

AI and Blockchain for Smart Traffic Management: A Decentralized and Intelligent Framework

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Abstract: The exponential growth in urban populations has placed tremendous stress on existing traffic infrastructures. As a result, cities are experiencing increased traffic congestion, extended travel times, and increased levels of pollution. To address these challenges, this paper proposes a novel intelligent traffic management framework that integrates Artificial Intelligence (AI) and Blockchain technology for enhanced urban mobility and system security. The primary objective of this study is to develop a decentralized and automated traffic control system that can optimize signal timing and predict congestion in real-time while maintaining secure and transparent data communication across stakeholders. The methodology involves a multi-phase approach starting with data collection from CCTV cameras, IoT-based road sensors, and GPS-equipped vehicles. These diverse data streams can be processed using Convolutional Neural Networks (CNNs) for vehicle detection and traffic density classification, and Long Short-Term Memory (LSTM) networks for time-series forecasting of congestion patterns. A private Ethereum blockchain can be deployed using tools like Ganache, where smart contracts developed in Solidity manage access control, log AI-generated decisions, and automate responses such as emergency vehicle prioritization. Integration of AI and blockchain components allows system nodes—such as smart traffic lights and control centers—to autonomously execute verified decisions. The proposed system will be implemented to improve traffic flow efficiency, minimize waiting times, and enable reliable vehicle prioritization across various traffic scenarios through AI-driven control mechanisms. The blockchain layer will be deployed to ensure tamper-proof and auditable records of all transactions and decision-making processes.

In conclusion, the proposed AI-Blockchain integrated system enhances the efficiency, transparency, and robustness of urban traffic management, representing a scalable and secure solution for future smart cities.

Keywords: Artificial Intelligence, Blockchain Technology, Traffic Congestion, Real-time Data Analysis, Intelligent Traffic Control Systems

I. Introduction

Smart cities require intelligent traffic control systems capable of handling large volumes of real-time data and ensuring secure communication. The need for intelligent traffic control systems has grown with the rise of smart cities and connected vehicles (Mollah et al., 2020). Traditional traffic systems operate in a centralized manner and often fail to provide real-time adaptability, security, and scalability. These systems are vulnerable to single points of failure, cyber-attacks, and operational bottlenecks (Ren et al., 2019). Moreover, they typically rely on static signal schedules and are not equipped to adjust dynamically to changing traffic conditions. Data collected from various sources is often underutilized or not securely shared, limiting coordination and decision-making across the network. Current infrastructure also lacks trust, transparency, and interoperability among key stakeholders such as transport authorities, emergency responders, and private vehicles (Rahman et al., 2024). This results in inefficiencies in managing congestion, emergency routing, and toll operations. To address these challenges, this paper proposes an intelligent and decentralized traffic management system that integrates Artificial Intelligence (AI) and Blockchain technologies. (Zhang et al. 2021) presented a blockchain - based trust architecture designed to enhance the reliability and security of data exchange among autonomous vehicles, emphasizing decentralized identity verification and tamper-resistant communication mechanisms within vehicular networks. AI enables dynamic analysis of real-time traffic data to optimize signal control and predict congestion patterns, while the blockchain layer ensures secure, immutable, and transparent data exchange among all involved entities (Queiroz et al., 2020). This combined framework aims to make intelligent traffic control systems more responsive, secure, and efficient- supporting the development of smarter and more sustainable cities in the future.

II. Literature Review

In recent years, traffic congestion and inefficiencies in urban mobility have drawn increasing attention from researchers and city planners. Various studies have explored the use of Artificial Intelligence (AI) and Blockchain independently in traffic systems, but their integration remains relatively underexplored. Artificial Intelligence, especially machine learning (ML) and deep learning techniques, has shown great potential in predicting traffic conditions, optimizing traffic signal timings, and detecting incidents. For instance, (Zhang et al. 2019) proposed a deep learning model using Long Short-Term Memory (LSTM) networks to predict traffic flow with high accuracy. (Ma et al. 2020) demonstrated that Convolutional Neural Networks (CNNs) could effectively analyze traffic camera images to detect congestion and classify traffic levels. Blockchain has been applied to ensure secure and decentralized data exchange in smart transportation. (Dorri et al. 2017) introduced a lightweight blockchain model for vehicular networks to provide privacy and data integrity. (Li et al. 2020) developed a blockchain-based traffic event recording system that prevents

