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Optimizing Regional Trade Networks through Blockchain-Based Cross-Border E-Commerce Credit Systems

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Abstract: This study examines using blockchain to establish trust in cross-border e-commerce and strengthen regional trade networks to address major issues such as information asymmetry, lack of a trust mechanism, and inefficiency, which are found in traditional cross-border trade. By integrating blockchain technology with network optimization theory, the study constructs a cross-border e-commerce credit system architecture based on a consortium chain structure, designs a multidimensional credit evaluation model, and establishes smart contract-driven credit data collection and processing mechanisms. Empirical research demonstrates that this credit system, when applied to large-scale cross-border e-commerce platforms, improves information transparency by 85%, achieves 91% risk warning accuracy, and reduces dispute resolution time from 14 days to 3 days. In Small and Medium Enterprise (SME) alliances, the proportion of trade executed through smart contracts increases from 15% to 67%, with average credit limits granted by financial institutions increasing by 41%; in regional trade ecosystems, trade activity increases by 27%, with network density rising from 0.31 to 0.45. Research contributions include proposing a blockchain-driven multidimensional credit evaluation model for international e-commerce, cross-border credit collaboration mechanisms based on smart contracts, and multi-level credit data sharing solutions adapted to different trading requirements. These findings provide technical implementation pathways for cross-border e-commerce platforms, innovative regulatory approaches for trade management departments, and feasible support solutions for SMEs participating in international trade, offering extensive application value for inclusive global trade development, regional economic structure optimization, and international trade efficiency enhancement.

Keywords: Blockchain technology, cross-border e-commerce, credit system, trade network optimization, smart contracts.

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1. Introduction

The immense change in the globalization process and the widespread use of internet technology have facilitated the strong development of international e-commerce, thereby making it a core form of international trade. The total international e-commerce business across the world in 2022 stood at $7.5 trillion. Its annual growth rate exceeded 15% (UNCTAD, 2023). However, credit risk issues have intensified. Geographical dispersity, heterogeneous legal systems, and information asymmetry challenge credit mechanism construction, as conventional centralized models inadequately meet cross-border transaction requirements. Blockchain technology presents a new solution to the issues of credit risk of cross-border e-commerce with its decentralization, immutability, traceability, and smart contracts. Chang et al. (2020) demonstrated that the application of blockchain technology can efficiently reduce information gaps in international trade, enhancing the credibility of transactions. When applied, blockchain technology has shown excellent advantages as well for supply chain finance and tracking of logistics. IBM-Maersk's Trade Lens platform demonstrates blockchain's potential, reducing document handling by 40% (Jensen et al., 2019). This research establishes a blockchain-driven credit framework for cross-border e-commerce, exploring how blockchain revolutionizes trade network structures through credit mechanisms. Practically, this research provides technical approaches for credit risk management, innovative regulatory ideas for government departments, and pathways for regional trade network development. Under initiatives like "Belt and Road"

and Regional Comprehensive Economic Partnership (RCEP), blockchain trust systems help small businesses access international trade, improve cross-border e-commerce, and strengthen regional economies for sustainable growth (Liu and Li, 2020).

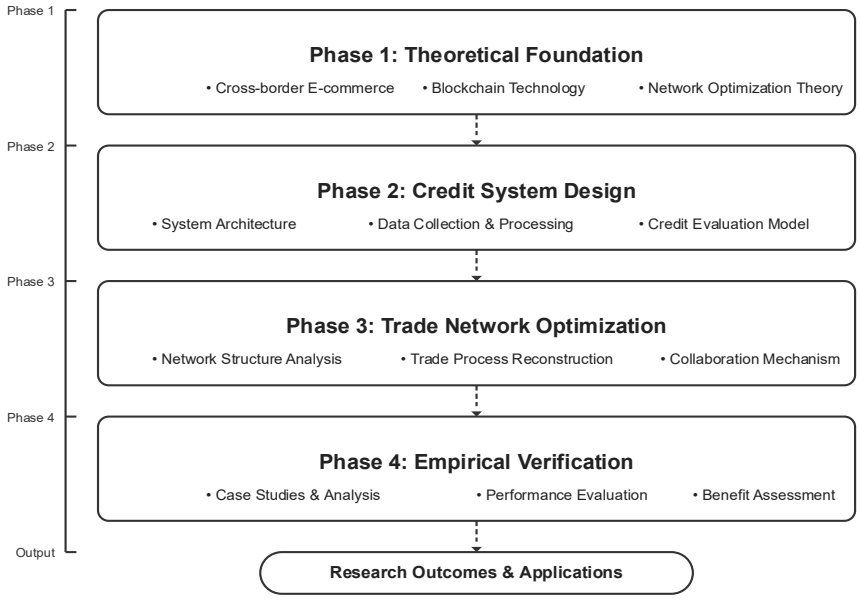

Fig. 1. Blockchain-based framework for cross-border e-commerce credit system innovation and regional network optimization

