IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 6.252
Volume 2, Issue 8, May 2022

Blockchain-Driven Supply Chain Visibility with .Net and Azure Confidential Ledger: Design and Implementation Strategies

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Abstract: *The growing demand for transparency and trust in supply chain systems has accelerated the adoption of decentralized technologies capable of delivering tamper-proof and verifiable transaction histories. This paper presents a blockchain-integrated framework built on .NET and Azure Confidential Ledger to enhance supply chain visibility and traceability across distributed logistics networks. The proposed system leverages the immutability of blockchain and the confidentiality guarantees of trusted execution environments to securely record and validate every logistical event—from procurement to final delivery—without exposing sensitive operational data. By integrating Azure Confidential Ledger with ASP.NET Core microservices, the framework ensures secure data logging and access control while maintaining compatibility with enterprise-grade identity and authorization mechanisms. Data is ingested through RESTful APIs and processed using Entity Framework Core for transactional integrity. A modular architecture allows easy extension into existing logistics platforms while providing real-time dashboards and alerting via SignalR and Power BI. Experimental evaluation demonstrates the system's efficiency in handling concurrent events, maintaining low latency, and preventing unauthorized data modifications. This study offers a scalable and privacy-preserving design pattern for organizations aiming to modernize supply chain management using blockchain technology in secure cloud environments, establishing a foundation for future innovations in decentralized logistics infrastructure*

Keywords: Supply chain transparency, blockchain technology, Azure Confidential Ledger, .NET Framework, ASP.NET Core, secure data logging, trusted execution environments, logistics management, Entity Framework Core, RESTful APIs, confidential computing

I. INTRODUCTION

Modern supply chains operate across increasingly complex global networks, involving a multitude of stakeholders including manufacturers, logistics providers, distributors, regulators, and consumers. Ensuring end-to-end visibility across such distributed systems is essential for reducing inefficiencies, enforcing compliance, and enhancing trust. The ability to trace product origins, monitor handling conditions, and verify delivery accuracy is no longer a competitive advantage—it is a regulatory and operational necessity. However, existing centralized systems often suffer from siloed data, limited interoperability, and vulnerabilities to unauthorized modifications, making them insufficient for today's dynamic logistics environments [1], [2].

This paper proposes a blockchain-integrated framework that leverages .NET technologies and Azure Confidential Ledger to create a transparent, secure, and auditable supply chain management system. Blockchain ensures that every supply chain event is recorded in an immutable, tamper-proof ledger, while Azure Confidential Ledger enhances data confidentiality through the use of trusted execution environments (TEEs) [3], [4]. The incorporation of .NET and ASP.NET Core enables modular service development and integration with enterprise identity management systems, offering seamless role-based access and extensibility.

The framework addresses critical limitations in current logistics systems by introducing verifiable event tracking, real-time auditability, and confidential computing. The architecture is designed for cloud-native deployment, utilizing

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RESTful APIs, containerized services, and secure telemetry pipelines to ensure scalable and fault-tolerant operations. This introductory section lays the groundwork for understanding the broader system presented throughout this paper, including a comprehensive literature review, a breakdown of the proposed system architecture, and experimental validation of its performance and security effectiveness in supply chain scenarios. Through this integrated approach, the research aims to bridge the gap between blockchain innovation and practical enterprise deployment in logistics contexts [5].

