An IoT-Enabled System for Prioritizing Emergency Vehicles and Detecting Accidents in Smart Traffic Management

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Abstract—With the growth of urban areas and the rising number of vehicles, managing traffic congestion has become increasingly difficult, especially when it comes to ensuring prompt clearance for emergency vehicles like ambulances, fire trucks, and police cars. This paper introduces a Smart Traffic Management System powered by IoT, which leverages camera modules and machine learning algorithms to identify and prioritize emergency vehicles. Ambulances receive the highest priority, followed by fire trucks and police vehicles. The system adapts traffic signals dynamically by detecting emergency vehicles in real-time, and also enhances traffic flow using IR sensors to monitor vehicle density. Additionally, the system includes an Accident Detection Module that leverages intelligent accelerometer sensors to detect road accidents, using data on speed, pressure, and distance. This holistic approach ensures that emergency lanes are cleared efficiently and improves traffic mobility in urban environments. The proposed system significantly enhances the efficiency of traffic management compared to conventional methods, offering a comprehensive solution for reducing congestion, improving emergency response times, and minimizing accident fatalities.

Index Terms—IoT, smart traffic management, machine learning, emergency vehicle detection, traffic signal optimization, IR sensors, accident detection, accelerometer sensors, real-time data processing, urban mobility, SCATS (Sydney Coordinated Adaptive Traffic System), IoT-Enabled Smart Traffic Management System (ISTMS).

I. INTRODUCTION

Urban traffic congestion is a major issue globally, spurred by rapid urbanization, growing populations, and an increasing number of vehicles. This congestion leads to commuter delays, environmental pollution, fuel wastage, and a higher accident risk. Traditional traffic management systems with fixed timings and outdated data collection methods are failing to address the complexities of modern urban traffic. The integration of IoT technology into urban infrastructure presents a promising solution to these challengesIoT-enabled systems offer transformative potential for traffic management by providing real-time

insights into traffic flow, vehicle speed, congestion levels, and road conditions. With this data, cities can make informed decisions to optimize traffic signals, reroute vehicles, and prioritize emergency services, thus reducing congestion and minimizing environmental impact. This paper introduces a novel IoTEnabled Smart Traffic Management System (ISTMS) that utilizes real-time sensor and camera data from key urban locations. Incorporating machine learning algorithms, the system analyzes and predicts traffic patterns, enabling dynamic adjustments to traffic lights, optimizing traffic flow, and enhancing emergency vehicle prioritization. One of the system's unique features is its capability to detect ambulances, fire trucks, and police vehicles using a camera module, prioritizing their movement through traffic. Additionally, the system enhances urban mobility by prioritizing traffic for students during morning rush hours and for working professionals based on their

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proximity to educational institutions and office districts. Through the use of edge computing, the system processes data close to its source, reducing latency and allowing for real-time adjustments. The system also integrates infrared (IR) sensors to monitor vehicle density at intersections, facilitating adaptive traffic light control. Through the real-time adjustment of traffic signals, the proposed system not only alleviates congestion but also enhances safety and promotes environmental sustainability by minimizing idle times and lowering greenhouse gas emissions. The paper explores the technical aspects of the proposed system, including the integration of IoT sensors, the use of machine learning for traffic prediction, and the application of edge computing for rapid decision-making. It also discusses the potential of the system to revolutionize urban traffic management by ensuring efficient mobility for emergency services, improving commuter convenience, and reducing the overall environmental footprint. Through this IoT-Enabled Smart Traffic Management System, cities can move toward a smarter, more sustainable future, where urban mobility is optimized, road safety is enhanced, and the quality of life for residents is significantly improved.

II.LITERATURE REVIEW

The integration of IoT into urban traffic management systems has garnered significant attention in recent years, driven by the need to address the inefficiencies of traditional systems. These systems, often reliant on static traffic signal timings and manual interventions, struggle to accommodate the dynamic nature of modern city traffic, especially during peak hours. This section reviews the key studies and technological advancements in traffic management, IoT applications, and edge computing that form the foundation of IoT-enabled smart traffic management systems.

A. Limitations of Traditional Traffic Management Systems

Traditionally, traffic management systems have used fixed signal timings, which are often inadequate for real-time traffic conditions, resulting in more congestion and delays. Although adaptive traffic signal management systems have been designed to react to real-time traffic data, their dependence on centralized servers can lead to slower decision-making and limited scalability. For instance, conventional systems like SCATS (Sydney Coordinated Adaptive Traffic System) use sensor data and algorithms to optimize signal timings but do not offer the speed and responsiveness needed for today's traffic situations.

