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SMART CONTRACT TECHNOLOGY FOR DIGITALIZATION AND AUTOMATION PROOF OF DELIVERY IN SUPPLY CHAIN MANAGEMENT

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Abstract: The Proof of Delivery (POD) document is essential for confirming the receipt of products and facilitating invoice generation in logistics operations. The persistent reliance on physical papers results in inefficiencies, including document loss, verification delays, and restricted visibility. This research introduces a blockchain technology-based smart contract POD system designed to enhance operational transparency, security, and efficiency. A case study at an Indonesian logistics company evaluates the transition from a manual to a digital Proof of Delivery (POD) process through prototype development and field trials. Essential findings indicate that blockchain facilitates unalterable, instantaneous documentation and verification, whereas smart contracts streamline multi-phase validation processes. The suggested approach decreases verification time from 20 days to mere minutes, mitigates human error, and enhances invoice precision. The prototype of a smart contract application suggests faster processing times and lower costs per transaction, among other benefits. Errors of inputs are also reduces, indicating a significant boost in data accuracy.

***Keywords**:* Block chain; Digital POD; Logistics Technology; Smart Contract; Supply Chain Efficiency

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1. Introduction

The proof of delivery (POD) document is an essential component of the logistics sector's process for confirming goods delivery and generating invoices. Currently, the POD method relies on physical papers, which present several challenges to operational efficiency in the supply chain, including the risk of document loss or damage, delays in the verification process, and a lack of visibility into the delivery status. Due to delays in issuing invoices for the payment process, this has a significant impact on the smoothness of cash flow.

Transparency, efficiency, and data security have presented major difficulties for SCM over the past few years. Conventional systems sometimes rely on manual procedures that are prone to human error and data manipulation (Dutta et al., 2020). Furthermore, a significant challenge in guaranteeing on-time delivery as promised is the inability to monitor the origin and status of items in real-time (Nofal et al., 2024). By means of transparent, unchangeable, auditable data, blockchain has been demonstrated in past studies to offer a solution to this problem (Sternberg et al., 2021).

Blockchain technology enables the creation of immutable transaction records, ensuring data connectivity and security, while also providing real-time tracking and verification. Blockchain-based document management becomes a solution that offers security, transparency, and efficiency to every actor in the supply chain management system(Hasan & Salah, 2018).

In supply chain management, blockchain technology present chances to create more creative and integrated digital solutions. Using smart contracts—which bring automation to the documentation and verification processes—one of the significant innovations resulting from the deployment of this technology is smart contracts with blockchain technologies not only improve security and openness but also offer a basis for a more complete digital revolution in document management inside supply chain management. Physical document procedures can be completely digital, helping to improve operational efficiency, data security, and transparency through a smart contract-based system.

A digital approach to replace the paper-based POD procedure is smart contracts. Durach et al. (2021) maintained that blockchain technology can lower data loss risk and speed up information validation in supply chain management systems. It is also to underline even further how the use of smart contracts in supply chain management may automatically verify delivery process visibility and accuracy enhancement. To achieve operational efficiency, this technology ensures that every procedure can be confirmed to be free from risk of counterfeiting or delays.

This study proposes a POD documentation system that features a smooth and integrated validation and verification process for items, from delivery to completion. The process consists of three stages: Stage 1, receipt of the shipment; Stage 2, validation of the shipment; and Stage 3, finalization of the shipment. The system's development concentrates on three key aspects: tracking, validation, and storing of delivery proof via a smart contract.

