Vehicle Actuated Traffic Signal using AI

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ABSTRACT

Traffic congestion in urban areas leads to capacity issues, intersection delays, increased congestion, fuel consumption, and air pollution. Advanced traffic management systems, including adaptive signals and intelligent transportation systems, offer solutions to mitigate congestion and improve road network efficiency. Utilizing live camera imagery and AI for real-time traffic density assessment, alongside adaptive signal control algorithms, reduces congestion and optimizes traffic flow, aligning with the trend of technology-driven transportation systems for environmental benefits. YOLO (You Only Look Once) is a renowned AI object detection algorithm, enabling a vehicle-activated traffic signal to adjust timing based on traffic density, reducing congestion, wait times, and pollution. A simulation and prototype demonstrate the proposed system's effectiveness compared to fixed-time signals. It dynamically adjusts green signal durations based on traffic density, prioritizing high-traffic directions to minimize delays, congestion, and fuel consumption. Results show significant improvements in vehicles crossing intersections, with potential enhancements through real-world data calibration. Leveraging existing CCTV infrastructure, the system reduces deployment and maintenance costs compared to other intelligent traffic control systems. Integrating into major cities can enhance traffic management, with future features like traffic rule violation detection, accident identification, signal synchronization, and emergency vehicle adaptation, offering comprehensive traffic flow and safety solutions.

1 Introduction

The escalating volume of vehicles in urban environments presents a pressing challenge for road networks, manifesting in reduced road capacity and a declining level of service. A significant contributor to traffic issues is the reliance on fixed signal timers at intersections, which lack adaptability to fluctuating traffic demands. Consequently, there is a growing imperative for innovative traffic control solutions under the domain of Intelligent Transport Systems. Presently, three primary traffic control methods are employed: manual controlling, conventional traffic lights with static timers, and electronic sensors. Manual control, though effective, demands a considerable workforce, rendering it impractical for comprehensive coverage across urban areas. Static timers fail to respond dynamically to real-time traffic conditions, while electronic sensors, despite their advancement, encounter challenges in accuracy, coverage, and cost-effectiveness. These limitations underscore the need for more sophisticated and budget-friendly solutions to address the evolving complexities of urban traffic management. The implementation of Smart Traffic Signal Control using AI, specifically integrating the You Only Look Once (YOLO) algorithm, serves multiple objectives with significant potential for improving urban traffic management. The system aims to enhance real-time traffic monitoring and response by efficiently detecting and classifying various vehicle types at junctions, allowing for dynamic signal timing adjustments based on traffic density to optimize vehicle flow and alleviate congestion. Additionally, it strives to contribute to environmental sustainability by minimizing fuel

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consumption and reducing emissions through traffic flow optimization, aligning with broader sustainable development goals. Moreover, the implementation seeks to establish a scalable and adaptable framework, enabling continuous learning and adaptation to changing traffic patterns, ensuring its long-term effectiveness in addressing the evolving needs of urban transportation. In recent years, the widespread use of video monitoring and surveillance systems in traffic management has become prominent, serving various purposes such as security and real-time information provision to travelers. These systems enable the estimation of traffic density and vehicle classification, offering opportunities for optimizing traffic flow and reducing congestion by adjusting traffic signal timers dynamically. This study aims to develop a traffic light controller, specifically designed to adapt to real time traffic conditions. By utilizing live footage from CCTV cameras at intersections, the system assesses real-time traffic density and adjusts the duration of green signals as needed, employing YOLO to precisely identify and categorize vehicles. The primary objective is to optimize green signal times to facilitate faster traffic clearance compared to static systems, thereby reducing delays, congestion, and waiting times, ultimately contributing to decreased fuel consumption and pollution.

2 Literature review

Early studies focused on optimizing signal timing through computer simulations, emphasizing the need for effective calculations of signal split and cycle lengths. One such study by Webster [1] used a combination of approximation formulas to calculate the average delay per vehicle, suggesting that adjusting green time allocation based on the highest flow-to-saturation-flow ratio could significantly reduce delays at signalized intersections. This approach provided a framework for understanding how variations in signal timing affect overall intersection capacity and has influenced subsequent research on adaptive signal systems. These early efforts laid the foundation for the growing use of adaptive and technology-driven systems that have become a central focus of more recent studies.

