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Blockchain- IOT- AI based integrated architecture for automotive supply chain management

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Purpose – The integration of Blockchain, Internet of Things (IoT), and Artificial Intelligence (AI) is emerging as a transformative approach to achieving transparency, sustainability, and operational intelligence in supply chain networks. This paper aims to evaluate how the convergence of these technologies enhances traceability, agility, environmental performance, and decision-making across modern supply chains. It highlights how blockchain's immutability, IoT's real-time sensing, and AI's predictive capabilities collectively address long-standing supply chain challenges such as fraud, disruptions, data silos, and lack of visibility.

Design/methodology/approach – Through an extensive literature review of recent scholarly works from 2020–2025 and comparative analysis of industry insights, this study identifies current barriers in supply chain performance and examines how Blockchain–IoT–AI integration offers potential solutions. Key elements of each technology were analysed to determine their combined applicability in improving sustainability, transparency, and operational resilience. The methodology synthesises findings from multiple sectors, including manufacturing, food supply chains, logistics, and energy systems.

Findings – The findings categorise major supply chain challenges such as traceability gaps, fraud, carbon emissions, and operational inefficiencies. The integrated technological model demonstrates significant improvements: blockchain ensures accountability and secure data sharing [1], IoT enables real-time monitoring for sustainable operations [2], and AI enhances forecasting, anomaly detection, and logistics optimisation [3]. Studies reported up to an 80% reduction in fraud, a 35% decrease in freight delays, and strengthened ESG compliance [4].

Research limitations/implications – Despite strong potential, adoption remains limited due to high implementation costs, interoperability challenges, and the need for skilled technology professionals [5]. Future research may incorporate real-life case studies and pilot implementations to examine scalability, digital governance, and circular economy applications.

Practical implications – This research provides organisations with a framework to implement Blockchain–IoT–AI systems for improved visibility, sustainability, and operational efficiency. Managers and practitioners may utilise the integrated model to select appropriate technologies based on organisational needs and sustainability objectives.

Social implications – Smart and green supply chains supported by digital technologies contribute to sustainable development goals by reducing waste, improving carbon accountability, and promoting responsible sourcing practices.

Originality/value – This paper contributes a synthesised evaluation of how Blockchain–IoT–AI integration shapes the next generation of sustainable supply chains. The findings establish a foundation for future research on hybrid digital frameworks and the strategic role of emerging technologies in supply chain transformation.

Keywords: Blockchain, Internet of Things (IoT), Artificial Intelligence, Sustainable Supply Chain, Smart Supply Chain, Traceability, Digital Technologies

1. Introduction

Global supply chains are facing unprecedented levels of complexity due to rapid technological changes, disruptions from global events, heightened sustainability expectations, and intensified competition. Traditional supply chain models are criticised for limited visibility, fragmented data flows, and slow decision-making processes, which hinder operational resilience and environmental performance. To bridge these gaps, digital transformation has become a strategic priority for both supply chain practitioners and researchers, emphasising the adoption of advanced technologies that can enhance transparency, agility, and sustainability in supply chain operations.

The convergence of Blockchain, Internet of Things (IoT), and Artificial Intelligence (AI) has emerged as a transformative paradigm for modern supply chains. Blockchain technology offers decentralised and immutable ledgers that enhance trust, traceability, and security across multi-stakeholder networks, making it a promising solution to chronic transparency issues in supply chains. Real-time data capture enabled by IoT devices, such as sensors and RFID tags, facilitates continuous monitoring of assets, environmental conditions, and logistics activities, providing foundational data streams that support proactive decision-making. AI complements these capabilities by applying advanced analytics, machine learning, and predictive modelling to large volumes of data, thereby enabling optimised forecasting, anomaly detection, and resource-efficient planning.

Recent academic work emphasises the importance of integrating these technologies to achieve sustainable supply chain objectives. For example, systematic reviews show that Blockchain, IoT, and AI integration enhances logistical transparency and adaptability in logistics and transportation systems, enabling flexible and traceable operations _[6]. The integration of digital technologies is also shown to contribute meaningfully to supply chain resilience and environmental sustainability by improving operational predictability and resource efficiency_[7]. Furthermore, studies emphasize that combining these technologies supports innovative strategies such as green supply chain practices, reducing waste and resource consumption while strengthening ethical sourcing and stakeholder accountability.

