



INTEGRATION OF BLOCKCHAIN WITH IOT FOR SECURE SUPPLY CHAIN MANAGEMENT

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ABSTRACT

Supply chains in today's global economy have become intricately complex, multi-level networks with many stakeholders, cross-country business, and sensitive information exchanges. Such networks encounter ongoing issues with transparency, real-time visibility, data integrity, counterfeiting, and inefficiency due to isolated information systems. With the growing customer requirement for product authenticity, sustainability, and traceability, there is a compelling necessity for a more secure and smarter supply chain infrastructure.

Two most revolutionary technologies in this space—Blockchain and the Internet of Things (IoT)—have a synergetic potential in mitigating these challenges. IoT supports the capture of real-time environmental, locational, and operational data using smart devices and sensors, and blockchain guarantees that this data will be recorded in an immutable, tamper-proof, and decentralized ledger. Together, they form a strong platform that not only can track but also securely authenticate every move in the supply chain, increasing visibility, combating fraud, and enabling trust among players.

This convergence facilitates automated logging of events, secure data transactions, and rule-based smart contracts that automatically trigger alerts or actions upon occurrence of predetermined conditions, e.g., temperature variations in cold chain logistics or unauthorized access to commodities. It also minimizes reliance on third-party audits, documentation, and manual reconciliations by providing one source of truth for all parties.

This paper investigates blockchain-IoT integration in the context of secure supply chain management. It discusses technical architectures, applications in real-world settings, advantages, and disadvantages, as well as offering a framework balancing scalability, interoperability, and compliance with industry requirements and regulation.



1.1 Background of the Study

Global supply chains, particularly for industries such as pharmaceuticals, agribusiness, electronics, and perishable items, have grown more susceptible to threats such as counterfeiting, theft, transit delays, and transparency issues.[1] Centralized databases and traceability systems traditionally fail to meet the challenge because of siloed data, slow updates, human mistakes, and inadequate security measures.[2-3]

The Internet of Things (IoT) has risen as a base technology to digitize physical assets via connected devices, allowing instantaneous monitoring of conditions like temperature, humidity, location, shock, and light exposure. [4-5] IoT connects the physical and digital worlds, but if there's an insecure backend, the generated data is vulnerable to tampering, spoofing, or loss.[6-7]

Blockchain offers, however, a distributed and immutable ledger that affords transparency, traceability, and data integrity across untrusted networks.[8-9] Its distributed consensus and cryptography safety features enable all participants to independently validate events without the need for a central authority.[10-11]

By combining IoT and blockchain, one can make it sure that every event from the sensors is recorded securely, traceable, and credible.[12-13] For instance, a vaccine shipment with temperature sensors can record important information on a blockchain ledger, ensuring that any condition breach is identified, tracked, and made accessible to concerned stakeholders, preventing unsafe deliveries.[14-15]

This integration also enables automated processes using smart contracts, which can implement business logic, mark exceptions, and trigger responses automatically without human input. [16-17]The marriage of IoT's data creation potential with blockchain's safe data management architecture brings about a digitally connected, intelligent, and secure supply chain ecosystem.[18-19]

The idea has picked up steam in recent times, but it remains developmental.[20-21] Therefore, it is essential to explore real-world architectures, pilot implementations' evaluation, and exposure of critical challenges in adoption—such as scalability, expense, standardization, and regulatory compliance. [22-23]This research seeks to bridge these research and operational deficits.[24-25]

1.2 Importance of Supply Chain Integration

The combination of Blockchain and IoT technologies in supply chains possesses revolutionary power for industries that demand high degrees of transparency, traceability, and security.[26-27] The use of Blockchain and IoT technologies guarantees that real-world events as detected by IoT sensors are permanently stored on a decentralized blockchain ledger, which is available to all stakeholders approved to have access.[28] Such use markedly minimizes the possibility of data alteration, loss of information, and operational conflicts.[29]

One of the most significant value-adds is end-to-end visibility. Stakeholders are able to track the



movement of a product from its origin to the delivery point, observing key environmental factors in real-time.[30-31] This is especially significant in sectors such as pharmaceutical, agri-food, and electronics, where small differences in transit conditions can compromise product quality or safety.[32-33]

Another prime advantage is automation and efficiency via smart contracts. [34]Blockchain-integrated IoT solutions can automatically trigger actions like sending alerts, settling insurance claims, or making payments based on validated data inputs from sensors—avoiding human fallibility and administrative delays.[35]