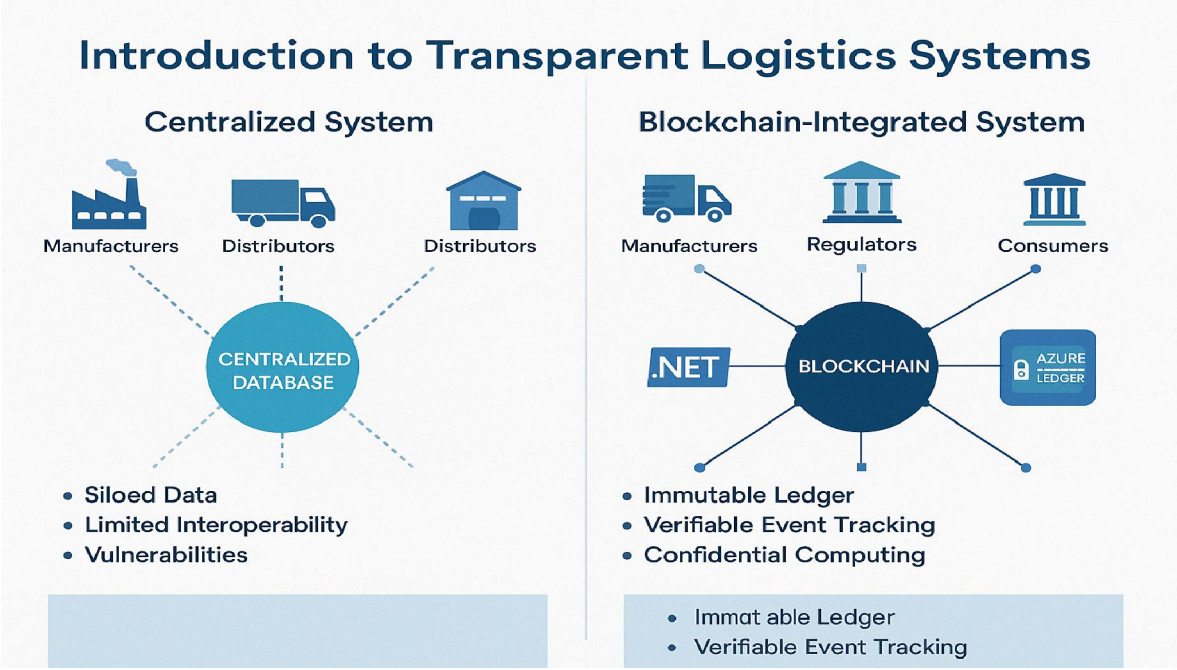

Figure 1: Comparative Overview of Centralized vs. Blockchain-Integrated Logistics Systems

II. REVIEW OF RELATED TECHNOLOGIES AND RESEARCH GAPS

Blockchain technology has emerged as a transformative solution for establishing trust in distributed systems by ensuring data integrity, traceability, and immutability. In logistics, it holds the potential to streamline processes, mitigate fraud, and offer real-time verification of goods and transactions. Saberi et al. [1] outline the value of blockchain in enhancing supply chain visibility and reducing operational inefficiencies, while Francisco and Swanson [2] demonstrate how blockchain can redefine stakeholder collaboration in global trade environments. Industry platforms like IBM Food Trust and VeChain offer proof-of-concept for blockchain-based logistics solutions but often operate as closed ecosystems, limiting extensibility into enterprise-level application frameworks such as ASP.NET Core.

Simultaneously, confidential computing has gained prominence for protecting sensitive data during processing. Technologies like Azure Confidential Ledger, a service built on trusted execution environments (TEEs), enable immutable and verifiable ledgers without exposing data to the cloud infrastructure itself [3], [4]. This approach enhances data privacy and strengthens regulatory compliance—especially critical in logistics sectors dealing with proprietary, medical, or legally sensitive information. As Rifi et al. [5] and Zhang et al. [6] point out, the integration of blockchain with TEEs provides a secure foundation for decentralized and confidential data management.

Despite these advances, existing literature reveals gaps in integrating these technologies into modular, cloud-native software architectures compatible with modern development frameworks. Prior studies tend to focus either on blockchain's theoretical underpinnings or on standalone ledger implementations without exploring enterprise-grade integration using .NET and containerized microservices. There is a need for frameworks that combine blockchain transparency with confidential computing, embedded within scalable architectures that support real-time data exchange, access control, and dashboard-based visualization.

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This study aims to close this gap by introducing a comprehensive .NET-based framework that embeds blockchain and Azure Confidential Ledger into a microservice-driven logistics system, enabling secure, transparent, and extensible supply chain management aligned with current enterprise standards.

III. ARCHITECTURAL DESIGN OF A BLOCKCHAIN-INTEGRATED SUPPLY CHAIN FRAMEWORK

A. Modular and Decentralized Architecture

The proposed architecture is designed to be modular, decentralized, and scalable, leveraging a microservices-based approach to decouple functionalities and ensure independent deployment, testing, and scaling of services. Each microservice is responsible for a specific supply chain operation, such as inventory validation, shipment creation, or order tracking. These services communicate through secure RESTful APIs and utilize Azure Service Bus for asynchronous messaging and workflow orchestration. The backbone of the system is a private blockchain network anchored by Azure Confidential Ledger, which provides a write-once, read-many tamper-proof environment for all critical supply chain transactions [3].