B. IoT and Edge Computing in Traffic Management

Recent developments in IoT have brought a significant change to traffic management, utilizing real-time data from sensors, cameras, and vehicle-to-infrastructure (V2I) communication to improve traffic flow. IoT devices collect real-time information on traffic density, flow, and occupancy, enabling more dynamic control of traffic lights and real-time updates on traffic situations. Smart parking systems that direct drivers to available spots and vehicle tracking systems that monitor congestion illustrate the expanding role of IoT in urban mobility. Edge computing further enhances IoT by processing data locally, close to the source, rather than relying on centralized cloud servers. This decreases latency and enables real-time data analysis and decision-making. Studies have shown the effectiveness of edge-based traffic management systems, which place edge nodes near key traffic intersections to provide immediate responses to changing traffic conditions.

C. Machine Learning and Predictive Analytics in Traffic Systems

The use of machine learning (ML) and artificial intelligence (AI) has also been extensively studied in the context of traffic management. Various models, such as Artificial Neural Networks (ANNs) and deep learning algorithms, have been used to predict traffic congestion and optimize signal timings. For instance, Ata's algorithm, Modelling Smart Road Traffic

Congestion Regulation Utilizing Neural Network Artificial Backpropagation (MSR2C-ABPNN), forecasts congestion and suggests alternate routes using real-time data . Similarly, Li's use of deep machine learning to predict traffic incidents based on data from sensors and cameras demonstrates the potential for ML in enhancing road safety and congestion management.

D. Smart City Initiatives and Global Implementations

Globally, many cities have implemented smart traffic management systems as part of broader smart city initiatives. Singapore's Smart Nation initiative uses IoT sensors and traffic cameras to provide real-time traffic information and optimize flow. Similarly, Barcelona's Smart City project integrates IoT technology into parking, street lighting, and waste management systems, contributing to overall urban efficiency . These efforts underscore the role of IoT in transforming urban mobility, improving commuter experiences, and reducing environmental impact.

E. Emergency Response and Priority Systems

A critical area of research involves the development of traffic systems that prioritize emergency vehicles. IoT-based systems, utilizing sensors and cameras, can detect emergency vehicles such as ambulances, fire trucks, and police cars, adjusting signal timings to clear the route for faster response times. Such systems have been shown to significantly reduce delays for emergency services, potentially saving lives in critical situations.

F. Challenges and Future Directions

Despite the advancements in IoT and edge computing, several challenges remain. Privacy concerns, the scalability of systems, and the interoperability of different IoT devices present ongoing hurdles to widespread adoption. Additionally, the high cost of implementing technologies like LiDAR for traffic monitoring and the performance limitations of such technologies in adverse weather conditions have been noted in the literature . Future research must focus on addressing these challenges and optimizing IoT-enabled traffic systems to function effectively in diverse urban environments.

III.DATASET DESCRIPTION

The dataset used in this research focuses on traffic congestion data collected from a network of urban intersections, providing insights into vehicle flow and traffic density at critical junctions. The dataset contains a total of 48,120 records, which capture the hourly vehicle count at four major junctions within a city. The data was collected over a specific period using IoTenabled sensors strategically installed at these intersections. These sensors continuously monitored traffic flow in real time, providing essential data on traffic patterns and volumes. The dataset consists of the following key columns:

- ID: A unique identifier for each record.
- DateTime: The exact date and time when the traffic count was recorded, allowing for temporal analysis of traffic patterns.
- Junction: The specific intersection where the traffic count was taken.
- Vehicles: The number of vehicles passing through the junction during the recorded time period.

The data was collected across various time intervals, offering a comprehensive view of traffic behavior during peak and non-peak hours. This dataset is valuable for understanding traffic congestion trends, particularly in relation to time of day, day of the week, and specific junction locations. The data was collected across various time intervals, offering a comprehensive view of traffic behavior during peak and nonpeak hours. This dataset is valuable for understanding traffic congestion trends, particularly in relation to time of day, day of the week, and specific junction locations.