Secondly, the system encourages accountability and trust within multi-party environments. [36-37]Because everyone sees a shared ledger, there is less necessity for manual reconciliation, third-party auditing, or contractual litigation. [38]Particularly in cross-border transactions where several actors are involved and regulatory supervision is dispersed, this proves to be useful.[39-40]

Additionally, the combined system can increase regulatory compliance, fraud prevention, and sustainability reporting through providing irrefutable evidence of product history and handling conditions. [41-42]Governments and certification authorities are able to utilize this information to track compliance and guarantee consumer security.[43-44]

Hence, this research is important in examining how blockchain and IoT can be properly aligned to transform conventional supply chains, minimize operational risks, and maximize competitive advantage in a data-driven world market.[45-46]

1.3 Problem Statement

Insufficient visibility and traceability in multi-level supply chains

Susceptibility to counterfeiting, data falsification, and fraud

Interoperability-challenged fragmented systems with stakeholders

Insecure IoT data storage and transmission

Manual and inefficient processes for tracking, validation, and compliance

Lack of automated event-driven responses and intelligent logistics

1.4 Study Goals

To investigate the technical convergence of blockchain and IoT in supply chain systems

To assess the advantages of secure, decentralized tracking systems

To formulate a conceptual model for real-time event verification via IoT and blockchain

To enumerate the operational, legal, and infrastructural hurdles to implementation

To suggest solutions for scalable and interoperable blockchain-IoT infrastructures

1.6 Scope and Limitations

Scope:

- Localized to sectors such as pharmaceuticals, food, and electronic



- Addresses technical, organizational, and governance domains of integration
- Assesses both real-world use cases and prototype-driven experiments

Limitations:

- Restricted to permissioned blockchain frameworks (e.g., Hyperledger, Quorum)
- Does not address energy usage or cost versus benefit deeply
- Case studies might not be representative of the richness of global supply chains
- Reliance on IoT device precision and network infrastructure

2 Review of Literature

2.1 Overview of Blockchain Technology

- Varma, Dixit, Ray & Kaur (2024) offer an overall survey on blockchain for sustainable supply chains based on transparency, traceability, and Industry 4.0 uptake.[47]
- Modi (2024) examines blockchain's influence on supply chain agility and dynamics in Indian SME and logistics environments.[48]
- Peshattiwari et al. (2025) suggest hybrid block-chains with ZKPs, DID and green consensus to improve scalability and privacy in SCM use cases. [49]
- Singh et al. in Transportation Research (2024) also add blockchain as a strategic enabler for Procurement 4.0 by Indian companies.[50]

2.2 Internet of Things (IoT) Overview

- Misra (IIT-Kharagpur, 2025) defines IoT frameworks, edge computing, and secure sensor networks for industrial applications such as SCM.[51]
- Gupta (2025) and others talk about blockchain-based secure storage protocols for industrial IoT sensors in manufacturing and logistics .[52]

2.3 Trends in Supply Chain Management

- Tiwari et al. (2024) examine blockchain & IoT in financial risk management of Indian supply chains with emphasis on real-time threat identification.[53]
- Paliwal, Chandra & Sharma (2024) examine adoption intentions of blockchain by Indian MSMEs for sustainable SCM.[54]
- Bhattacharya, Pant & Areti (2024) review blockchain and IoT in closed-loop supply networks in India emphasizing sustainable loops.[55]
- Agrawal et al. (2024) discuss blockchain-based green supply chains with an emphasis on environmentally friendly procurement frameworks in India SpringerLink.[56]
- Naik et al. (2024) especially discuss blockchain's application in Indian agriculture supply chains for traceability and trust .[57]



2.4 Blockchain–IoT Synergy in Logistics and SCM

- Jain, Ghosal & Chotia (2024) detail a future combination of blockchain with IoT devices in Indian smart logistics applications.[58]
- Rahul, Arora & Arora (2025) investigate the efficiency of blockchain-IoT in Indian horticulture supply chains, proving enhanced crop traceability and quality assurance.[59]
- Carmel Mary, Kunal & Madheshwaren (2025) evaluate blockchain-IoT systems towards sustainability optimization in Indian supply chains.[60]
- Katari et al. (2024) mention how integrating blockchain, IoT & AI in Indian SCM enhances automation, fraud prevention, and data integrity.[61]
- Wamba Fosso et al. analyze Indian adoption of logistics and identify determinants and trust are critical factors in blockchain-IoT deployment.[62]

