IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

# ETMS : Efficient traffic Management System

*An efficient signal management system*

[1]Prof. Shital Jade, [2]Hiten Bhanushali, [3]Sanjal Mali, [4]Omkar Londhe

[1]Computer Engineering Department

[1]Nutan Maharashtra Institute of Engineering & Technology, Talegaon Pune, India

***Abstract:*** This project tackles the problem of traffic congestion at crossroads and problems faced by traffic congestion at crossroads. Our idea is to create system which will count the number of vehicles in each lane of crossroads and by analyzing the count green light time and red-light time will be adjusted. i.e., the lane containing less vehicles will get less green time than usual and time reduced form such lanes will be added to the green light time of lanes containing maximum number of vehicles Existing system uses costly density sensors but we are going to use cameras installed on cross roads which will give inputs to our YOLO5 algorithm for counting vehicles and then input will be analyzed by machine learning model to adjust the timings of signal. The movement of cars through the intersection of numerous roads is monitored and managed by traffic signal control systems. Their goal is to make cars move smoothly in the routes for transportation. But because there are so many variables to consider, coordinating several traffic signal systems at nearby crossings is a challenging task. Approaching junctions with changing flows are not handled by conventional methods. Furthermore, the current traffic system does not account for accidents, emergency vehicle passing, pedestrian crossings, conflicting traffic light systems, and differences in vehicle flow over time. This results in congestion and traffic jams.

***Index Terms -*** Traffic Management System, Crossroad Congestion, Dynamic Traffic Signal Adjustment, Vehicle Counting, YOLOv5 Algorithm, Machine Learning in Traffic Control, Adaptive Signal Timing, Camera-Based Traffic Monitoring, Cost-Effective Traffic Solutions, Urban Mobility Optimization.

## I. Introduction:

Since 1912, traffic lights have been created as signaling systems to regulate traffic at intersections, pedestrian crossings, railroad tracks, and other places. Three universally recognized colors make up traffic lights: the green light permits traffic to go in the designated direction, the yellow light alerts cars to a potential short halt, and the red light forbids any traffic from moving. Many nations now struggle with traffic congestion, which has a major negative impact on city transportation systems. Even though autonomous traffic systems have taken the place of traffic cops and flagmen, optimizing massive traffic jams remains a significant challenge, particularly with several junction nodes. Infrastructures with sufficient funds are not being developed in tandem with the sharp rise in the number of cars and the continuously increasing number of road users. The construction of additional roadways, the installation of flyovers and bypass roads, the creation of rings, and road rehabilitation all provided partial remedies.

However, because so many different factors are involved, the traffic problem is extremely complex. First, the flow of traffic is influenced by the time of day, with morning and afternoon typically seeing the highest traffic; the days of the week with the least amount of traffic, Mondays and Fridays typically showing heavy traffic directed from cities to their outskirts and in the opposite direction, respectively; and the season, such as summer and holidays. The existing traffic light system relies on hard-coded delays, with predetermined transition times that do not reflect real-time traffic flow. The condition of one light at a junction that affects traffic flow at nearby intersections is the subject of the third point. Additionally, accidents, road construction, and broken-down vehicles that exacerbate traffic congestion are not taken into account by the traditional traffic system.

To address extreme traffic congestion, ease transportation issues, lower traffic volume and waiting times, shorten total travel times, maximize vehicle safety and efficiency, and increase the advantages in the economic, environmental, and health sectors, the traditional traffic system must be improved. In order to address numerous issues and enhance traffic management, this study suggests a straightforward, affordable, and real-time intelligent traffic light control system. This project proposes a simulation-based traffic management model to minimize vehicle congestion at intersections. The model dynamically adjusts traffic light schedules based on real-time traffic density, optimizing traffic flow across four-way intersections. Unlike conventional methods with fixed traffic light durations, this adaptive approach reduces inefficiencies caused by equal time allocation across lanes, irrespective of traffic volume. The model considers light and heavy traffic conditions, demonstrating superior performance over traditional traffic systems.

## II. Intelligent traffic control system

Research on intelligent traffic control system design is ongoing. In order to address this difficult issue, researchers worldwide are developing innovative approaches and cutting-edge solutions. The number of cars in the waiting queue, the extension of the waiting cars along the lane, the best times for green, yellow, and red lights that best suit the actual and verifiable situation, and the most effective routing combination are all estimated using models based on mathematical equations. The interdependencies among neighbouring intersections result in a convoluted formulation with onerous parameters. The worst part is that these characteristics change with time. They are also reliant, dangerous, and unintentional.

