НАУЧНО-ТЕХНИЧЕСКИЙ ВЕСТНИК ИНФОРМАЦИОННЫХ ТЕХНОЛОГИЙ, МЕХАНИКИ И ОПТИКИ
январь–февраль 2026 Том 26 № 1 http://ntv.ifmo.ru/
SCIENTIFIC AND TECHNICAL JOURNAL OF INFORMATION TECHNOLOGIES, MECHANICS AND OPTICS
January–February 2026 Vol. 26 No 1 http://ntv.ifmo.ru/en/
ISSN 2226-1494 (print) ISSN 2500-0373 (online)

КОМПЬЮТЕРНЫЕ СИСТЕМЫ И ИНФОРМАЦИОННЫЕ ТЕХНОЛОГИИ

COMPUTER SCIENCE

doi: 10.17586/2226-1494-2026-26-1-60-68

Optimizing technological transactions using a dual-layer blockchain for enhanced scalability

Thirunavukkarasu Kanimozhi[1]✉, Mani Inbavalli[2]

[1,2] Marudhar Kesari Jain College for Women (Autonomous), Vaniyambadi, 635751, India
[1] Affiliated to Thiruvalluvar University, Vellore, 632115, India

[1] kanilogu8479@gmail.com✉, https://orcid.org/0009-0006-6938-8922
[2] drinbavelu@gmail.com, https://orcid.org/0000-0002-0620-7200

Abstract

In the era of rapidly evolving digital infrastructures, ensuring the scalability and efficiency of technological transactions has become a critical challenge. Traditional blockchain models often suffer from limitations, such as high latency, restricted throughput, and network congestion, particularly under high transaction volumes. This paper proposes a novel dual-layer blockchain architecture designed to address these limitations by segregating transaction processing and consensus mechanisms into two distinct but interoperable layers. The first layer, a lightweight transactional layer, handles real-time data exchange and verification with minimal computational overhead, while the second layer focuses on robust consensus, security, and long-term data immutability. By decoupling these functions, the proposed model significantly improves scalability, reduces latency, and enhances system responsiveness. Experimental simulations demonstrate that the dual-layer approach outperforms conventional single-chain systems in terms of transaction throughput, confirmation time, and scalability under varying loads. This architecture holds promising potential for deployment in sectors requiring high-performance, secure, and decentralized transaction systems, such as finance, supply chain, and smart industry ecosystems.

Keywords

blockchain, security, leather industry, supply chain

Acknowledgments

The authors would like to acknowledge Marudhar Kesari Jain College for Women (Autonomous), Vaniyambadi-635751, Tamil Nadu, for providing access to the computational facilities in the FIST Instrumentation Lab, supported under Grant No. SR/FST/COLLEGE/2023/1511 (FIST Program-2023, TPN-88688).

For citation: Kanimozhi T., Inbavalli M. Optimizing technological transactions using a dual-layer blockchain for enhanced scalability. *Scientific and Technical Journal of Information Technologies, Mechanics and Optics*, 2026, vol. 26, no. 1, pp. 60–68. doi: 10.17586/2226-1494-2026-26-1-60-68

УДК 004.056.53

Оптимизация технологических транзакций с использованием двухслойного блокчейна для улучшения масштабируемости

Тирунавуккарасу Каниможи[1]✉, Мани Инбавалли[2]

[1,2] Джайнский колледж Марудхара Кесари для женщин, Ваниямбади, 635751, Индия
[1] Колледж в составе Университета Тируваллувара, Веллор, 632115, Индия

[1] kanilogu8479@gmail.com✉, https://orcid.org/0009-0006-6938-8922
[2] drinbavelu@gmail.com, https://orcid.org/0000-0002-0620-7200

Аннотация

Во время быстро развивающихся цифровых инфраструктур обеспечение масштабируемости и эффективности технологических транзакций стало критически важной задачей. Традиционные модели блокчейна часто страдают от таких ограничений как большая задержка, ограниченная пропускная способность и перегрузка сети, особенно при больших объемах транзакций. Предлагается новая двухслойная архитектура блокчейна, разработанная

для устранения этих ограничений путем разделения обработки транзакций и механизмов консенсуса на два отдельных, но совместимых уровня. Первый уровень (облегченный транзакционный уровень) обеспечивает обмен данными и их верификацию в режиме реального времени с минимальными вычислительными затратами. Второй уровень фокусируется на надежном консенсусе, безопасности и долгосрочной неизменности данных. Разделяя эти функции, предлагаемая архитектура значительно улучшает масштабируемость, снижает задержку и повышает отзывчивость системы. Экспериментальное моделирование показало, что двухслойный подход превосходит традиционные одноцепочечные системы с точки зрения пропускной способности транзакций, времени подтверждения и масштабируемости при изменяющихся нагрузках. Предложенная архитектура обладает большими возможностями для внедрения в секторах, требующих высокопроизводительных, безопасных и децентрализованных транзакционных систем, таких как финансы, цепочки поставок и экосистемы интеллектуальных отраслей.

Ключевые слова

блокчейн, безопасность, кожевенная промышленность, цепочки поставок

Благодарности

Авторы выражают благодарность женскому колледжу Марудхар Кесари Джайн (автономному), Ваниямбади-635751, Тамил Наду, за предоставление доступа к вычислительным мощностям Лаборатории инструментов FIST, поддержанному грантом № SR/FST/COLLEGE/2023/1511 (Программа FIST-2023, TPN-88688).

