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Traffic Signal Optimization Using Matrix Algorithm: A Blockchain Technology and AI Approach

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Abstract

With the exponential growth of the global population, particularly in underdeveloped regions, traffic congestion has become a pressing issue, exacerbated by limited resources and infrastructure. Conventional solutions like constructing new roads face feasibility challenges in third-world countries. In this context, we propose an innovative approach leveraging IoT, blockchain technology, Artificial Intelligence (AI), and sensor technologies for automatic traffic management. The proposed system aims to intelligently detect and respond to changing traffic conditions in real-time, optimizing signal timings to alleviate congestion. Through a comparative analysis, we evaluate the effectiveness of our proposed solution against traditional methods, which are facing many issues at present condition. This research contributes to addressing the escalating traffic challenges in underdeveloped countries, offering a sustainable and efficient approach to mitigate congestion and improve urban mobility.

Subject Areas

Cybersecurity & Machine Learning

Keywords

IoT, Blockchain, Matrix Algorithm, Traffic Congestion

1. Introduction

The rapid growth of urban populations has led to a significant increase in vehicle congestion, resulting in a myriad of problems, including inefficient traffic flow, elevated pollution levels, and heightened accident rates [1]. Traditional traffic management systems, often characterized by outdated infrastructure and reactive strategies, struggle to cope with the complexities of modern urban mobility. In recent years, advancements in technology have emerged as transformative solutions to address these challenges. Among these, the integration of Blockchain, the Internet of Things (IoT), and Artificial Intelligence (AI) has garnered attention for its potential to revolutionize traffic control mechanisms [2]. The existing research has primarily focused on isolated elements of these technologies, neglecting to explore their full potential in tandem [3]. However, the complexities of traffic management have escalated, leading to congestion, accidents, and environmental concerns that challenge cities worldwide.

Former studies have demonstrated the potential of Blockchain technology to provide a secure and transparent framework for data sharing among diverse traffic stakeholders, enabling real-time collaboration and trust [4]. In contrast, research highlights IoT devices, including smart sensors and connected vehicles, for their capabilities in collecting extensive traffic-related data, facilitating a granular understanding of mobility patterns. Although AI algorithms have shown promise in their ability to analyze and interpret this data, empowering predictive analytics and adaptive control strategies, many studies have lacked a comprehensive approach that integrates these technologies effectively.

In this article, we propose an innovative approach that harnesses the synergistic capabilities of Blockchain, IoT, and AI through the application of Matrix Algorithms. These algorithms provide a robust means for efficient computation and optimization of multiple variables, ensuring real-time responsiveness to dynamic traffic conditions. By exploring this novel intersection of technologies, we aim to create a more intelligent traffic control system that enhances safety, reduces congestion, and promotes sustainable urban mobility. While previous research has made strides in individual areas, our work seeks to address the immediate challenges of traffic management through a holistic framework that paves the way for future advancements in smart city infrastructure.

The application of blockchain is being applied to newer domains which show its significance such as energy harvesting, energy trading within microgrids, particularly energy systems [5], finance management [6], cloud computing [7], education [8], and decentralized power control systems [9]. It implies that the use of blockchain is significant in emerging domains. Moreover, the relevance of integrating blockchain and IoT networks is evident in various sectors, including healthcare and energy, due to their robust security features and versatile functionalities [10]. Notably, the application of blockchain technology in traffic management, which is illustrated in **Figure 1**, demonstrates the potential of combining these advanced technologies to tackle complex societal challenges.

The proposed model consists of an IoT server, a data storage system, a blockchain network, a local bridge, IoT devices, and mobile terminals. This efficient system is designed to be scalable, allowing for the integration of new devices in the future. The block diagram for the road traffic control system is depicted in Figure 2, highlighting the major components, including Traffic Management Centers (TMC), wireless systems (3G/5G, LTE), roadside sensors, and gateways. Control of the system relies heavily on information from these sensors and traffic data.

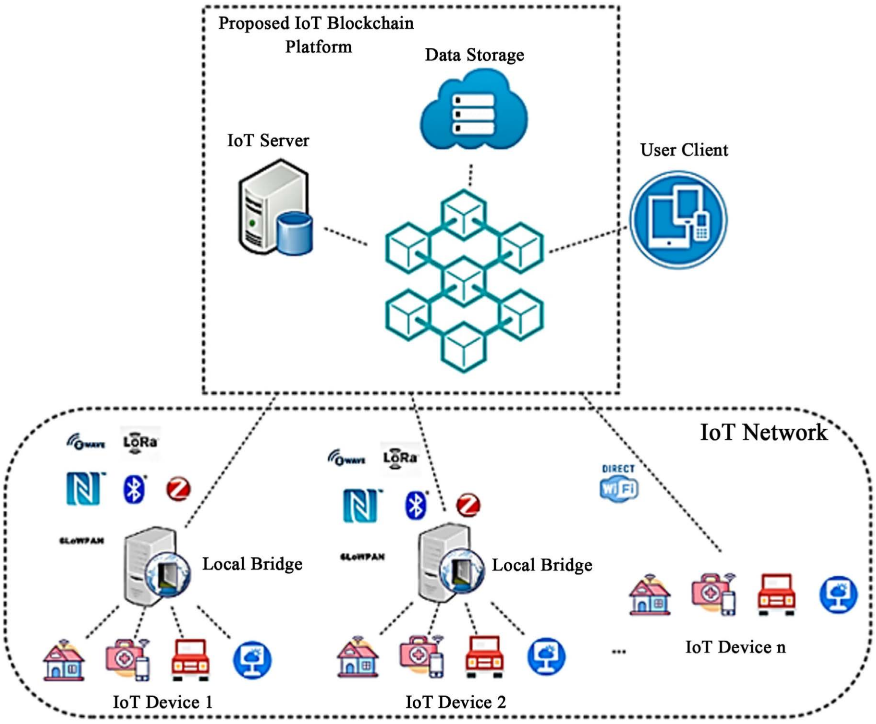


Figure 1. Blockchain, IoT and sensors model [1].

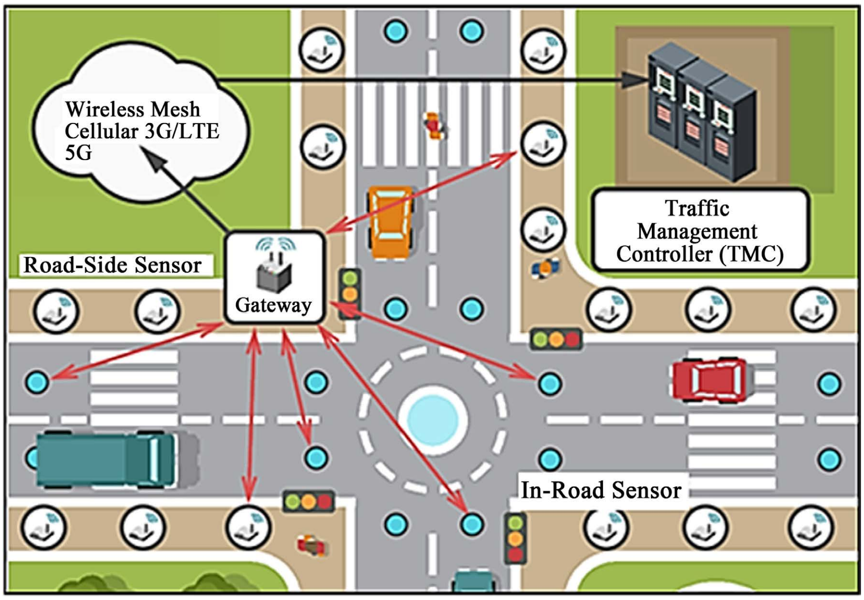


Figure 2. Traffic control and management system [2].

In third world countries like Pakistan the traffic management system largely relies on outdated manual processes that struggle to adapt to the complexities of modern urban mobility [11]. When traffic congestion occurs in any area, traffic signals are often turned off, leaving vehicle flow in the hands of traffic police officers on duty. These officers rely on hand signals and basic communication methods to direct traffic, which can lead to inefficiencies and increased delays, especially during peak hours. In urgent situations, such as when an ambulance requires passage through congested streets, traffic is often halted, and signals are disregarded to allow emergency vehicles to navigate swiftly. While this approach aims to prioritize life-saving services, it exacerbates disruptions for other road users, resulting in additional congestion and frustration. Furthermore, the dependence on human intervention introduces inconsistencies in traffic management, leading to unpredictable outcomes that can compromise overall road safety. The lack of automated systems creates a significant gap in responsiveness to changing traffic conditions, underscoring an urgent need for modernization and innovation in Pakistan's traffic control infrastructure.

2. Related Work

In the past years, an adequate amount of work has been carried out in the domain of traffic control. For instance, [12] explored the rapid development of communication technologies and the Internet of Things (IoT), focusing on issues like cyber-attacks and single points of failure. It proposes an integrated IoT platform that utilizes blockchain technology to ensure data integrity for sensors. However, the proposed platform does not incorporate Matrix algorithm or AI. Moreover, another study by [13] evaluates the security vulnerabilities inherent in IoT systems and advocates for blockchain as a solution. However, the author warns that if the internet falters, systems relying on blockchain could face global collapse. Most of the studies provide challenges mainly based on energy and scalability and a need for adaptive methodologies such as using AI. Furthermore, another study by [14] highlights security challenges within the Internet of Vehicles (IoV) and vehicular ad-hoc networks (VANETs), emphasizing the need to address security issues as these technologies evolve. However, the problem of scalability persists in the proposed framework.