It is therefore nearly impossible to find a dynamic, reliable, and practical solution. Scholars from several fields are working together to investigate workable ways to lessen traffic congestion. As a result, numerous approaches are frequently put forth in the literature and put into practice, taking advantage of the technological advancements of microcomputers, newly produced devices and sensors, and creative algorithms that model the complexity of traffic lights as much as possible.

Traffic congestion at intersections is a pervasive issue in urban areas, leading to increased travel time, fuel consumption, and environmental pollution. Intersections, being critical points in road networks, often become bottlenecks due to the conflicting movement of vehicles from multiple directions. Traditional traffic signal systems, which operate on fixed-time schedules, are unable to adapt to real-time traffic conditions. These systems allocate predetermined green and red-light durations, regardless of the actual traffic load on each lane. As a result, lanes with fewer vehicles may receive excessive green time, while congested lanes suffer from prolonged waiting times, exacerbating traffic congestion.

The inefficiency of fixed-time traffic signals becomes particularly evident during peak hours or in response to unexpected events such as accidents or road closures. In such scenarios, the inability to dynamically adjust signal timings leads to inefficient traffic flow, increased vehicle idling, and higher emissions. Moreover, the lack of real-time data on traffic conditions limits the ability of traffic management authorities to respond proactively to changing demands.

To address these challenges, there is a growing need for adaptive traffic management systems that can monitor real-time traffic conditions and adjust signal timings dynamically. Such systems have the potential to optimize traffic flow, reduce waiting times, and enhance overall transportation efficiency. By leveraging advancements in computer vision and artificial intelligence, it is now possible to develop intelligent traffic signal control systems that respond to real-time traffic demands.

### A. Objective:

The primary objective of this research is to propose a system for real-time vehicle detection and dynamic traffic signal control at intersections. The system aims to address the limitations of fixed-time traffic signals by using real-time data to allocate green and red-light durations based on the actual traffic load in each lane.

By doing so, the system seeks to minimize congestion, reduce waiting times, and improve the overall efficiency of traffic flow at intersections.

B. Contribution:

This research makes several key contributions to the field of traffic management:

1. Real-Time Vehicle Detection: The system employs YOLO (You Only Look Once), a state-of-the-art object detection model, to detect and count vehicles in real-time. YOLO's high accuracy and speed make it an ideal choice for this application, enabling the system to process traffic camera feeds efficiently.

2. Dynamic Signal Control Algorithm: A novel algorithm is proposed to dynamically adjust traffic signal timings based on the real-time vehicle counts in each lane. The algorithm prioritizes congested lanes while ensuring fairness to less congested lanes by maintaining minimum and maximum thresholds for green and red-light durations.

3. System Effectiveness: The proposed system is evaluated through simulations and real-world testing, demonstrating its effectiveness in reducing congestion and improving traffic flow. The results highlight the system's ability to adapt to varying traffic conditions and respond to real-time demands.

## III. Literature Review:

The following literature survey reviews recent research papers focused on vehicle detection and similar systems. The papers are presented in descending order, from the latest to older studies, highlighting their methodologies, findings, and contributions to the field.

1. Implementation Paper on Simulation Based Traffic Management System (2024):
The paper proposes a simulation-based traffic management model aimed at reducing vehicle congestion at intersections. It dynamically adjusts traffic light schedules in real-time based on traffic density, outperforming conventional fixed-duration systems. The model is tested under both light and heavy traffic conditions, demonstrating significant improvements in traffic flow efficiency. By allocating green signal durations proportionally to the number of vehicles on each road, the system reduces delays and enhances overall road safety. This approach is suitable for integration into smart-city transportation systems, providing an efficient solution for managing urban traffic congestion.

2. Short-Term Traffic Congestion Prediction Using Hybrid Deep Learning Technique:
This research explores explores innovative methods for predicting traffic congestion by using a combination of deep learning models, specifically convolutional neural networks (CNN) and long short-term memory (LSTM) networks. This hybrid model is designed to handle the complexities of traffic data by analyzing both spatial and temporal patterns in real-time. The study demonstrates that these integrated techniques outperform traditional methods, achieving higher prediction accuracy in urban settings by using traffic density, speed, and other variables as inputs.

## IV. Methodology:

4.1 System Architecture:
The proposed system architecture is designed to enhance traffic management through real-time vehicle detection and dynamic signal control. The architecture consists of four primary components:

A. Traffic Cameras for Data Acquisition: High-resolution traffic cameras are strategically placed at intersections to capture real-time video feeds of vehicular movement. These cameras are equipped with features such as night vision and wide-angle lenses to ensure comprehensive coverage under varying environmental conditions.