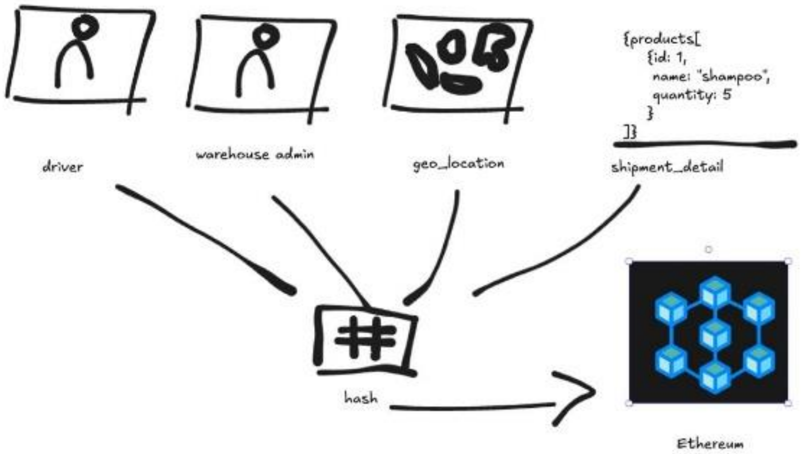

Figure 1: POD system development process

Figure 1 illustrates the guidance for the development of this system. The potential for document loss is anticipated to diminish with the application of this technology, which will also speed up the implementation of digital validation for goods receipt. This technology can integrate with Transport Management Systems (TMS), ensuring that all delivery records generated by the transporter are securely preserved in an immutable system. This ensures that the delivery data will remain accurate, allowing all interested parties to verify it openly and honestly.

This study aims to investigate the integration of smart contracts within blockchain architecture to digitise and automate Proof of Delivery (POD) processes. Leveraging immutable and distributed data systems enhances logistics operations by enabling automated, transparent, and secure management of documentation. The research focuses on evaluating operational transformation through a pilot project implemented at MG Logistics Company in Surabaya.

2. Literature Review

2.1. Blockhain in Supply Chain

Numerous studies have been conducted on the use of blockchain in supply chains. Research by Dutta et al. (2020) and Shwetha and Prabodh (2021) have explored the potential of blockchain for enhancing traceability and transparency. These studies have argued that, as a disruptive technology, blockchain can generate trust among stakeholders due to its immutability and transparency. Blockchain technology allows any party of the system to verify the authenticity of the stored information. Shwetha and Praboth (2021) have identified a number of food supply chain systems and evaluated food procurement and distribution systems, from production to consumption, that are recorded on the blockchain. The study argued that the use of blockchain enables customers to verify whether the seller's claims about food quality are indeed true.

Cuñat Negueroles et al.(2024) have examined the integration of blockchain with Internet of Things (IoT) technology in Digital Twin environments. Digital Twin is a software technology that models real-world phenomena in digitised environments and represents and monitors the reality of various processes, including IoT deployments. The study showed that use of the technology can support the Smart Logistics use case. Furthermore, Bellal et al. (2023) have examined the efficacy of blockchain in various geographical settings.

While studies have been conducted in different regions, a thorough study on deployments in Indonesia's logistics industry is particularly lacking. Moreover, most current research depends more on conceptual frameworks or small-scale simulations than on practical implementations in operational settings (Sternberg et al., 2021). Specifically, study of blockchain in supply chain, especially for its uses for POD validation still need development. Yurt et al. (2023) discussed POD implementation just theoretically, while also touching on logistics and modularising. Particularly with relation to the quantitative advantages of blockchain-based POD systems in real-world logistics operations, this results in a notable discrepancy between theoretical models and actual uses.

2.2. Proof of Delivery

Despite its importance for accuracy and effectiveness in smart delivery systems, there are still notable gaps in POD digitalisation implementations. A POD acknowledges the timely delivery of goods, including their documentation, in terms of time, place, quantity, quality, and completion, as agreed upon by the parties in the transaction (Madhwal et al., 2022). Madhwal et al. (2022) maintained that the certificate of POD can trigger the transfer of ownership of goods, financial payoffs for goods and their delivery services, as well as the acceptance or correction of prices according to the delivery conditions. It can also be a proof of repudiation or non-repudiation of the delivery conditions.

Hasan & Salah (2018) has identified challenges for accurate and trustworthy POD. They proposed the use of blockchain for POD in a generic form of delivery services. The POD, or 'last mile' of delivery, is crucial to record and prove that an item has reached its final and required destination. Courier companies use trackers and proof of delivery systems to ensure that the customers' order have been delivered on time and meet their expectations. Also, information about the initial course of devlivery is important for the record of all relevant parties.

Traditional proof of delivery systems are typically based on signed papers and documents which the couriers bring. Some courier services have used an electronic handheld device to obtain the recipient's signature or take necessary photos as proof of delivery. Hasan and Salah (2018) argued that this process is cumbersome and cannot justify total trust for delivery. They argued that the ideal proof of delivery requires accountability, authorization, auditability, integrity, punctuality and honesty. They recommended a blockchain POD system using a web-based model that includes interaction between three main entities: the seller, transporter, and buyer to acquire proof of delivery of a physical item. This system has included integrity, accountability, authorization, punctuality, and honesty as seen in the POD system. However, the solution has not yet identified the confidentiality and privacy.

