International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Real-Time Adaptive Traffic Control System For Smart Cities

[1]Vimala P, [2]Gokul R, [3]Abishek M, [4]Gokul K , [5]Jeevanandam A , [1] Assistant Professor,

[2] [3] [4] [5] Students,Department of computer science, Dhirajlal Gandhi College of technology(Autonomous),omalur,sikanampattysalem-636309,TamilNadu,India. [1] vimala.cse@dgct.ac.in, [2] gokulsunder78@gmail.com ,[3] abishekmuthu1967@gmail.com, [4] gokulkanagaraj374@gmail.com,[5] jeevanandam2708@gmail.com

ABSTRACT :

This project proposes an intelligent real-time traffic control system using computer vision and deep learning to optimize traffic flow by dynamically adjusting signal timings based on live vehicle counts from camera feeds. It incorporates emergency vehicle detection (ambulances, fire trucks, police cars) through deep learning models like YOLOv5, prioritizing their passage by modifying signals for faster response times. Additionally, a blog-based platform assists ambulance drivers with real-time traffic updates and optimal routes. By integrating vehicle counting, emergency recognition, and adaptive signal control, the system enhances traffic efficiency while ensuring priority access for critical services.

Key Features:

✔ **Real-time traffic adjustment using vehicle counts.**
✔ **AI-powered emergency vehicle detection.**
✔ **Blog platform for ambulance drivers.**
✔ **Deep learning (YOLO/Faster R-CNN) for accuracy.**

Introduction

In contemporary urban environments, traffic congestion has emerged as one of the most pressing challenges, leading to significant economic losses, environmental pollution, and, most critically, delays in emergency response times. Conventional traffic management systems, which rely on predetermined signal timings, are fundamentally inadequate to address the dynamic nature of vehicular flow. These static systems fail to adapt to real-time traffic fluctuations, resulting in unnecessary delays, increased fuel consumption, and heightened frustration among commuters. Moreover, the inability to prioritize emergency vehicles such as ambulances, fire trucks, and police cars exacerbates life-threatening situations, where every second counts. To mitigate these issues, there is an urgent need for an intelligent, adaptive traffic control system capable of responding to real-time conditions while ensuring the swift passage of emergency responders.

This project introduces an advanced **AI-driven traffic management system** that harnesses the power of **computer vision and deep learning** to revolutionize traditional traffic

control mechanisms. At its core, the system employs state-of-the-art object detection algorithms, including **YOLO (You Only Look Once) and Faster R-CNN (Region-based Convolutional Neural Networks)**, to monitor and analyze

creating smarter, more responsive urban transportation systems. Future work could explore the integration of additional sensors, such as IoT-enabled devices, to further enhance the system's accuracy and reliability. Ultimately, this

research contributes to the broader goal of developing intelligent transportation systems that prioritize both efficiency

vehicles, assesses traffic density, and dynamically adjusts signal timings to optimize flow and minimize congestion. Unlike static systems, this approach ensures that traffic lights respond intelligently to actual road conditions, reducing idle time at intersections and improving overall traffic efficiency.

A critical innovation of this system is its ability to **identify and prioritize emergency vehicles**. Through deep learning models trained on extensive datasets of emergency vehicles, the system can distinguish ambulances, fire trucks, and police cars from regular traffic. Upon detection, it automatically triggers a priority protocol, altering signal phases to grant these vehicles unimpeded passage. This feature is particularly vital in urban areas where traffic congestion often hinders emergency responders, potentially saving lives by significantly reducing response times.

To further enhance emergency response coordination, the project incorporates a **dedicated web-based platform** designed specifically for ambulance drivers and other emergency personnel. This platform provides real-time traffic updates, suggests optimal routes, and facilitates communication between drivers and traffic control centers. By integrating this platform with the AI-driven traffic system, emergency responders gain a strategic advantage, enabling them to navigate congested areas more effectively and reach their destinations faster.

The integration of **real-time vehicle counting, emergency vehicle recognition, and adaptive signal control** represents a holistic approach to modern traffic management. By leveraging deep learning techniques, the system not only addresses the inefficiencies of conventional traffic lights but also introduces a proactive mechanism for handling emergencies. The potential benefits of this system are manifold: reduced traffic congestion, lower fuel consumption and emissions, decreased travel time for commuters, and, most importantly, faster emergency response times that can save lives.