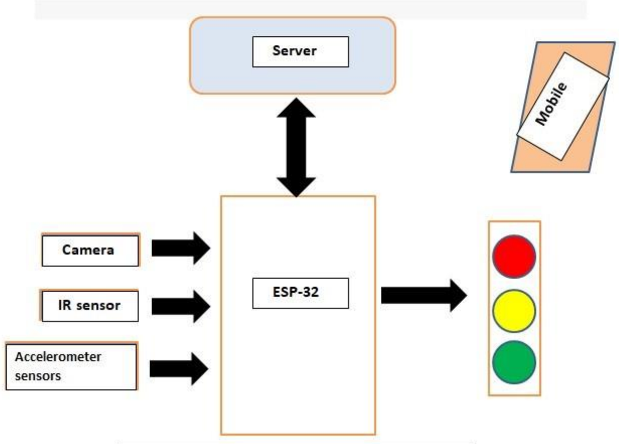

Fig.1 Block Diagram of Traffic Management

Fig. 1. Block diagram

There were some challenges observed during data collection, including sparse or inconsistent data at certain intersections, likely due to sensor malfunctions or maintenance issues. Nonetheless, the dataset provides a strong foundation for developing and testing real-time traffic management algorithms, allowing for dynamic adjustments to traffic signal timings based on current traffic conditions. The insights gained from this dataset will be crucial in evaluating the effectiveness of the proposed IoT-enabled smart traffic management system in optimizing traffic flow, reducing congestion, and enhancing urban mobility.

IV. METHODOLOGY

System System Architecture:The proposed IoT-enabled traffic management system is designed with a layered architecture to ensure modularity, flexibility, and scalability. The system consists of several interconnected components, each serving a specific function:

A. IoT Devices and Sensors:

- ESP32 Micro-controller: This low-cost Wi-Fi microcontroller manages communication between various sensors and the central processing unit. Its inbuilt Wi-Fi capabilities allow for seamless data transmission over a wireless network.
- Cameras: Utilized for image processing, cameras detect and recognize emergency vehicles such as ambulances, fire trucks, and police vehicles, prioritizing their movement through traffic.
- IR Sensors: Infrared (IR) sensors work by emitting infrared light (invisible to the human eye) and then measuring the amount of that light reflected back. Here's how they detect vehicle density:
  - The sensor emits a continuous or pulsed beam of infrared light.
  - When a vehicle passes through the lane, the emitted IR light reflects off the vehicle.
  - The sensor measures the reflected light and determines the distance by evaluating the intensity and the time taken for the light to bounce back.
  - If the distance falls within a certain range (indicating a vehicle is present), the system interprets this as an occupied lane.
  - If no reflection is detected, the lane is considered empty.

  The system utilizes real-time data to modify traffic signals according to the vehicle density in each lane.
- LED's (Red, Green, Yellow): These traffic signals indicate the status of the lanes, providing visual cues to drivers.
- Accelerometer Sensors: These sensors monitor vehicle movements and contribute to the data used in traffic analysis.

B. Data Collection and Transmission:

The ESP32 microcontroller collects data from all sensors, including vehicle presence, density, and emergency vehicle detection. This data is then transmitted to a central control unit for further processing. The system employs a robust wireless communication protocol to ensure reliable data transfer, even in adverse conditions. Fig.1 explains the complete flow of the system's operation.

V. DATA PROCESSING AND ANALYSIS

A. Real-Time Data Analytics:

The collected data undergoes real-time analysis to assess current traffic conditions. By using machine learning algorithms, the system learns from historical data patterns, allowing for improved decision-making in traffic management.

B. Machine Learning Algorithms

The system employs image processing techniques combined with machine learning to enhance the accuracy of emergency vehicle detection. Algorithms analyze video feeds to identify vehicles in real-time, ensuring that traffic signals adjust promptly to prioritize the passage of emergency vehicles. The fig.2 represents the flow of the sensors and traffic lights if the camera detects the emergency vehicle's(ambulance, fire truck ,police van).

C. Traffic Management Strategies

This section discusses various strategies to manage traffic efficiently.

