

# Smart Traffic Light System using AI Traffic Density Analysis

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**Abstract:** *Traffic congestion is a growing urban challenge, leading to delays, wasted fuel, and safety issues. This project introduces a flexible traffic light control system using artificial intelligence to ease congestion, cut wait times, and improve road safety. Reducing Traffic Congestion: By adjusting traffic light timings based on real-time data, the system enables smoother traffic flow at busy intersections, reducing delays and improving overall travel times. Optimizing Traffic Signal Timings: Using AI algorithms, the system efficiently manages green and red phases to meet the varying demands of traffic throughout the day, adapting dynamically to peak hours and minimizing stop-and-go situations. Enhancing Road Safety: The system prioritizes high-risk scenarios, such as emergency crossings, by adjusting signals to reduce accident risks, creating a more secure environment for both motorists and walkers. These systems optimize traffic flow, improve emergency response, and reduce environmental impact. While AI-based solutions offer significant advantages, challenges such as implementation complexity and scalability persist. This review highlights key advancements and future directions in intelligent traffic management.*

**Keywords:** Smart Traffic Management, Artificial Intelligence (AI), YOLO Object Detection, Deep Learning, Reinforcement Learning

## I. INTRODUCTION

As urban populations grow and more vehicles fill our roadways, traffic jams have turned into a pressing challenge for cities worldwide. The consequence of traffic jams extends far beyond delays and frustration for drivers; they also lead to increased fuel consumption, higher transportation costs, and greater carbon emissions, taking a toll on both the economy and the environment. Factors like limited road capacity, high demand during rush hours, and lengthy red-light delays all contribute to congestion. Traditional traffic lights, which operate on fixed schedules, often struggle to adapt to changing traffic patterns in real-time, creating inefficiencies that exacerbate the problem. This highlights the urgent need for smart traffic signal control systems. By using AI to adjust signals dynamically based on live traffic conditions, these systems can enhance traffic movement, minimize emissions and fuel consumption, and ultimately provide a smoother and safer experience for everyone on the road.

Population growth and urbanization have created an exponential rise in vehicular traffic, leaving roads severely congested, travel times increased, fuel consumption higher, and air pollution worse. Existing traffic management systems tend to be based on static signal timing plans that cannot dynamically respond to changing traffic conditions, particularly during peak periods, emergencies, or unexpected road incidents (Chen et al., 2020). This inefficiency underlines the absolute necessity for smart, real-time solutions for enhancing traffic flow and mitigating urban transport



challenges. New developments in artificial intelligence (AI), especially computer vision and machine learning, present a potential solution to overcome these challenges. AI-based traffic control systems leverage real-time information from sensors, cameras, and vehicle movement to optimize and learn from traffic signals (Gao et al., 2021). These systems can not only identify traffic volume but also filter emergency vehicles like ambulances, reducing response times and even saving lives. This study suggests an intelligent AI-driven traffic management system that utilizes real-time vehicle detection with the YOLO (You Only Look Once) object detection model and adaptive signal timing with live traffic data. Through the application of computer vision and optimization algorithms like Genetic Algorithms (GA), the system modifies signal lengths at intersections dynamically to optimize vehicle wait times and maximize traffic flow. Additionally, the suggested system has a special mechanism to identify and give priority to ambulances in real-time so that they get a green signal at relevant intersections.

### **Objective of Project:**

1. **Vehicle Detection and Counting:** Implement a deep learning-based approach using YOLO (You Only Look Once) to accurately detect and count the number of vehicles in images captured from surveillance cameras.
2. **Traffic Congestion Classification:** Classify traffic conditions into three levels—low, medium, and high congestion—based on predefined vehicle count thresholds to enable effective traffic flow monitoring.
3. **Emergency Vehicle Detection:** Identify and prioritize emergency vehicles (such as ambulances and fire trucks) in real-time to improve emergency response times and reduce delays in critical situations.
4. **Automated Traffic Status Monitoring:** Develop a user-friendly dashboard that allows traffic authorities to upload images, preview detections, and receive real-time updates on vehicle density and congestion levels.
5. **Model Optimization and Selection:** Provide options for selecting different YOLO models (YOLOv8s, YOLOv8n, YOLOv8x) to balance detection accuracy and computational efficiency based on specific use cases.
6. **Scalability and Cost-Effectiveness:** Design a fully software-based solution that can be deployed with minimal infrastructure modifications, making it a cost-effective and scalable approach for smart city applications.