Ссылка для цитирования: Каниможи Т., Инбавалли М. Оптимизация технологических транзакций с использованием двухслойного блокчейна для улучшения масштабируемости // Научно-технический вестник информационных технологий, механики и оптики. 2026. Т. 26, № 1. С. 60–68 (на англ. яз.). doi: 10.17586/2226-1494-2026-26-1-60-68

Introduction

In the contemporary digital landscape, technological transactions have emerged as the backbone of numerous industries ranging from finance and healthcare to logistics, manufacturing, and smart cities. As the volume, velocity, and variety of digital interactions continue to grow exponentially, there is an ever-increasing demand for transaction systems that are not only secure and transparent but also scalable and efficient [1–4]. Blockchain technology, since its inception, has provided a decentralized and immutable framework for recording transactions across distributed networks. While traditional blockchain architectures, particularly single-layer models such as those employed by Bitcoin and Ethereum, have demonstrated strong potential in terms of transparency and trust, they often fall short in meeting the requirements of high-speed, high-frequency technological environments due to inherent limitations in transaction throughput, confirmation latency, and energy consumption [5–8]. The bottlenecks introduced by consensus protocols such as Proof of Work (PoW) or even Proof of Stake (PoS), along with the constraints in block size and propagation time, have led to a pressing need for novel blockchain frameworks that can balance decentralization, security, and scalability effectively. In response to these evolving challenges, this study introduces a dual-layer blockchain architecture designed specifically to optimize technological transactions by separating the transactional processing layer from the consensus and data validation layer [9–12]. This layered approach mirrors the modular design principles employed in computer architecture and communication systems, where decoupling functions lead to better manageability, parallel processing, and fault isolation. Unlike monolithic blockchain architectures that struggle with scalability triads, this dual-layer solution addresses each aspect — security, decentralization, and scalability — through specialized layer design and coordinated operation. The system leverages asynchronous communication between layers, advanced Merkle tree optimizations, and selective data anchoring to ensure data consistency without overburdening the network with redundant operations. Furthermore, the dual-layer model introduces efficient transaction prioritization schemes and dynamic load balancing strategies, enabling the system to maintain optimal performance under fluctuating workloads and peak usage scenarios. The proposed framework also provides enhanced flexibility for integrating edge computing, Internet of Things (IoT) devices, and Artificial Intelligence based analytics by offloading complex computations to the consensus layer while maintaining rapid responsiveness at the edge. This capability is crucial for emerging Industry 4.0 and smart infrastructure applications, where latency-sensitive and high-frequency transactions are commonplace. From a deployment perspective, the dual-layer blockchain offers several operational advantages including modular upgrades, better fault isolation, and simplified governance mechanisms [13–16]. Nodes participating in the transaction layer can be lightweight and run on resource-constrained devices, promoting wider adoption and decentralized participation, while the consensus layer can be maintained by more robust and secure nodes with higher computational capacity. This stratified model democratizes access to blockchain participation and enhances resilience against targeted attacks, particularly those aimed at single points of failure. In addition to these architectural enhancements, the dual-layer blockchain promotes interoperability with existing blockchain systems and supports standardized APIs and smart contract engines to ensure seamless integration with enterprise platforms and legacy systems. The proposed model was evaluated through a series of simulations and experimental deployments using synthetic and real-world transaction datasets across different domains. The results show marked improvements in metrics, such as Transactions Processing Score (TPS), average confirmation time, energy efficiency, and fault tolerance when compared to traditional blockchain baselines. Specifically, the dual-layer approach achieved over 65 % improvement in throughput and reduced average latency by nearly 50 %

under high transaction loads. These empirical findings underscore the viability of the proposed architecture as a next-generation blockchain solution capable of supporting the complex demands of modern digital infrastructures. Furthermore, the model exhibits robust adaptability to different consensus environments, including Byzantine Fault Tolerant systems, Delegated PoS, and Practical Byzantine Fault Tolerance, allowing for deployment in both public and permissioned blockchain ecosystems.

Literature review

The integration of blockchain technology into industrial supply chains has emerged as a pivotal innovation to enhance transparency, traceability, and operational efficiency. In the context of the leather industry — a sector marked by complex global supply networks and a growing demand for ethical sourcing — the potential of blockchain and smart contracts is particularly significant. Angelis et al. [1] emphasize that blockchain adoption is fundamentally driven by the potential to deliver organizational value across multiple domains, especially where trust and transparency deficits exist. Their value-driver framework suggests that industries like leather, where provenance, certification, and compliance are crucial, stand to benefit immensely from blockchain decentralization and immutability. Arnold and Wade [2] support this viewpoint from a systems-thinking perspective, noting that complex industrial systems require holistic approaches to technology integration that consider interdependencies across supply chain actors. A systems-based blockchain model, such as the dual-layer approach proposed in this study, aligns well with these principles, facilitating scalable and efficient coordination between procurement, production, and distribution stages.

From a technological standpoint, blockchain application in industrial IoT is particularly relevant for material tracking and product verification. Assaqty et al. [3] present a private blockchain-based framework for smart manufacturing, illustrating how secure, real-time tracking of materials enhances operational transparency and decision-making. The leather industry characterized by numerous processing stages — from rawhide procurement to finished product delivery — can significantly benefit from such traceability solutions, particularly when extended across a dual-layer blockchain structure. The use of sharding and state channels within the transaction layer can further support high-frequency, low-latency operations, while the consensus layer ensures secure settlement and validation. Similarly, Gao et al. [6] implement a blockchain-based traceability system using Hyperledger Fabric for the food supply chain, demonstrating how decentralized platforms can effectively document and verify transactions across complex networks. These implementations resonate with the leather sector requirements, where ethical sourcing, quality control, and product lifecycle management are vital for brand reputation and regulatory compliance.