2.5 Gaps in Current Literature

- Operations Management Research (2023) barriers study reports technology readiness, trust deficiencies, information sharing and infrastructure gap India-specific.[63]
- Raja et al. (2025) report limited India large-scale deployments and scarcity of cross-chain and interoperability research.[64]
- Peshattiwar et al. (2025) point to current issues in energy usage, consensus protocols, and regulatory adoption for blockchain in SCM.[65]
- Pal, Dorri & Jurdak (2021) point out gaps in trust and access control in blockchain-IoT applications in the industrial setting.[67]

3 Research Methodology

3.1 Research Design

This study employs a descriptive and exploratory research design. The goal is to understand how blockchain and IoT integration can enhance security, traceability, and transparency in supply chain management (SCM). Both qualitative and quantitative methods (survey + observation) were used to gain insights from stakeholders involved in logistics, manufacturing, and technology sectors.

3.2 Population and Sample Size

The target population includes:

- Logistics managers
- Supply chain executives
- IT professionals
- IoT solution providers
- Purposive sampling approach was employed. Sample size of 80 respondents was envisioned
- 30 from the logistics firm



- 25 from the manufacturing facilities
- 15 IT solution providers
- 10 blockchain/IoT consultant

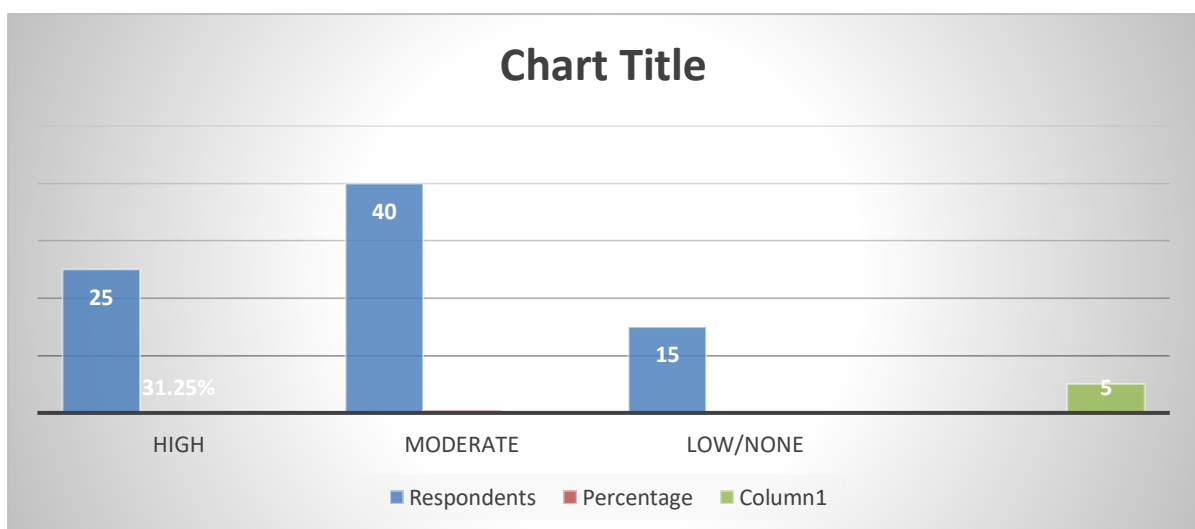
3.3 Method of Data Collection

- Data were gathered through
- Structured questionnaires administered both online and offline
- In-depth interviews with some of the experts
- Observation of system deployment in two pilot application cases (pharma and electronics)