As traffic systems became more complex, researchers turned to fixed-time traffic signal coordination, where the optimization of traffic flow became more intertwined with real-time data and simulations. In [2] an analytical model with a coevolutionary transport simulation is integrated to improve the coordination of fixed-time signals in real-world scenarios. The coupling of these models allowed for more effective synchronization of signals across large-scale networks, offering advantages over traditional signal systems. Their findings revealed that optimized fixed-time signals outperformed other methods by improving traffic flow and reducing congestion, highlighting the effectiveness of combining both theoretical models and real-time traffic simulations in large urban settings. This approach represents a significant step forward in ensuring that traffic management solutions can scale and adapt to the dynamic needs of modern cities.

Further advancements in traffic management have leveraged more affordable and accessible technologies, such as microcontroller-based systems. Another study demonstrated [3] how Arduino-based systems, utilizing infrared (IR) sensors, could dynamically adjust signal timing based on real-time vehicle detection. This low-cost solution provided a practical and adaptable alternative to traditional traffic signal control, allowing for adjustments to green light durations based on the volume of traffic detected at each phase. These systems proved to be particularly useful in localized or smaller-scale deployments, offering flexibility in areas where deploying large-scale infrastructure would be cost-prohibitive. While these systems are effective in limited settings, the potential for integration with larger urban traffic control systems remains an area for further exploration.

While previous studies primarily focused on optimizing fixed-time signal coordination, real-time signal adjustments, and microcontroller-based systems for localized applications, they often overlooked the

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integration of AI-driven dynamic signal control with existing infrastructure or real-time traffic flow data. These studies provided significant advancements in traffic management but did not fully explore the potential of combining AI object detection with live camera feeds to adapt signal timings based on actual traffic conditions.

3 Methodology and Data Collection

Our proposed system uses images from CCTV cameras at intersections to perform traffic density calculations via image processing and object detection algorithm. Employing YOLO for vehicle detection, the algorithm identifies various vehicle classes such as cars, bikes, buses, autorickshaws and trucks, facilitating accurate traffic density assessment. The signal-switching algorithm then adjusts green signal timers for each lane based on this density and other relevant factors, updating red signal times accordingly. To prevent lane starvation, green signal times are constrained within maximum and minimum values. Through simulation and prototype development, the system's effectiveness is showcased and compared with the existing system.

3.1 Working of Traffic Signals in Real-Time

The process begins with cameras capturing real-time videos at intersections. The system employs image processing techniques to detect vehicles within the captured frames. Following vehicle detection, the next step involves calculating the traffic density based on the number of identified vehicles. Subsequently, the green signal time for traffic lights is determined, likely influenced by the calculated traffic density. Finally, the traffic signal timer is updated accordingly, reflecting the dynamically assessed conditions to optimize traffic flow at the intersection.

3.2 Methodology

The methodology involved several key steps. Firstly, the process began with the selection of a suitable site for the study. Subsequently, a comprehensive survey of traffic volume at this selected site was conducted. The dataset collection phase comprised two distinct aspects: gathering videos for algorithm development and obtaining images for training the YOLO model. After the video dataset collection, a simulation was created using pygame to mimic real-time traffic scenarios. Simultaneously, After YOLO training, a prototype was developed with Arduino. These steps ensured a robust foundation for algorithm development and training, incorporating both simulated and real-world data sources to enhance the system's effectiveness and accuracy.

3.2.1 Site Selection and Preliminary Survey

The chosen site for this study is S. H. Junction in Changanassery. The selection was based on the observation that certain vehicles experience delays in crossing the road, whereas wasted green time is observed on another road. To provide a visual reference, Figure 1 presents a typical photograph of SH Junction in Changanassery. A traffic volume survey was conducted at the specified junction to assess the flow of vehicles. The survey involved obtaining accurate traffic volume counts, allowing for a thorough analysis of the vehicular movement at the location. By converting the collected data into Passenger Car Units (PCU), a standardized measure that represents the traffic load of different vehicle types, a more meaningful understanding of the overall traffic dynamics was achieved. Additionally, the identification of peak hours provided crucial insights into the times of the day when traffic congestion is at its highest.