More recently, [15] proposed a framework based on IoV that integrates Intelligent Transportation Systems (ITS) and IoT to improve efficiency and safety through advanced sensor technologies. A similar work by [16] discusses the integration of intelligent solutions in IoV using sensors and advanced wireless communication systems for faster decision-making. Moreover, [17] proposed a blockchain based roadside unit-assisted authentication for IoV. The authors claim that blockchain can enhance transportation efficiency, reduce energy consumption, and minimize traffic accidents; however, the reliance on wireless systems introduces more vulnerabilities to cyber-attacks. They propose a blockchain-based authentication protocol to protect the multi-Trust Authority in the network model.

In exploring blockchain and IoT, the author discusses security features like Proof of Work (PoW) and Practical Byzantine Fault Tolerance (PBFT) but notes their high energy consumption. A hybrid blockchain framework is suggested as an alternative for IoT applications [18]. A recent study by [19] also showed how billions of sensors create a smart environment through their ubiquitous sensing capabilities. Similarly, [20] provided a study based on Blockchain of Things (BCoT), showing the importance of blockchain in IoT. The authors outline the challenges posed by increased device connectivity, which introduces complexity and risks and outlined solutions to address the challenges.

The challenges related to the management of large datasets from IoT devices, and the risk of cyber-attacks are also addressed, advocating for the integration of IoT and blockchain as a remedial measure [21]. Another study by [22], outlined the importance of blockchain in the context of microgrids using IoT. Moreover, [23] outlined challenges of data security in the context of blockchain technology on smart grid, energy trading, and big data. Furthermore, [24] proposed a blockchain based architecture for traffic signal control systems improving security of the overall traffic signal system. The evolution of wireless technologies and IoT's centralized architecture raises significant security concerns [23]. Another study by [25], proposed a real time intelligent traffic control system for smart cities using wireless sensor networks. However, reliance on WSN poses security threats. Similarly, [26] proposed a blockchain based resource allocation model in fog computing. The proposed system uses blockchain to improve resource contribution in fog computing based on a reward and punishment mechanism to incentivize resource sharing, ensuring transparency and security. However, the focus is limited to fog computing without addressing its direct applications in traffic control.

There is a gap between theoretical security concerns and practical implementations [27]. A technique was proposed by [26] based on WSN for real time traffic and parking management. However, the use of WSNs is limited by energy consumption and deployment challenges, especially for large scale networks, lacking AI based real time adaptability and integration with blockchain for improved data reliability and security. Another study by [27] proposed an intelligent traffic control system leveraging a wireless sensor network (WSN) is proposed for monitoring road traffic and available parking in smart cities. This system provides drivers with real-time data on traffic conditions and parking space availability via a mobile app, thereby minimizing congestion [28]. Additionally, a fuzzy logic control system aims to reduce traffic volume and average wait times while optimizing safety Similarly, another study by [29] proposed an adaptive control for traffic signals however, it did not incorporate blockchain which is essential for security purposes.

Moreover, an Adaptive Traffic Signal Control algorithm for real-time intersection management has been introduced, with unique self-learning capabilities to enhance traffic safety [30]. Lastly, complex traffic behaviors are analyzed, and a new intersection representation is developed to improve traffic light scheduling and signal timing control [31]. Similarly, [32] proposed a traffic management framework for ambulance management. Overall, the body of literature underscores the importance of integrating blockchain with IoT for improved security and efficiency in various applications, especially in the context of traffic management and urban planning.

In summary, the state-of-the-art proposed many techniques in different domains and contexts to improve security of IoT systems using blockchain and AI. However, to the best of our knowledge, none of the studies proposed a framework integrating blockchain and AI using Matrix algorithm to structure a system for traffic management. In this research, we cover this gap by proposing a novel framework for traffic management integrating blockchain and AI.

3. Role of Blockchain and IoT in Traffic Management

The role of IoT and Blockchain in road traffic control is pivotal in enhancing the efficiency and responsiveness of traffic management systems. IoT devices, including smart traffic signals, connected vehicles, and real-time surveillance cameras, collect vast amounts of data on traffic conditions, vehicle movements, and environmental factors. This real-time data facilitates immediate insights into traffic flow and congestion patterns, allowing for proactive adjustments in signal timings and route management. Integrating Blockchain technology into this framework adds an essential layer of security and transparency, ensuring that the data collected by IoT devices is stored in a tamper-proof manner. By enabling secure communication between decentralized nodes, Blockchain ensures the integrity of traffic data and facilitates reliable information sharing among traffic management authorities, emergency services, and road users. This synergy can lead to optimized traffic routing, enhanced emergency response times, and improved overall road safety, creating a smarter and more resilient urban traffic ecosystem.

Table 1. Components of an IoT device.

Type	Devices	Function
Communication and Information Transmission	IoT Antennas	Used for the wireless communication of IoT devices by receiving, decoding and transmitting information via various wave types.
Data Retrieval and Information Processing	Nano Processors	An IoT processor must process data received from the IoT endpoints by performing suitable calculations.
Device Power and Life	Nano Batteries	Long-lifetime, high energy density and rechargeable batteries. Lithium-ion the most popular.

a. The term "Nano" means that these components are mainly manufactured based on Nanotechnology.

Table 1 shows the IoT components, Nano IoT devices play a transformative role in modern traffic control systems by enabling real-time monitoring and management of vehicular flows. These ultra-small, interconnected devices can be deployed throughout urban environments to collect data on traffic patterns, vehicle densities, and environmental conditions. By utilizing advanced algorithms and machine learning, the data gathered from these nano devices can optimize traffic signals, reduce congestion, and improve overall road safety. Furthermore, their ability to communicate with vehicles and infrastructure allows for seamless information exchange, paving the way for smart cities where traffic management is more efficient and responsive to current conditions. This innovation not only enhances the driving experience but also contributes to reduced emissions and energy consumption.

4. Road Traffic Control Issues and Challenges

The rapid increase in road traffic over the past decade has led to a significant rise in traffic incidents, particularly in underdeveloped countries like Pakistan and Bangladesh. Traditional traffic control systems are outdated and struggle to manage the surges in vehicle volume during peak periods, often leading to chaos and a heightened risk of accidents. Key challenges identified in addressing these issues are discussed in proceeding sub-headings.

4.1. Forecasting and Scheduling Traffic

The need for accurate predictions and scheduling of traffic patterns, especially during peak times and special events, is critical for effective management.

4.2. Efficient Path Algorithms

The development of algorithms that can effectively route vehicles within the road network is essential to alleviate congestion and optimize travel times.

4.3. Dynamic Traffic Management Systems

A more intelligent and dynamic traffic management system is needed that can adapt to changing conditions and optimize traffic flow in real-time, particularly during rush hours.

4.4. Mitigating Third-Party Interference

Protecting the integrity of the traffic management system against potential manipulations by third parties is crucial for maintaining effective control over traffic flows. Overall, there is a pressing need for modernization and innovation in traffic management to cope with growing traffic density and variable demand.

5. Proposed Solution for Traffic Control

Developing an effective traffic control solution involves a multi-faceted approach that combines technology, infrastructure, public policy, and community engagement. Here are some proposed solutions for traffic control. The following points should be considered.

Firstly, forecasting future traffic volume entails analyzing data from the past ten years to calculate the rate of traffic growth. Utilizing artificial intelligence, historical data can be analyzed and compared with current data to determine the percentage increase in traffic over the specified period. By assessing this growth rate, appropriate enhancements to the traffic system can be implemented, such as expanding infrastructure or adding new routes, to accommodate projected increases in traffic volume.

Secondly, synchronizing traffic signals with precise timing is crucial for ensuring the smooth operation of traffic flow. Employing an iterative design process allows intersections to leverage signal timing techniques, thereby optimizing service levels for all users. Additionally, the layout of traffic control devices plays a vital role in signal design, ensuring the proper positioning of signal heads for maximum visibility across all movements. The outdated traffic control system, depicted in Figure 3, relied on fixed signal timings for instance, 2 minutes for green lights, 2 minutes for red lights, and 10 seconds for orange/yellow lights in one cycle. All relevant data was transmitted to a nearby control office and subsequently aggregated in the main computer unit, as illustrated in Figure 3. The fixed timings often fail to accommodate fluctuating traffic demands, leading to inefficiencies and congestion during peak hours. Upgrading to a more dynamic and adaptive traffic control system, possibly utilizing IoT and blockchain technologies as discussed earlier, can address these shortcomings by allowing real-time adjustments to signal timings based on traffic conditions, ultimately enhancing traffic flow and safety.