II. Problem Description

The persistent challenge of urban traffic congestion represents one of the most pressing issues facing modern cities today, with far-reaching consequences that extend beyond mere inconvenience to significant economic, environmental, and public safety impacts. At the heart of this problem lies the fundamental inadequacy of conventional traffic control systems, which continue to rely on outdated technologies and methodologies that are ill-equipped to handle the complexities of 21st century transportation networks. These legacy systems, predominantly based on fixed-time signal cycles or rudimentary sensor inputs, fail to account for the dynamic, ever-changing nature of urban traffic flows, resulting in systemic inefficiencies that compound throughout entire transportation networks.

The limitations of current traffic management approaches manifest in several critical ways. First and foremost is the issue of inefficient traffic flow regulation, where rigid, predetermined signal timing schemes bear no relation to actual real-time traffic conditions. This disconnect leads to frequent instances of vehicles stopping unnecessarily at empty intersections while simultaneously creating artificial bottlenecks at congested junctions. During peak hours, these inefficiencies can reduce overall traffic throughput by as much as 30-40%, with commuters wasting an average of 42 hours annually sitting in traffic according to recent urban mobility studies. The economic implications are staggering, with major metropolitan areas losing billions in productivity each year due to traffic congestion-related delays.

More alarmingly, these outdated systems completely lack mechanisms for prioritizing emergency response vehicles, creating potentially life-threatening situations. Ambulances, fire trucks, and police vehicles routinely experience dangerous delays at signalized intersections, with response times increasing by 25-35% during congested periods. Research indicates that for every minute of delay in emergency medical response, patient survival rates can decrease by 7-10%, making the current system's failure to accommodate emergency vehicles a matter of literal life and death. The absence of any communication infrastructure between emergency vehicles and traffic signals represents a critical flaw in urban emergency response systems.

The environmental consequences of inefficient traffic management are equally concerning. Vehicles idling at poorly timed signals contribute disproportionately to urban air pollution, with studies showing that traffic intersections account for nearly 40% of a city's vehicular emissions despite representing only about 5% of total road space. The stop-and-go driving patterns enforced by current traffic systems increase fuel consumption by 15-25% compared to smooth-flow traffic conditions, unnecessarily accelerating fossil fuel depletion and greenhouse gas emissions at a time when cities are striving to meet ambitious climate goals.

Underlying these operational deficiencies is the fundamental isolation of traffic control systems from other urban infrastructure components. Traffic signals operate as independent units with no capacity for network-wide coordination, unable to share data with emergency services, public transportation systems, or emerging connected vehicle technologies. This siloed approach prevents the implementation of holistic traffic management strategies that could optimize flow across entire districts rather than at individual intersections.

The technological stagnation of traffic infrastructure is particularly glaring when contrasted with advancements in other urban systems. While cities have embraced smart technologies for utilities, public safety, and other services, traffic control systems have remained largely unchanged since their electromechanical origins in the mid-20th century. This resistance to innovation has created an infrastructure that cannot interface with modern IoT devices, lacks data collection and analysis capabilities, and provides no platform for future smart city integrations.

Compounding these technical shortcomings is the complete absence of predictive capabilities in current systems. Unlike modern AI-driven systems that can anticipate and prevent problems, conventional traffic controls remain purely reactive, responding only to vehicles already present at intersections with no ability to forecast developing congestion patterns or adjust proactively. This limitation becomes especially problematic during special events, accidents, or inclement weather when traffic patterns deviate dramatically from normal conditions.

The human cost of these systemic failures extends beyond emergency responders to affect all urban residents. Pedestrians face increased safety risks as frustrated drivers make dangerous maneuvers to circumvent congestion. Public transportation becomes unreliable when buses and trams get caught in traffic. Local businesses suffer from delayed deliveries and reduced customer access. The cumulative effect is a degradation of overall quality of life and economic vitality in urban centers.

These multifaceted problems share a common root cause: the continued reliance on traffic management paradigms developed for the automotive realities of the 1950s being applied to the vastly different transportation landscape of today. As urban populations grow and vehicle numbers increase, the shortcomings of conventional traffic systems will only become more pronounced, demanding innovative solutions that leverage modern technologies to create adaptive, intelligent transportation networks capable of meeting 21st century mobility challenges. The need for a fundamental reimagining of traffic management has never been more urgent, with implications that extend across public safety, environmental sustainability, economic productivity, and overall urban livability.