3. Research Method

3.1 Research Design

This study employs a mixed-methods approach combining qualitative and quantitative methodologies within a case study framework. This design enables a comprehensive exploration of both technical and operational aspects of blockchain implementation in POD management. The case study focuses on logistics company MG in Surabaya, Indonesia, which operates extensive transportation services and processes approximately 57.000 shipment transactions annually.

The research follows a four-phase sequential design: (1) preliminary analysis, including literature review and initial data collection; (2) prototype development of the blockchain-based POD system (which is so-called Cronus Platform) ; (3) implementation and testing in the operational environment; and (4) evaluation and analysis of results.

3.2 Data Collection

Data collection utilized many ways to guarantee a thorough comprehension of both existing procedures spoand implementation results:

1. Comprehensive interviews: Semi-structured interviews were performed with 12 stakeholders, comprising operations managers, administrative personnel, drivers, and IT professionals. The interviews examined contemporary POD issues, procedural impediments, and possible opposition to technological transformation.
2. Process observation: Direct observation of current POD operations, including defined workflows, time requirements, and error frequencies throughout 1000 shipment transactions over a one-week duration.
3. Document analysis: An evaluation of corporate records yielded quantitative data regarding transaction volumes, document processing durations, and financial data from 2023 to 2025 encompassing 478,000 cargo transactions. This was accompanied by a comprehensive examination of document status and processing times.

4. System performance data: Following installation, system logs and performance metrics were collected over a three-month period to evaluate processing times, error rates, and user interactions with the blockchain-based POD system.

3.3 Mathematical Modelling

The mathematical modeling provides a quantitative evaluation of smart contract implementation for digitizing Proof of Delivery (POD) systems in supply chain management. The framework consists of two interconnected models: one for time efficiency optimization and another for cost-benefit analysis. These models assess the transition from traditional paper-based POD systems to digital workflows enabled by blockchain technology.

Time efficiency modelling is used to quantify the reductions in processing time throughout the document lifecycle, from shipment completion to invoice creation. The framework model encompasses multiple process stages, from initial shipment receipt to final invoice generation. The model considers both deterministic process components and framework verification steps, as well as stochastic elements like document collection delays, verification errors, and system downtimes.

The cost-benefit analysis is designed to evaluate direct costs (labour, materials, storage) and indirect costs (delayed payments, lost documents) in both traditional and blockchain-based systems. The use of the total cost of ownership (TCO) aims to provide information about the viability of implementing the model. TCO is used to identify the factors influencing the delivery note return process and assess the associated costs. It will allow for a comparison and help evaluate the potential advantages of implementing smart contract technology in the logistics and supply chain management sector.

4. Results and Discussion

System Architecture – Connection between web applications with Arbitrum Blockchain

To evaluate the feasibility of using blockchain technology as an alternative to manual delivery notes, researchers have developed a digital application that supports integration between external blockchains and internal databases. The following section offers a detailed overview of the application's development process. The infrastructure framework described below depicts a streamlined, cloud-native architecture designed for maximum efficiency and scalability. This four-layer model adheres to modern software engineering best practices, ensuring simplicity while accelerating both development and deployment (See Figure 2).

1. **User Layer - External Stakeholders**
   The platform accommodates a range of stakeholders, including drivers, transport managers, dispatchers, and consignees. Users access the system via standard web browsers utilizing secure HTTPS protocols, thereby upholding data integrity and confidentiality across devices and locations. Additionally, each user interacts with the platform through interfaces specifically designed to support their distinct roles—for example, comprehensive dashboards for logistics managers and intuitive tracking portals for consignees monitoring shipments.
2. **Web Application Container – User Interface**
   The front-end layer functions as the main interface, seamlessly linking users to the smart contract within the blockchain system. This layer comprises multiple applications designed to meet the diverse needs of various supply chain stakeholders. The Web Portal offers logistics managers, shippers, and consignees a detailed dashboard for real-time shipment tracking. Built with Next.js, the portal features a responsive design optimized

for both desktop and tablet use. The web portal was developed utilizing **Progressive Web Applications (PWAs)**, offering users a seamless, native app-like experience within web browsers. This approach eliminates the necessity for separate mobile application development and ensures offline capabilities are supported. Users can record delivery confirmations without internet connectivity, with all data automatically syncing once the connection is restored. This engine is deployed on **Google Cloud Platform (GCP)** to provide serverless container hosting, automatically scaling the web application according to user demand. This configuration eliminates the need for manual infrastructure management while maintaining consistent performance during periods of increased traffic. The web application communicates with the backend API Service using JSON over HTTPS, maintaining secure and structured data exchange. This separation enables the independent scaling and deployment of front-end and back-end components.