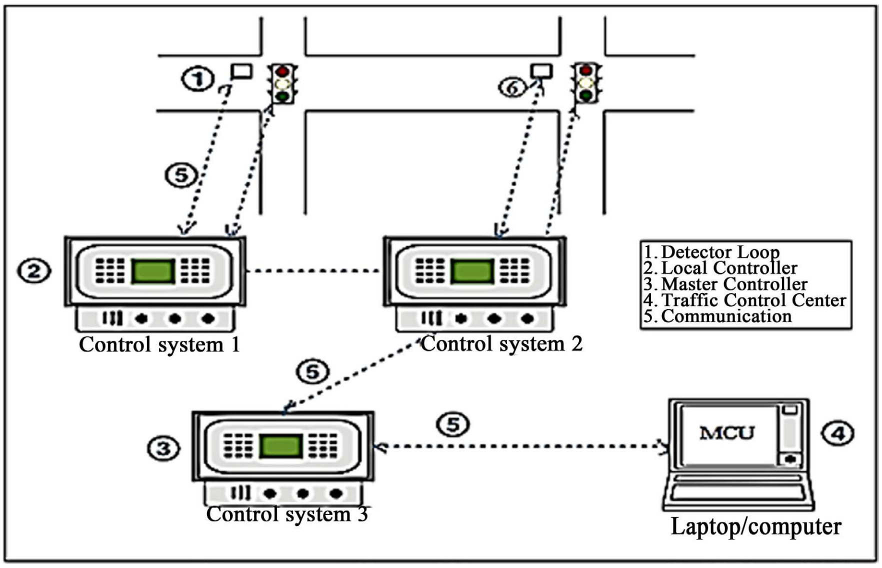


Figure 3. Road traffic control system.

There are significant limitations, particularly concerning emergency response times for ambulances. With fixed signal timings, the system lacks the flexibility needed to prioritize emergency vehicles and ensure swift passage through intersections. As a result, traffic police personnel often must manually override signals to facilitate the timely movement of ambulances, leading to potential delays and increased risks during emergencies. Moreover, the fixed timing system fails to account for fluctuations in traffic patterns throughout the day, resulting in inefficient traffic management and increased congestion during peak hours. This rigid approach also impedes the optimization of signal timings to accommodate varying traffic volumes and prioritize high-traffic routes. To address these shortcomings, modern traffic control systems incorporate dynamic signal timing algorithms that can adapt in real-time to changing traffic conditions. By leveraging advanced technologies such as IoT and artificial intelligence, these systems can prioritize emergency vehicles, optimize signal timings based on traffic flow, and improve overall traffic management efficiency. Additionally, integrating features like preemption systems for emergency vehicles ensures expedited response times and enhances road safety for all road users.

6. Proposed Traffic System Management and Design

In the design and implementation of a Traffic Management System (TMS). The focus is on traffic flow optimization and traffic safety enhancement, particularly in the realm of traffic signal control. The following outlines key components within these areas, providing a structured approach to designing an efficient traffic signal control system based on the previously outlined framework. The TMS can be categorized into two primary domains: Traffic Flow and Traffic Safety. Each domain further subdivides into four critical components: Traffic Optimization, Traffic Signal Control, Passenger Safety, and Environment Safety. This paper focuses specifically on Traffic Signal Control and Traffic Optimization as depicted in Figure 4.

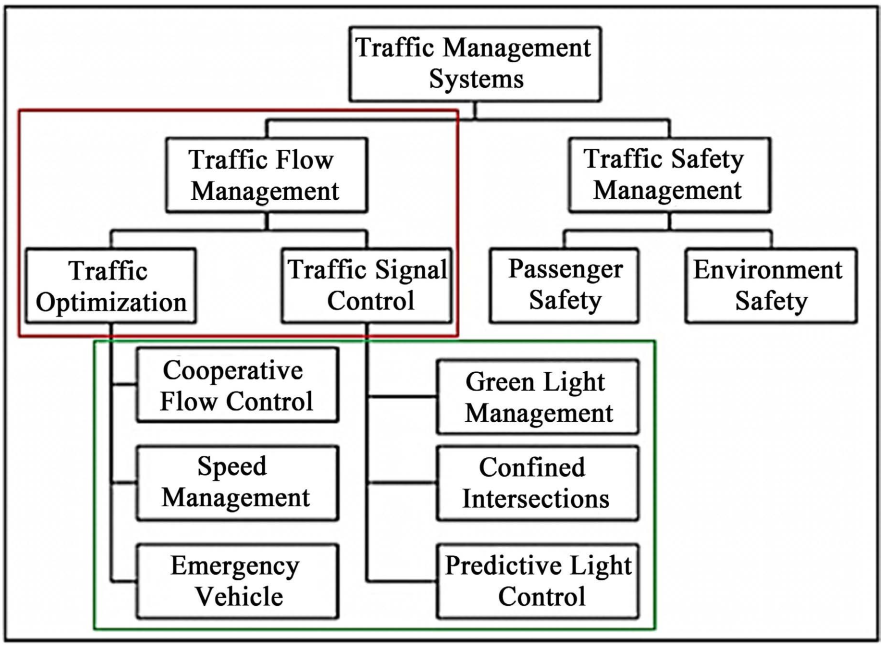


Figure 4. Traffic management system.

6.1. Road Traffic System Design

We present a road traffic system design for the proposed system. The overall traffic system design is predicated on several integral components, which work cohesively to manage vehicle and pedestrian movements as shown in **Figure 5**. The design must effectively address the interactions of both vehicles (represented by solid lines) and pedestrians (represented by dotted lines).

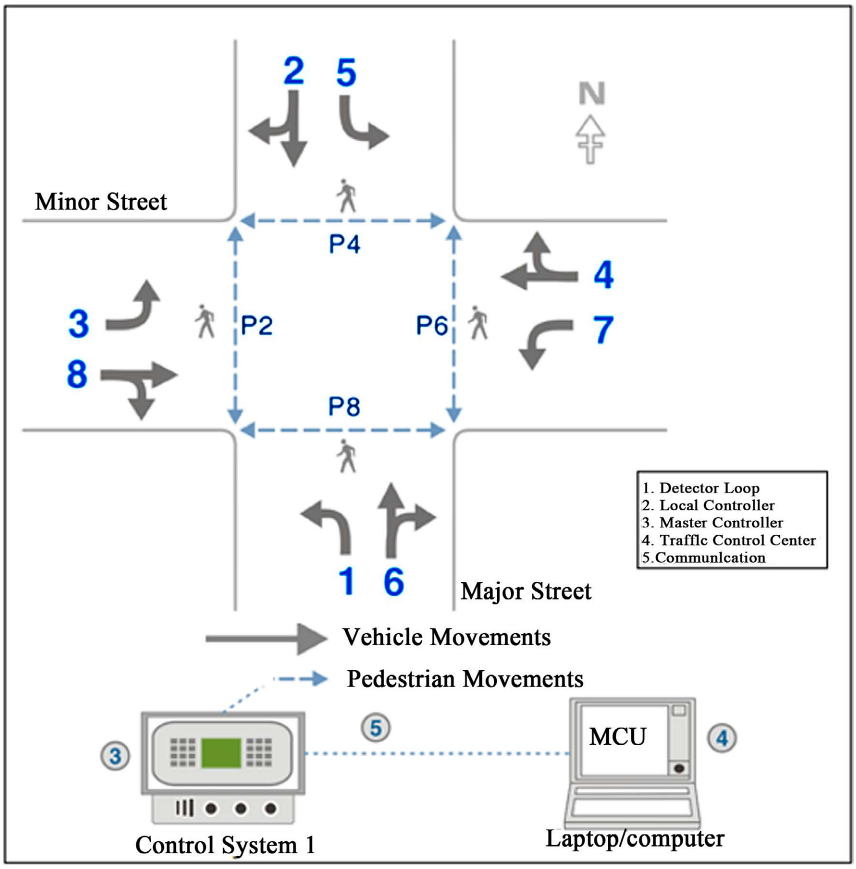


Figure 5. Traffic lines and turns.

6.1.1. Detection Systems

Deployment of detection technologies (such as cameras, inductive loops, and radar) at intersections to gather real-time data concerning vehicle counts, speeds, and traffic density. Utilization of this data enables traffic signal controllers to adapt signal timing dynamically, improving overall traffic flow while also collecting historical data to evaluate and enhance system performance.

6.1.2. Local Controller

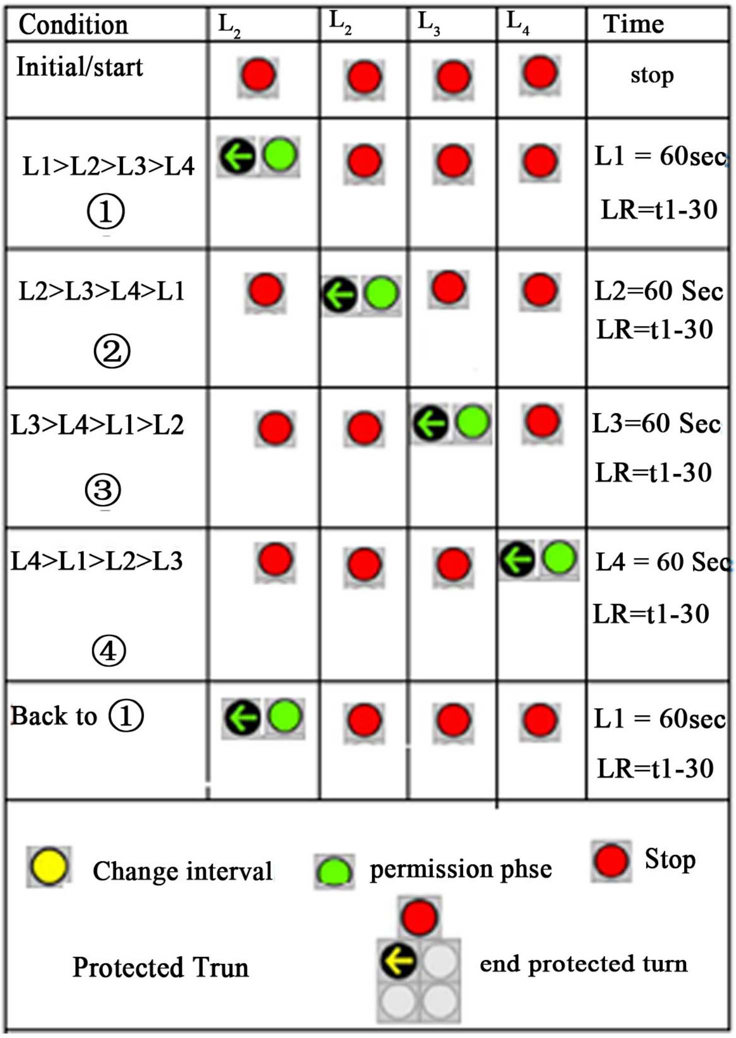
The local controller operates traffic lights according to pre-defined timing parameters and instructions derived from detection data. This autonomous operation allows it to respond effectively to immediate traffic conditions and to execute strategic decisions for optimizing signal phases, thereby ensuring smoother transitions for both vehicles and pedestrians.