III. Intelligent transport systems

Intelligent Transport System (ITS) Architectureoffers a framework for any form of technology-related initiative in the transport sector. The system architecture is a broad description of the facilities, ITS modules, interconnections, and information flow mapping for the different systems and subsystems that cover the ITS project. With a properly designed infrastructure, owners and stakeholders may define both the services provided by end-users, the data for these services, and the interconnection between the various sub-systems.

The preparation and implementation of ITS are in their infancy in India. There are several noteworthy achievements in ITS applications in India mainly in transport technology, traffic control, fare collection, and toll collection systems. However, there is currently no National ITS Plan or ITS Architecture

that has been established. In fact, the World Bank recommends that for those countries and regions that have not yet developed a national or regional ITS Architecture, the ITS Architecture Project Level is a suggested initial step towards starting the process of developing a national ITS Architecture
The ITS architecture as a whole involves many user services like Traveler information services, Traffic management services, Public transport services, Electronic payment services for Toll, Commercial vehicle operations, Emergency management services, Vehicle safety, and control system and Information warehousing services. In the metro cities of India, the existing traffic control system is inefficient because of randomness in the pattern of traffic density during the day. Because of this, even though the traffic level is much smaller, vehicles must wait for a long time. Hence, the traffic

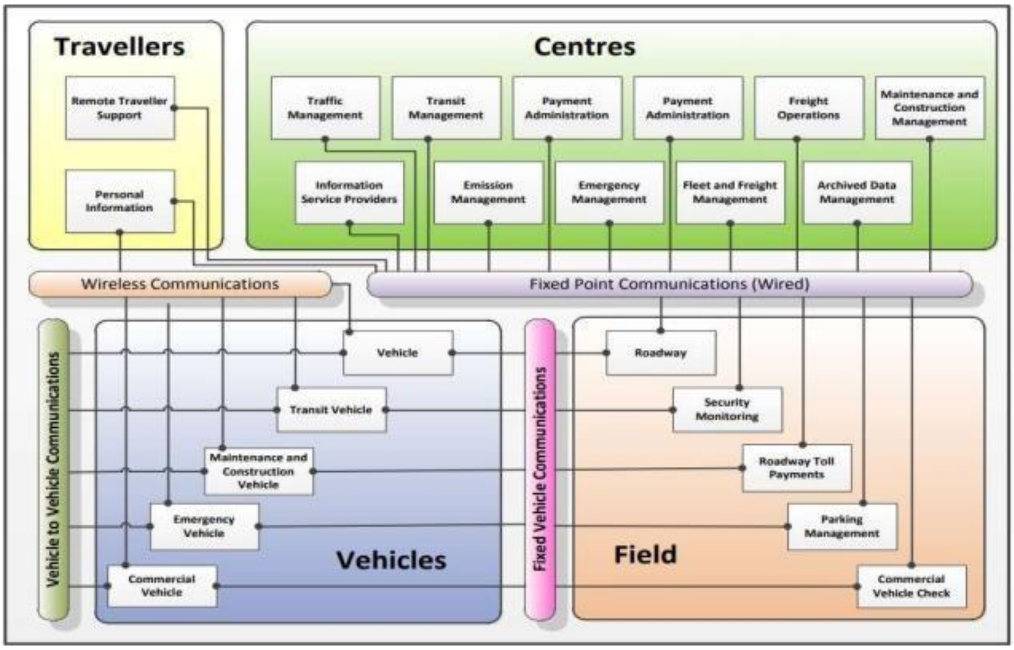
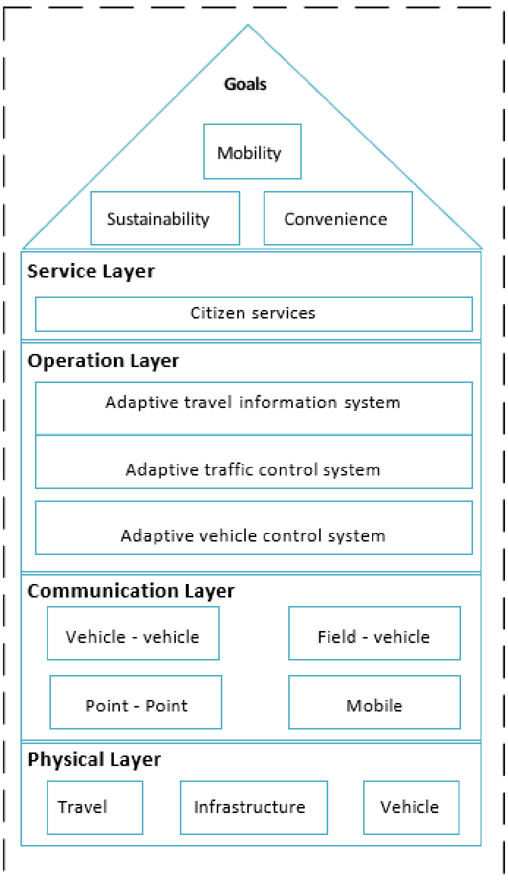