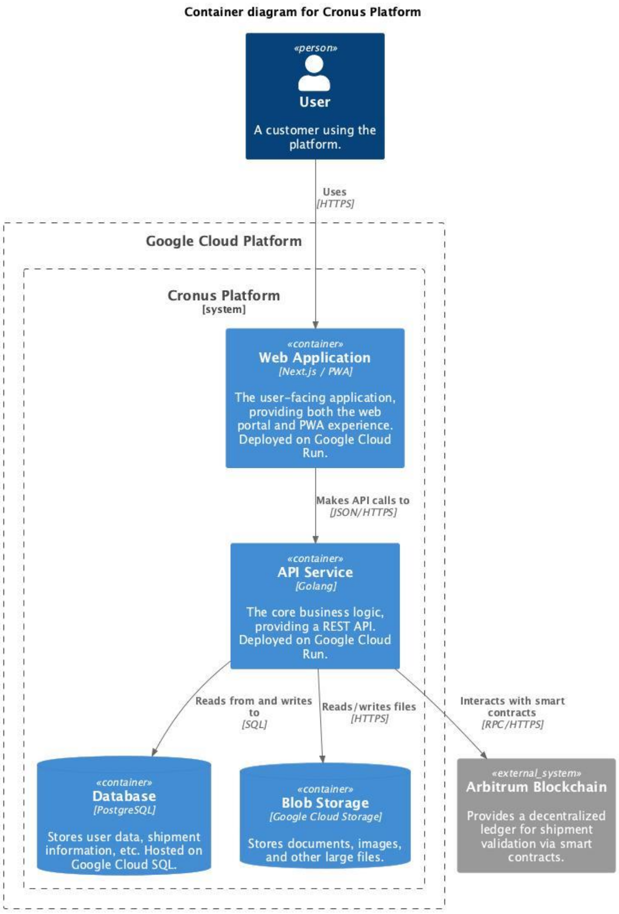

Figure 2. Infrastructure Diagram

3. **API Service Container - Business Logic Core**
   The API Service container encapsulates the core business logic, which is implemented in Golang. Golang was selected primarily due to its exceptional performance in managing concurrent tasks and its strong compatibility with blockchain integration. Acting as the central orchestrator, this container coordinates all POD-related processes. The service offers RESTful endpoints to facilitate shipment creation, status updates, delivery

confirmations, and document management. The API architecture follows established industry standards to ensuring seamless integration with external systems.

4. **Database Container - Structured Data Storage**
The Database container utilizes Google Cloud SQL's managed PostgreSQL service, which provides automated backups and high availability without requiring infrastructure management. PostgreSQL manages structured data such as user accounts, company profiles, shipment metadata, transaction logs, and audit trails. The relational database ensures data consistency and supports complex queries used in analytics and reporting. The API Service communicates with the database through standard SQL protocols, enabling efficient data operations and maintaining ACID compliance for business transactions.
5. **Blob Storage Container - File Management**
The Blob Storage container uses Google Cloud Storage to manage files at scale, including documents, images, delivery photos, and other large files used in POD operations. The API Service handles file read and write operations via HTTPS protocols, supporting various file types such as delivery images, PDF documents, and digital signatures. This setup separates file storage from the database to keep the database efficient while allowing access to files.
Google Cloud Storage provides several storage classes, allowing adjustments based on access frequency and cost. Files that are accessed frequently can be stored in hot storage, while those that are accessed less often can be automatically archived in lower-cost cold storage tiers.
The worldwide infrastructure of Google Cloud Storage enables file access across different locations, supporting supply chain operations that function in multiple regions. The Cronus database framework has been designed with consideration for international deployment, ensuring readiness should comprehensive development and implementation proceed.
6. **Arbitrum Blockchain - External Decentralized System**
The Arbitrum Blockchain functions as an external system that provides decentralized ledger capabilities. The API Service interacts with deployed smart contracts via RPC (Remote Procedure Call) over HTTPS. Smart contracts on Arbitrum are used for POD validation, automated payments, and maintaining immutable records. As a Layer 2 solution, Arbitrum offers faster transaction speeds and lower costs compared to the Ethereum mainnet, while maintaining security features. The blockchain technology ensures that POD confirmations are tamper-proof and transparently accessible to all supply chain participants, helping to resolve disputes and foster clearer trading relationships.

