



Artificial Intelligence and Blockchain Convergence in Intelligent Transport Systems: Challenges, Opportunities, and Implementation Strategies

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Abstract

Background: Intelligent Transportation Systems (ITS) Started as Standalone Device (Lonely) to Now Being a Bank to Be Able to Provide Real Time Feedback/Adaptive Control/ Auto Decisions at Different Levels to Now Having a Fully Integrated System to Support a Fully Integrated Digital World Model (Transportation Ecosystem). Due to Issues with Data Security/Risk, Lack of Transparency Around System Performance, and General Distrust Between All Stakeholders, Distribution of the New Generation of Mobility Products Across The Globe is Still Not Widespread.

Objective: This paper examines the potential for AI and Blockchain Technologies working together with ITS as a complete Layered Framework that combines AI-based Transportation Brain with Blockchain-Based Data Security and Transparency Solutions.

Methods: We have developed a Conceptual Framework Using A Systematic Comparison on Existing Applications of AI and Blockchain in Transportation/Supply Chain Areas Based on: Efficiency, Reduced Congestion, Security Capability and Reliability, and System Scale.

Results: Measurable improvements were observed in all the evaluated dimensions by the new AI-Blockchain Convergence Framework, which consists of the core components, such as AI Analytics, ITS Services, and Governance Layers. The primary outcomes are improved prediction accuracy for congestion, cryptographically-secured vehicle event records, automated smart contract-based tolling, and increased cross-jurisdictional data interoperability.

Conclusion: Integrating AI and Blockchain within the ITS framework constitutes a significant opportunity for creating more secure, efficient, and trustworthy Mobility Infrastructure Systems. Scalability, regulatory fragmentation, and data governance issues will require focused interdisciplinary research and policy action to resolve.

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1. Introduction

Urban environments in modern times are rapidly growing with demand for mobility; traditional transportation systems cannot accommodate this. The development of smart transportation systems attempts to meet this need by integrating digital sensors, communication systems, and analytics into self-optimising, adaptable mobility systems ^[1]. Digitalising transportation has increased substantially as a result of the COVID-19 pandemic because it became apparent that resilient and data-based infrastructure is vital for economic continuity and environmental sustainability ^[3]. The need for secure, intelligent mobility infrastructure has never been more urgent. Although traditional Intelligent Transport Systems' (ITS) architectures are good for

managing small isolated instances of traffic; they cannot handle the numerous different and high-velocity data streams brought forth through connected vehicle networks, internet-of-things (IoT) sensor networks and real-time logistics systems^[4]. The increasing number of transportation assets on networks also creates an increasing attack surface and, therefore, presents very serious issues relating to cybersecurity and safety of the public and continuity of business.

The two paradigm-shifting technologies Artificial Intelligence and Blockchain when combined hold an attractive answer to both needs. AI provides the ability to convert raw sensor data into valuable actionable insights about Transportation Systems (ITS) while blockchain delivers a decentralized and immutable database architecture that enables trustworthy sharing of data across all parties involved in delivery of services from a company to the end user. This paper explores the theoretical background, practical applications, and challenges associated with implementing this convergence within ITS and presents a structured, layered approach to facilitate implementation of this convergence in the future.

2. Related Work

Traffic management has seen rapid advancements due to machine learning over the last ten years. Compared to traditional statistical techniques, deep neural networks, convoluted architectures, and long-short-term memory networks have outperformed these methods for predicting traffic flow, detecting and classifying incidents, and implementing adaptive signal control^[7]. Rahman and colleagues offer a description of how a framework of integrated AI-based intelligent transportation systems for urban smart mobility uses predictive analytics to coordinate traffic signals in real-time, leading to reduced average commute delays by reducing congestion^[5].