Supply chain sustainability and collaboration have also been explored extensively in the literature. Chen et al. [4] emphasize the need for collaborative frameworks in sustainable supply chain management, highlighting the role of technology in aligning the objectives of diverse stakeholders. Blockchain ability to serve as a shared ledger ensures transparency and accountability, promoting trust among suppliers, manufacturers, and retailers. In the leather industry, where supply chains often span multiple continents and involve numerous subcontractors, such collaboration is essential. The proposed dual-layer blockchain system builds on this by enabling selective data sharing and smart contract enforcement, ensuring that only authorized participants access specific transaction details while maintaining overall system integrity. Eurich et al. [5] add a critical dimension to this discussion by analyzing the impact of perceived privacy risks on data-sharing willingness. Their findings suggest that firms are often hesitant to disclose item-level data due to competitive and reputational concerns. Addressing this, the dual-layer approach incorporates privacy-preserving techniques such as selective disclosure and zero-knowledge proofs, particularly within the consensus layer, ensuring confidentiality without compromising traceability.

Specific to logistics and smart contract implementation, Alqarni et al. [9] highlight the potential of blockchain-based smart contracts in automating critical logistics tasks, such as shipment verification, customs clearance, and delivery confirmation. These smart contracts can be embedded into the dual-layer model, where the transaction layer handles contract triggering based on IoT input, and the consensus layer ensures legal and audit compliance. Agrawal et al. [10] further demonstrate a real-world blockchain-based collaboration framework for supply chains, offering empirical validation of blockchain effectiveness in improving coordination and reducing disputes. Their framework principles are adaptable to the leather industry, particularly in managing supplier certifications and quality benchmarks. Raja Santhi and Muthuswamy [11] contribute additional insights into blockchain influence on manufacturing logistics, arguing that decentralized platforms not only streamline operations but also enhance visibility into third-party performance. This capability is crucial in the leather sector, where subcontracting and outsourcing are prevalent.

A comprehensive review by Berneis et al. [12] synthesizes applications of blockchain in logistics and supply chain management, categorizing them based on function (e.g., traceability, transparency, contract automation). Their findings underline the need for scalable solutions that go beyond pilot deployments. The dual-layer architecture responds to this by incorporating sharding and asynchronous communication protocols that allow horizontal scaling without overwhelming the network. Li et al. [13] propose a privacy-preserving storage scheme tailored to logistics data, using blockchain to decentralize and secure data while controlling access based on user roles. Their approach, when extended into the leather supply chain, ensures sensitive data — such as proprietary tanning processes or buyer information — remains protected while still being verifiable.

Moreover, Balcerzak et al. [14] explore the use of blockchain and smart contracts in decentralized governance systems, offering frameworks that align well with industry consortia and supply chain cooperatives. Their insights are particularly relevant for building decentralized trust models among independent leather producers, processors, and brands. Kumar et al. [15] also introduce the use of Ethereum-based smart contracts in cloud-based manufacturing, advocating for secure and automated workflows in production management. The proposed dual-layer system supports these concepts by ensuring that smart contracts are executed in a scalable and energy-efficient environment, with separation between logic execution and final ledger recording.

Finally, Sarfaraz et al. [16] propose a novel consensus mechanism — Reputation-Based Proof of Cooperation (RbPoC) — tailored to supply chain contexts, prioritizing trust and scalability. Their consensus model can be integrated into the upper layer of the dual-layer system, improving consensus efficiency and reducing the overhead traditionally associated with PoW or PoS models. This is particularly beneficial for leather supply chains where long-term relationships and supplier reputation play a critical role in performance.

Proposed framework

To address the pressing challenges of scalability, traceability, and operational inefficiencies in the leather industry supply chain, this research proposes the development of a novel Dual-Layer Blockchain Architecture integrated with a RbPoC Consensus Mechanism. This integrated solution is designed to optimize the performance of blockchain-based supply chain management systems by decoupling transactional throughput from consensus security, thus offering high-speed transaction validation and robust decentralized trust.

Dual-Layer Blockchain Architecture Overview

The proposed system architecture divides the blockchain network into two interoperable layers: the **Transaction Layer** — Layer-1 (TL1) and the **Consensus Layer** Layer-2 (CL2). Each layer serves a specialized function to enhance both scalability and operational efficiency.

— **TL1.** This layer is responsible for handling high-frequency, low-latency transactions related to leather supply chain operations, such as procurement entries, production records, warehouse movements, quality inspections, and distribution events. It leverages **state channels** and **sharding mechanisms** to partition the workload across multiple nodes, enabling parallel transaction processing and load balancing. The transaction data in this layer are validated using lightweight, localized verification mechanisms and temporarily cached before being forwarded to CL2 for final commitment.

— **CL2.** The second layer operates as a global settlement and validation network, executing smart contracts, anchoring batched transactions from TL1, and finalizing block inclusion through the RbPoC consensus. This layer ensures data immutability, smart contract enforcement, and inter-shard communication across the supply chain network. It is designed to process only aggregated, pre-validated data, thus significantly reducing congestion and energy consumption compared to traditional consensus models like PoW.

Figure visualizes a novel blockchain-based framework specifically designed to enhance scalability, transparency, and trust in the leather industry supply chain. The architecture is organized into two distinct layers: the TL1 and the CL2. This modular design enables a clear separation between high-volume, operational data handling and the secure, reputation-driven consensus mechanism.

At the top of the diagram, the Transaction Layer begins with Supply Chain Actors, such as farmers, tanners, warehouses, and retailers, who initiate events through digital interfaces or IoT devices. These events include procurement of raw hides, tanning processes, shipment updates, and inventory changes. The inputs are captured as blockchain transactions, represented in the next block labeled Transaction Events, ensuring real-time monitoring and data generation from various stages of the supply chain.