fig 1 Architecture of Intelligent Transportation Systems (ITS)

fig 2 Layered Architecture of Smart Transportation System



Adaptive traffic control system framework

The ATCS algorithm continuously changes traffic signal timings based on the demand for traffic at the intersections and projected arrivals from neighbouring intersections [4]. It greatly enhances travel time by pushing vehicles steadily through green lights and reduces congestion by creating smoother flow. frame in real-time, and the loop is iterated before the user wishes to interrupt it. Video pre-processing methods are used to enhance efficiency and precision in the calculation of traffic flow.

It is also a mixture of multiple operations. We used two methods to achieve two separate goals. Firstly, the video stream is transformed from the RGB color mode to the Gray scale. Three channel colors are translated to matching gray intensities. This stage decreases the volume of data to be processed and thus improves the speed of process. In the second stage of pre- processing, all video frames are equalized Histogram [8]. Histogram equalization results in an image with significantly higher contrast and does so by extending the distribution of the size of the image [9]. The histogram represents the pixel intensities of the image with the corresponding values in the chart [10]. A better outcome is reached when the picture is first transformed to a gray scale and the histogram is equalized as it increases the probability of an object being recognized.

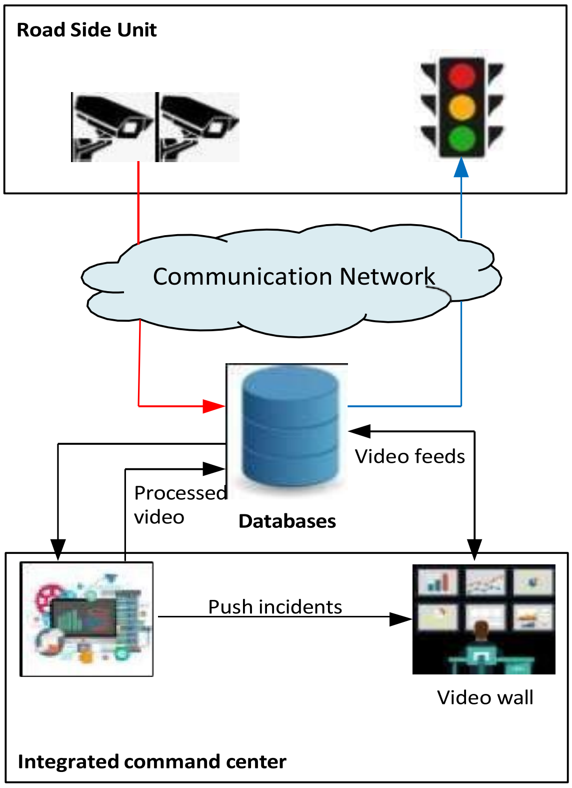


FIG 3 Smart Traffic Control System Using Communication Network

Using image processing, the proposed system adapts the traffic signal timer according to the random traffic density [5]. This model uses high-resolution cameras to detect shifting traffic patterns around the traffic signal and to manipulate the signal timer according to sending signals to the timer control system

Traffic congestion depends directly on the regulation of the traffic flow and thus on the timer of the traffic signal. As a result of this phenomenon, vehicles have to face an irregular pause during travel in metropolitan areas. At currently, traffic control systems in India lack intelligence and function as an open-loop system with no feedback or network sensing [5]. The goal of this work is to enhance the traffic control system by adding a sensing network that provides input to the existing network so that it can respond to evolving patterns of traffic density and provide the controller with the required

signals in real-time. Our key aim is to optimize vehicle transit delays in irregular hours of the day