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Figure 1. SH Junction, Changanaserry

3.2.2 Simulation Model

To develop a simulation using Pygame, real-time datasets were essential for an accurate representation of traffic dynamics. To capture relevant data, 10-minute-long videos were recorded at a specific intersection. Subsequently, the collected data was meticulously analyzed, with a focus on tabulating different values of waiting times and the number of vehicles waiting in queue after the signal time. This approach ensured that the simulation incorporated realistic scenarios, enhancing its applicability and reliability. The integration of real-time data into the simulation contributes to its authenticity. Pygame, a popular Python library for game development, was employed to create simulations based on the tabulated data. This versatile library provides a framework for interactive and visual applications, making it suitable for illustrating complex systems such as traffic scenarios. Leveraging the tabulated data, five simulations were developed to showcase both the existing and proposed traffic systems at a specified intersection. The simulations aimed to provide a comparative analysis, allowing to visually assess the performance and efficiency of the proposed traffic system approach in comparison with the current one. Each simulation ran for a total duration of 25 minutes, 300 seconds each, capturing snapshots of traffic patterns and dynamics in both scenarios. This simulation serves the purpose of visualizing the traffic system and comparing it to the existing static model. The simulated environment features a 4-way intersection equipped with four traffic signals. Each signal is accompanied by a timer, indicating the remaining time before the signal transitions. Additionally, each signal displays the count of vehicles that have traversed the intersection. Various types of vehicles, including cars, bikes, buses, trucks, and rickshaws, approach from all directions. To enhance realism, some vehicles in the rightmost lane execute turns as part of their traversal through the intersection.

3.2.3 Prototype development

Figure 2 illustrates the block diagram of an intelligent traffic control light system designed for a four-way traffic scenario. The key components include cameras, a microcontroller, a power supply, and a traffic light system. In contrast to the traditional traffic light system, which uniformly allocates the same time delay to all lanes irrespective of their traffic density, this smart system operates more efficiently. It determines the lengths of the green, yellow, and red-light phases based on the present traffic density. Utilizing YOLO and cameras, the system detects the presence of vehicles in any lane, transmitting this information (calculated density) to the microcontroller. Subsequently, the microcontroller appropriately configures the ON time

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for the green and red LEDs. Consequently, the timing of the traffic lights becomes contingent on the density of vehicles present in any of the four lanes, introducing a more responsive and intelligent traffic control approach.

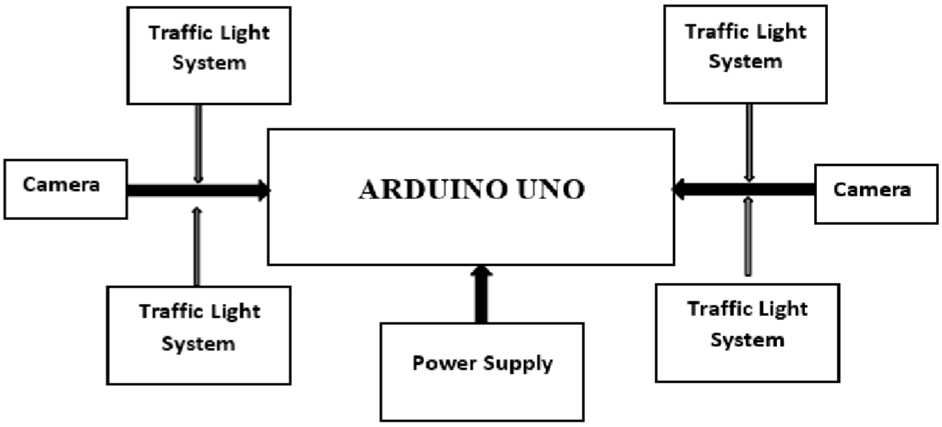

Figure 2. Block diagram of prototype

4 Results and Discussions

Following a meticulous tally of vehicles in each direction, we identified peak hours by converting the counts into PCUs (passenger car units). Notably, during the 4:00 PM to 5:00 PM timeframe, the highest number of vehicles was recorded, marking this period as the peak hour for vehicular activity at the intersection. From the observations conducted during the volume survey, we derived a layout that is visually represented in Figure 3.

