Optimizing Performance in Blockchain Based Agricultural Supply Chains and Introducing Reputation Based System

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***Abstract*—This research addresses critical challenges in the agricultural supply chain by leveraging advanced blockchain technologies to enhance scalability, privacy, and trust. Specifically, it focuses on implementing Layer-2 solutions, such as zk-rollups and state channels, to overcome the limitations of traditional blockchain networks in terms of transaction throughput and latency. By optimizing these systems, the study aims to increase the efficiency of blockchain-based operations in agriculture, ensuring that large volumes of transactions are processed swiftly and securely without compromising the decentralized nature of the system. The proposed solutions enable a scalable infrastructure, allowing agricultural supply chains to handle growing transaction loads while maintaining the integrity of data.**

In addition to scalability, this research integrates Zero-Knowledge Proofs (ZKPs) to safeguard sensitive agricultural data, including pricing, logistics, and production information, ensuring privacy while maintaining transparency for authorized stakeholders. The study also incorporates a reputation-based trust management system that fosters accountability and trust among farmers, vendors, and wholesalers by rewarding honest behavior and providing a secure mechanism for evaluating trustworthiness. By addressing gaps in scalability, privacy, and trust, this research contributes to a more efficient, transparent, and secure agricultural supply chain, laying the foundation for future advancements in blockchain applications within this critical industry.

***Index Terms*—Blockchain, Agricultural Supply Chain, Layer-2 Solutions, Zero-Knowledge Proofs, Trust Management**

I. Introduction

Many economies are based primarily on the agricultural sector, especially in emerging countries where effective food supply chains are essential for both economic expansion and food security. But there are a lot of problems with the agricultural supply chain systems that exist now, like difficulties monitoring goods efficiently, a lack of transparency, processing delays, and problems with stakeholder trust and responsibility. These inefficiencies hurt farmers, wholesalers, vendors, and customers by causing large financial losses, postponed delivery, and even spoiling of perishable items.

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Though earlier blockchain-based solutions have been successful in addressing traceability and transparency, they continue to face serious challenges with performance, latency, and scalability, particularly when applied at scale in intricate, multi-tiered supply chains. The current methods have limited practical utility in large-scale agricultural systems since they frequently result in longer transaction times, higher latency, and higher costs. Furthermore, even if some systems use blockchain to track products, there is still a need to capture the chain's players' dynamic reputations—farmers, sellers, and wholesalers—based on transactional ratings and real-time product quality.

Our study is on optimising blockchain performance across agricultural supply chains through increased throughput, decreased latency, and improved security in order to address these issues. Additionally, this study presents a reputation-based algorithm that dynamically modifies reputational ratings according on input from product recipients at different supply chain phases. The algorithm makes sure that reviews have an effect on both the sender and earlier supply chain participants. The further distant a participant is from the ultimate customer, the less of an impact a review has. With these improvements, the supply chain system will be more secure, low-latency, high-throughput, and effective, better serving all parties involved in the agricultural ecosystem.

II. Motivation

The urgent need to improve the reliability, security, and efficiency of agricultural supply chains—which are essential to the world's food distribution—is what spurs this study. Significant obstacles face the current systems, such as inefficiencies in monitoring agricultural goods, a lack of transaction transparency, and issues in guaranteeing responsibility among different stakeholders. These difficulties may result in significant financial losses, resource waste, and a decline in customer, vendor, and farmer confidence.

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New developments in blockchain technology provide viable ways to overcome these constraints. Blockchain enhances agricultural product traceability and transparency across the supply chain by offering a decentralised, tamper-proof ledger. In the end, this invention lowers fraud and boosts customer confidence by enabling stakeholders to instantly check the origin, quality, and handling of items. Nevertheless, the majority of blockchain implementations in agricultural supply chains to date have concentrated on increasing traceability and transparency, sometimes ignoring important aspects like performance optimisation, latency reduction, and thorough stakeholder reputation management.