By leveraging the blockchain as an external system, the platform can integrate with additional blockchain networks in the future, while allowing core business logic to operate independently of specific blockchain platforms.

Implementation

The system architecture uses a modular, sequential approach that includes merchants/shippers, transporters, consignees, and administrative parties. Each phase of the shipment lifecycle is encoded with a traceable and verifiable smart contract logic to ensure immutability, automation, and real-time transparency across the supply chain.

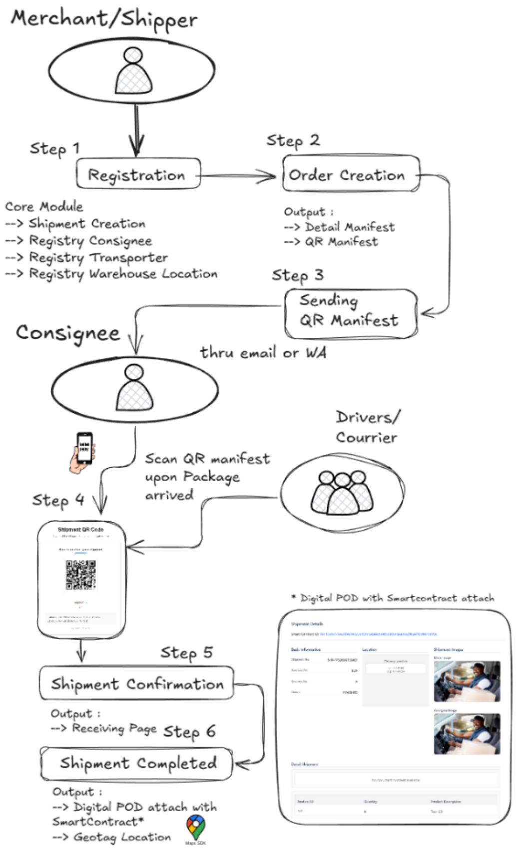

Figure 4. Framework Process Flow

There are 6 steps as shown in Figure 3 to implement the smart contract digitalization for the POD system:

Step 1: Registration and Core Module Initialization

The merchant or shipper implements the foundational data architecture within the blockchain system. This phase establishes the cryptographic foundation that ensures all future transactions authenticate each stakeholder interaction correctly and immutably record it on the blockchain ledger.

Step 2: Order Creation and Manifest Generation

The merchant initiates the order creation phase, during which a shipment request is officially generated. The system then generates a structured delivery manifest along with a QR-based shipment manifest.

Step 3: QR Manifest Distribution

The electronic delivery of the QR code to both the consignee and the courier through secure digital channels, such as encrypted email or messaging platforms. This approach replaces traditional physical exchanges and helps synchronize shipment status among all stakeholders before physical delivery.

Step 4: Package Arrival and QR Verification

The consignee uses a mobile device to scan the QR code attached to the shipment, triggering an on-chain smart contract event that confirms receipt by the authorized recipient. This scanning process opens a blockchain-secured receiving page, collecting metadata such as timestamp, geolocation, and recipient credentials to ensure strong digital proof of delivery.

Step 5: Shipment Confirmation and Smart Contract Execution

The smart contract checks validation parameters such as scan location and receiver identity. If verification is successful, a digital Proof of Delivery is automatically generated and attached to a smartcontract- Hash Code, which is securely stored on the Arbitrum blockchain and linked to the original shipment manifest to provide a traceable audit trail. The delivery status can then be accessed by authorized parties, supporting subsequent processes like invoicing or dispute resolution without manual intervention.

Step 6: Shipment Completion and Process Finalization

The smart contract updates the ledger to reflect that all contractual obligations have been fulfilled. This process creates a comprehensive, immutable, and transparent record that documenting the entire delivery process—from shipment start to recipient confirmation—eliminating reliance on paper documentation and streamlining verification procedures.

The integration of smart contracts and QR-code-enabled validation within the POD system provides a framework for automating shipment verification in supply chain operations. This digital approach enhances operational transparency, reduces administrative workload, and addresses logistical issues such as document loss or fraudulent claims. The proposed model shows potential for scalable use in logistics environments.

