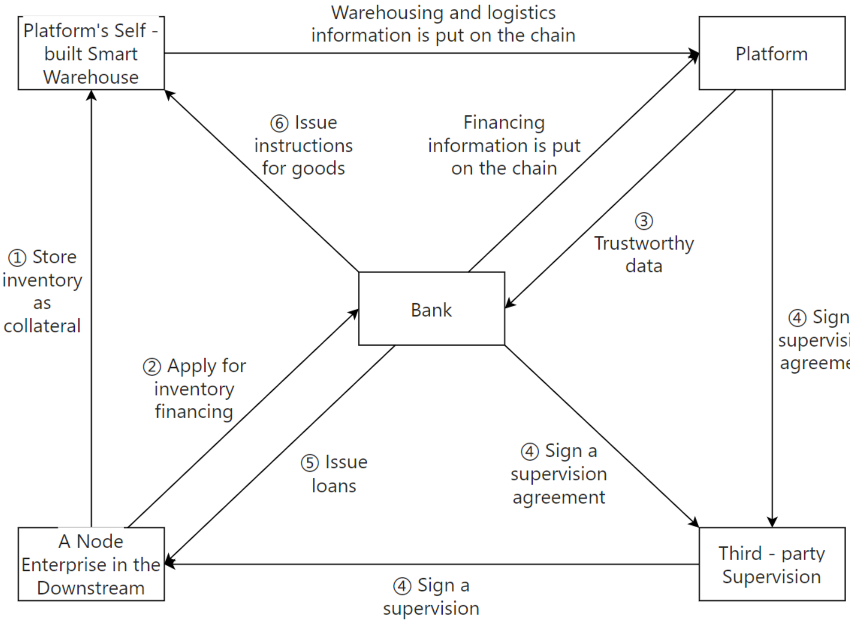

Figure 1. Example Workflow of Inventory Pledge Financing Business

At the implementation level, a hybrid experimental platform was built to support the collaborative operation of off-chain sensing, on-chain governance, and workflow orchestration. The ledger adopts a permissioned blockchain architecture to enable controlled governance of participants. The workflow engine supports the BPMN standard, allowing task-unit templates to be mapped into executable processes. An oracle component simulates trusted input from off-chain data to the blockchain, while the IoT side employs samplers and event generators to emulate data streams from RFID, GPS, and environmental monitoring. The experimental network involves core enterprises, financial institutions, warehousing and logistics service providers, as well as regulatory nodes. Load conditions were designed to cover both steady transaction submission and sudden concurrent bursts. Evaluation metrics include not only system-level performance indicators such as throughput and end-to-end latency, but also business-level indicators such as task completion rate, frequency of manual intervention, settlement accuracy, and risk-control event hit rate, thereby providing a comprehensive reflection of the model’s performance in operational contexts.

Simulation results demonstrate that the automation model and dynamic orchestration algorithm yield significant improvements across key dimensions. Compared with the baseline process dominated by manual operations, end-to-end processing delays are substantially reduced, primarily due to smart contracts automatically determining trigger conditions and the workflow engine optimizing task parallelism in real time. The frequency of manual interventions decreases notably, as many validation and authorization steps are replaced by auditable on-chain evidence, thereby lowering the risks of human error and delay. When IoT anomalies or network fluctuations occur, the algorithm can quickly perform localized reordering or trigger compensatory workflows, ensuring process continuity and final consistency. Meanwhile, the risk-control module leverages blockchain history and IoT behavioral data as dynamic constraints, enabling it to prioritize restricting high-risk flows and initiating review procedures when abnormal patterns emerge, thereby reducing potential credit exposure. It should be noted, however, that the extent of performance gains and reliability enhancements is closely tied to specific system parameters, network scale, and consensus configurations. The simulation results therefore primarily reflect relative improvements under the given experimental settings.

While the findings validate the model’s engineering feasibility and business value, the experiments also reveal several issues requiring further attention. First, the simulation relied on controllable assumptions regarding the reliability and preprocessing of IoT data; in real-world deployment, sensor tamper-resistance and multi-source verification must be strengthened. Second, the growth of on-chain evidence will incur storage and retrieval overhead, necessitating a more refined balance between data granularity and privacy protection. Third, the security and availability of oracles and off-chain executors are critical to system robustness, and should be safeguarded through multi-source oracles and redundant deployment. Based on these observations, future work should advance to small-scale field pilots to collect real operational data, perform performance tuning on consensus parameters and scheduler strategies, and introduce techniques such as differential privacy or homomorphic encryption to enhance sensitive data protection, thereby facilitating a smooth transition from simulation validation to production-level deployment.

4.2. System Performance and Business Effectiveness Evaluation

To rigorously assess the performance of the proposed automation model and dynamic orchestration algorithm in an engineering context, this study established a set of multidimensional indicators and corresponding testing methods on the hybrid simulation platform. Performance metrics cover system throughput and end-to-end latency, task completion and success rates, scheduling stability under concurrent conditions, on-chain storage and retrieval overhead, and additional costs arising from fault tolerance and compensation. Business effectiveness is evaluated through measures such as the frequency of manual interventions, loan-trigger accuracy, settlement consistency, and the hit rate of risk-control events. Measurement methods include end-to-end tracing to capture processing delays, event-driven load injection to assess concurrent throughput, fault injection to observe recovery time and compensation success, and baseline process comparison to quantify relative improvements from automation. To ensure statistical validity, each condition was tested repeatedly, and robust statistical methods were applied for significance analysis.