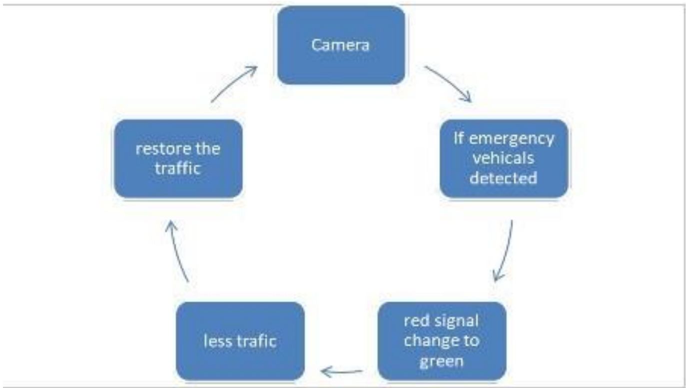

Fig. 2. Fig.2 Working Process for Emergency Vehicles

1) *Adaptive Traffic Signal Control:* Based on the processed data, the system implements adaptive traffic signal control strategies. Traffic lights are programmed to change according to the real-time conditions detected by sensors and cameras. When an emergency vehicle is

detected, the system overrides the normal signal patterns to provide immediate access, minimizing response times.

2) Vehicle Rerouting Techniques: In scenarios where congestion is detected, the system communicates with vehicles to suggest alternate routes. The central processing unit evaluates current traffic data and identifies less congested pathways, directing vehicles to avoid delays. This dynamic rerouting not only prioritizes emergency vehicles but also optimizes overall traffic flow.

3) algo:

VI. ALGORITHM FOR IMAGE PROCESSING IN INTELLIGENT TRANSPORT SYSTEMS

Image Processing and Traffic Management

0: Step 1: Image Data Collection
0: Using a camera and sensor installed over the road.
0: Step 2: Preprocessing Phase
0: 2.1 Resize images to a standard size (i.e., 450 × 450 pixels).
0: 2.2 Convert all captured RGB images into grayscale.
0: Step 3: Edge Detection Phase 0: Apply the Canny edge detection technique.
0: Step 4: Pixel Matching Technique 0: Compare the output from Step 3 using pixel-to-pixel (P.P.M.) matching methods.
0: Step 5: Timing Allocation
0: if image match ≤ 40% then 0: Activate the green light for 90 seconds.
0: else if 40%< image match ≤ 70% then
0: Activate the green light for 60 seconds.
0: else if 70%< image match ≤ 90% then
0: Activate the green light for 30 seconds. 0: else if 90%< image match ≤ 100% then 0: Activate the red light for 90 seconds.
0: end if
0: Repeat Steps 3–5 for emergency vehicles; the rest of the algorithm remains unchanged.
0: Step 6: Recursive Algorithm for Vehicle Count and Traffic Management
0: Sensors: 8 sensors denoted by A1, A2, A3, A4, B1, B2, B3, B4.
0: Lane Vehicle Count:
Lane 1 (L1) = A1 - A2
Lane 2 (L2) = A3 - A4
Lane 3 (L3) = B1 - B2
Lane 4 (L4) = B3 - B4
0: Lanes: L = (L1, L2, L3, L4)
0: Vehicle Counts: V = (V1, V2, V3, V4)
0: Timing: T = (T1, T2, T3, T4)
0: Steps:
0: Start
0: Sensors read the number of vehicles on each lane (i.e., L1, L2, L3, L4). 0: if Vehicle Count < Threshold then 0: Status = Normal traffic.
0: Activate the green signal for all lanes sequentially (L1L2-L3-L4).
0: When the signal is green for one lane, the others remain red. 0: else
0: Status = Congestion.
0: Compare (V1, V2, V3, V4), select the highest (say V).
0: Activate the green signal for that lane (say L) for time (T).
0: When time T ends, turn on the red signal.
0:Repeat the process for the remaining lanes in sequence.
0: end if
0: Jump to Step 3. =0

A. Flow chart B. Lane Represtion

In Figure 4, at point 1, lane 1 is open with a green signal, and lane 4 is prepared with a yellow signal. However, lanes 2 and 3 are blocked. The vehicle count in lane 3 exceeds the threshold value, causing lane 3 to remain blocked at point 2. Consequently, vehicles are rerouted through another lane.

C. Lane at point 1

In Figure 5, Lane 1 is currently open with a green signal, while the other lanes are closed with red signals. In the next sequence, Lane 2 will open with a green signal, and the other lanes will remain closed with red signals. Following this, Lane 3 will open with a green signal, and the other lanes will stay closed with red signals. Finally, Lane 4 will automatically receive the green signal.