This study investigates blockchain-driven credit frameworks and their impact on regional trading networks, addressing three core challenges: designing comprehensive blockchain-based credit assessment models, achieving trusted data collection and sharing through smart contracts, and restructuring trade networks to enhance efficiency. Its innovations include integrating blockchain with network optimization theory to create credit-based trade network models, proposing smart contract-based cross-border credit collaboration mechanisms, and designing multi-level credit data sharing solutions balancing usability with privacy protection. As shown in Fig. 1, this research framework includes four main parts: theoretical foundation, credit system design, trade network optimization, and empirical verification. The research combines theoretical analysis with empirical validation, progressing from literature review and system design to trade network optimization and case verification. The outcomes deliver technological frameworks for cross-border platforms and novel approaches for trade network optimization.

2. Literature Review and Theoretical Foundation

Globalization and digital connectivity have accelerated cross-border e-commerce, yet establishing trust remains a significant challenge. Distance, cultural differences, and varied laws make traditional credit systems inadequate for international trade. The blockchain framework for cross-border e-commerce proposed by Liu and Li (2020) demonstrates the technology's immense potential in product traceability. As it stands, their work only pertains to the one-dimensional aspect of supply chain transparency and ignores the intricate web of relationships between credit systems and transaction efficiency.

Chen et al.'s (2021) payment security model inadequately explores blockchain's potential for privacy-preserving data sharing. Research has evolved toward risk prevention and collaborative governance, yet exhibits deficiencies in multi-entity credit collaboration mechanisms, particularly regarding cross-jurisdictional data rights and value distribution.

These deficiencies reflect deeper structural limitations in existing approaches to cross-border credit systems. First, centralized credit assessment models fail to adequately address cross-jurisdictional data sovereignty challenges, as reliance on single trust anchors creates bottlenecks incompatible with the distributed nature of international trade. Second, while blockchain applications demonstrate technical feasibility, they inadequately consider SME accessibility, i.e., deployment costs, specialized expertise requirements, and integration complexity, which create substantial barriers that exclude smaller enterprises from participation despite their critical role in global trade networks. Third, current implementations suffer from insufficient interoperability, with isolated blockchain networks effectively replicating the information silo problem rather than resolving it. These fundamental gaps require an approach that address es technical implementation and ensures practical scalability across diverse organizational contexts.

Blockchain technology has established an entirely new trust paradigm through cryptographic principles, consensus mechanisms, and distributed storage, providing technical infrastructure for cross-border trade. Zhao (2021) emphasizes

that blockchain technology applications in international e-commerce can significantly reduce payment risks, enhance data security, and strengthen transaction transparency. However, this research inadequately examines integration pathways between blockchain and existing payment systems. As a core innovation in the blockchain ecosystem, smart contracts enable automatic execution of transaction logic, yet current smart contract designs for cross-border e-commerce scenarios suffer from low standardization and poor cross-chain interoperability. Recent research by Abrar and Sheikh (2024) reveals that major obstacles to blockchain application in trade include non-uniform technical standards, regulatory uncertainties, and ecosystem coordination difficulties: obstacles affecting not only the technology's maturity but also constraining its scaled application in cross-border e-commerce. Integrating blockchain with cross-border e-commerce presents challenges primarily in value transformation rather than mere technological replacement. This entails automating credit mechanisms and ensuring transparency via smart contract design innovations, addressing data island problems through multi-chain structural models, and realizing multi-tiered key control via hierarchical wallet technology which integrates decentralized blockchain systems with hierarchical organizational management. This approach goes beyond the scope of technology application: it reorients the focus towards the holistic ramifications of credit system innovation on trade network optimization.

A trade network theory offers a lens through which one can comprehend the complexities of cross-border e-commerce ecosystems, whereas blockchain technology provides the tools necessary for further refinement of these networks. The study of regional trade networks has progressed from investigating static topological structures toward evaluating dynamic evolution and resilience. However, traditional optimization approaches overlook the pivotal influence credit systems exert on the network information and development. Although proposing a multidimensional evaluation perspective, the blockchain impact framework for e-commerce constructed by Treiblmaier and Sillaber (2021) inadequately reveals how credit systems reshape trade network structures. Recent research by Morgan (2024) indicates that blockchain-supported cross-border payments are restructuring the global trade ecosystem by making payments more immediate, secure, and transparent. However, these innovations must progress in coordination with credit system innovations to maximize benefits. As shown in Table 1, existing cross-border e-commerce credit system research can be classified into five main directions, each with distinct characteristics but also evident limitations. Future research necessitates breaking domain boundaries, constructing interdisciplinary theoretical frameworks, and validating the actual impact of blockchain-driven credit system innovations on trade networks through empirical research. Table 1 illustrates that cross-border e-commerce credit system research exhibits multidisciplinary intersections, yet research in various fields remains relatively independent, lacking an integrated perspective. The literature reveals seve4ral distinct gaps. Technology application research emphasizes framework construction without fully considering operational complexity. Payment research overemphasizes technical security while neglecting user experience. Supply chain research fails to adequately address SME applicability. Credit assessment research has yet to find balance between data privacy and sharing. Finally, trade network research lacks systematic exploration from a credit mechanism perspective. Based on this analysis, this study proposes the integrating blockchain technology with network optimization theory to build a credit-based trade network optimization model. This model supports the technical implementation of cross-border e-commerce platforms and offers innovative ways for global trade management.