## **II. LITERATURE SURVEY**

- In 2018, Thorpe introduced a neural network-based value function for predicting waiting times at intersections. By 2023, researchers demonstrated that deep Q-learning methods could significantly reduce vehicle waiting times. Additionally, intelligent agents have been developed to optimize traffic signalling through local decision-making. Innovative systems using visual processing for vehicle identification further enhance traffic management adaptability (G. Sathya et al., 2023).
- Urban life is increasingly hectic due to population growth, leading to a significant rise in motor vehicles and traffic congestion (Carley and Christie, 2017). Traffic signals, designed to manage flow at busy intersections, often fail when certain lanes experience heavier traffic. This results in overcrowding in some lanes while others remain underutilized. Innovative automated traffic control systems can optimize signal timings to improve vehicle movement and reduce congestion.
- Divyansh Bagdi's 2021 literature survey provides an in-depth analysis of traditional traffic management systems, highlighting key issues and drawbacks associated with traditional traffic light management. The chapter discusses the signalized traffic system commonly implemented in urban areas, examining its effectiveness and the various types of traffic lights currently in use. It emphasizes that traditional systems often fail to manage traffic efficiently, particularly when certain lanes experience heavier congestion than others. This inefficiency leads to overcrowding in some lanes while others remain underutilized, necessitating a reevaluation of existing traffic management strategies.
- Seyedeh M. Mortazavi Azad and A. Ramazani's paper, received on August 2, 2023, and accepted on November 6, 2023, explores the use of traffic lights in urban areas to prioritize vehicles at intersections as a solution for traffic control. The authors focus on utilizing machine learning methods, particularly Q-learning coupled with deep neural networks, implemented in two intersection models: one for an individual intersection and another for two connected



intersections sharing actions. Their approach allows traffic lights to make intelligent decisions that reduce vehicle waiting times by effectively managing phase allocations. Simulations conducted using SUMO revealed a 34% reduction in average queue time at individual intersections and a 24% reduction in queue time across two intersections during heavy traffic scenarios.

- P. Joyson Silva, R. Vignesh, Binu Sukumar, and Nithish Kumar's 2023 research addresses the inefficiencies of India's traffic control systems, which struggle with unpredictable traffic density patterns. They propose an adaptive traffic light timer that uses image processing algorithms with a Raspberry Pi and OpenCV to analyze real-time traffic conditions. This system minimizes vehicle waiting times and increases the amount of vehicles passing by each lane, significantly improving traffic circulation. The strategy is noted for its efficiency and costeffectiveness compared to existing methodologies.

### **III. EXISTING SYSTEM**

In Current traffic management systems primarily rely on real-time data from sensors and cameras to regulate traffic flow. Traditional approaches include vehicle detection using image processing techniques, such as Gaussian mixture models and foreground detection, to estimate traffic density. Some systems use fixed-time traffic signals or sensor-based adaptive control, where traffic lights adjust based on vehicle count and congestion levels. While these methods have improved traffic flow, they still face challenges such as,

Inaccurate detection in extreme weather conditions, limited scalability, and high infrastructure costs. In the context of AI-based traffic management, existing systems highlight the need for more intelligent and adaptable solutions. By integrating deep learning and predictive analytics, traffic signals can dynamically adjust in real-time based on historical data and live traffic conditions. Advanced AI techniques can enhance vehicle classification, optimize traffic light timings, and improve congestion prediction. This approach aims to create a self-learning system capable of handling diverse traffic scenarios more efficiently than traditional rule-based or sensor-driven methods. Inference for the Project Analyzing the existing systems suggests that incorporating advanced AI techniques—such as deep learning for more accurate vehicle recognition and predictive analytics for dynamic signal timing—can significantly enhance traffic flow management. An integrated approach that combines multi-modal sensor data with sophisticated video analytics can further reduce congestion, improve safety, and offer a robust solution adaptable to changing traffic patterns.