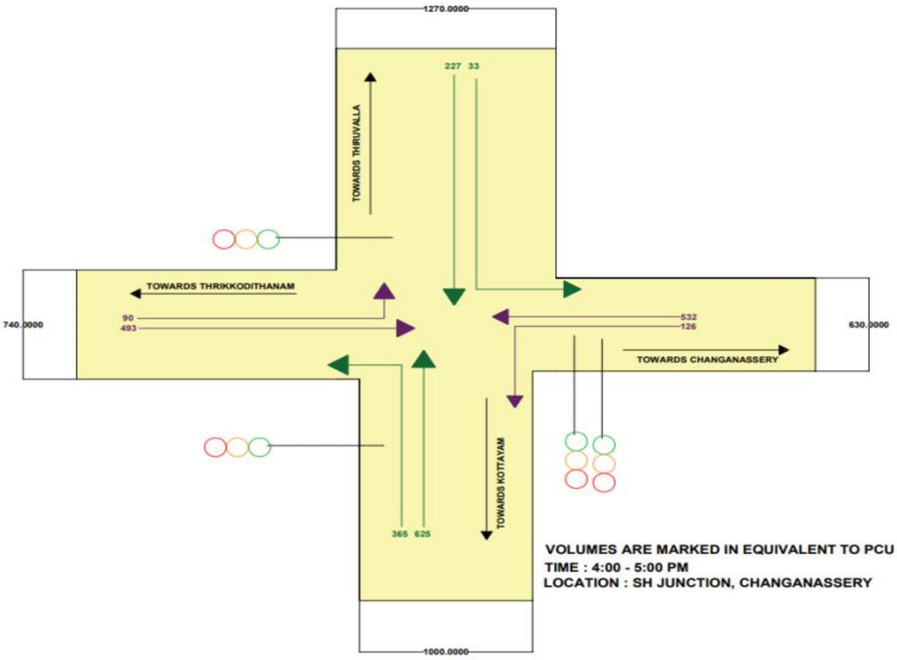

Figure 3. Layout of Intersection

4.1 Simulation Results

Collected data of 10 mins duration from videos were tabulated and upon examining the results, it becomes evident that in the Thrikkodithanam direction, not all vehicles manage to pass through the intersection during the green signal; there are some vehicles left behind. Conversely, in the other three directions—

Kottayam, Thiruvalla, and Changanassery—it is noted that the green signal time is not fully utilized, resulting in wasted time during which no vehicles pass through. A simulation was created using Pygame to replicate real-world traffic scenarios, aiding in the visualization and comparison of the system with the pre-existing static model. Figure 5 provides a snapshot of the conclusive result of this simulation. To evaluate and compare the performance of the current system with the proposed system, we conducted simulations using five different datasets. During these simulations, we focused on two key metrics to assess the efficiency of the traffic flow: the number of vehicles successfully passing through the Thrikkodithanam lane, and the waiting time experienced by vehicles in the other three lanes, namely Kottayam, Thiruvalla, and Changanassery. Figures 4 and 5show graphical representation of simulation results.

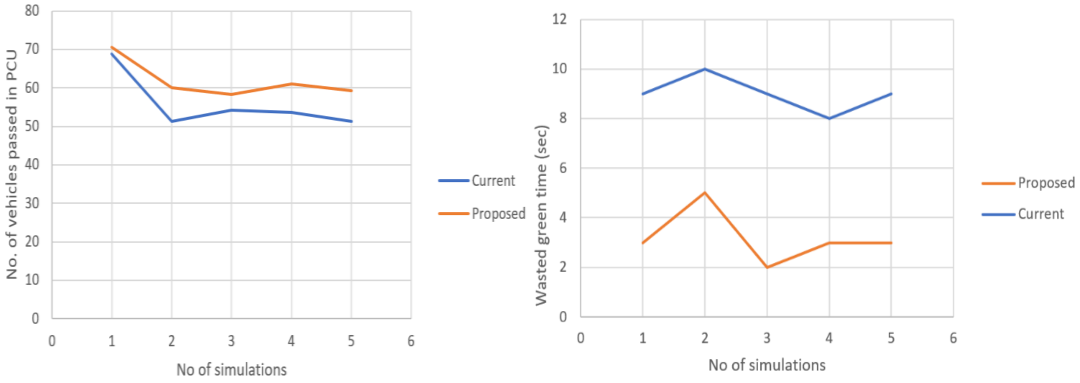

Figure 4. Comparison of the current system with the proposed system (Thrikkodithanam lane and Changanassery lane)