3. Blockchain-Based Cross-Border E-commerce Credit System Design

3.1. Credit System Architecture Design

The architecture of the credit system in this research consists of four layers: the data layer, network layer, consensus layer, and application layer. In the present systems for cross-border e-commerce, the efficiency of document recording and authorization of documents is excessively low. Combining blockchain technology with cryptographic asymmetric encryption methods effectively solves these issues (Hongmei, 2021). The framework prioritizes decentralized and distributed features, enabling three core capabilities: direct peer transactions, multi-stakeholder agreement, and unchangeable records, establishing a transparent and equitable international credit ecosystem.

This design adopts a consortium chain structure. Compared to traditional consortium chains, this system supports real-time transaction supervision by super nodes and incorporates new smart contracts to reduce opportunity losses for all participants (Fu et al., 2021). This guarantees both the transparency of credit information and the balance between regulatory requirements and commercial privacy. Figure 2 shows the blockchain credit system's hub design, where the core credit system connects to six key functional modules; Credit Data Collection, Full Transaction Tracking, Abnormal Data Management, Supply Chain Control, Smart Contract Execution, and Credit Evaluation Control. This radial architecture demonstrates the relative independence of each module while emphasizing their collaborative relationship, collectively forming an efficient and reliable cross-border e-commerce credit ecosystem.

3.2. Credit Data Collection and Processing Mechanism

Diverse data acquisition forms the cornerstone of cross-border e-commerce credit frameworks. This study incorporates five primary data categories: transactional records, shipping information, payment details, user activity patterns, and external verification data. Real-time, comprehensive data acquisition is achieved through smart contract-triggered data collection nodes. Privacy protection is a core consideration in the data collection process. The system uses zero-knowledge proofs and homomorphic encryption to protect sensitive data. Specifically, the implementation used zk-SNARKs (Zero-Knowledge Succinct Non-Interactive Arguments of Knowledge), deployed via the libsnark library, for transaction verification without revealing details; proof generation averaging 2.3 seconds per transaction. Homomorphic encryption utilized the SEAL framework, enabling financial institutions to perform creditworthiness calculations on encrypted data without decryption. These technologies were deployed in production environments across three pilot platforms (June-

December 2024), validating both technical feasibility and practical performance under real-world operational conditions (https://blog.webisoft.com/blockchain-cross-border-payments). Meanwhile, a layered data storage strategy separates identity data from transaction data, with differentiated access permissions to ensure user privacy during information sharing. As shown in Fig. 3, credit data processing follows a five-stage process: data collection, data validation, privacy processing, consensus verification, and credit application. The data validation stage includes data authentication, format verification, and digital signatures to ensure data authenticity and reliability. The privacy processing stage employs zero-knowledge proofs, homomorphic encryption, and data masking techniques to secure sensitive information.