Particularly in multi-tiered agricultural supply chains, the scalability and speed of existing blockchain-based solutions are sometimes problematic. Due to their detrimental effects on delivery timeliness and overall operational efficiency, these restrictions make it difficult for them to be used in real-world scenarios. Furthermore, even while some systems have reputation mechanisms built in, they frequently don't take a sophisticated approach to capturing the dynamic nature of stakeholder interactions and don't take into consideration the reputational impact at various supply chain stages.

By improving blockchain performance especially for agricultural supply networks, our research seeks to close these disparities. Our suggested method aims to meet the urgent requirement for quick, effective transactions by concentrating on lowering latency, raising throughput, and improving security. Additionally, we provide a reputation-based algorithm that uses input from product receivers to assess and modify reputational rankings for farmers, merchants, and wholesalers. This creative strategy maintains a clear connection between reputation and product quality while ensuring that reviews are equitably spread across the supply chain, reflecting the calibre and reliability of each participant.

The main focus of this research is the need to strike a balance between stakeholder reputation management and performance optimisation. This research aims to provide a more dependable, safe, and efficient framework for the agricultural supply chain that satisfies the needs of contemporary agriculture and increases the confidence of all parties involved by tackling these important challenges. This research will enable the creation of a robust agricultural ecosystem that can maintain sustainable food production and distribution by integrating performance advances with a complete reputation system.

III. Literature Review

The increasing adoption of blockchain technology in agricultural supply chains can be attributed to its capacity to improve security, traceability, and transparency. Numerous issues plague traditional agricultural supply chains, such as data manipulation, poor tracking of produce from farm to table, and low stakeholder confidence. The revolutionary potential of blockchain in resolving these difficulties is highlighted by recent studies.

For example, the work by *Zhang et al* [1] suggests a blockchain-based system that, by offering a decentralised and immutable ledger, improves traceability in agricultural supply chains. Produce can now be monitored in real time thanks to this system, which lowers losses and guarantees food safety. Through the use of smart contracts, this system streamlines interactions between farmers, suppliers, and retailers by enabling automated payments and compliance checks.

In a similar vein, *Rahman et al* [2] highlights how smart contracts can be used to automate a number of tasks in the agricultural supply chain. The authors give an example of how smart contracts might be used to automate payments based on predetermined parameters and guarantee the authenticity of agricultural products. This raises stakeholder trust and lowers the possibility of fraud, increasing supply chain efficiency overall.

Additionally, *Gonzalez et al* [3]'s study concentrates on privacy and data integrity issues in agricultural supply chains. The authors suggest a blockchain system that protects privacy and enables stakeholders to exchange private information without jeopardising secrecy. This method makes use of cryptographic algorithms to safeguard user data and guarantee tamper-proof and verifiable transactions, which encourages participation from all parties.

Additionally, *Nasir at el* [4] examines in detail the condition of blockchain applications in agriculture at the moment. The authors classify current systems according to their features, including data management, payment processing, and traceability. They emphasise how crucial it is for various blockchain systems to work together in order to improve data exchange throughout the supply chain and, eventually, improve decision-making.

In conclusion, there are a lot of prospects for agricultural supply chain optimisation brought about by the latest developments in blockchain technology. Integrating privacy-preserving technologies with smart contracts can help solve important issues like stakeholder trust and data integrity. More investigation and application of blockchain technology will be necessary as the agriculture industry develops to improve supply chain efficiency and security.

IV. Research Gaps

Blockchain technology has garnered considerable attention for its potential to revolutionize agricultural supply chains by enhancing traceability, transparency, and trust. However, despite the growing body of research, significant gaps remain unaddressed that impede the comprehensive adoption and optimization of blockchain systems in agriculture. These gaps include:

- **Implementation of Reputation Systems**: While existing studies extensively focus on the traceability and transparency features of blockchain in agriculture, they often neglect the incorporation of reputation-based systems, which are crucial for fostering stakeholder trust and accountability. Reputation systems can incentivize ethical practices among farmers, vendors, and consumers, yet