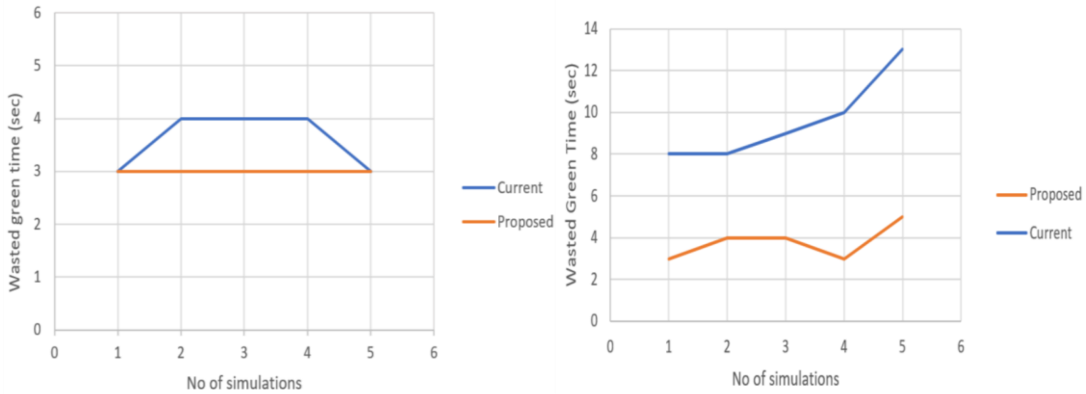

Figure 5. Comparison of the current system with the proposed system (Thiruvalla lane and Kottayam lane)

Our results demonstrate the effectiveness of using real-time video feeds for traffic simulations, providing a more accurate representation of traffic flow and congestion. This approach mirrors the methods described in [4], where real-time video feeds were used to estimate traffic bulkiness and congestion levels. In our work, we utilized video data to create simulations, enabling us to closely replicate real-world traffic patterns and evaluate the performance of our system.

Moreover, [5] addresses the need for adaptive traffic systems that can efficiently process and respond to real-time traffic data, highlighting the importance of using such data to improve traffic flow and reduce congestion. Similarly, our use of real-time video feeds for simulation demonstrates the potential of dynamic data-driven systems to optimize traffic management in urban environments. By leveraging real-time video data, our simulation model was able to adapt to varying traffic conditions, allowing for more accurate traffic signal control and improved traffic flow management. This approach aligns with the growing emphasis on integrating real-time data into traffic systems for better efficiency and safety. Based on these results, it is clear that our proposed system is more efficient than the current system at the selected site. All five simulation outcomes consistently demonstrate this improvement.

4.2 Prototype of proposed system

A prototype was developed to demonstrate the operation of the traffic signal system. For testing purposes, several components were necessary, including an LED traffic light module to display red, yellow, and green lights, an Arduino microcontroller to run the code, male-female wires for connections, a breadboard for circuit prototyping, an Arduino adapter for powering the board, and a laptop for control and monitoring. In this system, two webcams are positioned on either side of the road, alongside four traffic lights. The Arduino microcontroller manages the cameras, tallying the number of vehicles as they pass through the road. Signal adjustments occur when the camera detects traffic congestion. The system operates in three distinct cases: Case 1 - If no vehicles are present on the road, the light stays red until vehicles arrive (Figure 6); Case 2 - If there is varying traffic density at signals, the system prioritizes the road with the highest density by turning the light green (Figure 7); and Case 3 - If all roads exhibit equal density, the system activates a sequential arrangement, allowing the lights to operate normally by controlling the signals one after the other.