6.1.3. Master Controller

Deployment of detection technologies (such as cameras, inductive loops, and radar) at intersections to gather real-time data concerning vehicle counts, speeds, and traffic density. Utilization of this data enables traffic signal controllers to adapt signal timing dynamically, improving overall traffic flow while also collecting historical data to evaluate and enhance system performance.

6.1.4. Traffic Control Center (Signal System)

This central facility serves as the nerve center of the TMS, housing critical software and databases that manage the traffic signal systems. The control center is tasked with maintaining a comprehensive overview of system performance, allowing for timely adjustments to signal timings based on broader traffic patterns. The communication system plays a critical role in enabling coordination between system components. Various forms of communication are employed to facilitate seamless interaction between controllers and ensure effective implementation of the traffic plan, as depicted in Figure 6.



Condition	L_2	L_2	L_3	L_4	Time
Initial/start	🔴	🔴	🔴	🔴	stop
L1>L2>L3>L4 ①	⬅🟢	🔴	🔴	🔴	L1 = 60sec LR=t1-30
L2>L3>L4>L1 ②	🔴	⬅🟢	🔴	🔴	L2=60 Sec LR=t1-30
L3>L4>L1>L2 ③	🔴	🔴	⬅🟢	🔴	L3=60 Sec LR=t1-30
L4>L1>L2>L3 ④	🔴	🔴	🔴	⬅🟢	L4 = 60 Sec LR=t1-30
Back to ①	⬅🟢	🔴	🔴	🔴	L1 = 60sec LR=t1-30

🟡 Change interval 🟢 permission phse 🔴 Stop

Protected Trun ⬅ end protected turn

Figure 6. Current traffic signal control system.

Initially all signals are closed. When the traffic flow starts in line 1, a fixed time is allocated, and all other signals remain closed. On the next cycle the Line 1 signal closed and the next signal open let say Line 2. Same all signals open for fix time and closed in the loop. This method faces many issues such as the in traffic peak hours and mostly traffic stuck in the main roads.

7. Proposed Traffic Control by Using Matrix Method

The Matrix Method is an innovative approach employed in traffic control systems to enhance the efficiency of transportation networks. This systematic framework utilizes mathematical matrices to represent and analyze complex traffic flow patterns across multiple intersections and road segments. At its core, the Matrix Method aids in formulating optimal signal timings and control strategies based on real-time traffic conditions and historical data. We have incorporated the Matrix Method, which provides many benefits as discussed in the proceeding sub-sections.

7.1. Matrix Representation of Traffic Flows

Traffic flows can be represented using matrices, where each row corresponds to a particular road segment or intersection, and each column represents time intervals or vehicle counts. This structured representation allows for the efficient processing and analysis of large data sets, enabling traffic engineers to visualize and quantify traffic conditions.

7.2. Dynamic Signal Timing Optimization

By leveraging the data encapsulated within traffic flow matrices, the Matrix Method facilitates the development of dynamic signal timing plans. These plans are responsive to fluctuations in traffic volumes, which can vary significantly throughout the day. The ability to adjust signal phasing in real-time helps mitigate congestion and optimize the flow of both vehicles and pedestrians.

7.3. Utilization of Queuing Theory

The Matrix Method incorporates principles of queuing theory to predict and manage traffic congestion. By analyzing queues at traffic signals, engineers can make informed decisions about optimal signal durations and phases to minimize waiting times and improve overall transportation efficiency.

7.4. Integration with Intelligent Transportation Systems (ITS)

The Matrix Method seamlessly integrates with ITS, allowing for the incorporation of real-time data from various sources such as traffic detectors, cameras, and GPS-based systems. This integration ensures that the traffic control system is not only reactive but also proactive in its approach to managing traffic flow.

7.5. Simulation and Scenario Analysis

The Matrix method allows for the simulation of various traffic scenarios, enabling traffic planners to assess the impact of different signal control strategies under various conditions. This capability supports data-driven decision-making and facilitates the testing of innovative control measures without disrupting actual traffic. In summary, the application of the Matrix Method in traffic signal control represents a significant advancement in the pursuit of efficient and responsive transportation systems. By utilizing a structured Matrix approach, traffic planners can better analyze, optimize, and control traffic flows, ultimately contributing to improved urban mobility, reduced congestion, and enhanced safety for all road users. This method stands at the forefront of modern traffic management strategies, aligning with the needs of increasingly complex urban environments. We can express the traffic flow along the routes as shown in Equation (1).

$$F = \left[A/cdot\,D\right] \tag{1}$$

In Equation (1), A = Adjacency Matrix of the road network (captures the connectivity and flow capacities), F = Flow Matrix indicating the number of vehicles on each segment, and D = Demand Matrix for traffic between zones (represents vehicle demand between different zones). The Matrix Method employs optimization techniques to determine ideal traffic signal timings and flow distributions, aiming to minimize delays or maximize throughput through objective functions and constraints in Matrix form. Dynamic algorithms can adapt to time-varying traffic conditions, optimizing signal timings effectively. By utilizing state matrices, the method calculates optimal movement sequences to minimize delays at intersections for all traffic directions. Adaptive control mechanisms further enhance the system, allowing for real-time adjustments based on current traffic states and data inputs. Moreover, the Matrix model can be tested using traffic simulation software, such as VISSIM or Sim Traffic, which helps analyze its performance across various scenarios. The integration of real-time traffic data from sensors and cameras into the Matrix model ensures that control strategies are continuously updated for improved traffic management.

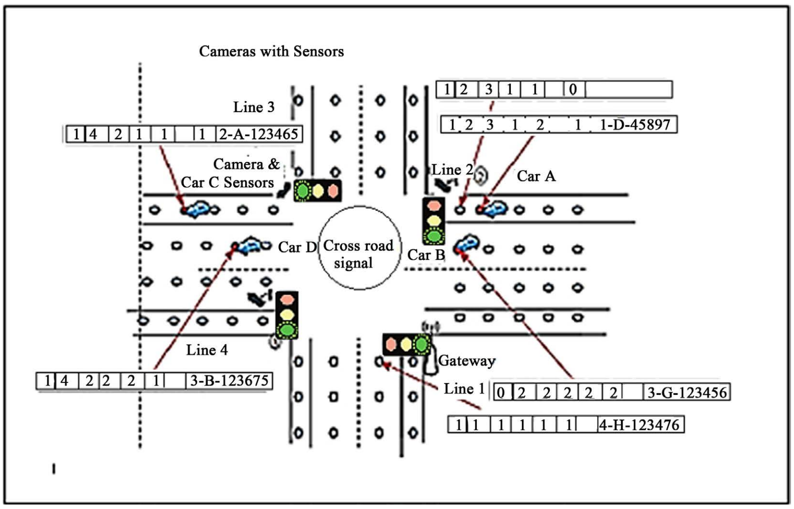


Figure 7. The traffic system.

In proposed system 4 video cameras are required for monitoring traffic position need and, wireless data network 3G or 5G to transfer real time data system and AI and blockchain to process fast data and secure communication in the networks given in Figure 7. To effectively implement traffic control systems using the Matrix Method, it is crucial to introduce and analyze the data samples collected by the system. This collected data serves as the foundation for understanding traffic patterns and making informed decisions regarding signal control and optimization strategies.

8. Data Collection and Processing

The system typically gathers various types of data, including vehicle counts, speeds, traffic density, and waiting times at intersections. Additional data can include pedestrian movements, weather conditions, and historical traffic patterns, which contribute to a comprehensive understanding of traffic behavior.

8.1. Data Collection

In our experimentation process, we collected the data is often from multiple sources.

8.1.1. Traffic Sensors

Inductive loop sensors, radar, or video cameras placed at strategic locations to monitor real-time vehicular flow.

8.1.2. GPS (Global Positioning System) Data

Information from GPS devices in vehicles can provide insights into traffic speeds and patterns.

8.2. Mobile Applications

Crowd-sourced data from navigation apps that users employ can help gauge traffic conditions.