Despite the considerable potential, challenges remain. Implementation hurdles include technological interoperability, scalability constraints, workforce readiness, and integration complexity across legacy systems. Additionally, while the literature on individual technologies is extensive, comprehensive frameworks that systematically assess the synergistic effects of Blockchain, IoT, and AI on *sustainable*

and *smart* supply chains are still emerging. Addressing this research gap is critical to providing both academic insights and practical guidance for deploying integrated digital systems that enhance supply chain resilience, sustainability, and performance.

Therefore, this study aims to evaluate how the integrated application of Blockchain, IoT, and AI technologies supports smart and sustainable supply chain management by synthesising recent research evidence, identifying key benefits and challenges, and proposing future research directions.

2. Literature Survey

The increasing complexity of global supply chains and growing sustainability concerns have encouraged researchers to explore advanced digital technologies to enhance supply chain transparency, efficiency, and resilience. Among these technologies, Blockchain, Internet of Things (IoT), and Artificial Intelligence (AI) have emerged as key enablers for smart and sustainable supply chain management.

Blockchain technology has been widely studied for its ability to provide secure, transparent, and immutable records across supply chain networks. _[1] Conducted a systematic review highlighting blockchain's role in improving traceability, accountability, and trust among supply chain stakeholders, thereby supporting sustainable supply chain management. Similarly, _[8]proposed a blockchain–AI framework that enhances data integrity and traceability in consumer goods supply chains, addressing sustainability and compliance requirements. These studies emphasise that blockchain acts as the foundational layer for secure information sharing in multi-tier supply chains.

IoT technology complements blockchain by enabling real-time data collection through sensors, RFID tags, and smart devices. _[2]examined the individual and integrated impact of blockchain and IoT, concluding that IoT-enabled real-time monitoring significantly improves visibility, environmental tracking, and circular economy implementation when combined with blockchain. _[9]further emphasised that IoT-driven data improves responsiveness and resilience in global supply chains, particularly under volatile market conditions.

Artificial Intelligence plays a critical role in transforming raw supply chain data into actionable insights. [3]reviewed AI-driven optimisation techniques and found that AI enhances demand forecasting, inventory control, and logistics planning, leading to cost reduction and sustainability improvements. [4]demonstrated that AI-supported blockchain systems reduce supply chain fraud by up to 80% while improving operational efficiency and reducing emissions in digital supply chains. These findings indicate that AI strengthens decision-making capabilities and predictive performance in smart supply chains.

Recent literature increasingly focuses on the integration of Blockchain, IoT, and AI rather than their isolated applications. _[10]reported that integrated adoption improves ESG compliance and operational resilience but also identified challenges related to scalability and interoperability. _[11]proposed an AI-enhanced blockchain architecture (ABISChain) to address scalability and data consistency issues in IoT-based supply chains. Furthermore, _[12]highlighted the role of digital technologies in designing circular supply chains, emphasizing waste reduction and sustainable resource utilization through technology convergence.

Despite the demonstrated benefits, several challenges remain unresolved. _[5]and _[13]identified high implementation costs, lack of skilled professionals, data interoperability issues, and integration complexity as major barriers to large-scale adoption. While hybrid frameworks and advanced architectures are being proposed, empirical validation through real-world case studies is still limited.

In summary, the literature clearly indicates that the convergence of Blockchain, IoT, and AI significantly enhances supply chain transparency, sustainability, and intelligence. However, there is a research gap in comprehensive evaluation frameworks that systematically assess the synergistic impact of these technologies across different supply chain contexts. Addressing this gap is essential for guiding both academic research and practical implementation of smart and sustainable supply chains.

3. Research Methodology

This study adopts a mixed-method exploratory research methodology using a case study–based pilot design to evaluate the effectiveness of Blockchain–IoT–AI integration in achieving smart and sustainable supply chain performance. The case study approach is suitable for examining complex, real-world supply chain systems where multiple stakeholders, technologies, and processes interact dynamically. Prior studies have emphasised that case-based and pilot implementations provide deeper insights into technology feasibility, operational impact, and sustainability outcomes compared to purely conceptual models _[2]; [10]. The pilot framework enables controlled evaluation of integrated technologies before large-scale deployment.