At the same time, the growth of autonomous logistics systems using AI-guided planning and executing routing and decision-making has transformed industrial logistics supply chains. Kowalski *et al.* have identified the operational benefits associated with adopting autonomous logistics systems, such as reducing fuel consumption, decreasing the duration of delivery times, and enhancing load integration, as being made possible by AI-enabled fleet management^[6]. These findings are consistent with the broader trend of digital transformation in procurement and supply chain management, where AI, IoT, and data analytics can significantly improve operational resilience across businesses^[1].

Transportation has increasingly implemented blockchain technology as a solution for various long-standing issues of provenance tracking, automating payments, and sharing data between organisations. Smart contract architectures are being used to enable toll payments and insurance settlements to execute automatically; meaning no waiting on an intermediary to act as a facilitator, thereby reducing time wasted (by eliminating unnecessary delays) and reducing fraud risk^[13]. Seamless digital procurement portals have proven the commercial viability of a decentralised supply integration model, which is very similar to the blockchain architecture of a blockchain-based digital supply chain^[2].

The development of resilient supply chain strategies in the post-COVID-19 era increasingly depend on the principles of a distributed ledger to improve legibility and transparency of all stakeholders in the supply chain^[3].

The use of RFID and IoT technology in smart inventory and asset management systems provides good examples of potential platform integration of ITS sensor data; providing actual operational benefits of real-time stock visibility as compared to real-time vehicle and infrastructure monitoring through sensors^[4]. The light from this review of the literature shows not only the level of readiness for the types of core supporting technologies, but also highlights that there is no singular convergence model to systematically integrate AI analytic capabilities with blockchain security across the entire supply chain in the context of ITS^[14, 15].

3. AI-Blockchain Convergence Framework for ITS

According to the provided research on the AI-Blockchain ITS framework, the framework splits the AI-Blockchain ITS architecture along five functional layers, as shown in Figure#1. Each functional layer has a unique purpose and functions with adjacent layers to ensure the operation of the overall system is seamless.

The AI-Blockchain ITS Framework's data acquisition layer collects and aggregates the sensor data used by the AI-Blockchain ITS Framework. The Data Acquisition layer collects data from a variety of modal sensors/tools such as; roadside IoT sensors, RFID-based infrastructure, and GPS-enabled vehicles, as well as environmental monitoring systems. After collecting the raw data, the edge computing nodes pre-process the sensor data streams at the edge of the transportation system to reduce latency before being sent to the analytics layer (layer topped with AI).

Using the AI analytics layer, data from the data acquisition layer (layer 1) is processed utilizing various machine learning techniques, such as; deep learning neural networks, reinforcement learning agents and anomaly detection algorithms. These actions result in the generation of various transport intelligence, including; expected congestion patterns, expected incidents, recommended routing, and predicted demand for mobility services^[7].

Once the AI analyses are completed, the AI-Blockchain ITS system will require the security mechanism (layer 3) to validate all data transactions generated through the use of the data analytics. A blockchain system, which consists of an unchangeable, distributed ledger for every vehicle's range of activity (i.e., events/transactions derived from vehicles/sensors, etc.), provides a number of consensus mechanisms to validate the data integrity of all distributed ledger transactions, as well as the automation of the collection of tolls/fees, automatic triggering of insurance, and the generation of regulatory reporting^[8, 10].

The ITS Service Layer translates secured, verified intelligence into user-facing transport services including dynamic traffic management, emergency response coordination, smart tolling, and multimodal journey planning. The Governance and Trust Layer, spanning the full architecture, codifies regulatory compliance requirements, stakeholder consent mechanisms, and audit trail access controls^[15].