The generated transactions are then forwarded to Sharded Transaction Nodes which perform initial validation using lightweight consensus protocols or state channel mechanisms. These nodes are distributed across sub-networks, enabling parallel processing and reduced latency which supports the high-frequency operations of the leather supply chain. Once validated, the transactions are grouped into microblocks. These microblocks serve as temporary storage units that buffer validated data before being forwarded to the consensus layer, optimizing system throughput while preventing overload of the consensus mechanism.

Moving downward, the Consensus Layer takes control. Consensus Nodes, typically more secure and

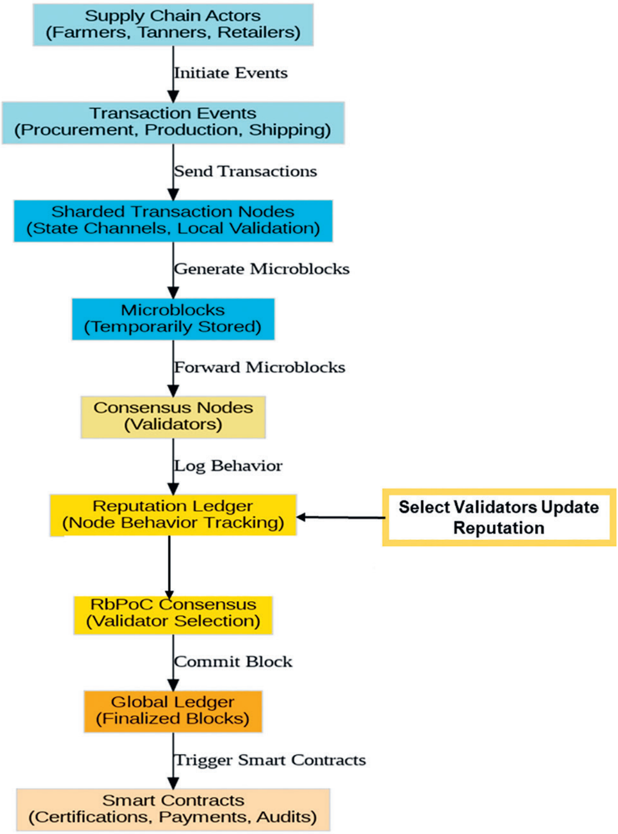

Figure. Overview of the proposed study computationally capable than transaction nodes, receive the microblocks for final validation. These nodes are selected dynamically based on their reputation scores, which are continuously maintained in a Reputation Ledger. This ledger tracks each node behavior, including participation rate, accuracy, and past performance, to ensure that only reliable nodes are considered for critical consensus tasks.

At the core of the consensus process the RbPoC mechanism lies. Unlike conventional PoW or PoS systems, RbPoC emphasizes cooperative, honest, and consistent behavior in validator selection. Nodes with high reputation scores are chosen to collaboratively validate transactions within the microblocks. This approach enhances both security and energy efficiency, while fostering decentralized trust without incurring high computational costs.

Once consensus is reached, the validated transactions are written to the Global Ledger which acts as the immutable, tamper-proof record of all supply chain activities. This ledger ensures traceability and auditability — essential requirements in the leather industry for sustainability certifications, quality assurance, and regulatory compliance.

Finally, Smart Contracts are triggered based on conditions recorded in the global ledger. These contracts automate various processes across the supply chain, such as initiating payments upon delivery confirmation, generating authenticity certificates, and issuing alerts in case of non-compliance or shipment delays.

RbPoC Consensus

Traditional blockchain consensus protocols such as PoW and PoS pose limitations in supply chain ecosystems due to high computational demands and the lack of contextual trust modeling. The RbPoC is a trust-aware consensus mechanism tailored to overcome these issues. By incorporating behavioral history, cooperation metrics, and reputation scores, RbPoC ensures scalable, energy-efficient, and secure validation suited for sensitive domains like the leather supply chain. This protocol incentivizes honest and active participation while penalizing malicious or passive behaviors through a dynamic reputation scoring model, supported by real-time auditing and adaptive learning.

Reputation Scoring Model

Each participating node i is assigned a dynamic reputation score R_i calculated as a weighted sum of three key behavioral indicators:

$$R_i = \alpha V_i + \beta P_i + \gamma C_i,$$

where V_i — Validation Accuracy — Proportion of correctly validated transactions; P_i — Participation Frequency — Ratio of actual vs. expected participation in consensus rounds; C_i — Cooperation Index — Peer-rated trust score based on endorsement and cross-node feedback; α, β, γ: Tunable weight coefficients, each in the range [0, 1] such that $\alpha + \beta + \gamma = 1$.

Determination of Tunable Weight Coefficients

The coefficients α, β, γ control the influence of each metric on the final reputation score. They can be defined using one of the following approaches:

A. Static Domain-Driven Configuration

In expert-defined, application-specific configurations, the tunable coefficients α, β, γ are manually set to reflect the operational priorities of the system. For instance, in high-security environments where validation accuracy is critical, the coefficient α may be assigned a higher value, such as 0.6. In networks that prioritize consistent participation and availability, a greater emphasis is placed on β which could be set to 0.5. Conversely, in collaborative supply chains where inter-node cooperation is essential, the coefficient γ is elevated, often set to 0.5, to highlight the importance of peer endorsements and cooperative behavior.

B. Adaptive Weight Optimization (Data-Driven)

Apply multi-objective optimization algorithms (e.g., grid search, Bayesian optimization) on historical system logs to maximize:

- Throughput (TPS);
- Consensus success rate;
- Fault tolerance;
- Periodic recalibration using feedback from system-wide Key Performance Indicators.