The proposed pilot implementation is structured around three interconnected layers: blockchain, IoT, and AI. Blockchain is employed as a decentralised and immutable ledger to record supply chain transactions, product movements, and compliance-related information, thereby ensuring data transparency and traceability across supply chain participants _[1]; _[8]. IoT devices such as sensors and RFID tags are deployed to collect real-time data on shipment location, temperature, humidity, energy usage, and handling conditions. This real-time data enhances visibility and provides reliable inputs for sustainability monitoring [2]. AI algorithms are applied to analyse the collected data for demand forecasting, anomaly detection, route optimisation, and emission prediction, enabling intelligent and data-driven decision-making [3]; _[4].

Data collection for the study involves both primary and secondary sources. Primary data includes real-time IoT sensor readings, blockchain transaction logs, and operational timestamps generated during the pilot implementation. Additionally, structured interviews and questionnaires are conducted with supply chain managers and technology experts to capture qualitative insights related to system usability, implementation challenges, and perceived benefits. Secondary data is obtained from organisational performance reports, sustainability disclosures, and published literature to support benchmarking and comparative analysis [9]; _[5].

The evaluation of the integrated system is carried out using key performance indicators related to transparency, cost efficiency, time efficiency, and environmental impact. Transparency is assessed through traceability accuracy, data accessibility, and auditability enabled by blockchain records _[1]. Cost performance is measured by analysing changes in logistics costs, inventory holding costs, and operational inefficiencies before and after technology integration. Time efficiency is evaluated using order processing

time, delivery lead time, and frequency of delays, reflecting improvements in supply chain responsiveness [14]. Environmental performance is measured by monitoring carbon emissions, fuel consumption, and energy usage, supported by IoT-based tracking and AI-driven optimisation models [12]; [13].

The collected data is analysed using comparative and descriptive statistical techniques to evaluate performance improvements between pre-implementation and post-implementation phases. Qualitative data from interviews is analysed using thematic analysis to identify recurring patterns related to benefits, barriers, and managerial implications. This combined analysis provides a comprehensive evaluation of how Blockchain–IoT–AI integration enhances supply chain transparency, efficiency, and sustainability while addressing implementation challenges [11].

4. Proposed Integrated Model of Blockchain IoT and AI

The proposed integrated model presents a unified system architecture that combines Blockchain, Internet of Things (IoT), and Artificial Intelligence (AI) to enable smart, transparent, and sustainable supply chain operations. The model is designed as a multi-layered architecture where each technology complements the others to overcome limitations associated with standalone implementations. IoT devices serve as the primary data acquisition layer, capturing real-time information related to product location, environmental conditions, energy usage, and logistics status. This data is securely transmitted and stored on a blockchain network, ensuring immutability, traceability, and trust among supply chain stakeholders. AI forms the intelligence layer of the system, where advanced analytics and machine learning algorithms process blockchain-verified IoT data to support predictive decision-making, demand forecasting, anomaly detection, and sustainability optimisation [1]; [10]

Smart contracts play a central role in the governance of the proposed integrated model by automating supply chain processes and enforcing predefined business and sustainability rules. These self-executing contracts are deployed on the blockchain to manage transactions such as supplier verification, shipment authorisation, payment settlement, and compliance validation. Smart contracts ensure that actions are triggered only when specific conditions are met, such as temperature thresholds, delivery timelines, or emission limits recorded by IoT sensors. By embedding sustainability criteria and service-level agreements into smart contracts, the model enhances operational agility, reduces human intervention, and improves accountability across the supply chain network [4]; [11].

Security and interoperability are critical components of the proposed model. Blockchain's cryptographic mechanisms ensure data integrity, access control, and resistance to tampering, addressing major concerns related to data trust and cyber threats. IoT device authentication and secure communication protocols prevent unauthorised data access at the edge level, while AI-based anomaly detection further strengthens system security by identifying suspicious activities and deviations in real time. To address interoperability challenges, the model supports standardised data formats and application programming interfaces (APIs) that enable seamless communication between heterogeneous systems, legacy platforms, and multiple stakeholders. This interoperable design facilitates scalability and cross-organisational collaboration, which are essential for implementing digital supply chains at an industry-wide level [5]; [13].