8.3. Historical Data

Previous traffic studies and analyses can provide valuable context for current conditions.

8.4. Data Processing

Once collected, the data must be processed and managed effectively. This involves cleaning and validating the data to ensure accuracy, followed by structuring it for analysis. The use of Matrix representations allows for efficient organization and manipulation of large data sets.

8.5. Data Analysis and Interpretation

The processed data can be analyzed using statistical and mathematical methods. This includes identifying traffic trends, peak hours, and bottlenecks. Insights generated from this analysis inform the development of objective functions and constraints essential for the Matrix method's optimization process.

8.6. Real-Time Updates

Integrating real-time data into the traffic control system is vital for adaptability. Current traffic conditions must be continuously updated in the matrix models to reflect changes in flow patterns, allowing for timely adjustments to signal timings and control strategies.

8.7. Feedback Loop

Establishing a feedback loop is important for system improvement. By comparing predicted traffic flow outcomes against actual conditions based on real-time data, the system can refine its model and optimize future decision-making processes. In short, the introduction of collected data samples is crucial for the successful implementation of traffic control systems using the Matrix Method. This data enables a comprehensive understanding of traffic dynamics and supports the optimization of signal control strategies that enhance overall traffic flow and safety.

9. Role of AI and Blockchain in Matrix Method

A system integrating AI, blockchain, and the Matrix method is discussed in the next sub-heading.

9.1. Data Structure

Sensors and cameras gather traffic data, which is structured in a Matrix format.

9.2. Data Storage on Blockchain

This data is recorded on a blockchain to maintain integrity and allow access for authorized stakeholders.

9.3. AI Analysis

AI analyzes the data, using historical and real-time information to optimize traffic flow, predict congestion, and suggest improvements.

9.4. Automated Response

Based on AI recommendations, smart contracts on the blockchain can implement traffic signal changes, inform drivers of alternate routes, and adjust traffic management strategies accordingly.

9.5. Feedback Loop

The system continually learns from new traffic patterns and adjusts algorithms, while the performance feedback is also recorded on the blockchain for continuous improvement. As shown in Figure 8. For sensing and monitoring the sensors and blockchain can be used. For data storing and management new nano batteries and big data systems can be used.

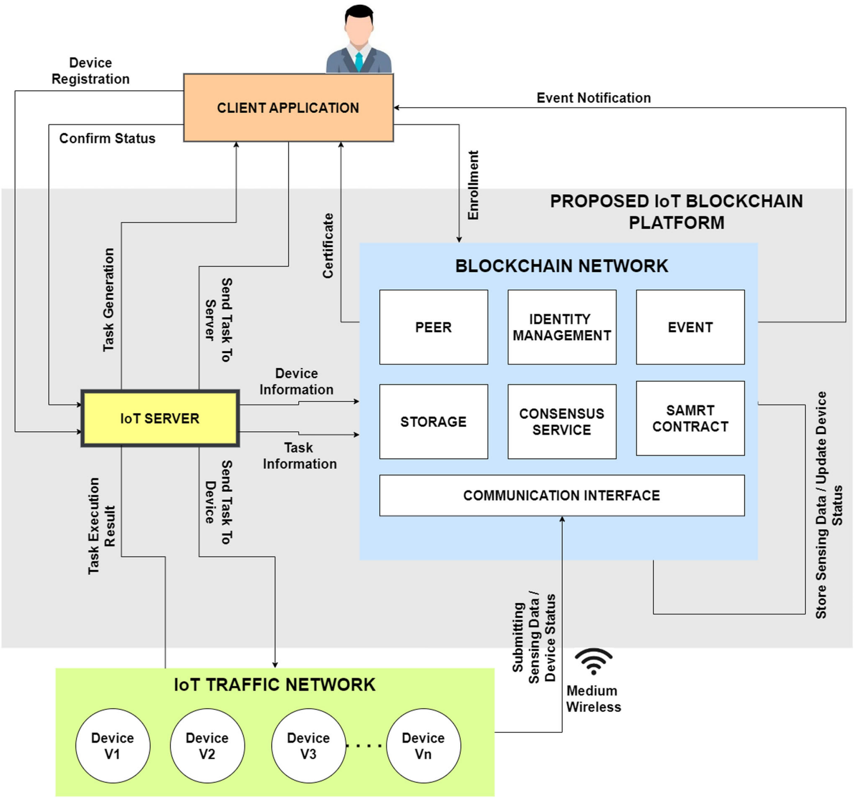


Figure 8. Proposed system architecture.

10. Simulation Results

The Matrix method for counting traffic in rows and columns typically involves creating a structured approach for organizing and analyzing data, such as vehicle counts at intersections, road segments, or specific locations. Here, we present a brief overview of how to approach it in the next sub-sections.

10.1. Step 1: Define the Matrix

Define a Matrix where the rows and columns represent different categories of traffic.

For example:

Rows: Different time periods (e.g., Morning, Afternoon, Evening)

Columns: Different vehicle types or lanes (e.g., Cars, Buses, Trucks)

Example Matrix:

\[\begin{array}{|c|c|c|c|}
\hline
\text{Time/Type} & \text{Cars} & \text{Buses} & \text{Trucks} \\
\hline
\text{Morning} & 150 & 20 & 30 \\
\text{Afternoon} & 200 & 30 & 50 \\
\text{Evening} & 100 & 10 & 20 \\
\hline
\end{array}\]

10.2. Step 2: Populate the Matrix

Collect data for each category and fill in the Matrix accordingly. You may gather this data through manual counting, sensors, cameras, etc.

10.3. Step 3: Calculate Totals

We can calculate totals for each row and column:

> **Row Totals (e.g., Total vehicles for a given period):**
> **Morning:** \(150 + 20 + 30 = 200\)
> **Afternoon:** \(200 + 30 + 50 = 280\)
> **Evening:** \(100 + 10 + 20 = 130\)
> **Column Totals (e.g., Total vehicles for a given type):****
> **Cars:** \(150 + 200 + 100 = 450\)
> **Buses:** \(20 + 30 + 10 = 60\)
> **Trucks:** \(30 + 50 + 20 = 100\)

The flowchart in Figure 9, shows the method of proposed Matrix algorithm to control the traffic signals dynamically. After initializing values to zero or resetting time, Line 1 activates a green signal for traffic flow. It operates on a fixed or automatic timer based on the traffic length Matrix, which influences the timing. All other signals remain red; once Line 1's time expires, it stops, and the next line turns green. This pattern continues, depending on the traffic Matrix length. The complete system is illustrated in Figure 10, detailing all components and their functioning. Data and video footage are gathered, and a Matrix algorithm calculates traffic volume for each side, allocating time accordingly.

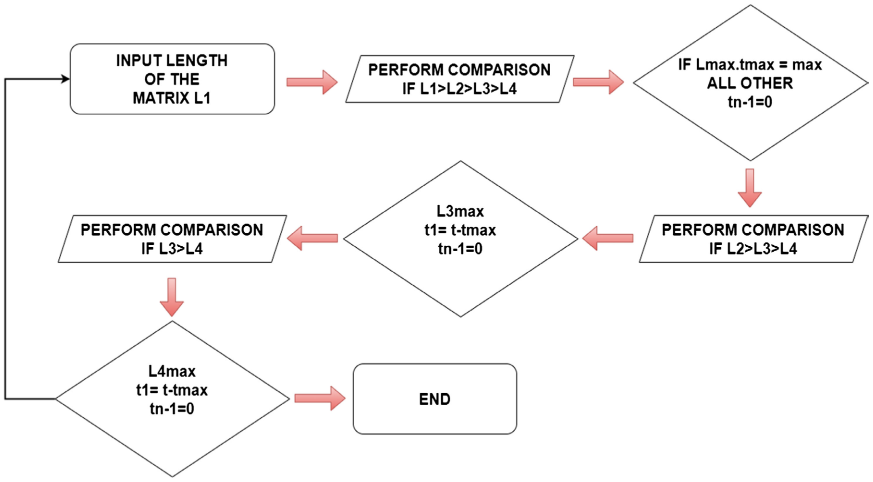


Figure 9. Flowchart of the proposed system.

We described a traffic signal control system for a junction with four roads and specified different conditions for managing the signal timings based on the traffic flow on each road. Let's break down each condition and its corresponding signal timing assignment:

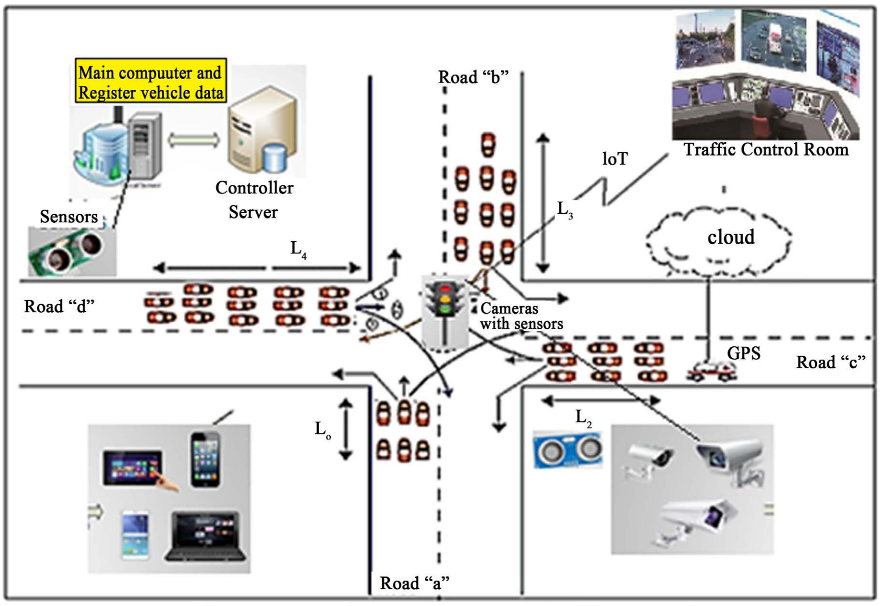


Figure 10. Proposed system to control traffic congestion.