Table 1. Comparison of cross-border e-commerce credit system research directions

Research Direction	Primary Research Methods	Focus	Core Conclusions	Limitations
Blockchain Technology Application Research	Framework construction, architecture design, case analysis	Using blockchain in cross-border e-commerce: methods and examples	Blockchain technology can significantly improve transaction transparency, data security, and information sharing efficiency; multi-chain structures and smart contracts serve as effective tools for resolving cross-border trust issues	Often remains at conceptual proof stage; lacks large-scale implementation cases; unclear integration pathways with existing systems
Payment and Financial Security Research	Mathematical models, optimization algorithms, risk assessment	Cross-border payment security, exchange rate risks, fraud prevention	Blockchain financial models can reduce payment risks, shorten settlement cycles, reduce intermediary costs; digital identity verification enhances transaction security	Insufficient consideration of regulatory compliance; excessive focus on technical aspects while neglecting user experience; lacks adaptability research for different payment habits
Supply Chain Management and Product Traceability	Process reconstruction, traceability mechanism design, information integration	Product quality traceability, logistics visualization, supply chain collaboration	Blockchain-empowered supply chain management can improve transparency and traceability; reduce counterfeit product risks; decrease document processing time; improve logistics prediction accuracy	Insufficient research on applicability to SMEs; high hardware infrastructure requirements; data acquisition and verification mechanisms remain incomplete
Trust Mechanisms and Credit Assessment	Credit model design, multidimensional data analysis, behavioral research	Cross-cultural trust building, multidimensional credit scoring, risk warning	Credit assessment models with multi-source data fusion possess higher accuracy; transparent credit mechanisms effectively reduce cross-border transaction risks; dynamic credit update mechanisms demonstrate stronger adaptability	Balance issues between data privacy protection and sharing; cross-border data sovereignty conflicts; challenges in integrating different credit cultures
Trade Network and Policy Research	Comparative analysis, policy research, network theory	Regional trade agreements, trade facilitation, network structure optimization	Blockchain-driven credit systems can lower trade barriers for SMEs; optimize regional trade network structures; enhance trade resilience; promote inclusive trade	Predominantly policy-level discussions; insufficient technical implementation pathways; inadequate consideration of regional differences; lacks empirical research support

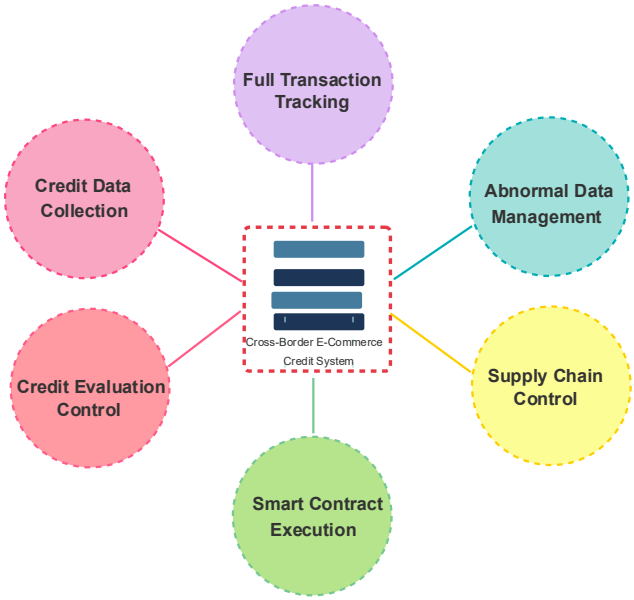

Fig. 2. Blockchain-driven cross-border e-commerce credit system architecture

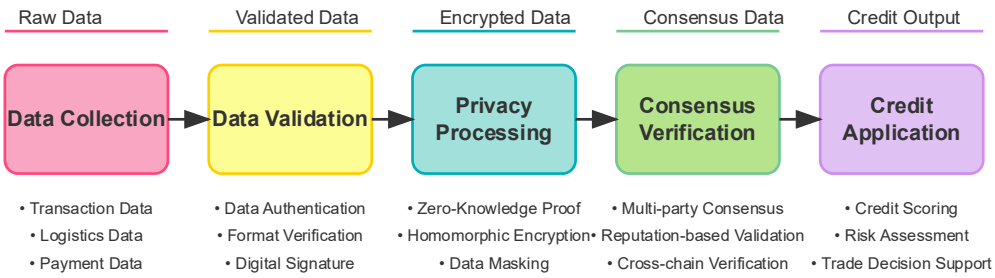

Fig. 3. Blockchain-based cross-border e-commerce credit data processing flow

This research designs a two-layer consensus mechanism: the first layer focuses on data truthfulness verification, using reputation-based consensus algorithms that dynamically adjust weights based on historical credibility of data providers; the second layer governs block generation, using an improved agreement protocol to ensure high transaction speed and system stability.

3.3. Credit Evaluation Model Construction

This research constructs a comprehensive scoring model encompassing five dimensions: transaction fulfillment capability, financial strength, logistics delivery, after-sales service, and compliance. Each dimension contains multiple sub-indicators, generating dimensional scores through weighted calculations, which are then combined non-linearly to produce the final credit score. The credit score calculation employs a weighted aggregation approach, mathematically formulated in Eq. (1)

$$CS = \sum_{i=1}^{n} (W_i \times D_i \times R_i) \tag{1}$$

Where:

CS represents the comprehensive credit score

W_i is the dimensional weight for dimension i

D_i is the dimensional score for dimension i

R_i is the reputation adjustment factor for dimension i

n is the number of dimensions in the credit scoring model

As expressed in Eq. (1), the comprehensive Credit Score (CS) integrates weighted dimensional scores with reputation adjustments. The innovation of this model lies in introducing the reputation adjustment factor Ri, which dynamically adjusts dimensional weights based on the timeliness and reliability of historical data.