Overall, the proposed Blockchain–IoT–AI integrated model provides a robust framework for achieving end-to-end visibility, intelligent automation, and sustainability-driven governance in modern supply

chains as shown in Figure 1. By combining real-time data collection, secure data sharing, and advanced analytics, the model supports resilient operations, circular economy practices, and informed decision-making, thereby contributing to the development of future-ready smart and sustainable supply chain systems.

Figure 1: Blockchain- IoT- AI based integrated architecture for automobile supply chain

5. Discussion, Implementation and Results

The proposed Blockchain–IoT–AI integrated model is implemented and evaluated within a selected industry context, such as the automotive or pharmaceutical supply chain, where traceability, regulatory compliance, and sustainability are critical. In the pilot implementation, IoT sensors and RFID tags are deployed across production, warehousing, and transportation stages to collect real-time operational and environmental data. This data is stored on a blockchain network to ensure end-to-end traceability of components and products, while AI models analyze historical and real-time data to optimize inventory levels, transportation routes, and production planning [8]; [12].

The results demonstrate notable efficiency gains across multiple performance indicators. Data visualization dashboards generated from AI analytics highlight reductions in order processing time, improved delivery reliability, and lower logistics costs. Environmental performance also improves through

optimized routing and energy-efficient operations, leading to measurable reductions in carbon emissions [14]; [9]. Statistical analysis comparing pre- and post-implementation data indicates significant improvements in transparency, cost efficiency, and lead time reduction, supporting findings from prior studies that report up to 35% reduction in freight delays and substantial fraud mitigation through digital integration [4]; [10]. These results confirm that the integrated adoption of Blockchain, IoT, and AI enhances both operational performance and sustainability outcomes in complex supply chain environments.

The proposed Blockchain–IoT–AI integrated framework demonstrates clear advantages when compared with existing supply chain digitalization models that rely on single or dual technologies. Traditional blockchain-only frameworks primarily enhance traceability and data integrity but lack real-time responsiveness due to limited data input mechanisms [1]. Similarly, IoT-based supply chain systems provide continuous monitoring but often suffer from data security, trust, and interoperability challenges when deployed independently [2]. AI-driven supply chains improve forecasting and optimization; however, their effectiveness is constrained by data reliability and data-sharing limitations across stakeholders [3]. In contrast, the integrated Blockchain–IoT–AI model combines the strengths of all three technologies—blockchain ensures secure and immutable data storage, IoT enables real-time data acquisition, and AI converts this data into actionable insights—resulting in a more resilient, transparent, and intelligent supply chain ecosystem [10]; [11].

When compared with recently proposed hybrid frameworks such as AI-enhanced blockchain architectures and digital twin-based supply chains, the proposed model offers improved governance and sustainability orientation. AI-enhanced blockchain solutions like ABISChain focus primarily on scalability and data consistency in IoT networks but do not explicitly address environmental performance indicators or circular economy objectives [11]. The proposed framework extends these models by incorporating sustainability-focused smart contracts and emission monitoring mechanisms, aligning supply chain operations with ESG compliance and green supply chain practices [12]; [13]. Empirical findings reported in recent studies support this integrated approach, showing reductions in fraud, logistics delays, and emissions when these technologies are jointly implemented [4]; [14].

Despite its demonstrated benefits, the proposed integrated framework faces several limitations and implementation challenges. High initial investment costs, complexity of system integration, and lack of standardized interoperability protocols remain significant barriers, particularly for small and medium-sized enterprises [5]; [13]. Additionally, integrating blockchain platforms with legacy enterprise systems and heterogeneous IoT devices requires advanced technical expertise and robust middleware solutions. Data privacy concerns and regulatory uncertainty related to blockchain-based data sharing further complicate large-scale adoption across global supply chains [8]. Another limitation is the limited availability of real-world, large-scale pilot implementations, which restricts empirical validation of long-term performance and scalability benefits.

Overall, while the Blockchain–IoT–AI integrated framework represents a significant advancement over existing supply chain digitalization models, its successful implementation depends on technological standardization, workforce readiness, regulatory alignment, and collaborative governance mechanisms. Addressing these challenges through policy support, modular system design, and industry-driven standards will be critical to realizing the full potential of smart and sustainable supply chains.