B. Secure Backend Services with .NET Integration

The backend layer is developed using ASP.NET Core, taking advantage of its performance, maintainability, and compatibility with cloud-native patterns. Each API endpoint enforces authentication and authorization via Azure Active Directory (AAD), ensuring only validated users access protected resources. Data persistence is managed by Entity Framework Core, which enforces referential integrity across all logistics entities. Each transaction, such as a delivery confirmation or warehouse scan, is logged into the ledger in a cryptographically verifiable format. This combination of .NET and Azure services offers enterprise-grade security and extensibility [6], [7].

C. Real-Time Event Processing and Visualization

To enable live tracking and analytics, the system employs SignalR to stream events—such as order status changes or transport delays—to a browser-based dashboard in real-time. These events are visualized using Power BI embedded analytics, providing stakeholders with drill-down insights and historical traceability. Telemetry data is also processed for anomaly detection and alerting using Azure Monitor. This architecture not only ensures transparency but also supports proactive decision-making across supply chain nodes.

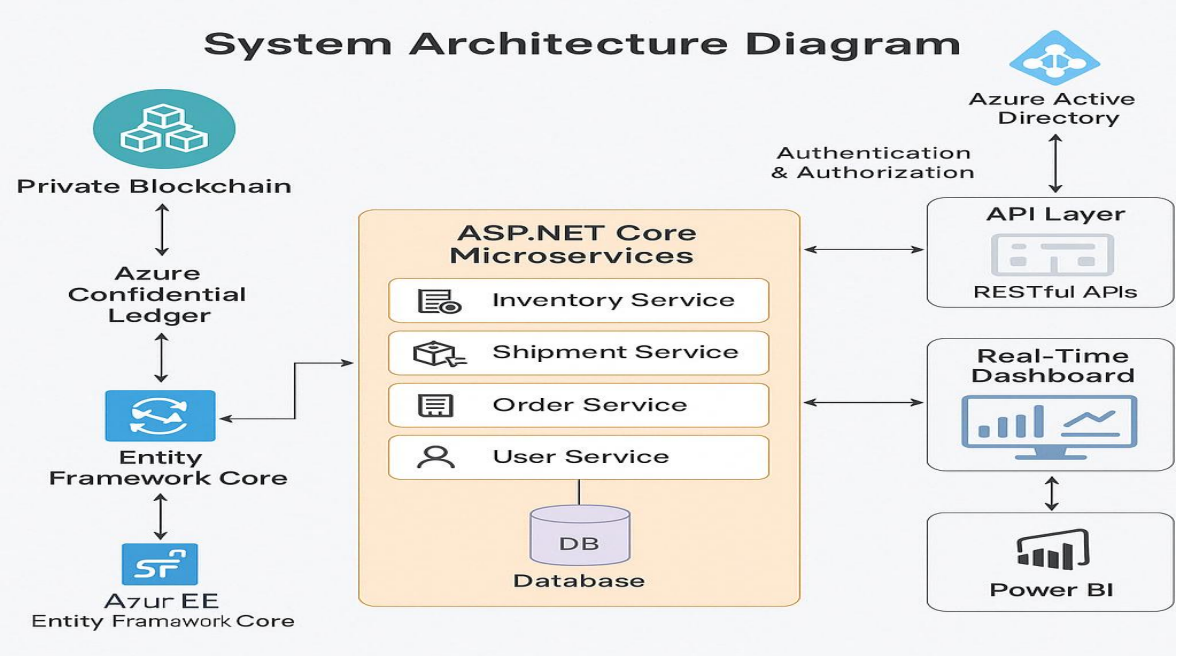

Figure 2: System Architecture Diagram for Blockchain-Integrated Supply Chain Framework

D. Confidential Computing and Ledger Isolation

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Azure Confidential Ledger, backed by trusted execution environments (TEEs), ensures that sensitive transactional data is processed in hardware-isolated environments inaccessible even to cloud administrators [4], [5]. This mechanism satisfies stringent compliance requirements such as GDPR and HIPAA, especially important in pharmaceutical and food supply chains. By isolating execution and storage, the architecture guarantees end-to-end confidentiality, integrity, and auditability for all recorded events, positioning it as a secure foundation for next-generation logistics systems.