Automated contracts enforce specific international payment transactions, which include initiating payments automatically to foreign service providers upon delivery (https://www.scnsoft.com/blockchain/cross-border-payments). The dynamic credit update mechanism designed in this research is based on an event-triggered model, binding credit score updates with key events on the blockchain, ensuring credit scores reflect the latest status of trading entities in real-time. The system also includes a credit repair mechanism that allows entities to restore their ratings gradually through positive trading behaviors, thereby maintaining overall system credibility. These credit evaluations are broadcast via the blockchain network and integrated with mainstream cross-border e-commerce platforms and payment systems to provide real-time data for transaction decisions. The system provides Application Programming Interface (API) access, allowing third-party applications to query credit evaluations. This expands the unity of the credit data and promotes the optimization of regional trade networks.

4. Regional Trade Network Optimization Methods

4.1. Trade Network Structure Analysis

Network structural attributes significantly influence trade efficiency. Blockchain-based trade network analysis methods can effectively identify core network nodes and evaluate network efficiency. Research indicates that regional trade networks typically exhibit small-world network characteristics, specifically, high clustering coefficients and relatively short average path lengths. These characteristics ensure the formation of regional trade clusters while maintaining the smooth flow of cross-regional trade (Antwi et al., 2022). Network topology analysis enables the identification of central trading nodes through high centrality measures. These nodes significantly influence the entire trade network and the movement of goods within a region.

Existing blockchain network optimization research primarily optimizes its performance by improving the P2P topology structure, reducing information redundancy, and decreasing the size of data exchanged between nodes (Antwi et al., 2022). In trade networks, blockchain-based topology optimization models improve the conventional random connection approach by selecting nodes based on geography, trade activity, and reputation, among other criteria, thus creating more efficient networks. For example, research shows that blockchain topology optimization based on node clustering can significantly increase network throughput, resulting in higher transaction processing capacity and fewer confirmation delays.

Assessing network effectiveness in a blockchain scenario requires evaluating multiple elements, including throughput, confirmation time, and consensus protocol efficiency. Smart contracts introduce a new dimension to this assessment, making it more objective and automated. Blockchain technology enhances trust among supply chain participants, maximizes transaction efficiency, and reshapes the architecture of networks themselves (Antwi et al., 2022). In multi-tiered trading networks, a blockchain system efficiency assessment emphasizes not only the individual transaction speed but also the resilience and long-term health of the entire network's continuous optimization. 4.2. Blockchain-Based Trade Process Reconstruction

International commerce faces numerous challenges, such as information asymmetry, complex procedures, redundant intermediaries, and substantial compliance costs. Blockchain technology addresses these issues innovatively through distributed recording, data permanence, and automated contract execution. When shipments arrive in poor condition, smart contracts can trigger automatic insurance claims or refunds without manual intervention. This event-triggered automatic execution mechanism greatly simplifies the traditionally complex dispute resolution process, thereby improving trade efficiency and trust. Blockchain reconstructs trade processes through consensus-based transaction verification, reducing fraud, digitized document processing, automated smart contract payment settlement, and traceable improves coordination among buyers, suppliers, and banks.

Note: Blockchain optimization achieves 64.3% total time reduction, with most significant improvements in document processing (70% reduction, from 5 to 1.5 days), payment settlement (71.4% reduction), and customs clearance (57.1% reduction)

As shown in Fig. 4, significant differences exist in processing time between traditional and blockchain-optimized trade processes. The traditional process spans approximately 14 days across five key stages (transaction initiation, document processing, payment settlement, customs clearance, and delivery completion), with document processing requiring the longest duration of 5 days. Payment settlement and customs clearance each require 3.5 days. In contrast, the blockchain-optimized process compresses the total timeline to 5 days, representing a 64.3% reduction. The most substantial time saving occurs in document processing, where automated verification and standardized documentation cut the duration from 5 days to 1.5 days, a 70% improvement. Smart contract automation reduces payment settlement from 3.5 days to 1 day (a 71.4% gain). Similarly, customs clearance, facilitated by transparent and traceable regulatory data, is shorten end from 3.5 days to 1.5 days, a 57.1% reduction.