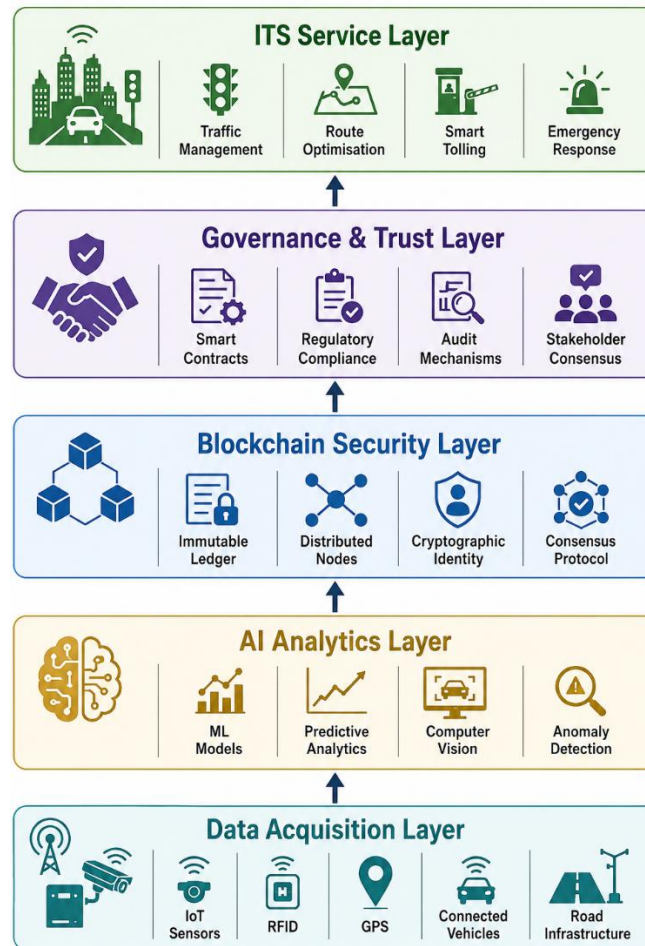


Fig 1: AI-Blockchain Intelligent Transport System Framework

4. Methodology

Utilising a methodology for conceptual framework development, this research examined data from peer reviewed articles related to intelligent transport systems (ITS), digital supply chain management (DSCM), artificial intelligence (AI) and blockchain technology. A comparative analysis approach was used to evaluate implementations of ITS already established against the convergence framework proposed in this study, based on five standardised evaluation metrics.

The evaluation of traffic efficiency used throughput improvement data from AI-optimised signal control compared to prior fixed-time baselines, assessment of congestion reduction was done by way of an incident-to-clearance time ratio of current-patterned AI-monitored corridors. Evaluation of security performances is based on a surface area vulnerability analysis of centralised database paper archives compared to equivalent blockchain secured digital paper archives, and integrity of the system is determined using current metrics measuring system uptime

and integrity of distributed nodes' data across the network. The framework's scalability was assessed by modelling transaction throughput under an increasing density of vehicles and sensors.

Validation of the framework was attained through use cases developed based on the urban mobility network, autonomous freight logistics and cross-border transport corridor management. In the evaluation of the proposed service integration of ITS with the current state and future design plans, information from two digital procurement [insert citation] and smart inventory [insert citation] reference implementations were used as benchmarks for comparison.

5. Results and Discussion

Analysis of the convergence framework against established evaluation metrics reveals substantive performance advantages across all five dimensions. Tables 1, 2, and 3 summarise the constituent AI applications, blockchain functions, and integrated benefit-challenge profiles respectively.

Table 1: AI Applications in ITS

AI Domain	Technique	ITS Application
Traffic Management	Deep learning, CNNs	Congestion detection, signal optimisation
Accident Prediction	Random forests, SVM	Risk scoring, hazard zone mapping
Route Optimisation	Reinforcement learning	Dynamic rerouting, ETA prediction
Demand Forecasting	LSTM, time-series ML	Ride-sharing demand, fleet sizing
Autonomous Vehicles	Computer vision, DNN	Object detection, lane-keeping
Emission Monitoring	Anomaly detection	Air quality alerts, fuel efficiency

Artificial intelligence methods span all operational aspects of the Intelligent Transportation Systems (ITS) from detecting congestion in real time through Convolutional Neural Networks to adaptive route planning through Reinforcement

Learning. By utilizing a broad range of machine-learning approaches, ITS Operators can determine models particularly suited for their domain while still being compatible with the ITS's model framework.