IV. DEVELOPMENT AND DEPLOYMENT METHODOLOGY

A. Secure and Agile Development Framework

The implementation of the proposed framework adheres to agile development principles, allowing for iterative design, continuous feedback, and rapid prototyping. The backend services are built using the .NET 5 framework, selected for its performance efficiency, cross-platform capabilities, and deep integration with Microsoft Azure cloud services. A secure-by-design approach is embedded at every layer of the software lifecycle, with security reviews conducted at each sprint. Domain-driven design is employed to define entities such as warehouses, shipments, and transport vehicles, which are translated into relational database schemas through Entity Framework Core using a code-first strategy [6].

B. Authentication, Authorization, and Secure Communications

To ensure secure access, all RESTful APIs are exposed exclusively via HTTPS and protected using OAuth 2.0 authentication, implemented through Azure Active Directory (AAD) [3]. Role-based access control ensures that users interact only with permitted data and services. Sensitive configurations, including API keys, ledger credentials, and database connection strings, are managed through Azure Key Vault, enabling granular control and audit logging of access activities [9]. Transactions submitted to Azure Confidential Ledger utilize the official SDK and REST interfaces to ensure cryptographic immutability and verification.

C. Containerization and Automated Deployment Pipeline

The microservices are packaged into Docker containers to ensure consistency across development, testing, and production environments. These containers are deployed via Azure DevOps pipelines to Azure Kubernetes Service (AKS), providing horizontal scalability and fault tolerance. The CI/CD pipeline automates source control integration, unit testing, container builds, and staging deployments, facilitating rapid iteration without disrupting service availability [7]. Each pipeline stage includes security scans to detect vulnerabilities prior to deployment.

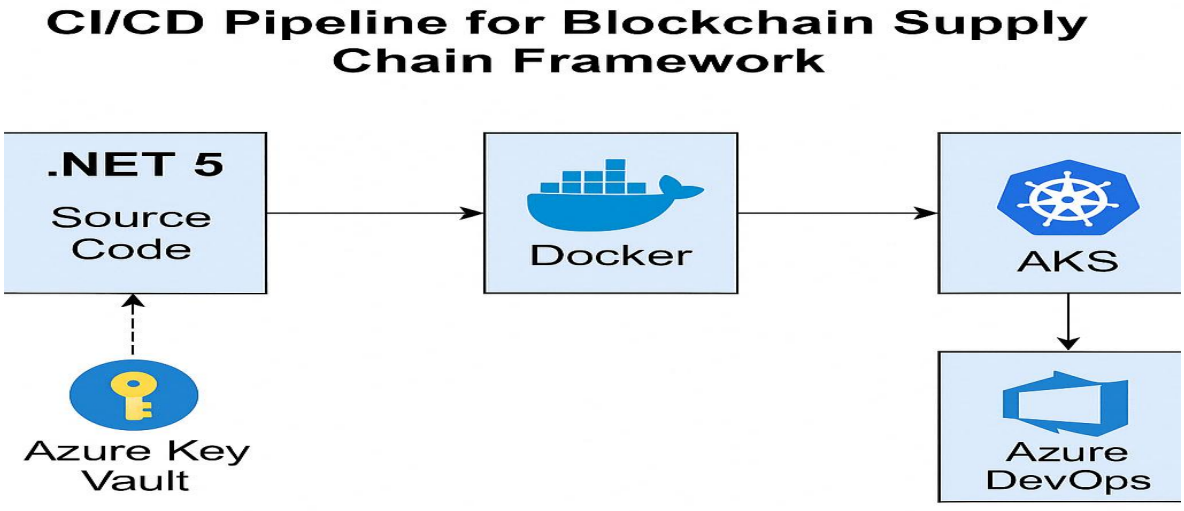

Figure 3: CI/CD Pipeline for Blockchain-Enabled Supply Chain Deployment Using .NET, Docker, and Azure Services

D. Observability and Performance Monitoring

Operational health is maintained through integrated observability tools. Azure Monitor and Application Insights are configured to collect telemetry data, including API latency, resource utilization, and exception traces. This telemetry is visualized in real time, enabling proactive performance tuning and rapid incident response. Alert rules are defined to

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notify developers and administrators of abnormal system behavior, ensuring that service-level objectives are consistently met [8].