B. YOLO-based Vehicle Detection and Counting: The system employs the YOLO (You Only Look Once) model for real-time object detection. YOLO is chosen for its speed and accuracy, making it suitable for processing video feeds in real-time. The model is trained to detect various vehicle types, including cars, trucks, and buses, enabling precise counting and classification.

C. Dynamic Signal Control Algorithm: The core of the system is a dynamic signal control algorithm that processes vehicle counts from each lane and adjusts traffic light signals accordingly. This algorithm ensures that traffic flow is optimized by prioritizing lanes with higher vehicle counts, thereby reducing congestion and improving overall traffic efficiency.

D. Integration with Traffic Light Hardware: The system interfaces with existing traffic light infrastructure, allowing for seamless communication and control. This integration is crucial for implementing the dynamic signal control strategy effectively.

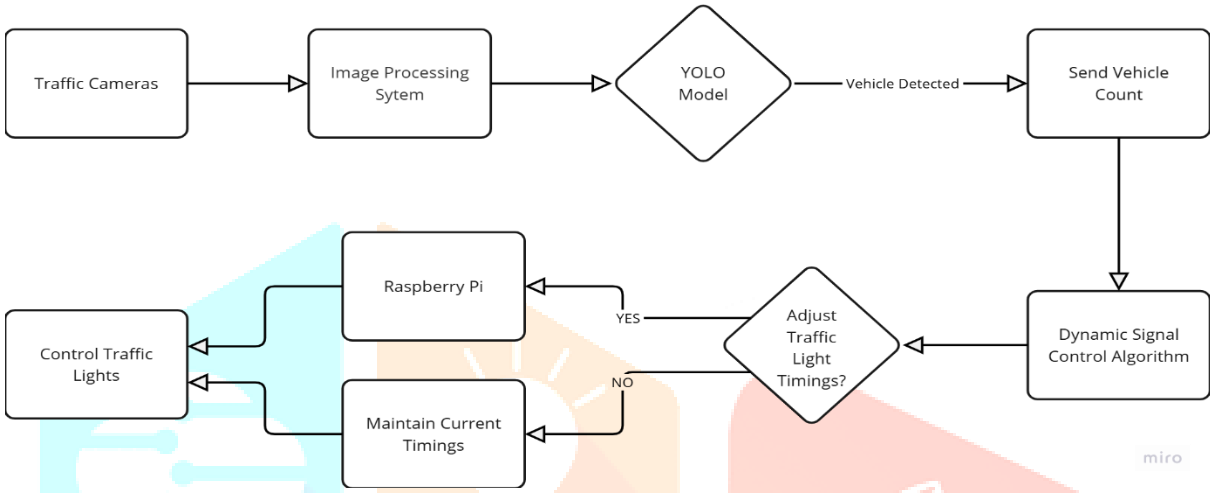


Fig.1: System Architecture

6.2 Vehicle Detection and Counting

Hand-crafted and manually extracted object attributes are the only source of information used by traditional machine learning algorithms for vehicle detection. The feature vector is derived from the appearance or motion characteristics of the pixels in an image. In essence, the identification algorithms use a three-step process to recognize cars based on their shape and visual traits. First, they perform background modelling or background subtraction by erasing the background. The second stage, which comes after the background's movement, contains the remaining blobs and their placements. Using the retrieved data and observed blobs, classification techniques are applied in the third stage to identify the various vehicle classes. These algorithms perform well for offline films with a steady background and favourable weather conditions. But especially susceptible to abrupt changes in the background, unusual weather, and problems with color and shape.

Finding the quantity of things of a particular class that have been identified and followed within a picture or video is known as object counting. This can be accomplished by counting the number of things that satisfy criteria through object recognition, tracking, and categorization. For instance, object identification, tracking, and classification could be used by an object counting system in a traffic video to determine how many cars are on the road. All things considered, object detection, tracking, classification, and counting are crucial phases in computer vision systems that have a wide range of uses in fields including robotics, autonomous vehicles, and surveillance. Tracking the quantity of distinct things found or examining how objects move across predetermined borders are two methods for object counting.