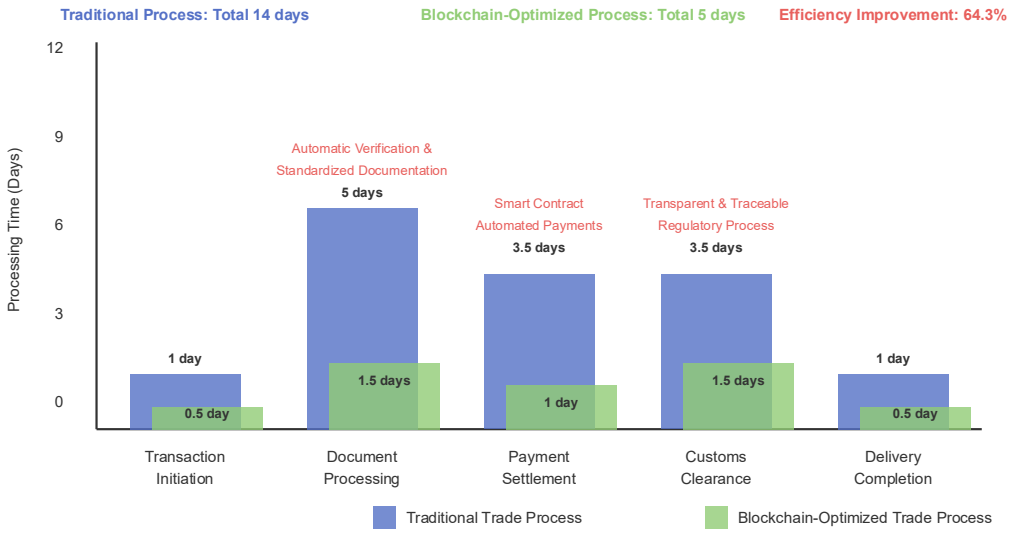

Fig. 4. Processing time comparison between traditional and blockchain-optimized trade processes

By comparing traditional trade processes with blockchain-optimized processes, improvements become clearly visible. Quantitative analysis of improvements in efficiency indicates that through the re-engineering of letters of credit via smart contracts, the performance of the payment process is improved, and overall supply chain efficiency is enhanced. In the future, as blockchain technology develops and gains wider adoption, trade process reconstruction will gradually shift from optimizing individual links to integrated full-process integration, achieving higher-level trade network optimization.

4.3. Trade Network Collaboration Mechanism Design

Blockchain provides a technological foundation for trade network collaboration mechanisms. Smart contract-based collaborative incentive mechanisms automatically execute rewards and penalties through coded rules, ensuring that all parties fulfill their obligations as agreed, thus forming a self-driven collaborative environment. In this process, sensitive data is shared between parties through secure, off-chain private computation (Wang and Peeta, 2024). When it comes to inter-organization of information transmission, blockchain technology creates a balance between information dissemination and privacy protection using decentralized storage as well as control of access. Blockchain architecture tracks detailed information provenance, including who provided what data, to whom, when, through which channel, and for what purposes, all of which is verifiable (Wang and Peeta, 2024). This verifiable and open information framework considerably reduces information asymmetry in trade networks, hence promoting increased collaboration.

Traditional dispute resolution relies on judicial arbitration or other third-party intermediaries, which increases both the duration and cost of the process. Blockchain technology, through smart contracts and on-chain governance, provides innovative solutions. Pre-established dispute resolution protocols can be activated automatically when specific conditions are met, such as delivery delays or quality shortcomings, triggering penalty execution. This drastically simplifies the dispute-handling process. Moreover, blockchain provides transparent and tamper-proof transaction records and can enable more efficient and fair dispute resolution through Decentralized Autonomous Organizations (DAOs) (Wang and Peeta, 2024). This innovative approach allows trade network disputes to be resolved quickly and economically, further optimizing the efficiency of regional trade networks.

5. Empirical Analysis and Verification

This section focuses on validating the practical applicability and assessing the efficacy of the proposed framework through multi-scenario case examination and a heuristic analysis of blockchain-based cross-border e-commerce credit systems. To obtain reliable empirical data, this research selected three typical application scenarios: large-scale cross-border e-commerce platforms, small and medium-sized import-export enterprise alliances, and regional trade ecosystems. A comparative analysis of key indicators before and after implementation. Empirical evidence indicates that blockchain credit frameworks deliver substantial advantages in real-world implementation, especially regarding data transparency, operational efficiency, and risk mitigation. Case selection followed rigorous criteria to ensure representativeness: large platforms required annual cross-border transaction volumes exceeding 100,000, operations across five or more countries, and established data infrastructure supporting blockchain integration; SME alliances required 30 to 50 member enterprises with demonstrated trade relationships exceeding two years and diverse industry representation; regional ecosystems required baseline network density above 0.25, the presence of both business-to-business (B2B) and business-to-consumer (B2C) transactions, and regulatory environments that permitted blockchain experimentation.