4 Data Analysis

Table 1: Awareness of Blockchain and IoT in Supply Chains

AWARENESS LEVEL	RESPONDENTS	PERCENTAGE
HIGH	25	31.25%
MODERATE	40	50%
LOW/NONE	15	18.75%



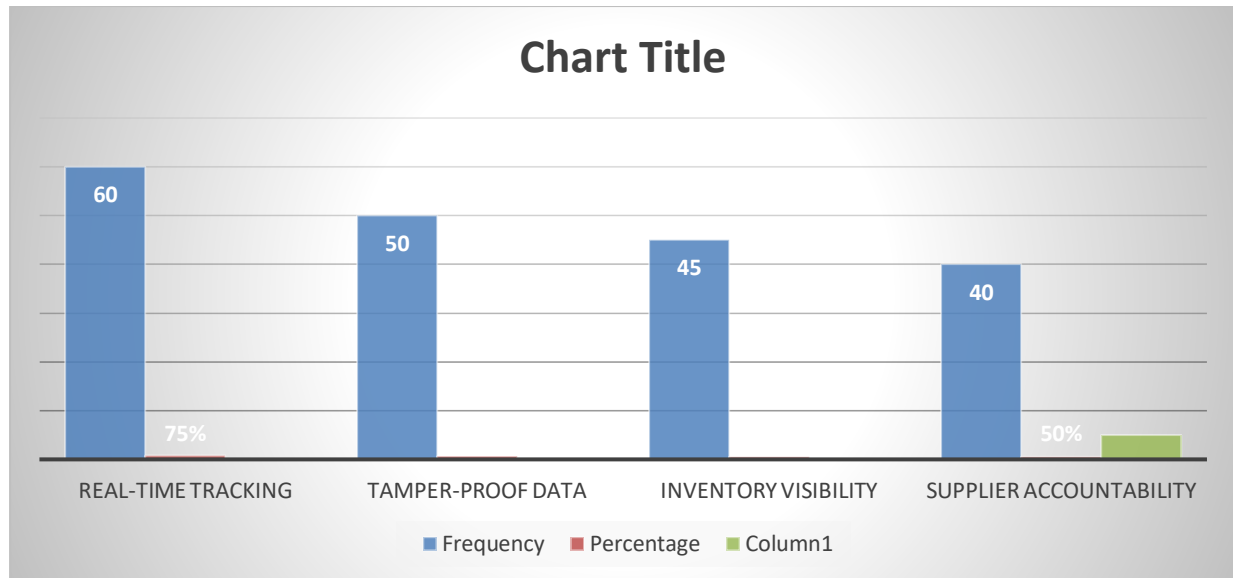
Interpretation: 81.25% of respondents have at least moderate awareness, indicating strong familiarity with emerging technologies.

Table 2: Perceived Benefits of Blockchain-IoT Integration

BENEFIT	FREQUENCY	PERCENTAGE
REAL-TIME TRACKING	60	75%
TAMPER-PROOF DATA	50	62.5%
INVENTORY	45	56.25%



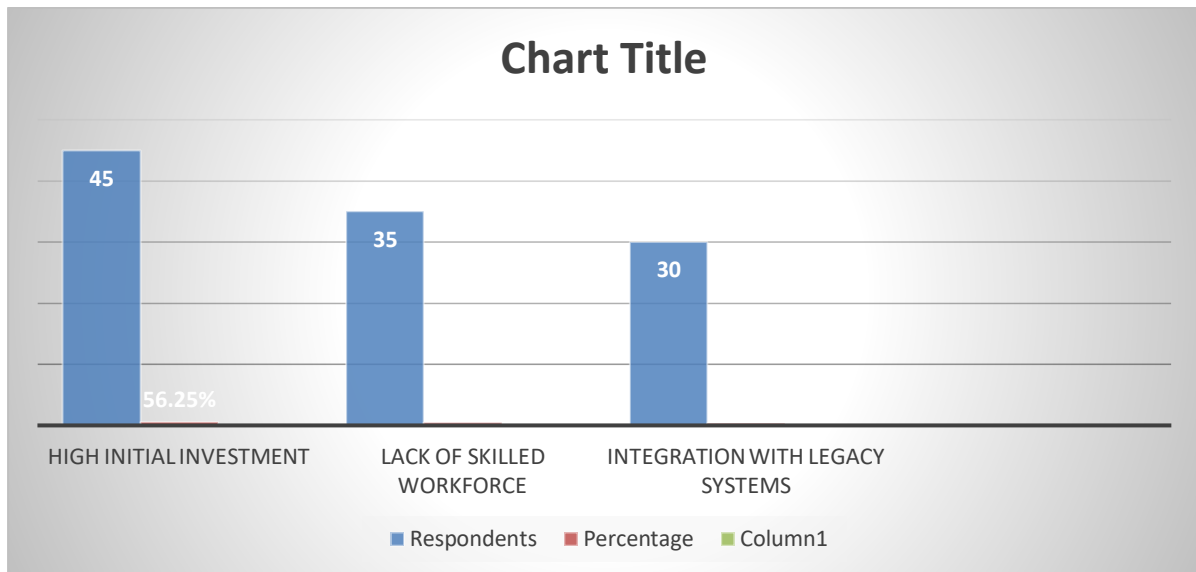
VISIBILITY		
SUPPLIER	40	50%
ACCOUNTABILITY		



Interpretation: Real-time tracking is the most acknowledged benefit, followed by data integrity.