### **IV. METHODOLOGY**

Traffic flow is highly unpredictable, and static signal timers exacerbate congestion by failing to adapt to real-time traffic conditions. To address this, a system that dynamically calculates optimal green light durations based on current traffic levels at each signal would be far more effective. By allowing the direction with heavier traffic to receive a longer green light, and reducing the wait for less congested directions, this adaptive approach can greatly improve traffic flow. Unlike traditional systems with fixed, hard-coded light patterns that lead to unnecessary delays, this responsive system can reduce congestion, shorten waiting times, and decrease the likelihood of accidents. Additionally, by cutting down on idling, it can reduce fuel consumption, thus contributing to lower air pollution levels in urban areas. The primary goal of this initiative is to develop a traffic light regulation system employing Computer Vision that adapts in real-time to current traffic conditions. Our proposed system leverages live video streams from surveillance cameras at intersections to calculate traffic density by detecting and analyzing vehicles at each signal. Based on this data, the system dynamically adjusts the green light duration to optimize traffic flow. To ensure precise timing, vehicles are grouped into types such as cars, bikes, buses/trucks, and rickshaws, allowing for a more accurate calculation of the required green signal time. Our envisioned system will assess snapshots from CCTV cameras at intersections to assess traffic patterns in real time through Image manipulation and Computer Vision. To detect vehicles, we employ a customized YOLO (You Only Look Once) object detection specifically tailored for object detection. Using this traffic density data, a scheduling algorithm will determine the optimal green light phase for each signal and adjust the stop



signal times for the other directions accordingly. This dynamic approach aims to enhance traffic circulation and minimize congestion by responding to real-time traffic conditions at each junction.

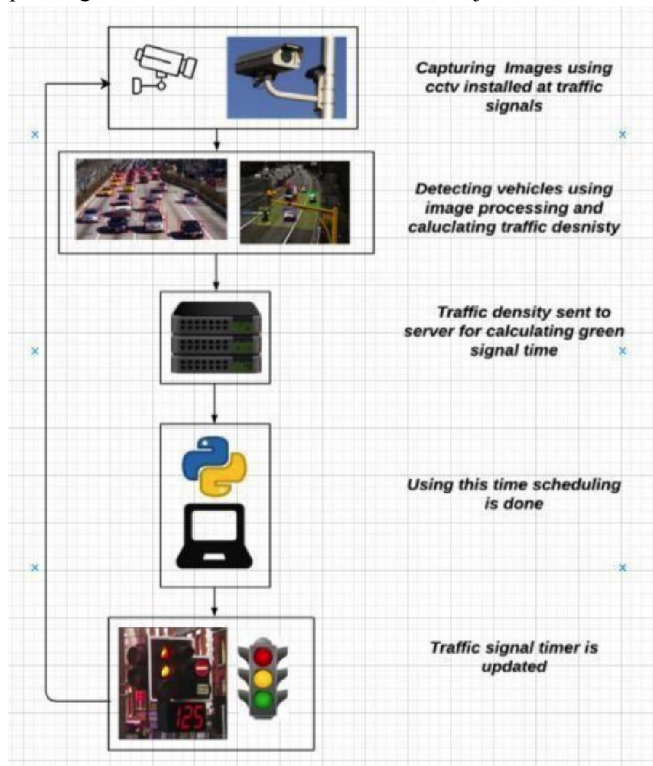


Fig. 1. Algorithm of System

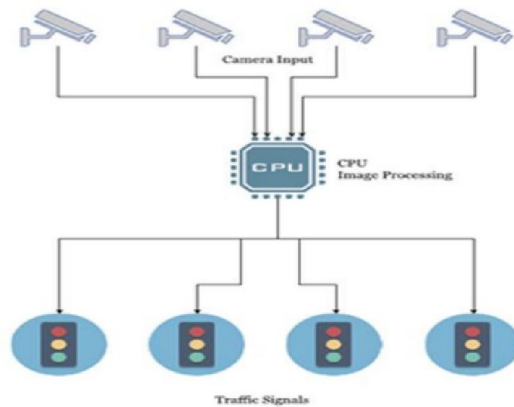


Fig. 2. System Architecture

The methodology for implementing a Smart AI-based Traffic Management System with real-time monitoring and adaptive traffic light control is structured in several stages:

1. Data Collection and Preprocessing Traffic Data Sources: Live feeds from CCTV cameras, IoT sensors, GPS systems, and satellite imagery are utilized for real-time data collection. Data Preprocessing: The raw traffic data undergoes image enhancement, noise reduction, and object detection preprocessing using OpenCV and deep learning techniques.



2. Object Detection and Classification Deep Learning Model: YOLOv8 (You Only Look Once) is used for detecting and classifying vehicles, pedestrians, and emergency vehicles.

Bounding Box and Labeling: Each detected vehicle is assigned a category (e.g., car, bus, ambulance), and its movement is tracked.