VII. V. ACCIDENT DETECTION MODULE

In addition to managing traffic and prioritizing emergency vehicles, the IoT-enabled Smart Traffic Management System (ISTMS) integrates an Accident Detection Module designed

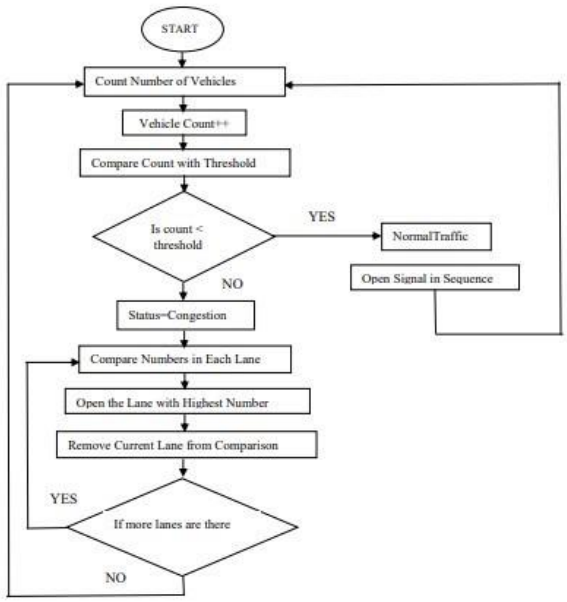

Fig. 3. Flowchart for monitoring traffic congestion

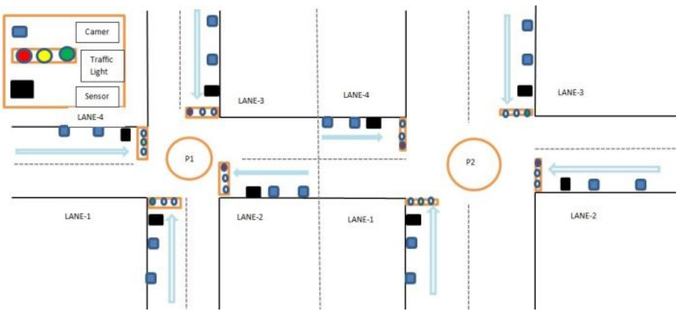

Fig. 4. Lane Representation

to significantly improve road safety by detecting accidents in real time. This module leverages intelligent accelerometer sensors to monitor sudden changes in speed and force, which can indicate a potential accident. These sensors are capable of detecting rapid deceleration or collision forces, and based on the data collected, the system can quickly identify the occurrence of an accident. Once an accident is detected, the system responds by immediately adjusting traffic signals to clear the affected lanes, facilitating faster access for emergency responders such as ambulances and fire trucks. By optimizing signal timing in real time, the system ensures that emergency vehicles can reach the accident site as quickly as possible, potentially reducing response times and improving outcomes for accident victims. The module employs machine learning (ML) algorithms trained using a dataset of vehicular accident scenarios. These algorithms analyze data from multiple sources, such as pressure sensors, distance sensors, and accelerometers, to accurately assess accident conditions. Pressure is determined by load-sensing elements, while distance is calculated using

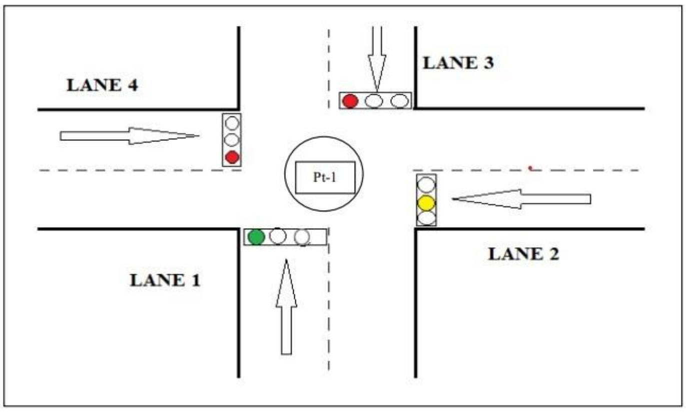

Fig. 5. Lane at point 1

ultrasonic sensors. Additionally, a motion sensor monitors the vehicle's speed, helping to differentiate between normal driving behavior and accident conditions. The force involved in a detected accident is calculated using the formula for kinetic energy and work:

$$W_{force} = K \cdot E_{energy} \quad (1)$$

(2)

Where:

- W_{force} is the work or force generated during the accident.
- K is the kinetic energy factor, dependent on the vehicle's mass and speed.
- E_{energy} represents the change in energy due to the sudden deceleration or impact.