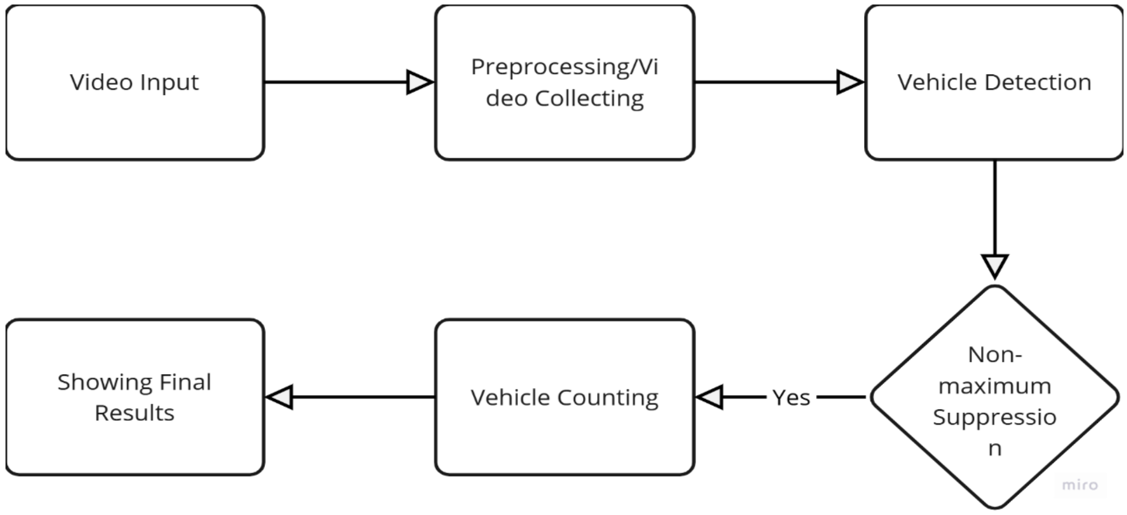


Fig.2: Vehicle Detection & counting

A. YOLO Model:

The choice of the YOLO model, specifically YOLOv5 or YOLOv8, is based on its state-of-the-art performance in real-time object detection tasks. YOLO's architecture allows for high-speed processing, making it ideal for applications requiring immediate feedback, such as traffic management. YOLOv5 and YOLOv8 offer improvements in accuracy and speed over previous versions, making them suitable for deployment in urban environments with varying traffic conditions.

B. Training Process:

The training process involves collecting a diverse dataset of annotated traffic images that represent various conditions, including different times of day, weather conditions, and traffic densities. The model is trained using transfer learning techniques, leveraging pre-trained weights to accelerate convergence and improve detection accuracy. Data augmentation techniques, such as rotation, scaling, and color adjustments, are employed to enhance the model's robustness against real-world variations.

C. Region of Interest (ROI):

Defining ROIs is critical for accurate vehicle counting. Each lane at the intersection is designated as an ROI, allowing the system to focus on specific areas where vehicles are expected to pass. This targeted approach minimizes counting errors and enhances the reliability of the data collected.

6.3 Dynamic Signal Control Algorithm

A. Input:

The dynamic signal control algorithm receives real-time vehicle counts from each lane, which are derived from the YOLO-based detection system.

B. Logic:

The algorithm operates on the principle of adaptive traffic signal control:

- Green Signal Priority: Lanes with higher vehicle counts are assigned green signal priority. This prioritization helps alleviate congestion by allowing more vehicles to pass through the intersection.

- Dynamic Duration Adjustment: The algorithm adjusts the green and red-light durations based on real-time data. For instance, if a lane experiences a sudden increase in traffic, the green light duration for that lane can be extended.
- Threshold Maintenance: To ensure fairness, the algorithm maintains minimum and maximum thresholds for green light durations. This prevents scenarios where one lane is consistently favoured over others, promoting equitable traffic flow.

Example

For instance, if Lane A has 10 vehicles and Lane B has 5 vehicles, the algorithm may allocate 60% of the cycle time to Lane A and 40% to Lane B. This allocation is dynamically adjusted based on real-time counts, ensuring that traffic signals respond effectively to changing conditions.