The approach suggested in this work consists of segmenting the problem into two sub-problems, first of which is to calculate traffic volume using classifiers under the Viola Jones Object Detection System. Using open cv library in the C/C++

Environment, real-time traffic estimation was obtained

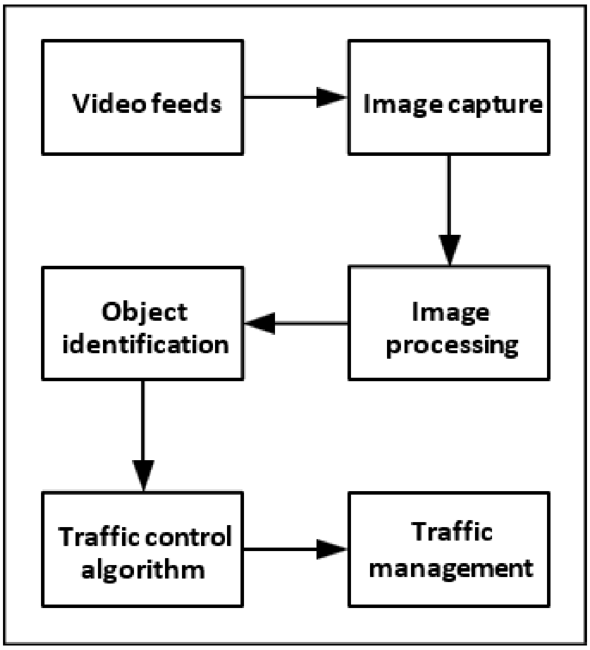


FIG 4 Video-Based Traffic Monitoring Workflow

Video feed acquisition:

The control algorithm is intended to control 4-way and 2- way approach intersection. This includes taking video data from various cameras and manipulating the input by suitable filters and algorithms. The video feed is obtained via the automated operations supported by OpenCV using the Direct Display (Dshow) techniques. The use of Dshow helps us to process multiple feeds at comparatively higher speeds compared to other techniques. The camera feeds are processed in the Integrated Control Center with the aid of big data as a backend technology.

Pre-processing of video:

Video processing is achieved by the repeated trials of the techniques of image processing to video frames. Video feeds from various cameras are collected and analyzed frame by
frame in real-time, and the loop is iterated before the user wishes to interrupt it. Video pre-processing methods are used to enhance efficiency and precision in the calculation of traffic flow. It is also a mixture of multiple operations. We used two methods to achieve two separate goals. Firstly, the video stream is transformed from the RGB color mode to the Gray scale. Three channel colors are translated to matching gray intensities. This stage decreases the volume of data to be processed and thus improves the speed of process. In the second stage of pre- processing, all video frames are equalized Histogram [8]. Histogram equalization results in an image with significantly higher contrast and does so by extending the distribution of the size of

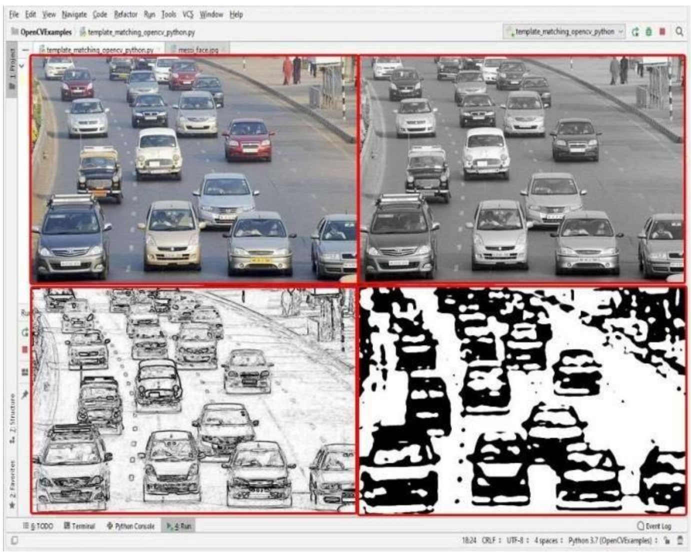


FIG 5 Stages of Vehicle Detection Using Image Processing

For our analysis, we only needed the total number of items observed, which will apply to the number of vehicles in the queue at the traffic intersection approach. The cumulative number of vehicles recognized shall be taken into account. The count for each approach of the intersection shall be fed to the algorithm for the determination of the appropriate action.