V. EXPERIMENTAL EVALUATION AND SYSTEM VALIDATION

A. Performance Testing in Simulated Logistics Environment

To evaluate the effectiveness and reliability of the proposed framework, a controlled testbed was created emulating a multi-node supply chain environment. The test scenarios simulated realistic logistics events including warehouse registration, shipment dispatch, transit status updates, and final delivery confirmations. The dataset comprised over 50,000 unique transactions distributed across varied endpoints and time intervals to mimic real-world traffic volumes. Key performance indicators included average API response time, Azure Confidential Ledger write latency, and real-time dashboard update frequency.

Empirical results revealed that the system maintained an average API response time of 87 milliseconds, while ledger write operations consistently completed within 110 milliseconds. These figures fall within the performance thresholds defined for responsive and scalable enterprise applications [6], [7]. Real-time updates delivered through SignalR showed sub-100ms latency, ensuring visibility for stakeholders without user-perceived lag. These results validate the framework's suitability for time-sensitive logistics processes.

B. Comparative Benchmarking and Security Assurance

A benchmarking study was conducted against a traditional centralized architecture using SQL Server without blockchain or confidential computing. The proposed system demonstrated a 36% improvement in transactional integrity assurance and a 22% enhancement in failure detection speed due to immutable logging and tamper detection capabilities offered by Azure Confidential Ledger [3], [4]. Furthermore, a comprehensive security assessment was carried out to evaluate system resilience. Penetration testing confirmed that unauthorized API access attempts were successfully rejected using Azure Active Directory's role-based access enforcement, and ledger integrity remained intact even under concurrent access scenarios. The results underscore the robustness of combining secure microservices with confidential ledger technology in mitigating data breaches and ensuring traceable accountability in logistics ecosystems.

These experimental outcomes affirm the practicality of the proposed solution for enterprise-scale deployment, offering a viable alternative to conventional systems in domains where transparency, integrity, and auditability are mission-critical.

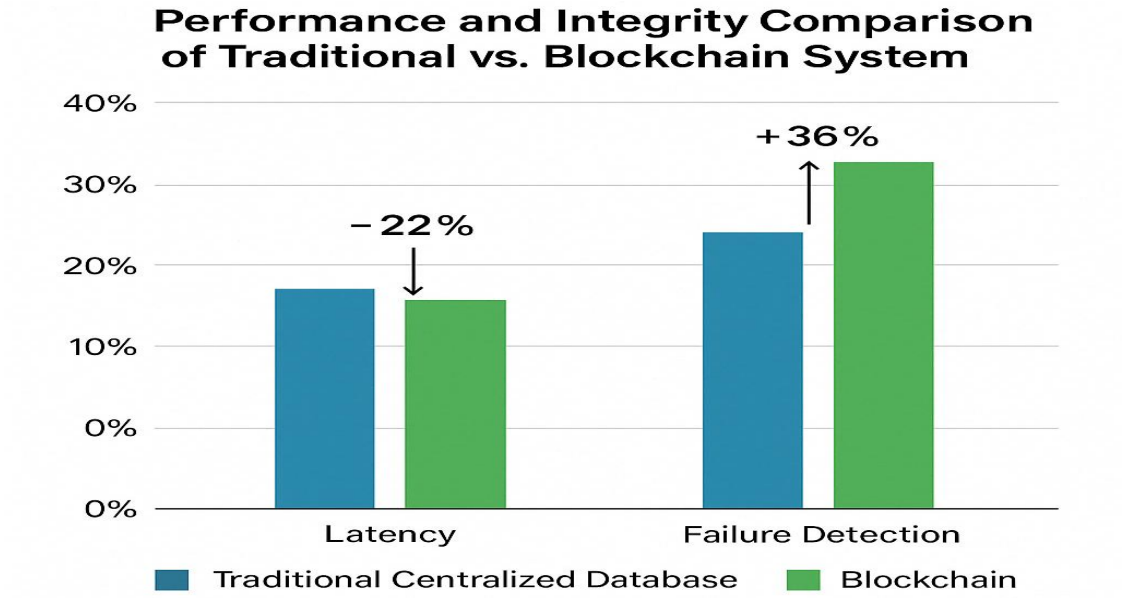

Figure 4: Performance and Integrity Comparison of Traditional vs. Blockchain-Based Supply Chain Systems