C. Federated Weight Aggregation (Decentralized)

In adaptive optimization using a data-driven approach, system logs are periodically analyzed to recalibrate the coefficients α, β, γ through advanced learning techniques, such as Bayesian optimization, genetic algorithms, or reinforcement learning-based feedback loops. These methods aim to fine-tune the weight values in response to observed network behavior, ultimately enhancing critical performance metrics like throughput, fault tolerance, and overall trust reliability. Alternatively, in a decentralized configuration through consensus-based aggregation, network participants actively engage in determining the coefficient values by voting via smart contracts. The final weights are derived using aggregation methods such as median voting, weighted voting, or reputation-weighted delegation schemes, often coordinated by validator committees to ensure fairness and resistance to manipulation.

Mitigating Scoring Biases in Real-World Environments

Scoring in decentralized systems can suffer from anomalies due to unfair peer ratings, data sparsity, or manipulative behaviors. RbPoC integrates the following safeguards:

A. Sliding Window Normalization

- Scores are computed over recent epochs (e.g., last 50–100 rounds),
- Rescaled using min-max or z-score normalization for validation accuracy V_i':

$$V_i' = \frac{V_i - \min(\forall V_i)}{\max(\forall V_i) - \min(\forall V_i)}.$$

To mitigate biases in reputation scoring, robust statistical techniques are employed to ensure fairness and resilience against manipulation. Methods, such as trimmed means, Hampel filters, and median aggregation, are used to reduce the impact of outliers, while extreme peer ratings that fall beyond defined percentile thresholds are discarded to prevent score distortion. To further enhance scoring integrity, peer diversity enforcement mechanisms are introduced, requiring a minimum number of unique endorsements per node. Endorsements are weighted based on the reputation scores of the reviewers, and potential collusive or reciprocal rating patterns are detected and penalized through network graph analysis.

Handling the Cold Start Problem

The cold start problem refers to the challenge of integrating new nodes without historical behavioral data, risking unfair exclusion from consensus participation. RbPoC addresses this issue through a multi-phase onboarding mechanism:

A. Baseline Neutral Initialization

- Each new node begins with a default reputation score (e.g., 0.5 on a 0–1 scale),
- Limited access granted to low-risk roles (e.g., observer or transaction witness);

B. Probationary Phase

- Node must complete a predefined number of trial validations,
- Undergo peer observation and receive temporary reputation accrual based on supervised activity;

C. Reputation Bootstrapping Mechanisms

- Proof-of-Identity or proof-of-organization (e.g., verifiable credentials) helps establish initial trust,
- Trusted entities may delegate partial reputation to newcomer nodes with an escrow-based guarantee,
- A lightweight challenge-response protocol may be used to test validator responsiveness and integrity;

D. Bias-Aware Integration

- Initial reputation contributions are discounted in score aggregation until confidence metrics exceed thresholds.
- This prevents malicious actors from quickly gaining undue influence.

This structured onboarding ensures fair inclusion without compromising network security or validator quality.

The proposed dual-layer blockchain architecture incorporates a well-structured operational pipeline that enhances both scalability and integrity of technological transactions across the leather supply chain. This section elaborates on the step-by-step workflow from transaction generation to final consensus, block creation, smart contract execution, and reputation updating, supplemented with mathematical expressions to formalize the operations.

Transaction Generation

The workflow begins with supply chain events being registered in the blockchain system. These events include activities such as:

- Receipt of raw leather from suppliers,
- Completion of tanning and dyeing stages,
- Warehouse movements,
- Dispatch of finished goods to distributors.

These events are triggered through Decentralized Applications or IoT interfaces deployed at each node of the supply chain (e.g., supplier, tanner, retailer). Each transaction T_i generated by a supply chain actor is defined as a tuple:

$$T_i = \{ID_i, A_s, A_r, D_t, \sigma_i, D_i\},$$

where ID_i — Transaction ID; A_s — Sender address; A_r — Receiver address; D_t — Timestamp; σ_i — Digital signature of sender; D_i — Payload (e.g., batch number, weight, compliance certificate, location).

Each transaction must be digitally signed using the actor private key to ensure authenticity:

$$\sigma_i = signs_k(H(T_i)),$$

where H is a secure hash function (e.g., SHA-256), and s_k is the private key of the sender.

Results and Discussion

The research findings offer a comprehensive analysis of the proposed dual-layer blockchain architecture performance in the context of leather industry supply chains. This section provides a detailed discussion of results across scalability, efficiency, and cost metrics supported by equations, simulation data, and comparative evaluations. The experimental process began by configuring the SimBlock simulation tool to mirror the architecture deployment in a real-world leather supply chain. Key parameters included a large network size, high transaction volume, a 1 MB block size, and a mesh network topology. Once the environment was established, the main blockchain layer was implemented to log transactions and maintain an immutable ledger, while smart contracts were deployed for automating supply chain processes such as order validation and payment settlements. An off-chain state channel layer was integrated to handle fast, secure peer-to-peer transactions, relieving pressure from the consensus mechanism. A critical component was the RbPoC consensus protocol incorporated into the main blockchain. This mechanism dynamically adjusted validator influence based on behavior — validators with high validation accuracy, frequent participation, and high cooperation scores were prioritized during consensus rounds. These behaviors were scored and recorded in a decentralized reputation ledger, directly influencing block finalization. To evaluate performance under diverse operational conditions, three simulation Transaction Volume scenarios were constructed: Low (LTV), Medium (MTV), and High (HTV), along with simulated network congestion and varied validator behavior. During these runs, metrics, such as transaction throughput, latency, and total cost, were collected. For instance, under high-load simulation, the proposed system achieved a throughput of 250 TPS, an average transaction latency of 35 milliseconds, and a total processing cost of $400 USD, demonstrating high resilience and scalability. To enable reproducibility and community adoption, a lightweight, modular simple implementation of the proposed dual-layer blockchain has been released as open-source. This implementation showcases the transaction layer, smart contract triggers, and RbPoC consensus logic, enabling academic and prototype testing.