TABLE I. PERFORMANCE OF CLASSIFIER FOR OBJECT DETECTION

Vehicle type	Detected	Not detected	Accuracy
Cars	40	3	93%
Bikes	52	3	94.5%
Trucks & Buses	48	2	96
Ambulances	15	1	93.7%

the image [9]. The histogram represents the pixel intensities of the image with the corresponding values in the chart [10]. A better outcome is reached when the picture is first transformed to a gray scale and the histogram is equalized as it increases the probability of an object being recognized

FIG 6 Emergency Vehicle Detection in Traffic Using Object Detection

Extraction of data:

Data Extraction refers to the acquisition of data/information that is most suited to our specifications from pre-processed video streams. Many variables can be derived using various techniques. In case of object detection, the related variables may be Motion, Colour, Size, Object Centre, Direction, Total Count, etc. For our analysis, we only needed the total number of items observed, which will apply to the number of vehicles in the queue at the traffic intersection approach. The cumulative number of vehicles recognized shall be taken into account. The count for each approach of the intersection shall be fed to the algorithm for the determination of the appropriate action.

D. Traffic control algorithm:

The control algorithm is responsible for controlling traffic at the intersection when is supplied with data. The algorithm was coded explicitly in the C/C++ interface to make it more effective and stable. The algorithm complies with the following simple principles for the management of traffic signals used in conjunction to minimize traffic congestion at the intersection

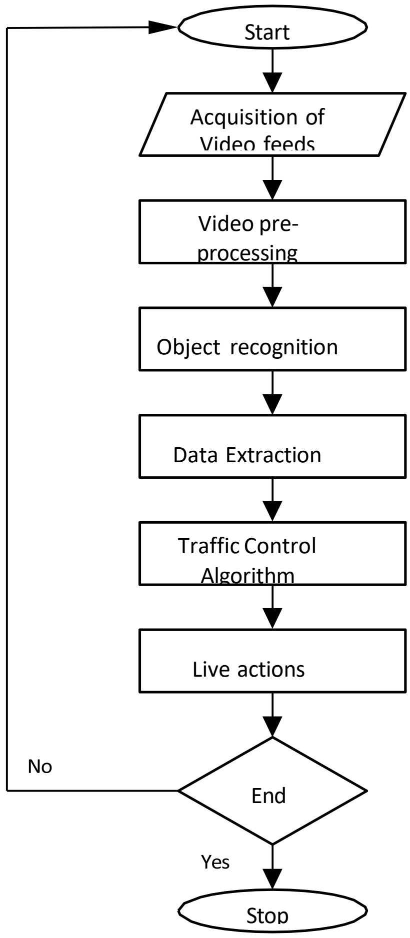


FIG 7 Vehicle Detection and Counting in Traffic

In set A – conventional approach, the 100 vehicles are spawned in random lane and the traffic lights operate in fixed timing mode. So, the overall time to resolve 100 vehicles in for set A simulation is around 240 seconds.

In Set B, the overall time is 160 seconds in which the control algorithm employs pre-surveyed data of each lane. In set A & set B simulation when ATCS is programmed the total time of resolving the conjunction on hundred vehicle in 105 sec. which is very much less than traditional approach . it is noted that the suggestion algorithm resolves congestion within shorter span time

Conclusion :

The proposed **intelligent real-time traffic control system** leverages **computer vision and deep learning** to revolutionize urban traffic management by dynamically optimizing signal timings, prioritizing emergency vehicles, and assisting ambulance drivers with real-time route guidance. By integrating **YOLOv5-based vehicle detection, adaptive signal control algorithms, and a blog-style emergency driver assistance platform**, the system addresses critical inefficiencies in traditional traffic systems—reducing congestion, minimizing emergency response times, and improving overall road safety.

However, challenges such as **hardware scalability, dataset diversity for emergency vehicles, and system latency** must be carefully addressed during implementation. Future enhancements could include **Vehicle-to-Infrastructure (V2I) communication** for even faster emergency alerts

In conclusion, this project presents a **scalable, AI-driven solution** to modern traffic problems, with tangible benefits for both daily commuters and emergency services. By combining cutting-edge technologies like **computer vision, deep learning, and IoT**, the system not only optimizes traffic flow but also **saves lives**—making it a vital step toward smarter, safer cities. With further refinement and real-world testing, it has the potential to set a new standard for **intelligent transportation systems worldwide**.

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