tampering and enhances trust among autonomous vehicles. These studies highlight blockchain's ability to reduce reliance on centralized authorities while improving transparency. There is a growing interest in combining AI with blockchain to create trustworthy intelligent systems. (Zhou et al. 2021) proposed a framework for intelligent transportation that integrates AI-based traffic prediction with blockchain - based data sharing. This integration offers better real-time adaptability and a tamper-proof environment. However, challenges such as processing speed, scalability, and integration with existing infrastructure remain. The existing research shows strong potential in both AI and blockchain when applied to smart traffic systems. Yet, their full integration in a unified, real-time, and privacy-preserving framework is still emerging. This paper aims to address that gap by proposing a system that combines both technologies to enhance traffic flow, data security, and system reliability.

Problem Identification

The rapid urbanization and rise of smart cities have increased the demand for intelligent traffic management systems that can efficiently handle real-time data and ensure secure communication across various entities. Traditional traffic systems, with their centralized architectures, static signal scheduling, and limited adaptability, are increasingly incapable of addressing dynamic urban mobility challenges. These systems suffer from vulnerabilities such as single points of failure and lack of scalability. Moreover, the current traffic infrastructure often fails to facilitate secure, trustworthy, and transparent data sharing among key stakeholders, including traffic authorities, emergency services, and private vehicles. While Artificial Intelligence (AI) and Blockchain technologies have individually shown strong potential in addressing traffic-related challenges, their combined use in a decentralized and privacy-preserving traffic management system has not been extensively explored. There's a growing need for a smarter solution that combines the real-time decision-making power of AI with the security and transparency of blockchain. Current traffic systems struggle to keep up with today's complex urban mobility needs—they're often slow, centralized, and vulnerable to errors or cyber-attacks. This research aims to address gap by proposing a modern traffic management system that brings together AI and blockchain technology. The goal is to create a more efficient, secure, and adaptable way to manage city traffic, making urban transportation safer, smoother, and better suited for the future.

Proposed System Architecture

The proposed intelligent traffic management system is designed to enhance urban mobility through integration of artificial intelligence, blockchain technology, and smart automation together. The system comprises four key components, each performing critical roles to ensure efficient, secure, and real-time traffic control. These components are described in detail below:

AI Module

The Artificial Intelligence (AI) Module serves as the brain of the traffic control system. It uses advanced deep learning techniques, primarily Convolutional Neural Networks (CNNs) and Long Short-Term Memory (LSTM) networks, to process and interpret both video and sensor data.

Vehicle Detection and Counting: The AI module analyzes real-time video footage from roadside cameras and uses object detection algorithms to accurately identify and count vehicles at intersections and on road segments.

Traffic Congestion Prediction: By using historical traffic patterns along with live data, LSTM models predict future congestion levels. These time-series models are particularly effective in handling sequential data like traffic flow.

Optimal Signal Timing: Based on real-time vehicle density and traffic flow, the system dynamically adjusts the signal light durations to optimize traffic movement and reduce unnecessary waiting times.

This module continuously learns from traffic patterns. It enables proactive traffic management instead of merely responding to problems after they arise.

Blockchain Layer

To keep data secure, transparent, and tamper-proof, the system uses a special type of Ethereum-based blockchain layer. This blockchain acts as a decentralized ledger that records all traffic data and decisions made by the AI module.

Secure Data Storage: Traffic events, vehicle logs, congestion data, and AI-generated control decisions are encrypted and hashed before being added to the blockchain. This safeguards the data from unauthorized alterations and maintains its integrity.

Permissioned Access: As it uses a private blockchain, only authorized entities (such as city traffic departments, emergency services, or law enforcement agencies) can read or write data to the blockchain, enhancing control and privacy.

Auditability and Traceability: All transactions and signal changes can be audited in real-time or after they occur, enabling complete transparency in legal scenarios.