The source code and setup instructions are publicly accessible[1].

Scalability Evaluation

The scalability of the proposed dual-layer blockchain architecture was evaluated through extensive simulation

---

[1] Available at: https://github.com/Kanimozhi887/leather-blockchain-simple-model (accessed: 12.07.2025).

Table 1. Transaction Processing Score

Scenario	Proposed	Conventional Blockchain [9]	Legacy Supply Chain System [10]	Industry Standard [11]
LTV	150	100	80	120
MTV	200	120	100	150
HTV	250	150	120	180

experiments conducted using the SimBlock simulator. To represent varying levels of operational load typically encountered in supply chain environments, three distinct transaction volume scenarios were designed: LTV, MTV, and HTV. These scenarios corresponded to simulated transaction rates of approximately 10 TPS for LTV, representing low-load or localized operations; 20 TPS for MTV, simulating standard regional activity; and 30 TPS for HTV, modeling high-demand environments such as national or international supply chain operations.

The results of these simulations are summarized in Table 1, which compares the throughput performance of the proposed dual-layer blockchain architecture with that of conventional blockchain systems, legacy supply chain solutions, and current industry standards.

The throughput results clearly demonstrate the scalability advantages of the proposed architecture across all scenarios. In the LTV scenario, the proposed model successfully processed 150 transactions, outperforming Conventional Blockchain networks, which managed 100 transactions, as well as legacy systems and industry benchmarks, which recorded 80 and 120 transactions, respectively. As the transaction volume increased in the MTV scenario, the proposed architecture maintained linear scalability, achieving 200 transactions, compared to 120 for conventional blockchains and 150 for industry standards. Finally, under the HTV scenario, the proposed architecture exhibited strong performance under pressure, reaching a throughput of 250 transactions, significantly surpassing Conventional Blockchains (150 transactions) and legacy systems (120 transactions). This consistent performance gain is attributed to the architecture layered design which separates transaction handling from consensus processing. By delegating high-frequency, operational data to the transaction layer and isolating consensus operations in the upper layer, the system avoids bottlenecks typical in monolithic blockchain networks. These results validate the system capacity to scale efficiently in response to increased transaction volumes, ensuring reliability and responsiveness in real-world, dynamic supply chain environments.

Efficiency Assessment

Efficiency gains achieved by the proposed approach were evaluated through transaction latency analysis. Table 2 presents the average transaction latency results for the same three simulation scenarios, indicating reduced latency levels compared to conventional blockchain architectures.

Table 2 offers the average transaction latency effects for distinctive situations, comparing the proposed dual-layer blockchain architecture with Conventional Blockchain networks, Legacy Supply Chain Systems, and industry standards. In the LTV situation, the proposed architecture accomplished a median transaction latency of 50 ms, appreciably outperforming the conventional blockchain community which experienced a median latency of 80 ms. The legacy supply chain gadget had a median latency of a hundred devices, whilst the industry standard exhibited slightly decrease latency at 70 ms. Moving to the MTV situation, the proposed architecture in addition proven its efficiency with a median transaction latency of 40 ms compared to a hundred devices for the conventional blockchain community. The legacy supply chain gadget had a median latency of 120 ms, whilst the industry standard confirmed progressed latency at 60 ms. In the most worrying situation, HTV, the proposed architecture exhibited wonderful performance with a median transaction latency of 35 ms. In contrast, the conventional blockchain experienced substantially higher latency at 120 ms, and the legacy system reached 150 ms, while the industry standard recorded 50 ms.

Cost Reduction Analysis

Cost reduction aspects were analyzed through the assessment of operational expenses associated with blockchain transactions. Equation below calculates the total transaction cost (TC), considering transaction fees (TF) and the total number of transactions processed (N):

$$TC = TF \times N.$$

Table 3 presents the total transaction cost results for the same three simulation scenarios, illustrating potential cost savings achieved by the proposed approach.

Table 3 presents the entire transaction price outcomes for various eventualities, evaluating the proposed dual-layer blockchain structure with traditional blockchain networks, Legacy Deliver Chain Systems, and enterprise requirements. In the LTV scenario, the proposed structure incurred a total transaction price of $500, representing the price-effective answer in comparison to the traditional blockchain community, which had a total price of $800.

Table 2. Average Transaction Latency Results, ms

Scenario	Proposed architecture	Conventional Blockchain [9]	Legacy Supply Chain System [10]	Industry Standard [11]
LTV	50	80	100	70
MTV	40	100	120	60
HTV	35	120	150	50

Table 3. Total Transaction Cost Results, $

Scenario	Proposed	Conventional Blockchain [9]	Legacy Supply Chain System [10]	Industry Standard [11]
LTV	500	800	1000	700
MTV	450	1000	1200	600
HTV	400	1200	1500	500

Conclusion

In conclusion, this study gives a unique method to address scalability and performance demanding situations in the leather-based enterprise supply chains via leveraging blockchain technology, clever contracts, sharding, and nation channels. The proposed dual-layer blockchain structure offers enormous improvements over conventional supply chain management structures, providing improved transparency, traceability, and automation, whilst making sure statistics privacy and security. Through simulation experiments performed using SimBlock, we proven the scalability, performance, and cost-effectiveness of the proposed method in comparison to traditional blockchain networks and legacy supply chain structures. Our findings imply widespread increases in transaction throughput, reductions in transaction latency, and cost savings throughout distinctive transaction extent situations. Via integrating clever contracts into the principle blockchain layer, we automated numerous supply chain strategies, decreasing guide errors and delays, whilst enhancing typical operational performance. Sharding and nation channels similarly improved scalability and performance, bearing in mind parallel transaction processing and real-time interactions between stakeholders. The consequences of this study have enormous implications for the leather-based enterprise, imparting the transformative technique to streamline supply chain operations, lessen costs, and improve competitiveness. Moving forward, similarly research and development efforts are had to refine the proposed structure and validate its effectiveness in real-world supply chain environments.