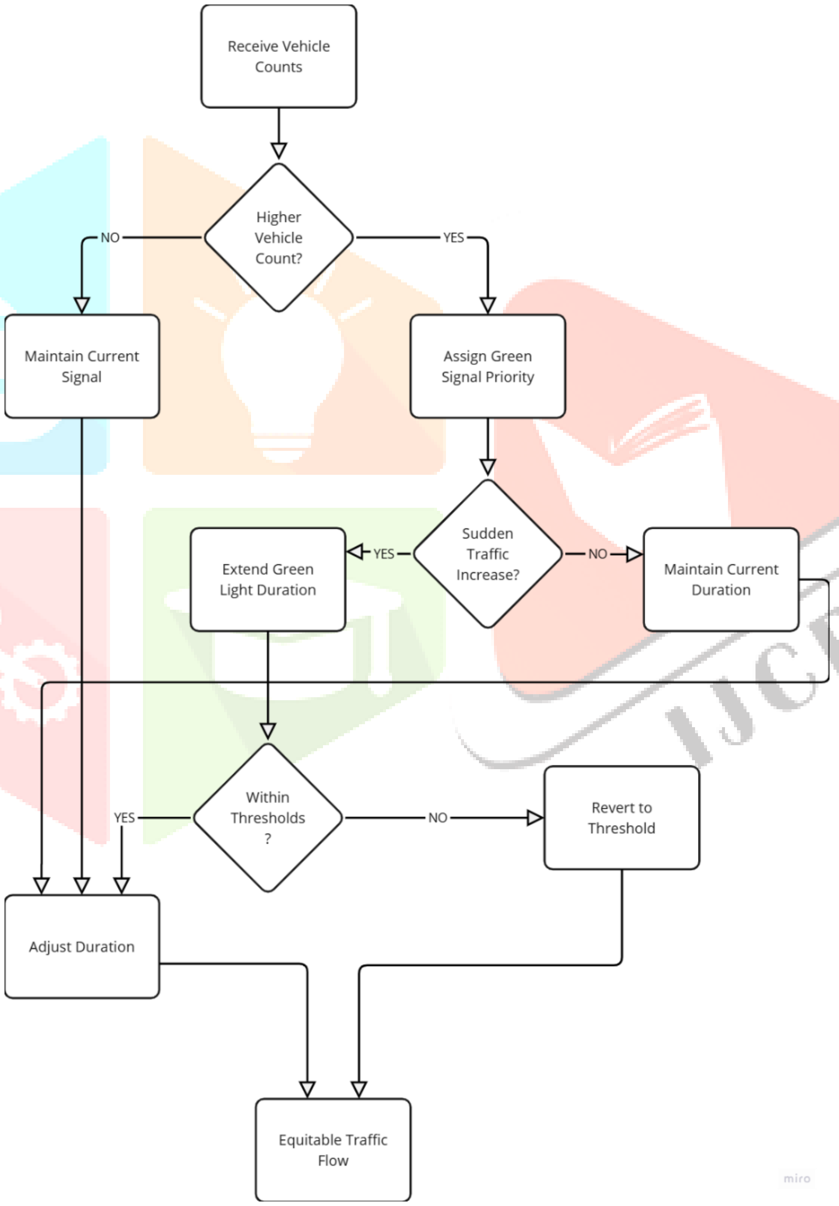


Fig.3: Logic Algorithm

6.4 Integration with Traffic Lights

A. Hardware:

The integration of the system with traffic lights is facilitated through microcontrollers, such as Raspberry Pi or Programmable Logic Controllers (PL Cs). These devices serve as the interface between the detection system and the traffic light control mechanisms, enabling real-time communication and signal adjustments.

B. Communication:

The system employs communication protocols such as MQTT or HTTP to send control signals to the traffic lights. MQTT is particularly advantageous due to its lightweight nature and ability to handle multiple connections efficiently, making it suitable for real-time applications. The control signals dictate the state changes of the traffic lights based on the outputs from the dynamic signal control algorithm.

## V. Implementation:

A. Tools and Technologies

The implementation of the proposed system involves a combination of software and hardware components to achieve real-time vehicle detection and dynamic traffic signal control.

1] Software:

- Python: The primary programming language used for developing the system due to its extensive libraries and ease of use.
- OpenCV: A computer vision library used for image processing tasks such as capturing video feeds, defining regions of interest (ROIs), and pre-processing images for vehicle detection.
- PyTorch: A deep learning framework used for implementing and deploying the YOLO model for vehicle detection.
- Flask: A lightweight web framework used to create an API for communication between the vehicle detection module and the traffic signal control system.
- Other Libraries:
- NumPy: For numerical computations and array manipulations.
- Pandas: For data processing and analysis.
- Matplotlib/Seaborn: For visualizing results and performance metrics.

2] Hardware:

- Traffic Cameras: High-resolution IP cameras installed at intersections to capture real-time traffic images. These cameras should have night vision capabilities to handle varying lighting conditions.
- Processing Unit: A compact, GPU-enabled device used for real-time inference of the YOLO model. Its high processing power makes it suitable for edge computing applications.
- Raspberry Pi: A microcontroller used to control traffic lights and communicate with the central processing unit.
- Traffic Light Controllers: Microcontrollers or PLCs (Programmable Logic Controllers) integrated with the Raspberry Pi to manage signal timings.