3. Real-Time Traffic Monitoring and Congestion Analysis Traffic Density Calculation: The system estimates traffic congestion by counting the number of vehicles at intersections and calculating the queue length and waiting time. Pattern Analysis: Historical traffic patterns and realtime data are used to predict peak hours, bottlenecks, and potential congestion zones.

4. Adaptive Traffic Signal Control Dynamic Signal Timings: Traffic lights are adjusted dynamically using reinforcement learning algorithms based on real-time traffic conditions. Priority Handling: Emergency Vehicle Detection: The system prioritizes ambulances and fire trucks by changing traffic signals accordingly. Public Transport Optimization: Public buses are given priority during high congestion periods.

5. System Optimization & Performance Enhancements GPU Acceleration: CUDA and OpenVINO frameworks enhance deep learning model execution speed. Multithreading: Parallel processing is implemented to maintain real-time performance while detecting multiple objects. Edge Computing: AI models are deployed on edge devices near traffic intersections to reduce latency.

6. Visualization & User Interface Graphical Dashboard: A real-time interface using PyQt5 provides visual monitoring of traffic conditions. Historical Data Reports: Traffic reports are stored in JSON/CSV format for long-term analysis.

7. Evaluation Metrics & Expected Outcomes Traffic Throughput Improvement: The number of vehicles passing through intersections increases. Reduction in Queue Length: Vehicles spend less time at signals. Lower Fuel Consumption: Reduced idling leads to lower CO<sub>2</sub> emissions. Faster Emergency Response Time: Ambulances and fire trucks navigate traffic efficiently.

## V. ALGORITHMS

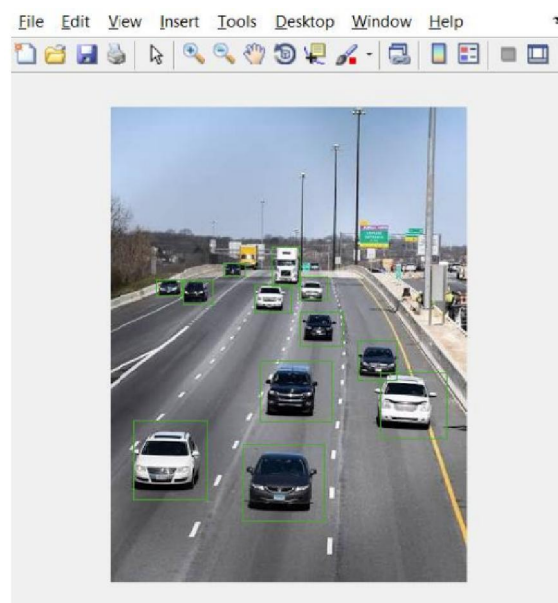


Fig. 3. Vehicle Detection in AI



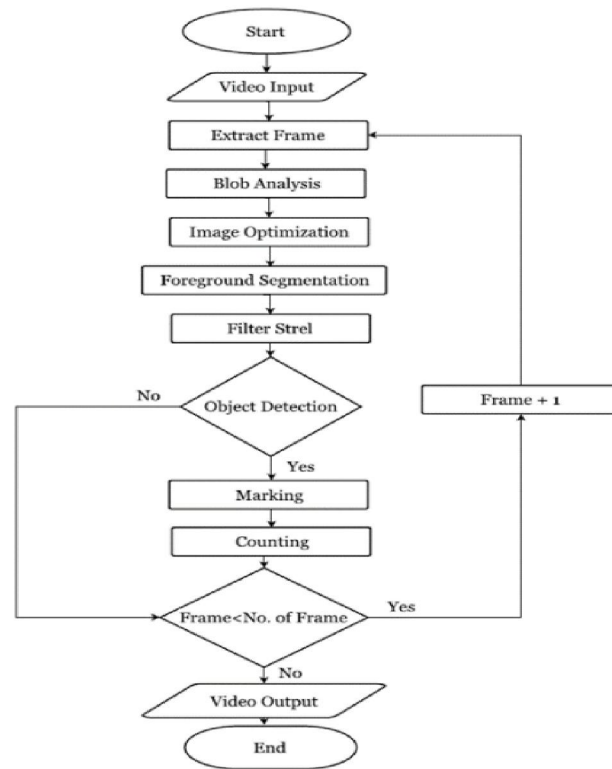


Fig. 4. Wokflow Diagram

The Signal Switching Algorithm adjusts the go signal duration depending on the traffic density data provided via the vehicle detection module, while updating red light timings for other directions. The algorithm operates in a cyclical manner, switching signals according to each timer. It receives input from the sensing module, which provides vehicle data in JSON structure, with each detected vehicle labeled as a key, accompanied by confidence levels and coordinates as values.