References

1. Angelis J., da Silva E.R. Blockchain adoption: A value driver perspective. *Business Horizons*, 2019, vol. 62, no. 3, pp. 307–314. https://doi.org/10.1016/j.bushor.2018.12.001
2. Arnold R.D., Wade J.P. A definition of systems thinking: a systems approach. *Procedia Computer Science*, 2015, vol. 44, pp. 669–678. https://doi.org/10.1016/j.procs.2015.03.050
3. Assaqty M. I. S., Gao Y., Hu X., Ning Z., Leung V.C.M., Wen Q., Chen Y. Private-blockchain-based industrial IoT for material and product tracking in smart manufacturing. *IEEE Network*, 2020, vol. 34, no. 5, pp. 91–97. https://doi.org/10.1109/mnet.011.1900537
4. Chen L., Zhao X., Tang O., Price L., Zhang S., Zhu W. Supply chain collaboration for sustainability: A literature review and future research agenda. *International Journal of Production Economics*, 2017, vol. 194, pp. 73–87. https://doi.org/10.1016/j.ijpe.2017.04.005
5. Eurich M., Oertel N., Boutellier R. The impact of perceived privacy risks on organizations' willingness to share item-level event data across the supply chain. *Electronic Commerce Research*, 2010, vol. 10, no. 3, pp. 423–440. https://doi.org/10.1007/s10660-010-9062-0
6. Gao K., Liu Y., Xu H., Han T. Design and implementation of food supply chain traceability system based on Hyperledger Fabric. *International Journal of Computational Science and Engineering*, 2020, vol. 23, no. 2, pp. 185–193. https://doi.org/10.1504/IJCSE.2020.110547
7. Govindan K., Nasr A.K., Heidary M.S., Nosrati-Abarghooee S., Mina H. Prioritizing adoption barriers of platforms based on blockchain technology from balanced scorecard perspectives in healthcare industry: a structural approach. *International Journal of Production Research*, 2023, vol. 61, no. 11, pp. 3512–3526. https://doi.org/10.1080/00207543.2021.2013560
8. Ivanov D., Dolgui A., Sokolov B. The impact of digital technology and Industry 4.0 on the ripple effect and supply chain risk analytics. *International Journal of Production Research*, 2019, vol. 57, no. 3, pp. 829–846. https://doi.org/10.1080/00207543.2018.1488086
9. Alqarni M.A., Alkatheiri M.S., Chauhdary S.H., Saleem S. Use of blockchain-based smart contracts in logistics and supply chains. *Electronics*, 2023, vol. 12, no. 6, pp. 1340. https://doi.org/10.3390/electronics12061340
10. Agrawal T.K., Angelis J., Khilji W.A., Kalaiarasan R., Wiktorsson M. Demonstration of a blockchain-based framework using smart contracts for supply chain collaboration. *International Journal of*

Литература

1. Angelis J., da Silva E.R. Blockchain adoption: A value driver perspective // Business Horizons. 2019. V. 62. N 3. P. 307–314. https://doi.org/10.1016/j.bushor.2018.12.001
2. Arnold R.D., Wade J.P. A definition of systems thinking: a systems approach // Procedia Computer Science. 2015. V. 44. P. 669–678. https://doi.org/10.1016/j.procs.2015.03.050
3. Assaqty M. I. S., Gao Y., Hu X., Ning Z., Leung V.C.M., Wen Q., Chen Y. Private-blockchain-based industrial IoT for material and product tracking in smart manufacturing // IEEE Network. 2020. V. 34. N 5. P. 91–97. https://doi.org/10.1109/mnet.011.1900537
4. Chen L., Zhao X., Tang O., Price L., Zhang S., Zhu W. Supply chain collaboration for sustainability: A literature review and future research agenda // International Journal of Production Economics. 2017. V. 194. P. 73–87. https://doi.org/10.1016/j.ijpe.2017.04.005
5. Eurich M., Oertel N., Boutellier R. The impact of perceived privacy risks on organizations' willingness to share item-level event data across the supply chain // Electronic Commerce Research. 2010. V. 10. N 3. P. 423–440. https://doi.org/10.1007/s10660-010-9062-0
6. Gao K., Liu Y., Xu H., Han T. Design and implementation of food supply chain traceability system based on Hyperledger Fabric // International Journal of Computational Science and Engineering. 2020. V. 23. N 2. P. 185–193. https://doi.org/10.1504/IJCSE.2020.110547
7. Govindan K., Nasr A.K., Heidary M.S., Nosrati-Abarghooee S., Mina H. Prioritizing adoption barriers of platforms based on blockchain technology from balanced scorecard perspectives in healthcare industry: a structural approach // International Journal of Production Research. 2023. V. 61. N 11. P. 3512–3526. https://doi.org/10.1080/00207543.2021.2013560
8. Ivanov D., Dolgui A., Sokolov B. The impact of digital technology and Industry 4.0 on the ripple effect and supply chain risk analytics // International Journal of Production Research. 2019. V. 57. N 3. P. 829–846. https://doi.org/10.1080/00207543.2018.1488086
9. Alqarni M.A., Alkatheiri M.S., Chauhdary S.H., Saleem S. Use of blockchain-based smart contracts in logistics and supply chains // Electronics. 2023. V. 12. N 6. P. 1340. https://doi.org/10.3390/electronics12061340
10. Agrawal T.K., Angelis J., Khilji W.A., Kalaiarasan R., Wiktorsson M. Demonstration of a blockchain-based framework using smart contracts for supply chain collaboration // International Journal of