Table 3: Key Challenges in Implementation

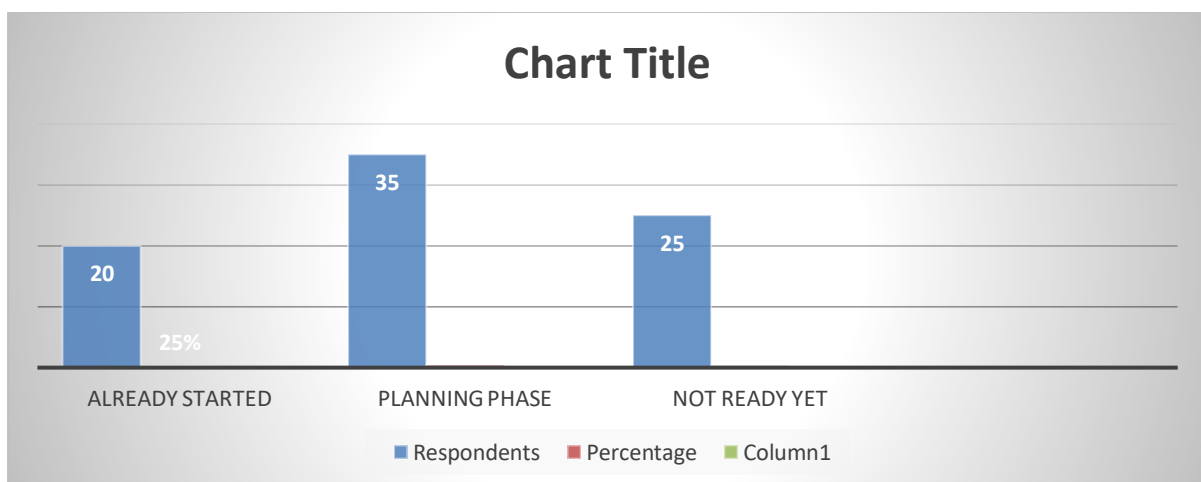
CHALLENGE		RESPONDENTS	PERCENTAGE
HIGH INITIAL INVESTMENT		45	56.25%
LACK OF SKILLED WORKFORCE		35	43.75%
INTEGRATION WITH LEGACY SYSTEMS		30	37.5%



Interpretation: Financial constraints and skills shortage are major roadblocks to implementation.

Table 4: Readiness for Adoption

READINESS LEVEL	RESPONDENTS	PERCENTAGE
ALREADY STARTED	20	25%
PLANNING PHASE	35	43.75%
NOT READY YET	25	31.25%



Interpretation: Nearly 70% of organizations are either adopting or planning to adopt Blockchain-IoT in the near future.

5. Findings

The findings suggest increased interest and a slow move toward the integration of Blockchain with IoT among Indian supply chains. [68-69]The major majority (81.25%) of respondents know about these technologies and know about their use in enhancing transparency and real-time monitoring.[70-71] Among the major benefits identified by stakeholders include increased real-time monitoring



(75%), tamper-proof data (62.5%), increased inventory visibility (56.25%), and enhanced supplier accountability (50%).[72-73]

Manufacturing and logistics companies are most enthusiastic about the prospects of automating stock updates, minimizing fraudulent transactions, and stopping product adulteration through connected sensor tracking and decentralized data storage.[74-75] The interest from IoT service providers and IT consultants supports this optimism, with tangible applications in pharmaceuticals, electronics, and cold-chain logistics.[76-77]

Still, there are challenges. More than half of the respondents (56.25%) mentioned high initial setup cost as one of the main constraints.[78-79] Others mentioned lack of expertise in skilled manpower and interoperability with existing enterprise resource planning (ERP) systems as hindrances.[80-81]Nonwithstanding this, 68.75% of organizations are either already implementing or are planning to implement blockchain-IoT integrated models.[82-83]