First Loop:

```
If $L1 > L2 > L3 > L4$L1 > L2 > L3 > L4, then:
Assign $L1 = t2 = 60$L1 = t2 = 60 sec (Green light for Road 1)
Assign $L2 = L3 = L4 = 0$L2 = L3 = L4 = 0 sec (Red light for Roads 2, 3, and 4)
If $L2 > L3 > L4 > L1$L2 > L3 > L4 > L1, then:
Assign $L2 = t2 = 60$L2 = t2 = 60 sec (Green light for Road 2)
Assign $L1 = L3 = L4 = 0$L1 = L3 = L4 = 0 sec (Red light for Roads 1, 3, and 4)
If $L3 > L2 > L4 > L1$L3 > L2 > L4 > L1, then:
Assign $L3 = t2 = 60$L3 = t2 = 60 sec (Green light for Road 3)
Assign $L1 = L2 = L4 = 0$L1 = L2 = L4 = 0 sec (Red light for Roads 1, 2, and 4)
If $L4 > L2 > L3 > L1$L4 > L2 > L3 > L1, then:
Assign $L4 = t2 = 60$L4 = t2 = 60 sec (Green light for Road 4)
Assign $L1 = L2 = L3 = 0$L1 = L2 = L3 = 0 sec (Red light for Roads 1, 2, and 3)
```

Second Loop:

```
If $L1 = L2$L1 = L2 and $L3 = L4$L3 = L4, then:
Assign $L1 = t1 = 60$L1 = t1 = 60 sec (Red light for Road 1)
Assign $L2 = t2-60$L2 = t2−60 sec (Green light for Road 2)
Assign $L3 = t3-(t2-60)$ L3 = t3−(t2−60) sec (Yellow light for Road 3)
Assign $L4 = t4-(t3-(t2-60))$ L4 = t4−(t3−(t2−60)) sec (Change Signal for Road 4)
```

Third Loop:

```
If $L1 = L2 = L3 = L4$L1 = L2 = L3 = L4, then:
Assign $L1 = 60-t2-t3-t4$L1 = 60−t2−t3−t4 sec (Green light for Road 1)
Assign $L2 = 60-t1-t3-t4$L2 = 60−t1−t3−t4 sec (Green light for Road 2)
Assign $L3 = 60-t1-t2-t4$L3 = 60−t1−t2−t4 sec (Green light for Road 3)
Assign $L4 = 60-t1-t2-t3$L4 = 60−t1−t2−t3 sec (Green light for Road 4)
```

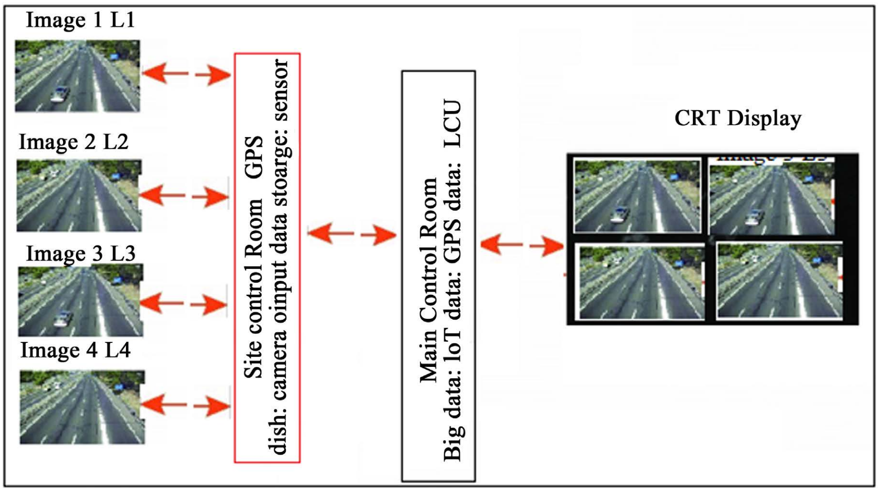


Figure 11. Proposed working for traffic control room.

These conditions define how the traffic signal timings should be adjusted based on the relative traffic volumes on each road. The real scenario is given in Figure 11. To create a graph of the equation provided, we need specific values for the traffic volumes (L1, L2, L3, L4) and time intervals (t1, t2, t3, t4). Without specific values, I can't generate a precise graph, but I can show you a basic visualization of how such a graph might look using arbitrary values. Let's assume we have some arbitrary traffic volume data and time intervals. We'll plot the traffic volume against time for each direction separately and then integrate these curves to find the total green time. We utilized the following Python code using Matplotlib to generate a basic visualization.

```
# Arbitrary traffic volume data
Time Intervals = [0, 100, 200, 300] # Example time intervals
L1 = [100, 150, 200] # Example traffic volume for direction 1
L2 = [120, 180, 240] # Example traffic volume for direction 2
L3 = [80, 100, 120] # Example traffic volume for direction 3
L4 = [90, 110, 130] # Example traffic volume for direction 4
# Plotting traffic volume against time for each direction
plt. figure (figsize = (10, 6))
plt.plot (time intervals [:-1], L1, label='Direction 1')
plt.plot (time intervals [:-1], L2, label='Direction 2')
plt.plot (time intervals [:-1], L3, label='Direction 3')
plt.plot (time intervals [:-1], L4, label='Direction 4')
plt.xlabel ('Time intervals')
plt.ylabel ('Traffic volume')
plt.title ('Traffic volume over time for each direction')
plt.legend ()
plt.grid (True)
plt. show ()
```

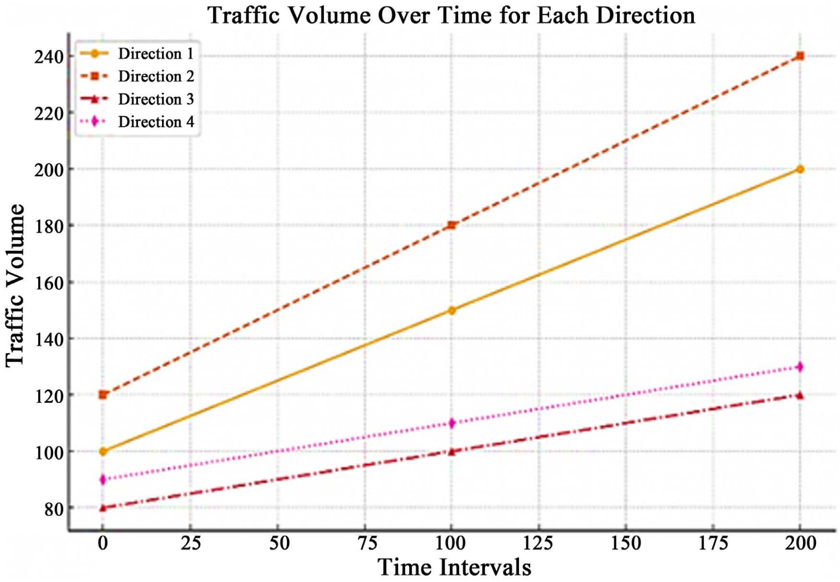


Figure 12. Traffic volume control over time.

The plot of the traffic volume and time interval pattern is given below in Figure 12. The shows the traffic volume over time for four different directions, labeled as Direction 1, Direction 2, Direction 3, and Direction 4. Following is the key detail:

- **X-axis (Time Intervals)**: The horizontal axis represents time intervals (0, 100, 200). These intervals could be minutes, hours, or any other unit of time.
- **Y-axis (Traffic Volume)**: The vertical axis shows the traffic volume, representing the number of vehicles or a similar metric.
- Additional Details are as follows:
  - **Direction 1 (blue line with circles):** The traffic volume starts at 100 at time interval 0, increases to 150 at 100, and reaches 200 at 200.
  - **Direction 2 (orange line with squares):** The traffic volume starts at 120 at time interval 0, increases to 180 at 100, and reaches 240 at 200.
  - **Direction 3 (green line with triangles):** The traffic volume starts at 80 at time interval 0, increases to 100 at 100, and reaches 120 at 200.
  - **Direction 4 (red line with diamonds):** The traffic volume starts at 90 at time interval 0, increases to 110 at 100, and reaches 130 at 200.