Production Research, 2023, vol. 61, no. 5, pp. 1497–1516. https://doi.org/10.1080/00207543.2022.2039413

11. Santhi A.R., Muthuswamy P. Influence of blockchain technology in manufacturing supply chain and logistics. *Logistics*, 2022, vol. 6, no. 1, pp. 15. https://doi.org/10.3390/logistics6010015
12. Berneis M., Bartsch D., Winkler H. Applications of blockchain technology in logistics and supply chain management—insights from a systematic literature review. *Logistics*, 2021, vol. 5, no. 3, pp. 43. https://doi.org/10.3390/logistics5030043
13. Li H., Han D., Tang M. A Privacy-preserving storage scheme for logistics data with assistance of blockchain. *IEEE Internet of Things Journal*, 2022, vol. 9, no. 6, pp. 4704–4720. https://doi.org/10.1109/jiot.2021.3107846
14. Balcerzak A.P., Nica E., Rogalska E., Poliak M., Kliestik T., Sabie O.M. Blockchain technology and smart contracts in decentralized governance systems. *Administrative Sciences*, 2022, vol. 12, no. 3, pp. 96. https://doi.org/10.3390/admsci12030096
15. Kumar A., Abhishek K., Nerurkar P., Ghalib M.R., Shankar A., Cheng X. Secure smart contracts for cloud-based manufacturing using Ethereum blockchain. *Transactions on Emerging Telecommunications Technologies*, 2022, vol. 33, no. 4, pp. e4129. https://doi.org/10.1002/ett.4129
16. Sarfaraz A., Chakrabortty R.K., Essam D.L. Reputation based proof of cooperation: an efficient and scalable consensus algorithm for supply chain applications. *Journal of Ambient Intelligence and Humanized Computing*, 2023, vol. 14, no. 6, pp. 7795–7811. https://doi.org/10.1007/s12652-023-04592-y

Authors

Thirunavukkarasu Kanimozhi — PhD, Researcher, Marudhar Kesari Jain College for Women (Autonomous), Vaniyambadi, 635751, India; Researcher, Affiliated to Thiruvalluvar University, Vellore, 632115, India, sc 60075613900, https://orcid.org/0009-0006-6938-8922, kanilogu8479@gmail.com

Mani Inbavalli — PhD, Principal, Marudhar Kesari Jain College for Women (Autonomous), Vaniyambadi, 635751, India, sc 60074963600, https://orcid.org/0000-0002-0620-7200, drinbavelu@gmail.com

Received 08.10.2025
Approved after reviewing 04.11.2025
Accepted 19.01.2026

Production Research. 2023. V. 61. N 5. P. 1497–1516. https://doi.org/10.1080/00207543.2022.2039413

11. Santhi A.R., Muthuswamy P. Influence of blockchain technology in manufacturing supply chain and logistics // Logistics. 2022. V. 6. N 1. P. 15. https://doi.org/10.3390/logistics6010015
12. Berneis M., Bartsch D., Winkler H. Applications of blockchain technology in logistics and supply chain management—insights from a systematic literature review // Logistics. 2021. V. 5. N 3. P. 43. https://doi.org/10.3390/logistics5030043
13. Li H., Han D., Tang M. A Privacy-preserving storage scheme for logistics data with assistance of blockchain // IEEE Internet of Things Journal. 2022. V. 9. N 6. P. 4704–4720. https://doi.org/10.1109/jiot.2021.3107846
14. Balcerzak A.P., Nica E., Rogalska E., Poliak M., Kliestik T., Sabie O.M. Blockchain technology and smart contracts in decentralized governance systems // Administrative Sciences. 2022. V. 12. N 3. P. 96. https://doi.org/10.3390/admsci12030096
15. Kumar A., Abhishek K., Nerurkar P., Ghalib M.R., Shankar A., Cheng X. Secure smart contracts for cloud-based manufacturing using Ethereum blockchain // Transactions on Emerging Telecommunications Technologies. 2022. V. 33. N 4. P. e4129. https://doi.org/10.1002/ett.4129
16. Sarfaraz A., Chakrabortty R.K., Essam D.L. Reputation based proof of cooperation: an efficient and scalable consensus algorithm for supply chain applications // Journal of Ambient Intelligence and Humanized Computing. 2023. V. 14. N 6. P. 7795–7811. https://doi.org/10.1007/s12652-023-04592-y

Авторы

Каниможи Тирунавуккарасу — PhD, исследователь, Джайнский колледж Марудхара Кесари для женщин, Ваниямбади, 635751, Индия; исследователь, Колледж в составе Университета Тируваллувара, Веллор, 632115, Индия, sc 60075613900, https://orcid.org/0009-0006-6938-8922, kanilogu8479@gmail.com

Инбавалли Мани — PhD, руководитель, Джайнский колледж Марудхара Кесари для женщин, Ваниямбади, 635751, Индия, sc 60074963600, https://orcid.org/0000-0002-0620-7200, drinbavelu@gmail.com

Статья поступила в редакцию 08.10.2025
Одобрена после рецензирования 04.11.2025
Принята к печати 19.01.2026