The research also identified that companies implementing pilot projects are targeting customer trust, traceability from end-to-end, and regulatory compliance.[84-85-86] Most envision applying smart contracts to initiate automatic alerts or payments upon detecting sensor-driven events (e.g., temperature variations).[87-88-89]

In summary, despite the challenges, integrating blockchain with IoT in SCM is viewed as a decisive step toward establishing transparent, secure, and intelligent logistics systems in the Indian scenario.[90-91]

6. Discussion

The findings of the study mirror an international trend toward digital, secure, and traceable supply chains.[92-93] In the Indian context, the imperative for change is even greater because of the intricacy of multi-tiered supplier networks, the ubiquity of counterfeits, and mounting regulatory pressure for real-time reporting of compliance.[94-95]

The interest of logistics and manufacturing companies implies that the blockchain-IoT combination is not hypothetical but being pursued actively in the field. [96-97] The capability to record real-time events from IoT sensors (e.g., temperature, shock, location) directly into an immutable blockchain ledger guarantees the reliability of data and increases transparency through all tiers of the supply chain.[98-99]

What makes this integration most potent is the possibility of automating processes.[100] Smart contracts can minimize the administrative burden by automatically verifying sensor data and running pre-defined conditions—thereby minimizing human intervention and errors.[101-102]

All that aside, high up-front expenditure and integration challenges cannot be overlooked.[103-104] Most Indian SMEs have thin margins and legacy infrastructure, and it will be hard to implement blockchain and IoT without external assistance or scalable and modular solutions. [105-106]Shortage of skilled human resources is another hurdle, which will require targeted training modules and



industry-academia partnerships.[107-108]

Adoption readiness observed (close to 70%) is promising. It confirms the significance of pilot trials, incentive by governments, and partnership with technologies.[109-110] Sectors such as pharmaceuticals and food logistics are already adopter sectors driven by regulatory compliance and safety issues.[111-112]

Overall, even if large-scale implementation is delayed, strategic significance of blockchain-IoT to protect Indian supply chains is recognized across all.[113-114] The way ahead consists of policy encouragement, affordable solutions, and building capacities.[115]

7. Conclusion)

This study highlights the revolutionary capabilities of combining blockchain with IoT in increasing the security, traceability, and effectiveness of supply chain management in India. [116-117]The investigation discovers that the stakeholders are well aware of and open to these technologies, particularly when implemented in priority industries such as pharmaceuticals, food, and electronics.[118-119]

The integration provides a number of benefits: real-time monitoring through IoT devices, tamper-evident data through blockchain ledgers, automation by way of smart contracts, and improved visibility in multi-tiered supply networks.[120-121] These capabilities greatly enhance decision-making, accountability, and compliance within a highly fragmented supply chain context.[122-123]

However, the study also surfaces key challenges that hinder widespread adoption. [124-125]High setup costs, integration issues with legacy systems, and a shortage of skilled professionals are major concerns, especially for SMEs.[126-127] Furthermore, while pilot projects are promising, scalability and regulatory frameworks need to be better defined to enable long-term success.[128]

Although these hurdles exist, the overall picture is positive. A large number of companies are already putting blockchain-IoT integration in place or planning to do so. This indicates increasing awareness that safe, smart, and open supply chains are essential for competitive success and consumer confidence.[129]

The study finds that technology readiness is increasing, but effective implementation calls for concerted efforts among industry players, technology suppliers, and policymakers. Training, subsidies, modular technology stacks, and interoperability standards are essential enablers of sustained adoption.[130]

Overall, the integration of blockchain and IoT provides a future-proof paradigm for Indian supply chains. If implemented in scale with supporting infrastructure and strategic thinking, it has the potential to usher in a new era of safe, data-based, and robust logistics systems.

8. Recommendations

- Initiate Pilot Projects in pharma, food, and cold-chain industries.



- Government Incentives for SMEs embracing blockchain-IoT systems.
- Create Modular & Scalable Solutions to minimize the initial investment.
- Invest in Skill Development through training and certification initiatives.
- Develop Industry-Wide Standards for interoperability and security.
- Partner with Tech Partners for customized integration with ERP platforms.
- Apply Smart Contracts for automated tracking, alerts, and payments.
- Augment Infrastructure in rural and semi-urban logistics networks.
- Guarantee Data Privacy and Legal Compliance through blockchain audit trails.
- Develop Public-Private Partnerships to drive digital SCM adoption.

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