The algorithm parses this data to determine the total count of each vehicle type, which is then used to calculate the optimal green light duration. Red signal times are adjusted for other directions accordingly. This algorithm is intended to be scalable, allowing for application across any quantity of signals at an junction. The Algorithm was developed with the following key factors in mind:

1. Processing Time: The duration needed for the algorithm to compute traffic density and determine the interval of the go signal, which informs the optimal moment for image capture.
2. Lane Count: The lane count at the junction.
3. Vehicle Counts by Class: The overall vehicle count in each category (cars, trucks, motorcycles, etc.).
4. Traffic Density: Calculated according to the above factors.
5. Start-Up Delay: The lag encountered by each vehicle during start-up, together with the increasing, non-linear delay affecting vehicles further back in the queue.
6. Average Speed per Vehicle Class: The average time taken for each vehicle class to clear the intersection once the go signal is activated.
7. Green Light Duration Limits: Minimum and maximum time thresholds for the green phase to prevent prolonged waits and traffic congestion.



## **VI. IMPLEMENTATION**

### **A. Importing Required Libraries**

The project begins by importing necessary libraries such as PyQt5, YOLO, PIL, numpy, and random. These libraries facilitate GUI creation, object detection, image processing, and traffic signal adaptation.

### **B. Loading and Processing Traffic Images**

The system allows users to upload traffic images from four different lanes. These images are processed using YOLOv8 to detect vehicles, including cars, buses, trucks, and motorcycles. Additionally, a separate custom-trained YOLO model detects ambulances to prioritize emergency vehicles.

### **C. Preprocessing Traffic Data**

The captured images undergo preprocessing, including format verification and resizing. The YOLO models analyze the images to count the number of vehicles in each lane. If an ambulance is detected, that lane is given the highest priority.

### **D. Extracting Traffic Density Features**

The system extracts key traffic features such as vehicle count and ambulance presence. This information is used to determine optimal traffic light timings. The priority-based scheduling ensures efficient traffic flow.

### **E. Traffic Signal Adaptation with AI**

Based on vehicle density, the system calculates signal durations dynamically. The green light duration is adjusted using predefined rules based on vehicle count. If an ambulance is detected, the system immediately grants priority to that lane.

### **F. GUI and Real-Time Monitoring**

The system features an interactive GUI using PyQt5. It displays lane images, detected vehicle counts, and signal statuses in real time. A countdown timer ensures users are informed of the remaining signal duration for each lane.

### **G. Traffic Light Control Algorithm**

The model processes the detected vehicle data and determines the optimal sequence for signal changes. The cycle follows:

- Green signal for the lane with the highest priority.
- Transition to yellow before switching to the next lane.
- Red signal for other lanes until their turn arrives.

### **H. Real-Time Adaptation of Traffic Timings**

The system continuously updates traffic signals based on live input. As vehicle density changes, new images are analyzed, and signal durations are recalculated. This ensures efficient traffic flow and minimizes congestion.

## **VII. CONCLUSION**

In conclusion, the implementation of an AI-based smart traffic management system offers a transformative approach to addressing urban congestion and optimizing traffic flow. By integrating real-time monitoring, adaptive traffic signal control, and advanced machine learning techniques, the proposed system enhances road efficiency, reduces vehicle wait times, and prioritizes emergency vehicles. The use of deep learning models, such as YOLOv8 for object detection, combined with technologies like PyQt5 for GUI development and OpenCV for image processing, ensures a robust and scalable solution. Additionally, the system contributes to environmental sustainability by minimizing fuel consumption and lowering carbon emissions. With its potential to revolutionize traffic management, this AI-driven solution paves the way for smarter, safer, and more efficient urban mobility. The suggested adaptive traffic control system dynamically adjusts green signal durations based on real-time traffic volume at each signal. By allocating longer green times to directions with higher traffic volumes, the system reduces unnecessary delays, minimizes congestion, and shortens waiting times. This efficiency not only improves the flow of vehicles through intersections but also helps reduce fuel consumption and emissions, supporting a cleaner urban environment.



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