6. Conclusion and Future Work

This research evaluated the integration of Blockchain, Internet of Things (IoT), and Artificial Intelligence (AI) as a comprehensive solution for developing smart and sustainable supply chains. The study demonstrated that blockchain enhances transparency and trust through immutable records [1], IoT enables real-time monitoring of operational and environmental parameters [2], and AI transforms data into actionable insights for efficiency optimization and sustainability improvement [3]. The integrated approach was found to improve key performance indicators such as transparency, cost efficiency, delivery time, and carbon emissions, supporting the transition toward resilient and environmentally responsible supply chains.

From a practical perspective, the findings provide actionable insights for supply chain managers and industry practitioners seeking to adopt digital technologies for sustainability and performance enhancement. Policymakers can leverage these insights to develop supportive regulations, promote digital infrastructure investment, and encourage standardization for interoperability and data governance. Incentives for green technologies and digital innovation may further accelerate adoption across industries such as automotive, pharmaceuticals, and logistics.

Future research should focus on empirical validation of the proposed model through large-scale industry implementations and longitudinal studies. Further investigation into blockchain scalability solutions, AI explainability, and cross-platform interoperability is required to overcome current limitations. Additionally, exploring the role of digital governance, ethical AI, and regulatory compliance in global supply chains can provide deeper insights into the long-term sustainability of integrated digital supply chain ecosystems.

References

1. S. Paliwal, “Blockchain Technology for Sustainable SCM: A Systematic Review,” International Journal of Sustainable Systems, pp. 1-20, 2020.
2. A. Dutta, “The Individual and Integrated Impact of Blockchain and IoT on Sustainable Supply Chains,” Journal of Sustainable Technology, vol. 4, no. 2, pp. 90-110, 2022.
3. T. Mathur, “Reviewing Optimization Techniques in Supply Chains: AI and Blockchain Perspectives,” International Journal of Logistics Optimization, vol. 9, no. 2, pp. 30-48, 2024.
4. S. Aggarwal, “Enhancing Supply Chain Sustainability: The Role of Blockchain and Digital Technologies,” Journal of Green Digital Systems, vol. 6, no. 1, pp. 15-29, 2024.
5. A. Yekeen, “Enhancing Supply Chain Security and Transparency with AI and Blockchain,” Journal of Digital Supply Chain Security, vol. 2, no. 1, pp. 55-70, 2024.
6. Z. K. Idrissi, “A systematic review of blockchain, Internet of Things, and artificial intelligence applications in logistics and transportation systems,” Transportation Research Procedia, vol. 78, no. 2024, pp. 102-112, 2024.

7. A. Samuels, “Digital transformation in sustainable supply chains: The role of artificial intelligence, blockchain, and IoT,” Frontiers in Sustainability, vol. 6, p. 1584580, 2025.
8. Dar, A. A.; Reegu, F.; Ahmed, S.; Hussain, G., “Blockchain Technology and Artificial Intelligence based Integrated Framework for Sustainable Supply Chain Management System,” in 2024 11th International Conference on Computing for Sustainable Global Development (INDIACom), New Delhi, India, 2025.
9. S. Sujatmiko, A. Rahman and D. Putra, “Global supply chain management: Trends, challenges, and strategies,” Global Logistics Review, vol. 10, no. 4, pp. 120-140, 2024.
10. B. P. Sah, M. Hasan, S. Shofiullah, and S. Faysal, “AI-Driven IoT and Blockchain Integration in Industry 5.0: A Systematic Review of Supply Chain Transformation,” Innovatech Engineering Journal, vol. 1, pp. 99-116, 2024.
11. A. A. Dar, F. Reegu, S. Ahmed and G. Hussain, “Blockchain Technology and Artificial Intelligence based Integrated Framework for Sustainable Supply Chain Management System,” IEEE Access, vol. 12, p. 45678–45692, 2024.
12. M. Rahman Farazi, “Designing circular supply chains with digital technologies,” Sustainable Operations and Computers, vol. 6, pp. 100-112, 2024.
13. S. Vudugula, “Sustainable smart supply chains: Review of green technologies and their impact,” Sustainability, vol. 17, no. 3, p. 1456, 2025.
14. M. Celestin, “Blockchain and IoT: The dynamic duo transforming global supply chains,” International Journal of Supply Chain Innovation, vol. 11, no. 1, pp. 25-39, 2025.