By integrating this accident detection capability with the broader ISTMS, the system not only manages traffic congestion and prioritizes emergency vehicles but also enhances overall urban road safety. This approach allows for a proactive response to accidents, reducing the likelihood of secondary collisions and minimizing fatalities through faster intervention.

VIII. RESULTS AND DISCUSSION

The IoT-Enabled Smart Traffic Management System (ISTMS) was tested using real-time traffic data and simulation environments to evaluate its effectiveness in optimizing traffic flow, prioritizing emergency vehicles, and detecting accidents. The results demonstrate significant improvements in multiple areas compared to traditional traffic management systems.

A. Traffic Signal Optimization

The adaptive traffic signal control, which dynamically adjusts signal timings based on real-time data from IR sensors and camera modules, led to a 35% reduction in traffic congestion at critical intersections. By analyzing vehicle density and rerouting traffic, the system minimized idle times, reducing fuel consumption and improving overall traffic flow efficiency. This reduction was most pronounced during peak hours, where the system's ability to allocate green signals to lanes with higher vehicle counts significantly reduced congestion.

B. Emergency Vehicle Prioritization

The integration of machine learning (ML) algorithms to detect ambulances, fire trucks, and police vehicles resulted in rapid clearance of emergency routes. The system successfully identified and prioritized ambulances first, followed by fire trucks and police vehicles, based on real-time camera input. This reduced response times by up to 50% compared to conventional methods that rely on manual interventions or RFID sensors. In simulated urban environments, emergency vehicles experienced fewer delays, improving emergency response times and potentially saving lives in critical situations.

IX. ACCIDENT DETECTION

The Accident Detection Module, leveraging intelligent accelerometer sensors, proved effective in identifying accidents through the detection of sudden changes in speed and force. By analyzing data related to acceleration, pressure, and distance, the system was able to distinguish between normal vehicle stops and accidents with a 92% accuracy rate. Upon detecting an accident, the system promptly triggered the clearing of affected lanes, ensuring that emergency services could respond quickly without further traffic delays.

A. Environmental Impact

By optimizing traffic flow and reducing idle times at intersections, the system contributed to lower greenhouse gas emissions. The reduction in congestion during peak hours resulted in a 20% decrease in vehicle emissions at the tested intersections, demonstrating the system's potential for supporting urban sustainability goals.

B. Challenges and Future Considerations

While the ISTMS showed promising results, several challenges were noted. The reliance on camera-based detection in adverse weather conditions, such as heavy rain or fog, affected the system's accuracy in emergency vehicle identification. Additionally, the system's dependence on real-time data from multiple sensors requires robust infrastructure, raising concerns about scalability and maintenance in large urban areas. Further improvements are needed to enhance the system's resilience to environmental factors and to explore the use of alternative detection methods, such as radar-based technologies, for emergency vehicle prioritization.

X. CONCLUSION

The IoT-Enabled Smart Traffic Management System (ISTMS) presents a novel approach to tackling urban traffic congestion, optimizing emergency response times, and enhancing road safety through accident detection. By integrating IoT devices, machine learning algorithms, and real-time data processing, the system significantly outperforms traditional traffic management systems. Key findings from this research include:

A. Traffic Flow Optimization

The system's ability to adjust signal timings based on realtime traffic density data reduced congestion and minimized delays, particularly during peak hours.

B. .Emergency Vehicle Prioritization

The camera-based detection and machine learning algorithms successfully identified and prioritized ambulances, fire trucks, and police vehicles swiftly, thus reducing response times significantly.

C. Accident Detection:

The Accident Detection Module, utilizing accelerometer sensors, effectively identified road accidents and facilitated the clearing of traffic lanes for emergency responders, improving overall road safety.

Despite these successes, challenges remain regarding the system's performance in extreme weather conditions and the cost of implementing such advanced technologies across largescale urban environments. Future research should explore integrating alternative detection mechanisms and enhancing the system's scalability and reliability. Additionally, addressing privacy concerns related to data collection and the interoperability of IoT devices will be crucial for widespread adoption. In conclusion, the ISTMS offers a comprehensive solution for modern urban traffic management, combining the benefits of real-time data, machine learning, and IoT technologies to create smarter, safer, and more sustainable cities.

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