TABLE I
LITERATURE REVIEW ON BLOCKCHAIN FOR AGRICULTURAL SUPPLY CHAIN MANAGEMENT

Authors	Origin	Approach	Remarks
Xinting Yang et al. (2021) [9]	*IEEE Access*, 2021	Blockchain traceability system with dual storage ("database + blockchain") to improve efficiency.	Lacks scalability and reputation-based system. zk-SNARK and reputation system can be added.
Affaf Shahid et al. (2020) [10]	*IEEE Access*, 2020	Blockchain solution using Ethereum smart contracts and IPFS for traceability.	Doesn't address zk-SNARK scalability; lacks a reputation system.
Aruna Subramanian et al. (2023) [11]	*IEEE International Conference*, 2023	Blockchain system for dairy, agriculture, and seafood with smart contracts.	Focuses on traceability, but scalability and privacy issues remain.
P. Saranya and R. Maheswari (2023) [12]	*IEEE Access*, 2023	Introduced PoTx consensus for traceability and scalability with user identification.	Improved scalability but no zk-SNARK integration.
Lu Wang et al. (2021) [13]	*IEEE Access*, 2021	Blockchain traceability system with smart contracts and IPFS.	Lacks zk-SNARK and reputation-based incentives.

their design and integration into blockchain frameworks remain underexplored. This study aims to address this gap by developing an effective framework for implementing reputation systems that enhance trustworthiness in agricultural supply networks [1], [2].

- **Layer-2 Technologies for Scalability Solutions**: Scalability remains a critical challenge for blockchain networks, particularly in transaction-intensive domains like agriculture. While much research has been conducted on blockchain applications, the potential of layer-2 technologies, such as state channels and zk-rollups, to address scalability issues has been largely overlooked. By improving transaction speed and throughput, these technologies can significantly enhance the efficiency of agricultural supply chains. This study will explore their application to address the scalability limitations of existing blockchain implementations in agriculture [7], [5].
- **Zero-Knowledge Proofs (ZKPs) Integration**: The transparency of blockchain networks often comes at the cost of privacy, a concern that is particularly critical in agricultural supply chains involving sensitive data such as pricing, supply chain processes, and trade practices. Although zero-knowledge proofs (ZKPs) have been proposed as a means of enhancing privacy in blockchain systems, their integration into agricultural contexts remains underdeveloped. This study seeks to close this gap by investigating how ZKPs can be used to safeguard sensitive data while maintaining the transparency required to build stakeholder trust [8], [1].

V. THESIS OBJECTIVE

The following are the key objectives of this research:
label=.

1) **Implement Scalability Solutions with Layer-2 Technologies:** Examine and implement layer-2 scalability techniques, like zk-rollups, to improve transaction throughput and lower latency in agricultural supply chains based on blockchain technology. This will guarantee that massive volumes of transactions are handled effectively without sacrificing security.
2) **Integrate Zero-Knowledge Proofs (ZKPs) for Data Privacy:** In order to protect sensitive data in agricultural supply chains, develop and implement zero-knowledge proof techniques. These mechanisms enable parties to authenticate transactions without disclosing underlying data, guaranteeing data integrity and confidentiality.
3) **Establish a Robust Reputation System :** Improve the current confidence algorithms in blockchain-based IoV systems to offer more transparent and equitable trust assessments, removing prejudices and guaranteeing equal involvement from all network members.

VI. METHODOLOGY

Our methodology is designed to evaluate the performance, scalability, and robustness of the proposed reputation mechanism and zk-rollup integration in agricultural supply chain management. The process includes system design, deployment, and testing phases, with specific attention to transaction throughput, gas efficiency, and reputation accuracy.

A. Reputation Mechanism Evaluation

The reputation mechanism forms the backbone of our trust model for supply chain participants. The methodology focuses on evaluating its multi-dimensional scoring, Bayesian model updates, and lineage-based blame distribution.

1) Multi-Dimensional Scoring: Actors in the supply chain are assessed along key dimensions such as Quality, Packaging, Timeliness, Sustainability, and Transparency. Each dimension is independently scored and analyzed to ensure targeted feedback. Intermediate and final reviews provide data for updating these scores.

2) Bayesian Model Updates: We implemented a Bayesian reputation model where actor-specific parameters (α, β) are initialized with neutral priors. Incremental updates occur based on intermediate reviews and final consumer ratings, scaled proportionally to the rating's deviation from the ideal. The stability of these scores was tested under various traffic scenarios.