System Evaluation and Analysis

System evaluation and analysis were performed with three key supply chain stakeholders to assess the usability and operational feasibility of the proposed blockchain-based Proof of Delivery (POD) system. This simulation aimed to evaluate the system's performance in typical business scenarios and its capacity to execute smart contract protocols in a multi-user environment. The simulation involved collaborative participation from a shipper, a consignee, and a transporter/driver.

After implementing the system in a simulated scenario, the evaluation is conducted. There are three criteria used to evaluate the POD system: user acceptance testing, technical performance, and mathematical modelling.

User Acceptance Testing (UAT)

User Acceptance Testing (UAT) is a phase in the process of validating the functional, technical, and usability aspects of the digital Proof of Delivery (POD) system before full-scale deployment. UAT aims to confirm that the system, which includes smart contract-based automation and blockchain-integrated transaction tracking, aligns with user requirements, meets operational expectations, and functions as intended under business conditions.

The result of the MVP during UAT shows that information is flowing as per design, with the result demonstrating outstanding performance. The details are as follows.

- Network Latency: < 500ms for blockchain queries
- QR Code Processing: < 2 seconds scan-to-verification time including picture upload
- Smart Contract Execution: < 10 seconds for POD generation
- Manifest Generation Time: <5 seconds per order
- QR Code Accuracy: 100% scan success rate
- Concurrent Processing: 100 orders/minute capacity

Technical performance

Technical performance was tested using log system analysis that mimicked the actual performance of the systems' phases. The technical performance is as follows.

- Average Latency response rata-rata: 482 ms
- Time to execute the smart contract: <10 detik
- QR code scanning accuracy: 100%
- Digital system error: 0%

Mathematical modeling

The mathematical modeling consists of the evaluation for the time efficiency optimization and the total cost of wonership (TCO). Based on the simulated scenario, which utilized data from 2023 to 2025, encompassing 478,000 cargo transactions, a comparison was conducted. The manual system took 36 hours to complete all 6 steps of the POD system, while the smart contract with blockchain technology took 20 minutes to complete. The smart contract has 109 times faster than the manual one.

To evaluate the economic feasibility of implementing a smart contract-based digital system compared to a manual system in the Proof of Delivery (POD) process, TCO calculation was performed. This TCO calculation considers the number of transactions, the cost per transaction, and a 10% annual time discount rate.

The TCO of the manual system was calculated based on a total cost per transaction of Rp25,000, which includes document printing, administrative labor, data correction, physical archiving, and document returns. With an estimated number of transactions of 72,000 over three years (2,000 transactions per month), the TCO of the manual system after discounted net present value is Rp1.35 billion.

For a smart contract-based digital system, the total cost consists of two components: (1) the initial system development cost of IDR 320,000,000 (one-time cost), and (2) the operational cost per transaction of IDR 18,500. Therefore, the TCO calculation for the blockchain system provides a superior economic value of IDR 1.32 billion. There is Rp 30 million cost reduction for three year period.

5. Conclusion

This study provides empirical validation of blockchain-enabled Proof of Delivery (POD) systems through comprehensive simulations involving three major logistics stakeholders in Indonesia. The findings show significant quantitative improvements and positive qualitative feedback, thus laying a solid foundation for the adoption of blockchain technology in supply chains within emerging markets.

The blockchain POD system demonstrated enhancements across all evaluated metrics. Process time faster by 109 times compared to traditional methods. Cost per transaction was cut by 26% (saving IDR 30 million for 3 year period). Manual data entry errors dropped from 8.5% to 0%, indicating a significant boost in data accuracy. Technical performance goals were achieved, with an average response time of 2 seconds, a 100% QR scanning success rate, and full system uptime throughout the testing period.

This study makes a significant contribution to the supply chain digitalization literature by providing empirical validation of blockchain proof-of-delivery (POD) systems within real-world settings, thereby addressing existing gaps in research on practical implementation. The adoption of a three-stakeholder simulation methodology creates a replicable framework for future technology validation studies. The findings offer quantitative measurement frameworks for assessing blockchain performance and introduce user acceptance models relevant to technology adoption in emerging markets. Additionally, mathematical modeling of process efficiency, cost-benefit analyses, provide valuable methodological advancements for ongoing blockchain research.

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