From the perspective of system performance, dynamic orchestration demonstrated superior real-time responsiveness and resource efficiency in most test scenarios. Enabled by smart contracts' automatic triggers and the workflow engine's dynamic adjustment of parallelism, end-to-end processing latency decreased significantly under stable loads. During sudden concurrency peaks, the combination of heuristic real-time scheduling and periodic offline optimization sustained high throughput, thereby avoiding performance collapses associated with single-strategy scheduling. Meanwhile, the granularity of on-chain recording and the choice of evidencing strategy had a direct impact on storage and retrieval overhead. Writing large volumes of raw data to the ledger frequently increased blockchain costs; thus, adopting on-demand on-chaining and digest-based proofs provided a manageable balance between performance and privacy. It should be emphasized that the degree of performance improvement is constrained by underlying system parameters such as consensus mechanisms, oracle latency, and network bandwidth, requiring parameter tuning under different deployment environments to achieve optimal results.

On the business side, the automation model significantly reduced reliance on manual verification, as many steps previously requiring human checks were replaced with on-chain evidence and IoT receipts, thereby lowering delays and operational errors. The orchestration algorithm, by embedding risk constraints in real time, improved anomaly detection and risk interception. When anomalies in collateral or transportation occurred, it was able to promptly downgrade or suspend loan disbursement, ensuring a dynamic balance between capital flow and risk exposure. Comparative experiments further revealed that compensation workflows and consistency assurance mechanisms effectively reduced the probability of unrecoverable errors during network partition or node failure; however, the compensation operations themselves incurred additional costs and delays, necessitating explicit compensation-trigger thresholds and cost–benefit trade-offs in strategy design.

Robustness and security evaluations revealed the system's behavioral patterns under common fault conditions. By injecting sensor failures, network jitter, and oracle anomalies, this study verified the feasibility of localized reordering and compensatory workflows, with observed recovery times and final consistency meeting design targets, thus demonstrating strong resilience. Equally important, the simulations also exposed several limitations and directions for improvement. These include strengthening the trust model of oracles to mitigate single points of failure, adopting layered storage and index optimization to control the long-term operational costs of growing on-chain evidence, and introducing techniques such as differential privacy or encrypted search to protect sensitive data in compliance with regulations. Based on these findings, future work should include small-scale field pilots, fine-tuning consensus parameters, oracle strategies, and scheduler weights according to real network conditions and business volumes, so that the advantages observed in simulation can be reliably transferred into production deployment.

5. Conclusion and Outlook

This research constructed and validated a supply chain finance business process automation framework that deeply integrates blockchain and Internet of Things (IoT) technologies. It proposed a process modeling method based on standardized task units and a dynamic workflow orchestration algorithm driven by real-time events. Through a layered system design, this framework organically combines the real-time perception of physical assets, the automatic triggering of on-chain rules, and the controllable coordination of off-chain execution, thereby shifting business processes from being labor-intensive to data-driven, and from passive approval to active orchestration. At the algorithmic level, mechanisms such as hierarchical constraint validation, hybrid scheduling strategies, and online reconfiguration/compensation were introduced, with risk control elements embedded into the scheduling objectives. This enables processes to maintain high efficiency, auditability, and a certain degree of self-adaptive capability in environments characterized by multi-party participation, heterogeneous resources, and compliance constraints.

Simulation and prototype implementation results indicate that the proposed scheme demonstrates significant advantages in key business metrics. The automated process substantially reduced end-to-end processing latency and the frequency of manual intervention. The synergy between smart contracts and the workflow engine enhanced task parallel processing capability and settlement accuracy. When IoT anomalies or network fluctuations occurred, the orchestration algorithm quickly performed local rescheduling or triggered compensation workflows, thereby ensuring business continuity and eventual consistency. Meanwhile, the on-chain evidence and complete decision logs provided reliable data support for regulatory auditing and subsequent risk modeling, highlighting the system's value in terms of transparency and traceability.

Despite the aforementioned achievements, the study also revealed several practical constraints and areas for improvement. Firstly, the authenticity and tamper-resistance of IoT data remain weak points in the system's trustworthiness, necessitating reliance on multi-source verification and stronger endpoint protection. Secondly, the reliability of oracles and the strategy for on-chain data storage directly impact performance and cost. A more refined balance between data granularity, privacy, compliance, and efficiency needs to be found in storage management. Thirdly, the algorithm's performance is influenced by the underlying consensus mechanism, network environment, and system parameter configuration. Targeted performance tuning and stress testing are required for actual deployment.

Looking forward, several directions warrant further in-depth exploration. Priority should be given to conducting small-scale field pilots to obtain operational data from real business flows and network environments, based on which consensus parameters, oracle strategies, and scheduler weights can be adjusted. On the technical front, exploring cross-chain interoperability, decentralized data provisioning based on multi-source oracles, and the introduction of privacy-enhancing technologies such as differential privacy, homomorphic encryption, or multi-party computation could meet stricter compliance requirements. Algorithmically, integrating online learning, reinforcement learning, or meta-learning could achieve self-adaptive tuning for non-stationary business environments. Concurrently, formal methods could be employed to verify the correctness of smart contracts and workflows to reduce logical vulnerability risks. Finally, attention should be paid to governance and economic incentive design, clarifying the obligations and profit distribution among participants to promote the transition of the technical solution towards a sustainable industrialization path.

In summary, the model and orchestration method proposed in this paper provide an actionable technical pathway for the evolution of supply chain finance towards intelligence and trustworthiness. Through subsequent iteration and refinement in real-world scenarios, it is expected to play a greater role in reducing financing costs, improving business efficiency, and strengthening risk control, thereby promoting the development of supply chain finance service models towards automation, collaboration, and ecosystemization.

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