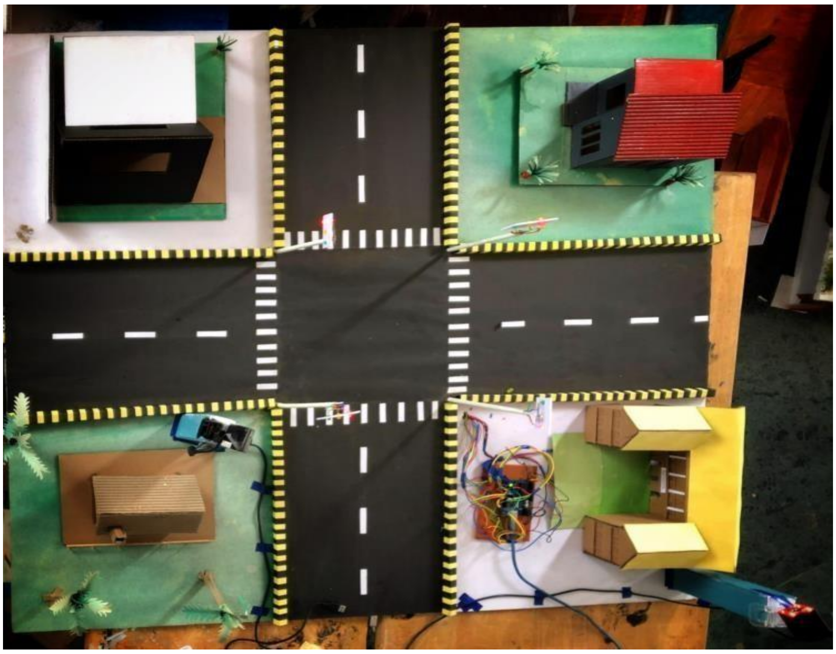

Figure 6. The practical smart traffic light system case 1

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Figure 7. The practical smart traffic light system case 2

4.2.1 Testing

We conducted testing to evaluate the system and verify each of its functions, ensuring compliance with the required specifications. Four cases were covered, including: Initially, all traffic lights remain red until vehicles are detected. In instances of higher traffic density on a specific road, priority is given to turning the traffic light green for that road. When all roads exhibit equal density, the system activates a sequential arrangement between the roads. If two roads have identical density levels, priority is granted to turning the traffic light green for the road that experienced congestion first.

4.3 Proposed system in Changanassery

Maximum Green Time per Phase (G) = 35s
Lost Time per Phase (L) = 2s (typically used to account for the transition time or delays)
Amber Time per Phase (A) = 2s
Phase Duration = 35s + 2s + 2s = 39s
Total Cycle Time = 4 × 39s = 156 s
Thus, the maximum cycle time for the traffic signal, considering the given parameters, is calculated as 156 seconds for our site which currently is 120s.

Our study successfully integrated YOLO with CCTV cameras to enhance traffic management by dynamically adjusting signal phases based on real-time vehicle detection and traffic density. YOLO's ability to accurately detect vehicles in real-time makes it an ideal tool for adaptive traffic control. This is in line with the approach used in [6], which also utilized YOLO for optimizing traffic signal timings. The integration of YOLO with existing CCTV infrastructure in our system highlights its practicality for urban traffic management. This real-time detection enables efficient signal utilization, reducing congestion and improving road safety without the need for additional hardware. YOLO’s power in vehicle detection and its ability to adapt signal phases based on traffic conditions proves its potential for transforming traffic management in smart cities.

5 Conclusions

In conclusion, the proposed system effectively improves traffic management by dynamically adjusting green signal durations based on real-time traffic density. By allocating longer green times to higher-traffic directions and minimizing delays for less-congested areas, it reduces waiting times, congestion, and fuel consumption, leading to lower pollution levels. Simulation results indicate a significant improvement over existing systems in terms of vehicle throughput. This adaptive approach, utilizing real-time video feeds, also offers practical advantages over current systems like pressure mats and infrared sensors. The system's minimal hardware requirements—leveraging existing CCTV cameras—reduce deployment and maintenance costs, making it a cost-effective solution for cities. Integration with real-time video data allows for adaptive signal adjustments based on traffic density, enhancing safety, traffic flow, and overall efficiency. The successful prototype implementation highlights the potential for future innovations in intelligent traffic management systems. Future work could focus on integrating features like detecting traffic violations, identifying accidents or breakdowns, synchronizing traffic signals, prioritizing emergency vehicles, and incorporating multi-modal transportation considerations. Moreover, further research could explore the potential integration of this system with applications like Google Maps, providing access to collected data for visualization and predictions.

6 Conflict of interest

The authors declare no conflicts of interest related to this research.

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