Smart Contracts

Smart contracts are autonomous code segments deployed on the blockchain that execute specific tasks automatically when certain conditions are met. They streamline traffic-related operations by enforcing predefined rules and conditions. +

Emergency Vehicle Priority: Smart contracts detect emergency vehicles using GPS and adjust the traffic lights automatically to give them priority route.

Real-time Signal Adjustments: These contracts enforce dynamic traffic signal modifications as instructed by the AI module without human intervention.

Automated Toll Collection and Access Control: Toll payments and access to restricted zones can be managed using smart contracts tied to vehicle identities, reducing delays and manual checks. By automating operations, smart contracts reduce reliance on manual input, enabling faster responses and minimizing the chances of human mistakes.

User Interface / Dashboard

A critical component of the system is the web-based User Interface (UI) or dashboard that offers an intuitive and interactive platform for traffic operators and system administrators.

Real-time Monitoring: The dashboard displays live video feeds, traffic densities, and signal status, which enables operators to observe and validate system behavior.

Alerts and Notifications: In case of anomalies, such as sudden congestion, accidents, or sensor malfunctions, the dashboard generates alerts to facilitate immediate response.

Manual Override and Control: While the system is largely autonomous, traffic officers can change the signals using a control panel when needed, giving them flexibility.

Analytics and Reporting: Historical data and AI decisions can be visualized and exported for performance review, trend analysis, and urban planning purposes.

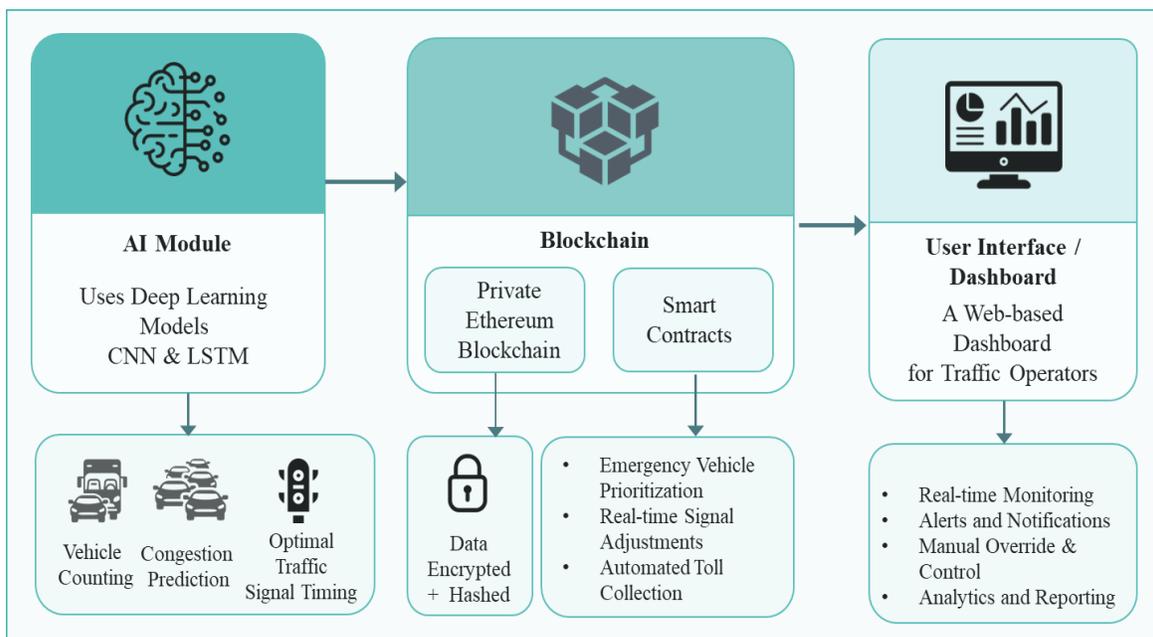


Figure 1: System Architecture Diagram

The UI is designed to be responsive and accessible from various devices, including desktops, tablets, and mobile phones, making it easy for authorities to stay connected with the system at all times.

III. Methodology

The development and deployment of the proposed intelligent traffic control system follow a structured methodology involving **data acquisition, machine learning model training, blockchain infrastructure setup, and system integration**. Each step plays a crucial role in building a robust, responsive, and secure traffic management framework. The major stages of the methodology are explained in detail below:

Data Acquisition

Data is the foundation of the entire system. To ensure a comprehensive understanding of real-time traffic dynamics, the system collects multimodal data from various reliable sources.