In simulation the values of the parameters used in our procedures were determined through a structured approach that combined literature review, data collection, model calibration, sensitivity analysis, expert consultation, simulation trials, and real-time adjustments. This comprehensive methodology ensured that the parameters were both relevant and effective in achieving accurate and meaningful results in simulation. The mathematical equation for the traffic signal is shown in Equation (2).

$$T_{Green} = \int_{0}^{t1} \sum_{1}^{n} L_1 dt + \int_{t1}^{t2} \sum_{1}^{n} L_2 dt + \int_{t2}^{t3} \sum_{1}^{n} L_3 dt + \int_{t3}^{t4} \sum_{1}^{n} L_4 dt \qquad (2)$$

The input data contains three matrices as shown in Equation (3).

$$Mmov = \left[(m,n)1, \cdots (m,n)\, p \right] \tag{3}$$

$$Mlane = (m/n) \tag{4}$$

$$M_{com} = \begin{bmatrix} cd \cdots\cdots\cdots cd \\ cd \cdots\cdots\cdots cd \end{bmatrix} \tag{5}$$

Table 2. Timing plan for traffic.

Line	Time minutes	Line 1	Line 2	Line 3	Line 4
L_1	t_{max}	on	off	off	off
L_2	t_{mini}	off	on	off	off
L_3	t_{mini}	off	off	on	off
L_4	t_{mini}	off	off	off	on
L_1	tmini	on	off	off	off
L_2	t_{max}	,	,	,	,
L_3	t_{mini}	,	,	,	
L_4	t_{mini}	L_{n-1}	L_{n-2}	L_{n-3}	L_{n-4}

a. The term "Nano" means that these components are mainly manufactured based on Nanotechnology.

The algorithm sets the number of vehicles whose phase arrives before the green light is greater than, when it is equal to Lth, only Lth cars will be released during the green time. After that, the lights will be switched to other phases for service. For the setting of Lth, it can largely avoid the unfairness caused by a certain phase occupying the green light for a long time. According to the above process, the average queue length, average cycle time, and timing matching formula obtained are as shown in (1), (2), and (3).

The traffic control system is given in Figure 9. In which the length of the traffic measure from four side of road L1, L2, L3 and L4 (See Table 2). The length of the traffic Matrix is measured and according to that the time of the signal can vary such as for longer Matrix longer time is assigned to line and for shorter Matrix, short time can be assigned to line. The AI algorithm performance is shown in Figure 12 and the traffic intensity versus time graph is given in Figure 13.

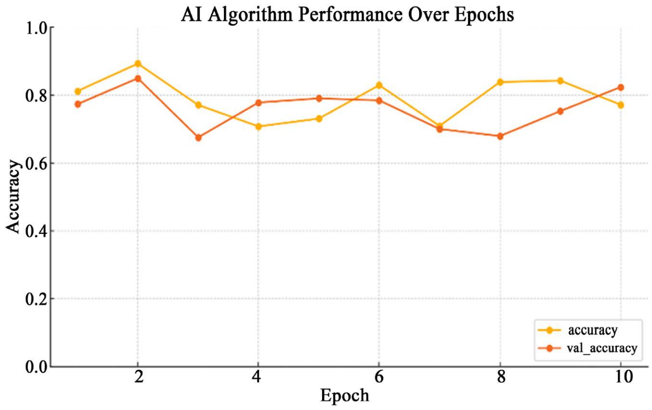


Figure 13. AI algorithm performance.

11. Implementation of AI in Traffic Control

Artificial Intelligence (AI) can significantly enhance road traffic monitoring systems by leveraging advanced algorithms and data analytics. It can provide real-Time traffic monitoring, computer Vision via using AI-powered cameras, can classify vehicles, pedestrians, and congestion points.

11.1. Sensor Data Integration

AI can process data from various sensors (e.g., inductive loops, radar) to provide a comprehensive view of traffic conditions in real-time.

11.2. Traffic Flow Prediction

AI models can predict future traffic patterns based on historical data, current conditions, and external factors such as weather or events.

11.3. Incident Detection

Machine learning algorithms can identify unusual patterns indicating accidents, breakdowns, or other incidents, allowing for quicker response times.

11.4. Adaptive Traffic Signals

AI can optimize traffic light timings dynamically based on real-time traffic conditions to minimize congestion and improve traffic flow.

11.5. Route Optimization

AI can provide drivers with real-time suggestions for the fastest routes, considering current traffic conditions and historical data (See **Figure 14**).

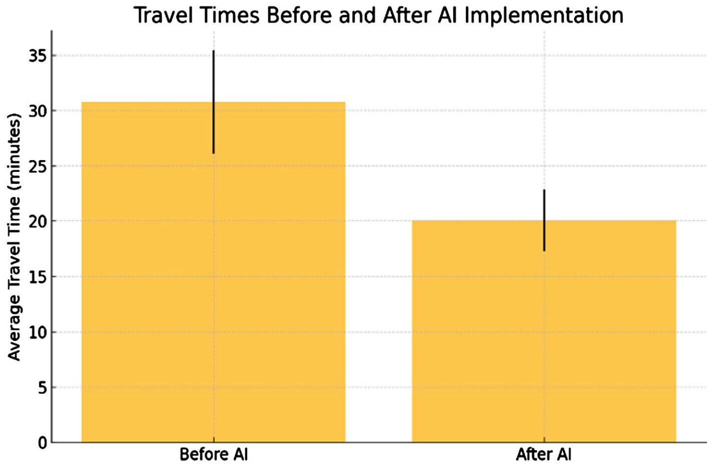


Figure 14. Comparison of times before and after AI implementation.

11.6. Anomaly Detection

AI systems can identify traffic violations such as speeding, running red lights, and illegal turns by analyzing video feeds and sensor data.

11.7. Road Condition Monitoring

AI can analyze road conditions and detect issues like potholes or debris, informing maintenance crews promptly. Moreover, AI can analyze long-term traffic data to identify trends and patterns, helping city planners design better road networks and improve infrastructure.

11.8. Behavior Analysis

Understanding driver behavior through AI can lead to more effective traffic management strategies and educational campaigns to promote safer driving habits. In addition, AI can predict high-risk areas and times for accidents, enabling preventive measures. In the event of an accident, AI can help dispatch emergency services more efficiently by analyzing the quickest routes and predicting the impact on traffic.

11.9. Environmental Impact and Emission Reduction

By optimizing traffic flow and reducing congestion, AI can help lower vehicle emissions and improve air quality. Moreover, AI can provide feedback and suggestions to drivers to adopt more fuel-efficient driving practices. There are many use case scenarios where AI has been employed for traffic monitoring. Google Maps uses AI to provide real-time traffic updates and route optimization. Waze employs crowd-sourced data and AI to alert drivers about traffic conditions, accidents, and hazards. Furthermore, AI-powered cameras are used by traffic authorities to monitor and manage traffic flow and detect violations.

Integrating AI into road traffic monitoring systems offers cities a robust solution for improved traffic management, enhanced safety, and reduced environmental impact. This integration leverages advanced technologies, such as AI algorithms and nanosensors, to optimize traffic flow and monitor conditions more accurately. The accompanying figures demonstrate how these technologies contribute to system accuracy and operational efficiency. Additionally, the provided codes and graphs highlight practical applications and the benefits of utilizing AI and nanosensors in both research and traffic control systems, underscoring their transformative potential in urban transportation management. As per the given figures, it is noticeable that the AI technique can be used to reduce the average travelling time for vehicles.

12. Conclusions

In this research, we have introduced an innovative solution to the challenges of road traffic control by harnessing the power of IoT and blockchain technology. Traditional approaches often falter under heavy traffic loads, leading to inefficiencies and unfair signal timing. In contrast, our proposed method dynamically adapts signal timing in real-time, utilizing a Matrix Technique for precise analysis. Our traffic control system integrates blockchain technology, IoT, and sensor technology to continuously monitor and regulate traffic flow.

We have utilized Matrix analysis to illustrate the effectiveness of our approach in optimizing signal timing based on traffic density, thereby reducing congestion and promoting equitable traffic management. This research sets the stage for the deployment of automated traffic control systems on a large scale, promising significant improvements in alleviating congestion and enhancing urban mobility. By leveraging cutting-edge technologies, such as AI, we pave the way for more efficient and sustainable transportation networks in the future.

Future Work

The implementation of new technologies, such as nanosensors and high-speed internet services, can enhance research accuracy and system efficiency. Nanosensors offer precise data collection at the microscopic level, enabling more detailed and reliable results. High-speed internet services facilitate rapid data transmission and real-time analysis, reducing latency and improving the responsiveness of research systems. Together, these advancements contribute to more robust and efficient research methodologies, ultimately accelerating scientific discoveries and innovations.

Contributions

Mishaal Ahmed: Topic Introduction, Literature Review, Methodology and Research implementation. **Faraz Liaquat**: Simulation, Result Comparisons. **Muhammad Ajmal Naz**: Writing-Original Draft Preparation, Data visualization and investigation. **Manzar Ahmed**: Manuscript Preparation, Proof-Reading. **Afshaar Ahmed**: Finalizing Images and Evaluation of Experiments.