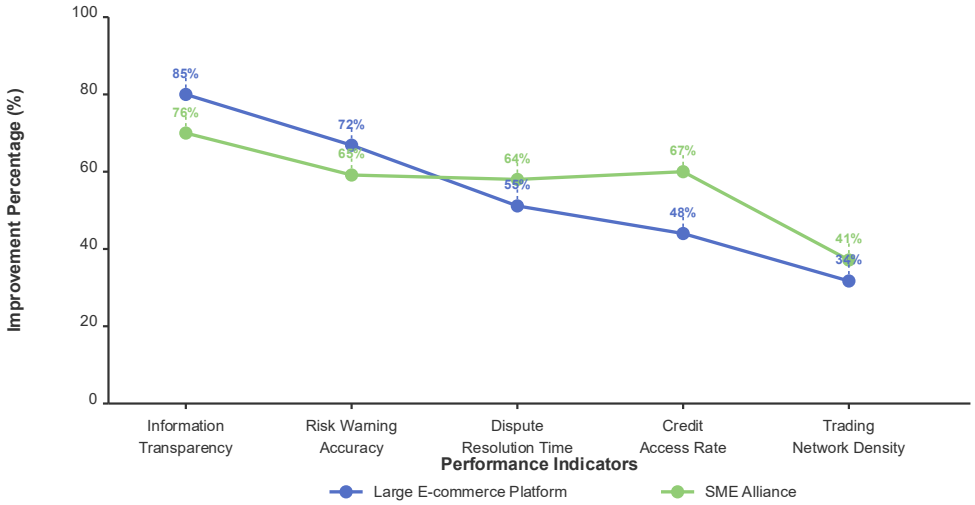

Fig. 5. Performance improvements across three scenarios: large platforms, SME alliances, and regional ecosystems

Note: Data from 12-month pilot (January-December 2024) across three implementation scenarios.

As shown in Fig. 5, in the case of large-scale cross-border e-commerce platforms, deploying blockchain nodes throughout various supply chain links enabled the real-time recording and sharing of transaction information, reducing participants' average information acquisition time from 24 hours to 1.2 hours, reduced information asymmetry by approximately 85%. Baseline measurements from six-month pre-implementation observation (January-June 2024) quantified information asymmetry through temporal lag analysis. The risk warning accuracy baseline of 72% was derived from historical false positive and false negative rates in the platform's existing fraud detection system over the preceding 12-month period.

The platform adopted a multidimensional credit evaluation model based on transaction history, improving risk warning accuracy from 72% under traditional modes to 91%, effectively curbing common cross-border e-commerce issues such as malicious breaches of contract and product quality counterfeiting. Dispute resolution time shortened concurrently, with average resolution periods decreasing from 14 days to 3 days, substantially reducing transaction friction costs, which fully validates the practicality and effectiveness of the blockchain credit evaluation model proposed in this research.

The application case of small and medium-sized import-export enterprise alliances demonstrates the universality of blockchain credit systems. Composed of 37 small and medium enterprises, this alliance previously faced difficulties in financing and high costs in establishing trust. Following the implementation of blockchain credit systems, trust levels among alliance members improved significantly. The proportion of trade executed automatically through smart contracts rose from 15% to 67. Furthermore, the average credit limit granted to SMEs by financial institutions increased by 41%, while financing costs decreased by 2.7 percentage points, directly promoting the expansion and deepening of regional trade networks. Statistical analysis confirms this increase is highly significant ($p < 0.01$, n=37 enterprises, paired t-test), representing average growth from $127,000 to $179,000 per enterprise. Control group analysis of 25 non-participating SMEs showed only 3% credit limit growth during the same period, validating the causal relationship between blockchain implementation and observed improvements.

The assessment of regional trade ecosystems concentrates on quantitative analysis of long-term economic and social benefits. As illustrated in Fig. 6, traditional trading systems, scores across six key dimensions generally ranged between 40%-45%, exhibiting mediocre performance: economic returns, risk prevention, trade efficiency, resource utilization, environmental impact, and social inclusivity. After implementing blockchain credit systems, scores across these six dimensions rose dramatically between 83% and 90%, with the economic returns dimension showing the highest improvement rate thus far. In a regional trade network encompassing 215 enterprises, the promotion of blockchain credit systems increased overall trade activity by 27%, added 194 new trade relationships, and elevated network density from 0.31 to 0.45. This network optimization manifests not merely as increased trade volume but, more importantly, promotes efficient resource allocation and rational flow. Through sustainable development indicator assessment, blockchain credit systems have reduced trade friction, lowered audit costs, and improved resource utilization efficiency, projected to contribute approximately 4.3% growth to the regional economy over the next five years.

Notable findings from empirical findings reveal implementation challenges for current blockchain credit systems, including technological maturity limitations, high initial costs, and governance mechanisms that have not yet fully crystallized (Chang et al., 2019). Comparative analysis of cases across different scales and industries has identified key factors for sustainable development: adaptive technological architecture, multi-party participatory governance structures,

progressive implementation pathways, and compatibility with existing systems. These findings provide important references for subsequent research and practice, contributing to the widespread application and continuous optimization of blockchain credit systems.