CCTV Surveillance Cameras: High-resolution video feeds from roadside cameras are captured continuously to monitor traffic density, vehicle types, and movement patterns.

IoT Sensors: Loop detectors, infrared counters, and ultrasonic sensors embedded in roads or mounted on poles gather information such as vehicle speed, lane occupancy, and weather conditions like fog or rain.

GPS Data from Vehicles: Location and velocity data from GPS-enabled public transport and emergency vehicles helps to monitor movement trends and congestion across city.

This combination of visual, spatial, and environmental data provides rich input for training AI models and making informed traffic decisions.

Model Training

Once the data is collected and preprocessed (e.g., noise removal, frame extraction, timestamp synchronization), it is used to train two primary types of deep learning models:

a. CNN (Convolutional Neural Network)

CNNs are used for following image-based classification tasks:

- Detecting and counting vehicles in a frame.
- Classifying traffic intensity into levels (e.g., low, moderate, and heavy).
- Identifying road anomalies like accidents or blockages.

The model is trained on labeled traffic video datasets, fine-tuned with city-specific footage to improve accuracy under local conditions.

b. LSTM (Long Short-Term Memory Networks)

LSTM models are utilized for time-series prediction tasks, especially focused on:

- Prediction of traffic flow and congestion levels for upcoming time intervals.
- Anticipation of peak-hour behavior based on historical data and temporal patterns.

These models handle sequences of data across time windows, enabling the system to make proactive signal adjustments and plan detours or alerts in advance.

Blockchain Deployment

To ensure the integrity, transparency, and security of traffic data and AI decisions, permissioned blockchain architecture is established using Ethereum:

a. Private Ethereum Blockchain

The system uses a private Ethereum network that is restricted to authorized nodes such as traffic control centers, smart signals, and law enforcement agencies.

The blockchain functions as a secure and immutable distributed ledger used to record:

- AI-generated traffic decisions.
- Logs of signal changes and emergency overrides.
- Vehicle toll and access records.

b. Smart Contracts

Smart contracts are written in Solidity, Ethereum's native programming language, to:

- Manage access permissions based on roles (e.g., emergency vehicles, admin nodes).
- Validate AI decisions and automate signal changes.
- Record and authorize toll transactions or violations.

These contracts ensure autonomous, rule-based decision enforcement without needing manual intervention.

System Integration

The final step involves integrating the AI and blockchain components into a unified, functional system where all nodes interact seamlessly. The AI-based traffic management system generates real-time decisions and insights—such as when to change traffic signals, prioritize emergency vehicles, or reroute traffic. These AI outputs are encoded into blockchain transactions, meaning every decision made by the AI is converted into a secure and verifiable action recorded on the blockchain. Each connected node in the

system-whether it's a traffic light, a control center, or another smart device-acts as a blockchain participant (or node). These nodes are capable of reading, verifying, and executing the smart contracts based on the incoming data they receive.