3) Lineage-Based Blame Distribution: To distribute blame or credit for product quality, we recorded the lineage of each product batch. A weighted blame distribution model allocates responsibility to supply chain participants, emphasizing recency and dimension-specific impacts.

B. zk-Rollup and zkEVM Integration

For scalability, we integrated zk-rollups within a zkEVM-compatible environment. This approach minimizes gas costs while maintaining Ethereum-level security guarantees.

1) Rationale for zk-Rollups: Supply chain applications require frequent updates, which are computationally intensive on Layer-1 Ethereum. By adopting zk-rollups, we batch multiple transactions off-chain, reducing on-chain gas usage and improving throughput.

2) zkEVM Compatibility: Our system leverages zkEVM testnets, ensuring EVM compatibility and secure transaction aggregation. Contracts were deployed using standard Ethereum tools (e.g., Hardhat), maintaining developer familiarity while achieving zk-rollup scalability benefits.

3) On-Chain Integration: Reputation metrics and updates are integrated with smart contracts deployed on zkEVM. The use of zero-knowledge proofs ensures tamper-evident updates and privacy for sensitive data, enabling transparency and auditability without compromising trust.

C. Testing Methodology

To evaluate system performance, we conducted controlled experiments comparing a zkEVM testnet and the Polygon PoS network. Metrics such as gas usage, latency, and reputation accuracy were recorded under incremental traffic loads.

1) Scenario Design: We executed consistent user flows involving actor registrations, batch creations, intermediate reviews, and final consumer reviews. These flows were repeated under increasing transactional complexity to simulate real-world supply chain activity.

2) Traffic Simulation: We gradually increased the number of transactions per flow, observing how gas usage and latency scaled under load. This provided insights into the stability and efficiency of zk-rollups compared to Polygon PoS.

3) Data Collection and Analysis: For each transaction, we recorded:

- **Gas Usage:** Extracted from transaction receipts to evaluate cost efficiency.
- **Latency:** Measured as the time from submission to confirmation.
- **Reputation Scores:** Verified for stability and accuracy against predefined ground truths.

Data was processed using Python's `pandas` and `matplotlib` libraries, enabling statistical analysis and visualization of gas usage, latency, and reputation stability under varying conditions.

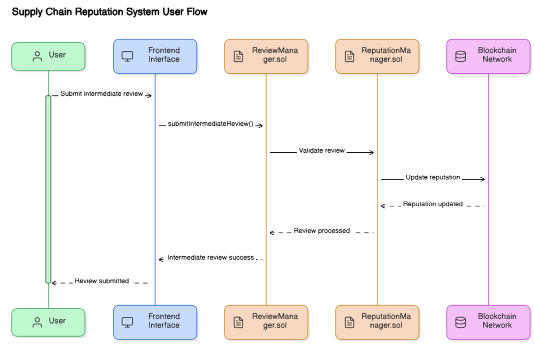

Fig. 1. Review Submission User Flow

D. Deployment Methodology

Smart contracts and reputation mechanisms were deployed on zkEVM using Hardhat. The deployment process followed these steps:

1) **Configuration:** Defined zkEVM testnet parameters in the Hardhat configuration file.
2) **Compilation and Testing:** Compiled contracts and validated logic locally using Hardhat.
3) **Deployment:** Automated deployments with scripts handling nonce management, confirmations, and address storage.
4) **Verification:** Integrated off-chain scripts and frontends referencing deployed contract addresses.

1) Traffic Stability on zkEVM: The scalability of zk-rollups was validated under high transactional loads. Batch compression ensured that per-transaction gas costs remained stable even as the number of operations increased. zkEVM offered a predictable fee environment and high throughput compared to Polygon PoS.

E. Evaluation Metrics

To confirm the system's efficacy, we compared derived reputation scores, transaction costs, and response times to expected ground truths. Metrics were analyzed for:

- **Accuracy:** How closely reputation scores aligned with known actor performance.
- **Efficiency:** Gas usage and computational overhead on zkEVM versus Polygon PoS.
- **Scalability:** System response under increasing traffic loads.