Fig. 6. Comparative performance assessment: traditional vs. blockchain credit systems across six dimensions

Note: Normalized scores (0-100 scale) for economic returns, risk prevention, trade efficiency, resource utilization, environmental impact, and social inclusivity demonstrate comprehensive advantages of blockchain implementation.

6. Conclusion

This research integrates blockchain with network optimization theory to construct an innovative credit framework for cross-border e-commerce, elucidating how blockchain reshapes trade processes and optimizes regional trade networks. Empirical analysis demonstrates that blockchain-based credit systems significantly outperform traditional models in information transparency, risk warning accuracy, dispute resolution efficiency, and credit accessibility. Theoretical contributions include a blockchain-driven multidimensional credit evaluation model that addresses gaps in how credit mechanisms reshape trade network structures. Methodologically, the research proposes smart contract-based credit collaboration mechanisms that resolve the information island problem in traditional systems. On the application level, it designs multi-level data sharing solutions across different entities that enhance information usability while ensuring privacy protection.

Practical value manifests in providing technical implementation pathways for cross-border e-commerce platforms, innovative regulatory approaches for trade management departments, and feasible support solutions for SMEs participating in international trade. However, practical implementation faces multifaceted barriers requiring systematic attention. Regulatory compliance challenges include navigating diverse data protection regimes (e.g., GDPR in Europe and varying standards in the Asia-Pacific), obtaining licenses for cross-border financial data processing, and meeting evolving anti-money laundering and know-your-customer requirements across jurisdictions. Technical and cross-platform functionality barriers remain substantial. Cross-chain protocols achieve limited functionality; smart contract standards vary significantly across platforms (Ethereum, Hyperledger, Corda), and legacy system integration requires extensive custom development. Economic barriers include high initial deployment costs ($150,000-$500,000), ongoing infrastructure maintenance expenses, and requirements for specialized blockchain expertise. Governance challenges encompass establishing stakeholder consensus on protocol upgrades, designing dispute resolution frameworks combining on-chain automation with off-chain judgment, and balancing decentralization principles with regulatory oversight requirements. Addressing these barriers necessitates collaborative initiatives involving technology standardization bodies, regulatory harmonization efforts, open-source development to reduce costs, and hybrid governance models balancing autonomy with accountability.

This research acknowledges several important limitations. First, blockchain adoption exhibits significant global heterogeneity, with substantial disparities between developed and developing economies in technological infrastructure and regulatory frameworks. Therefore, findings may not generalize jurisdictions with restrictive blockchain policies. Second, the 12-month empirical validation period may inadequately capture long-term sustainability challenges, including scalability constraints as transaction volumes grow, evolving governance complexities as networks expand, and potential technological obsolescence. Third, substantial initial deployment costs ($150,000$500,000) and ongoing operational expenditures constitute significant barriers for resource-constrained SMEs, despite demonstrated benefits. Fourth, the cryptographic security assumptions underlying zero-knowledge proofs and homomorphic encryption may face future vulnerabilities from quantum computing advances, potentially necessitating system re-architecture. Finally, interoperability challenges across heterogeneous blockchain platforms remain incompletely resolved, with cross-chain protocols requiring manual intervention in numerous scenarios. These limitations indicate that widespread adoption will necessitate coordinated efforts among technology providers, regulatory authorities, and industry stakeholders to systematically address technical, economic, and policy barriers.

Future research should focus on several key areas. First, it should develop cross-chain interoperability standards to address data circulation barriers between different blockchain systems. Second, research must enable the deep integration of regulatory technology (RegTech) with blockchain credit systems to achieve a dynamic balance between compliance and efficiency. Third, studies should investigate digital identity and decentralized identifier (DID) application mechanisms in cross-border trade to construct a globally unified and trusted digital identity system. Finally, research is needed on security enhancement technologies in the quantum computing era to address potential future security challenges. As relevant technologies mature and application scenarios continue to diversify, blockchain-driven cross-border e-commerce credit systems will play increasingly important roles in promoting inclusive development of global trade, optimizing regional economic structures, and enhancing international trade efficiency.

Author Contributions

Lili Du contributes to methodology, software, draft preparation, and manuscript editing. Xuefang Zhang contributes to software, validation, and analysis. Yaping Zhu contributes to data collection and draft preparation. Dejie Wang contributes to software and visualization. All authors have read and agreed with the manuscript before its submission and publication.

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Institutional Review Board Statement

Not applicable.

Declaration of Artificial Intelligence (AI) Tools

The authors used AI tools solely for language editing and readability improvement. The authors reviewed and verified all content and take full responsibility for the accuracy and integrity of the manuscript.

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