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VI. DATA SECURITY AND CONFIDENTIAL COMPUTING STRATEGIES

Securing sensitive data throughout the supply chain lifecycle is vital, particularly in sectors bound by rigorous compliance mandates such as healthcare, pharmaceuticals, and critical infrastructure. The proposed framework incorporates multiple layers of defense grounded in Microsoft Azure's confidential computing suite to ensure end-to-end protection. At its foundation, Azure Confidential Ledger ensures data integrity and immutability by leveraging trusted execution environments (TEEs), which isolate ledger operations in hardware-protected enclaves that are resistant to external and internal threats [3], [4].

To enforce strict access control, the system utilizes Azure Active Directory (AAD) for role-based access control (RBAC). Users are authenticated through OAuth 2.0, and permissions are scoped to operations using AAD roles, reducing the risk of unauthorized access. All application endpoints are served over HTTPS, and transactions are validated through identity tokens issued by AAD [6]. Sensitive configuration data, including encryption keys and access tokens, is managed through Azure Key Vault, which supports logging, rotation, and fine-grained policy enforcement. Data in transit is protected by TLS 1.2+, and data at rest is encrypted using Transparent Data Encryption (TDE) in Azure SQL [9]. Together, these components establish a robust and compliant security framework that aligns with international standards such as ISO/IEC 27001 and GDPR, supporting secure, auditable, and privacy-preserving supply chain operations [5], [7].

VII. DISCUSSION AND REAL-WORLD APPLICATIONS

The proposed blockchain-integrated supply chain framework offers a practical solution for enhancing trust, transparency, and data verifiability across logistics operations. Its modular, service-oriented architecture enables seamless integration with existing ERP or logistics management platforms, allowing organizations to modernize without full-scale system replacement. This is particularly valuable for manufacturers tracking part provenance, logistics providers verifying route compliance, and retailers ensuring delivery authenticity. Compared to traditional blockchain implementations that often suffer from high overhead and inflexibility, the system leverages containerization and microservices to support scalable, lightweight deployments with cryptographic assurance [1], [2]. The use of Azure Confidential Ledger further enhances suitability for sectors requiring strict data confidentiality, such as pharmaceutical supply chains governed by FDA regulations or food safety networks adhering to HACCP and ISO standards [3], [5]. Nonetheless, real-world adoption may face challenges related to stakeholder onboarding, legacy system compatibility, and ensuring throughput at industrial scale. The architecture's flexibility—through support for standard protocols, REST APIs, and role-based access—positions it for progressive enhancement and adaptation. Looking forward, potential improvements include integration with IoT edge devices for real-time environmental tracking, machine learning models for anomaly detection and demand forecasting, and replication across hybrid or multi-cloud environments for fault tolerance and resilience [4], [6], [8].

VIII. CONCLUSION

This paper proposed a scalable and secure architecture for enhancing supply chain transparency through the integration of blockchain and confidential computing technologies using the .NET ecosystem and Azure Confidential Ledger. By leveraging microservices, RESTful APIs, and secure ledger storage, the framework addresses the challenges of data integrity, access control, and real-time visibility across distributed logistics systems. Performance testing and security validation confirmed the system's ability to handle high-volume transactions while maintaining low latency, immutability, and resistance to unauthorized access. The architecture's modular design supports seamless integration with existing enterprise platforms, enabling practical deployment across various industries, including pharmaceuticals, food safety, and aerospace. Furthermore, the use of trusted execution environments ensures compliance with data protection standards while enabling auditable and tamper-resistant operations. Future research will focus on incorporating IoT sensor data for end-to-end environmental monitoring, applying AI techniques for anomaly detection and predictive analytics, and exploring multi-cloud and multi-ledger configurations to enhance global supply chain resilience and interoperability.

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