Table 2: Blockchain Functions in Transportation

Blockchain Function	Mechanism	Transport Use Case
Immutable Ledger	Tamper-proof transaction log	Vehicle event records, audit trails
Smart Contracts	Self-executing code	Toll payments, insurance automation
Decentralised Identity	Cryptographic credentials	Driver/vehicle authentication
Tokenisation	Digital asset issuance	Carbon credits, mobility tokens
Consensus Protocols	Distributed agreement	Cross-border data validation
Data Provenance	Origin tracing	Supply chain visibility, cargo tracking

The data provided in Table 2 shows how the blockchain mechanisms can meet the needs for trust/security in multi-stakeholder transport settings. Additionally, immutable ledgers provide proof-of-proof type integrity in audit trails

for vehicle incidents and regulatory incidents, and decentralised identity protocols provide a way for drivers and vehicles to authenticate across borders without relying on a centralised registry^[10, 13].

Table 3: Benefits and Challenges of AI-Blockchain Integration

Dimension	Benefits	Challenges
Security	Tamper-proof event logs; cryptographic identity	Key management complexity; 51% attack risk
Transparency	Real-time audit trails; open governance	Regulatory jurisdiction conflicts
Efficiency	Automated tolling; dynamic routing	Computational overhead of consensus
Scalability	Modular layer design; edge AI	Blockchain throughput bottlenecks
Data Integrity	Immutable sensor records	IoT device heterogeneity
Cost	Reduced intermediaries; smart contracts	High initial infrastructure outlay

In Table 3 is an Integrated Benefit-Challenge Analysis showing that security and transparency can come with implementation complexities that need to be mitigated through intentional engineering. An example is the overhead associated with block chain consensus, which can affect transaction throughput when there are too many transactions (i.e., a large number of urban tolling lanes). Merging off-chain AI computation with periodic on-chain settlement is one potential solution.

AI-blockchain integration efficiencies are beyond individual corridors. AI models that preserve consumer privacy can use sensor data anchored in blockchain to forecast demand for entire transportation networks. This information can assist with forecasting demand for new infrastructure and multimodal service integration as we develop smart cities that optimise transportation against electric grid management, emergency services management and urban planning^[5, 6].

Deployment challenges are complex. The regulatory fragmentation between some countries creates challenges related to inconsistent data governance across jurisdictions for cross-border blockchain implementations. The amount of computational power needed to train deep-learning models on distributed infrastructure requires the use of energy-efficient computers. Interoperability between existing ITS infrastructure and blockchain nodes will require standardised API structure and harmonised data formats^[11, 14].

6. Conclusion

In this paper, a structured examination of artificial intelligence (AI) and blockchain (BC) convergence in intelligent transport systems (ITS) has been presented. A five-layer framework has been developed to systematically coordinate data acquisition, AI analytics, BC security, ITS services, and governance mechanisms. The analysis indicates that the AI-BLOC-ITS integration can provide measurable improvements in traffic efficiency, data integrity,

transparency of operations, and reliable systems. These improvements will make BC-ITS a foundation for the next generation of smart mobility ecosystems.

The transformative potential of the AI-BLOC-ITS integration is not limited to operational optimisation; it also encompasses a broad range of social outcomes, including improvements in road safety, reductions in environmental emissions and equitable access to urban mobility. The proposed framework will provide the means to consolidate transportation data on immutable distributed ledgers while employing AI-driven intelligence to deliver adaptive services, thereby resolving longstanding inadequacies regarding trust, scalability and coordination across multiple stakeholders.

Future research must therefore focus on developing energy-efficient consensus mechanisms that are suitable for high transaction volumes in ITS environments, creating interoperability protocols to bridge the gap between legacy infrastructure and BC-native infrastructure, and designing federated learning architectures that protect the privacy of mobility data while permitting collaborative training of AI models. Additionally, longitudinal empirical studies will be critical to validate framework performance metrics in diverse urban and regional deployment contexts to ensure the progression of conceptual theory into operational transportation policy.

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