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Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Profiroiu, C.M., Bodislav, D.A., Burlacu, S. and Rădulescu, C.V. (2020) Challenges of Sustainable Urban Development in the Context of Population Growth. *European Journal of Sustainable Development*, **9**, 51-57. https://doi.org/10.14207/ejsd.2020.v9n3p51

[2] Mari Kirthima, A. and Pushpa, S.K. (2021) Evolving Technological Advancements and Its Effectivity Study in Intelligent Traffic System. In: Silhavy, R., Silhavy, P. and Prokopova, Z., Eds., *Software Engineering Application in Informatics*, Springer International Publishing, 447-457. https://doi.org/10.1007/978-3-030-90318-3_37

[3] Englund, C., Aksoy, E.E., Alonso-Fernandez, F., Cooney, M.D., Pashami, S. and

Åstrand, B. (2021) AI Perspectives in Smart Cities and Communities to Enable Road Vehicle Automation and Smart Traffic Control. *Smart Cities*, **4**, 783-802. https://doi.org/10.3390/smartcities4020040

[4] Bharadiya, J. (2023) Artificial Intelligence in Transportation Systems a Critical Review. *American Journal of Computing and Engineering*, **6**, 34-45. https://doi.org/10.47672/ajce.1487

[5] Ahmed, A., Liaquat, S.F., Rizvi, H.H., Ahmed, M., Rizvi, J.A. and Ahmed, M. (2022) Harvesting Sea Wave Energy by Using Point Absorber and Blockchain Technology. *VFAST Transactions on Software Engineering*, **10**, 94-100. https://doi.org/10.21015/vtse.v10i2.967

[6] Toorajipour, R., Oghazi, P., Sohrabpour, V., Patel, P.C. and Mostaghel, R. (2022) Block by Block: A Blockchain-Based Peer-to-Peer Business Transaction for International Trade. *Technological Forecasting and Social Change*, **180**, Article 121714. https://doi.org/10.1016/j.techfore.2022.121714

[7] Sarmah, S.S. (2019) Application of Block Chain in Cloud Computing. *International Journal of Innovative Technology and Exploring Engineering*, **8**, 4698-4704. https://doi.org/10.35940/ijitee.l3585.1081219

[8] Villegas-Ch, W., Palacios-Pacheco, X. and Román-Cañizares, M. (2020) Integration of IoT and Blockchain to in the Processes of a University Campus. *Sustainability*, **12**, Article No. 4970. https://doi.org/10.3390/su12124970

[9] Farhi, L., Laila, U., Ahmed, A., Ahmed, M., Ahmed, M. and Siddiqui, F.A. (2022) Application of Blockchain Technology in Energy Sector for Sustainable Future. *VAWKUM Transactions on Computer Sciences*, **10**, 11-23. https://doi.org/10.21015/vtcs.v10i2.1268

[10] Krichen, M., Ammi, M., Mihoub, A. and Almutiq, M. (2022) Blockchain for Modern Applications: A Survey. *Sensors*, **22**, Article No. 5274. https://doi.org/10.3390/s22145274

[11] Sharma, A., Awasthi, Y. and Kumar, S. (2020) The Role of Blockchain, AI and IoT for Smart Road Traffic Management System. 2020 *IEEE India Council International Subsections Conference* (*INDISCON*), Visakhapatnam, 3-4 October 2020, 289-296. https://doi.org/10.1109/indiscon50162.2020.00065

[12] Alfa, A.A., Alhassan, J.K., Olaniyi, O.M. and Olalere, M. (2020) Blockchain Technology in IoT Systems: Current Trends, Methodology, Problems, Applications, and Future Directions. *Journal of Reliable Intelligent Environments*, **7**, 115-143. https://doi.org/10.1007/s40860-020-00116-z

[13] Sadawi, A.A., Hassan, M.S. and Ndiaye, M. (2021) A Survey on the Integration of Blockchain with IoT to Enhance Performance and Eliminate Challenges. *IEEE Access*, **9**, 54478-54497. https://doi.org/10.1109/access.2021.3070555

[14] Abbas, S., Talib, M.A., Ahmed, A., Khan, F., Ahmad, S. and Kim, D. (2021) Blockchain-Based Authentication in Internet of Vehicles: A Survey. *Sensors*, **21**, Article No. 7927. https://doi.org/10.3390/s21237927

[15] Chang, W., Chen, L. and Su, K. (2019) DeepCrash: A Deep Learning-Based Internet of Vehicles System for Head-On and Single-Vehicle Accident Detection with Emergency Notification. *IEEE Access*, **7**, 148163-148175. https://doi.org/10.1109/access.2019.2946468

[16] Dandala, T.T., Krishnamurthy, V. and Alwan, R. (2017) Internet of Vehicles (IoV) for Traffic Management. 2017 *International Conference on Computer*, *Communication and Signal Processing* (*ICCCSP*), Chennai, 10-11 January 2017, 1-4. https://doi.org/10.1109/icccsp.2017.7944096

[17] Xu, Z., Liang, W., Li, K., Xu, J. and Jin, H. (2021) A Blockchain-Based Roadside Unit-Assisted Authentication and Key Agreement Protocol for Internet of Vehicles. *Journal of Parallel and Distributed Computing*, **149**, 29-39. https://doi.org/10.1016/j.jpdc.2020.11.003

[18] Aggarwal, V.K., Sharma, N., Kaushik, I., Bhushan, B. and Himanshu, (2021) Integration of Blockchain and IoT (B-IoT): Architecture, Solutions, & Future Research Direction. *IOP Conference Series: Materials Science and Engineering*, **1022**, Article 012103. https://doi.org/10.1088/1757-899x/1022/1/012103

[19] Al-Khazaali, A.A.T. and Kurnaz, S. (2021) RETRACTED ARTICLE: Study of Integration of Block Chain and Internet of Things (IoT): An Opportunity, Challenges, and Applications as Medical Sector and Healthcare. *Applied Nanoscience*, **13**, 1531-1537. https://doi.org/10.1007/s13204-021-02070-5

[20] Miraz, M.H. (2019) Blockchain of Things (BCoT): The Fusion of Blockchain and IoT Technologies. In: Kim, S. and Deka, G., Eds., *Advanced Applications of Blockchain Technology*, Springer, 141-159. https://doi.org/10.1007/978-981-13-8775-3_7

[21] Saida, A. and Yadav, R.K. (2022) Review on: Analysis of an IoT Based Blockchain Technology. *International Journal of Education and Management Engineering*, **12**, 30-37. https://doi.org/10.5815/ijeme.2022.02.04

[22] Voumick, D., Deb, P. and Khan, M.M. (2021) Operation and Control of Microgrids Using IoT (Internet of Things). *Journal of Software Engineering and Applications*, **14**, 418-441. https://doi.org/10.4236/jsea.2021.148025

[23] Hasan, M.K., Alkhalifah, A., Islam, S., Babiker, N.B.M., Habib, A.K.M.A., Aman, A.H.M., *et al*. (2022) Blockchain Technology on Smart Grid, Energy Trading, and Big Data: Security Issues, Challenges, and Recommendations. *Wireless Communications and Mobile Computing*, **2022**, Article 9065768. https://doi.org/10.1155/2022/9065768

[24] Li, W., Nejad, M.M. and Zhang, R. (2019) A Blockchain-Based Architecture for Traffic Signal Control Systems. 2019 *IEEE International Congress on Internet of Things* (*ICIOT*), Milan, 8-13 July 2019, 33-40. https://doi.org/10.1109/ICIOT.2019.00018

[25] Hilmani, A., Maizate, A. and Hassouni, L. (2020) Automated Real-Time Intelligent Traffic Control System for Smart Cities Using Wireless Sensor Networks. *Wireless Communications and Mobile Computing*, **2020**, Article 8841893. https://doi.org/10.1155/2020/8841893

[26] Wang, H., Wang, L., Zhou, Z., Tao, X., Pau, G. and Arena, F. (2019) Blockchain-Based Resource Allocation Model in Fog Computing. *Applied Sciences*, **9**, Article No. 5538. https://doi.org/10.3390/app9245538

[27] Tariq, U., Ahmed, I., Bashir, A.K. and Shaukat, K. (2023) A Critical Cybersecurity Analysis and Future Research Directions for the Internet of Things: A Comprehensive Review. *Sensors*, **23**, Article No. 4117. https://doi.org/10.3390/s23084117

[28] Jafari, S., Shahbazi, Z. and Byun, Y. (2022) Improving the Road and Traffic Control Prediction Based on Fuzzy Logic Approach in Multiple Intersections. *Mathematics*, **10**, Article No. 2832. https://doi.org/10.3390/math10162832

[29] Essa, M. and Sayed, T. (2020) Self-Learning Adaptive Traffic Signal Control for Real-Time Safety Optimization. *Accident Analysis & Prevention*, **146**, Article 105713. https://doi.org/10.1016/j.aap.2020.105713

[30] Soltani-Sarvestani, M.A., Azimifar, Z., Wong, A. and Safavi, A.A. (2020) An Innovative Eigenvector-Based Method for Traffic Light Scheduling. *Journal of Advanced Transportation*, **2020**, Article 1462430. https://doi.org/10.1155/2020/1462430

[31] Dumka, A. and Sah, A. (2020) Smart Ambulance Traffic Management System

(SATMS)—A Support for Wearable and Implantable Medical Devices. In: Dey, N., Ashour, A.S., Fong, S.J. and Bhatt, C., Eds., *Wearable and Implantable Medical Devices*, Academic Press, 215-228.
https://doi.org/10.1016/b978-0-12-815369-7.00009-4

[32] Tong, L., Guan, Z., He, M. and Xiong, L. (2019) Signal Timing Model of Urban Intersection Based on Double Restraint Gravitational Model. *The Journal of Engineering*, **2019**, 9162-9165. https://doi.org/10.1049/joe.2018.9208