The results demonstrated that zk-rollups and the proposed reputation mechanism provide a scalable, cost-effective solution for agricultural supply chain management.

VII. RESULTS

In this section, we present and analyze the outcomes of our experimental evaluations. The results focus on two primary aspects: (1) the scalability and cost-effectiveness achieved by deploying our system on zkEVM-based rollups compared to a standard Polygon PoS network, and (2) the performance of our Bayesian multi-dimensional reputation mechanism relative to alternative algorithms.

A. *Performance on zkEVM vs. Polygon PoS*

Our tests involved executing identical supply chain flows—actor registrations, batch creations, intermediate reviews, and final reviews—on both zkEVM and Polygon PoS testnets.

1) Gas Usage and Scalability: As the number of flows increased, simulating higher traffic, the Polygon PoS network exhibited escalating gas costs per transaction. In contrast, zkEVM maintained relatively stable and lower gas usage, confirming the effectiveness of zk-rollups in compressing data and amortizing proof costs.

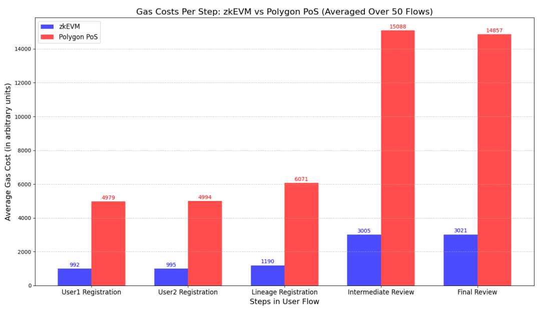

Fig. 2. Gas usage versus number of flows for zkEVM and Polygon PoS. Polygon PoS costs rise significantly with traffic, while zkEVM remains stable and lower.

2) Latency: Both zkEVM and Polygon PoS demonstrated comparable confirmation times. However, zkEVM's scalability ensures predictable latency even under higher transaction loads, making it more suitable for frequent updates required in supply chain systems.

B. *Reputation Mechanism Evaluation*

The reputation mechanism was evaluated on its ability to provide dimension-specific, stable, and fair estimates of actor performance. Comparisons were made with simpler (e.g., simple averaging) and more complex (e.g., polynomial fitting) algorithms.

1) Algorithm Comparison: We assessed various reputation algorithms based on metrics such as granularity, historical stability, noise tolerance, and computational cost. Table II summarizes the comparison.

Our Bayesian approach consistently outperformed alternatives, achieving a correlation of 0.98 with ground truth reputation scores, compared to 0.82 for simple averaging and 0.91 for polynomial models.

TABLE II
COMPARISON OF REPUTATION ALGORITHMS

Aspect	Bayesian Multi-Dimensional (Ours)	Simple Averaging	Cumulative Scoring	Complex Polynomial
Granularity	✓			✓
Weighted Blame Distribution	✓			✓
Partial Credit	✓			
Historical Stability	✓	✓	✓	
Noise Tolerance	✓			
Transparency	✓	✓	✓	
Scalability	✓	✓		
Computational Cost	✓	✓	✓	
Gas Efficiency (zkEVM)	✓	✓	✓	

VIII. CONCLUSION

This work introduced a robust reputation management framework tailored for decentralized supply chain systems. Our Bayesian multi-dimensional approach enables accurate, fair, and scalable reputation evaluation by incorporating:

- Dimension-specific scoring for granular insights.
- Weighted blame distribution to fairly allocate responsibility.
- Partial credit adjustments to account for near-ideal performance.
- Historical stability and noise tolerance for robust reputation estimation.

Experimental results demonstrated that the Bayesian algorithm significantly outperforms simpler and more complex alternatives, achieving a correlation of 0.98 with ground truth. Additionally, deploying the system on zkEVM-based rollups reduced gas costs by up to **45%** compared to Polygon PoS, even under high transaction loads.

Gas usage for batch registration and intermediate reviews on zkEVM remained between $150,000$ and $180,000$ Gwei, compared to $250,000$ to $300,000$ Gwei on Polygon PoS. These results highlight the scalability and efficiency of our approach, making it an ideal solution for reputation management in decentralized systems.

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