B. Dataset

The performance of the vehicle detection model relies heavily on the quality and diversity of the dataset used for training and testing. The following datasets were considered:

1] COCO (Common Objects in Context):

A large-scale dataset containing images of everyday scenes with 80 object categories, including vehicles-trained YOLO models on COCO were fine-tuned for vehicle detection.

2] KITTI:

A dataset focused on autonomous driving scenarios, containing images and annotations for vehicles, pedestrians, and cyclists. High-quality images with precise annotations, suitable for traffic-related applications.
Used for testing the model's performance in traffic scenarios.

C. Testing Environment

The system was tested in both simulated and real-world environments to evaluate its performance and effectiveness.

1] Simulation:

- Tools: Simulation software such as SUMO (Simulation of Urban Mobility() was used to create a virtual intersection with varying traffic conditions.

- Scenarios:

  I. Balanced traffic: Equal vehicle distribution across all lanes.
  II. Congested lanes: High vehicle density in one or more lanes.

- Metrics: Average waiting time, queue length, and traffic flow efficiency were measured to assess the system's performance.

D. Real-World Intersection:

Setup:

1. Traffic cameras were installed at a real intersection to capture live traffic data.
2. The YOLO model was deployed for real-time vehicle detection.
3. A Raspberry Pi was used to control the traffic lights based on the dynamic signal control algorithm.

E. Testing Phases:

Phase 1: Baseline testing with fixed-time traffic signals to measure existing performance metrics.
Phase 2: Deployment of the proposed system to compare its performance with the baseline.

Metrics:
- Detection accuracy: Measured using mAP (mean Average Precision).
- Counting accuracy: Compared manual vehicle counts with system counts.
- Traffic flow improvement: Measured reductions in waiting time and queue length.

F. Implementation Workflow:

1] Data Acquisition: Traffic cameras capture images at fixed intervals (every 5–10 seconds). Images are pre-processed (resized, normalized) for input to the YOLO model.

2] Vehicle Detection and Counting: The YOLO model processes the images and detects vehicles in predefined ROIs for each lane. Vehicle counts are recorded and passed to the dynamic signal control algorithm.

3] Dynamic Signal Control: The algorithm calculates green and red-light durations based on vehicle counts. Control signals are sent to the traffic light controllers via the Raspberry Pi.

4] Performance Monitoring: Real-time data on traffic flow, waiting times, and queue lengths are logged for analysis.
The system's performance is evaluated against predefined metrics.

## VI. Conclusion:

The adaptive traffic management system presented in this project demonstrates significant improvements over traditional fixed-time traffic light systems by adjusting signal durations dynamically based on real-time traffic density data. The results from simulations indicate that the adaptive model effectively addresses several persistent issues in urban traffic management, such as congestion, long waiting times, and inefficient traffic flow.

Key Achievements:

1. Reduced Congestion: By adapting green light durations according to vehicle density at intersections, the system minimizes congestion, especially during peak hours when traffic volume is high. Roads with higher vehicle counts are prioritized, reducing queues and ensuring smoother transitions between traffic phases.

2. Improved Traffic Flow: Traditional fixed-time systems allocate equal time to each lane regardless of traffic volume, leading to inefficient flow. This adaptive model optimizes the allocation of green lights, decreasing overall travel time by allowing a more consistent and predictable traffic flow. This improvement is especially critical in densely populated urban centers, where traffic buildup is common.

3. Enhanced Road Safety: By reducing sudden stops and minimizing the time vehicles spend waiting at intersections, the system enhances road safety. The adaptive model lowers the likelihood of accidents caused by aggressive driving and abrupt lane changes, which are often triggered by lengthy waits at intersections.

4. Environmental and Economic Benefits: Shorter idle times at intersections help reduce fuel consumption and decrease emissions. This model supports sustainability goals by minimizing the environmental impact of urban traffic. Additionally, shorter travel times have economic benefits, saving time and fuel costs for commuters and logistics operators.

5. Potential for Integration into Smart Cities: As cities move towards adopting smart infrastructure, this adaptive traffic management system aligns well with modern urban planning. The model’s reliance on real-time data and its compatibility with IoT sensors and AI-driven analytics make it a scalable solution for smart cities, where technology is used to improve efficiency and quality of life.

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