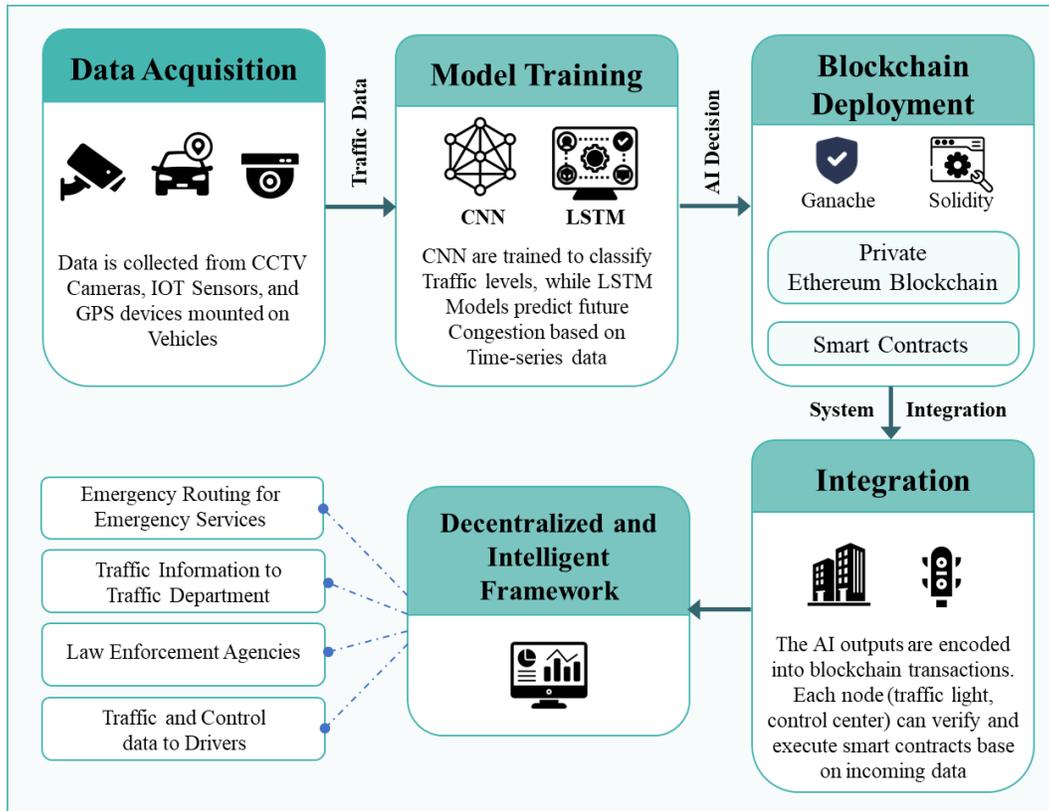


Figure 2: Intelligent Traffic Control System

This decentralized setup ensures consistency across all devices, security, since all actions are verified before execution, transparency, because all decisions and actions are recorded and can be audited later. In Smart Contract Execution, each node such as a smart traffic light or local controller runs a lightweight blockchain client. Upon receiving a relevant transaction (e.g., emergency vehicle detected), it verifies and executes the appropriate smart contract, such as switching to green in the direction of the emergency. All stakeholders, including city traffic managers and analytics teams, can query the blockchain to retrieve real-time traffic decisions and logs, ensuring transparency and accountability. This tightly coupled system allows full automation, easy tracking of actions, and strong reliability, making traffic management smarter and more trustworthy.

IV. Results and Discussion

Based on the proposed method, we expect the system to deliver a range of positive outcomes once implemented. Although the system is still in the proposal stage, the combination of AI and blockchain holds strong potential for improving traffic management.

The AI module, using models like CNN and LSTM, is expected to accurately detect vehicles, analyze traffic flow, and predict congestion in real time. This would allow for smarter and quicker traffic signal adjustments. The use of blockchain is aimed at securely storing traffic data and AI-driven decisions in a tamper-proof way. AI can help understand and respond to traffic conditions more effectively, while blockchain ensures transparency and security in decision-making.

Smart contracts are designed to automate important tasks such as giving priority to emergency vehicles, adjusting signals based on live traffic, and handling tolls without manual work. Automating tasks through smart contracts can reduce delays and human errors. However, several practical aspects need to be considered during actual implementation, such as system scalability, real-time data processing capabilities, and infrastructure costs.

The user dashboard is planned to provide traffic operators with a real-time overview of road conditions, alerts, and control features to make faster and better decisions. Future development may also include integrating external data sources like weather or event updates and improving the AI models over time. Overall, the proposed solution is designed to develop a traffic control system that is smarter, more secure, and highly responsive to real-time conditions.

V. Conclusion

This paper presents a novel framework that combines AI-driven intelligence, blockchain-enabled trust, smart contract automation, and a user-friendly interface to build a modern, scalable, and secure traffic management solution. It not only enhances operational

efficiency but also contributes to safer roads, reduced congestion, and better urban planning through data-driven insights. The methodology effectively combines deep learning for predictive intelligence, blockchain for secure data handling, and smart contracts for automated control enforcement. By systematically integrating these technologies, the proposed solution aims to modernize traffic management infrastructure and pave the way for smarter, safer, and more sustainable urban mobility.

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