International Journal of Research and Technology (IJRT)
International Open-Access, Peer-Reviewed, Refereed, Online Journal
ISSN (Print): 2321-7510 | ISSN (Online): 2321-7529
| An ISO 9001:2015 Certified Journal |

Analysis of Intelligent Traffic Management System using Artificial Intelligence and Computer Vision

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Abstract
The problem of traffic jam at the intersection of the streets in the city is an old issue, which results in wastage of time, use of more fuel, and more pollution of the environment. Traditional systems of traffic signals, which rely on a fixed schedule or fixed timer, tend to be inefficient at the peak time or responding to unknown changes in traffic flow. In order to address these shortcomings, the proposed Smart Traffic Light Control System will combine machine learning algorithms with vehicle detection systems in order to optimize signal timing dynamically. The vehicle detectors, real-time traffic analysis units, adaptive signal control functions, and coordination systems of the different intersections make up the system architecture. Cameras or radar devices are used as sensors to record continuous data of vehicle movements at intersections. Computer vision and detection algorithms are used to identify and track the vehicles and the information is processed as a measure of the current traffic density. Patterns are analyzed with a machine learning model and a prediction of the traffic demand is made and signal phases can be modified. Adaptive signal control algorithms dynamically allocate green time and favor lanes of greater demand and distribute green time evenly. Moreover, the coordination of the adjacent intersections ensures the minimization of the number of stops, minimization of delays, and an increase in the movement of traffic. The system helps to reduce greenhouse gas emissions by idle vehicles as well as enhancing road safety; it also makes the road system efficient and avoids the congestion problem before it occurs. The suggested framework is in line with the smart city programs, which excellently add to the sustainability, safety, and efficiency of transportation systems. The system is a major improvement when compared to the traditional method of traffic control as it combines artificial intelligence with intelligent traffic sensing. Its results demonstrate its possible impact in changing the movement of people in cities and provide scalable solutions to the problem of congestion and improving the lifestyles of people in cities.
Keywords: Smart Traffic Light Control, Machine Learning, Vehicle Detection, Adaptive Signal Control, Intelligent Transportation System

1. INTRODUCTION

Urbanization has become a great opportunity to grow, develop economically and get better living conditions but on the other hand, it has raised a serious threat in the sphere of urban movement. Traffic congestion is one of the most acute problems existing in the contemporary cities. Deteriorating traffic jams, excessive high rates of personal vehicle increase, lack of road systems and the poor transport systems have resulted in the overcrowded roads, growing pollution, fuel waste and high productivity losses. The necessity to have sophisticated and smart solutions to control the traffic movement effectively has never been higher. The old system of traditional traffic management that is more or less dependent on fixed timers or manually operated signals cannot handle the dynamics of the modern urban traffic environment. Consequently, the movement has shifted to intelligent transportation systems (ITS) using the latest technological advances in the fields of artificial intelligence (AI), machine learning and computer vision to offer real-time, adaptive, and scalable solutions.

One of the paradigm shifts in terms of the city managements of the transportation network is the Intelligent Traffic Management System (ITMS) which operates on the basis of the artificial intelligence and computer vision. The data on real-time traffic challenge is not limited to unforeseeable increases in demand, unlike conventional methods, which tend to operate slowly, AI-based systems can analyze large volumes of real-time data, learn trends, and make decisions quickly to optimize signal timings, identify violations, and minimize congestion. Specifically, computer vision is very crucial in managing traffic because it enables monitoring of vehicles at a low cost by using cameras that are not invasive. With AI algorithms combined with visual data, systems will be able not only to count vehicles and estimate their density by classifying them into categories (cars, buses, trucks, and motorcycles) and taking more targeted approaches to traffic control.

Real-time object detection, such as vehicles on a busy road, has been transformed by the increased use of deep learning models, such as YOLO (You Only Look Once), SSD (Single Shot Detector), and Faster R-CNN. These models are able to process high-resolution video feeds with high accuracy and speed thus they can be used in live traffic management applications. YOLOv8 in recent years has become one of the strongest frameworks with high-speed and real-time vehicle detection accuracy rates of more than 90 percent in a variety of classes. Through such elaborated models as part of the traffic control mechanisms, the limitation of inefficiency of the fixed signal systems can be surpassed, and, instead, a scheme of adaptive traffic light control, which is demand-dependent and dynamically distributes the green times in response to the real conditions of the roads, can be implemented.

In addition to congestion suppression, intelligent traffic management based on AI also touches upon the safety issue. The cause of accidents that are common in the urban areas are traffic violations like red-light jumping, over-speeding, and indiscipline in the lanes. Systems can create time stamped evidence that can be used by enforcement agencies to act more efficiently through automated violation detection with the help of computer vision. This minimizes the reliance on manual surveillance and assists in constructing safer roads with heightened adherence to the traffic rules. Moreover, AI can be used to prioritize emergency vehicles including ambulances and fire trucks by dynamically adjusting signals to make green corridors, and thus, save life-saving time in an emergency situation.

The second major advantage of AI-based systems is that they help in environmental sustainability. Due to reduced time taken by vehicles to idle at traffic lights and increases in the smooth flows, fuel consumption will decrease and greenhouse gas emissions will also reduce. Intelligent traffic management is the new feature of environmentally-friendly urban construction as cities all over the world struggle to achieve sustainability and minimize their carbon footprints. In addition, the implementation of such systems into larger smart city systems enables municipal government to gather and process useful data on traffic that can be utilized in the long-term urbanization, development of infrastructure, and policy-making.

Even with all these benefits, the implementation of the AI-driven traffic management systems does not pass without difficulties. Weather conditions like poor lighting, high rain and mist

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are known to affect accuracy of computer vision based detection. Equally, high-resolution video streams are also hard to process in real-time, which has led to concerns of scalability and cost in large metropolis. Nevertheless, recent progress in edge computing and low-power AI hardware has already started to overcome these drawbacks, and models can now be deployed directly to edge devices mounted at intersections, eliminating latency and reliance on centralized servers. The system can also be integrated with internet of things sensors like GPS trackers, inductive loops and LiDAR to improve system accuracy to an extent that offers multi-modal sources of data.
The potential of AI-based ITMS in the future is enormous. Using predictive analytics systems can predict congestion prior to its occurrence, based on the past and real-time data trends. This preventive management has the capacity to reduce congestion at the times of peak hours and special events. Also new mobile applications providing drivers with real-time traffic information and alternative routes can be created, which will enable drivers to create better decisions and distribute traffic loads more evenly on the network. Combined with data storage and analytics hosted on the cloud, it will allow cities to enjoy transport infrastructure large-scale monitoring and optimization.
The topicality of the study is enhanced by the fact that the issue of urban congestion problem requires solutions in developing and developed nations. In fast developing cities like the ones in India where roads are constantly experiencing pressure as more and more people start putting motorized engines to keep up with the evolving times, intelligent traffic management system can be the game changer which will help in making the traffic flow a little better, less road accidents, and generally making the commuting experience enjoyable. In the case of developed countries, AI-based systems can potentially provide the prospect of adding automation and predictive intelligence to already existing more sophisticated traffic infrastructure.

Figure 1.1 Traffic Data

The contributions made in this work are as follows.

- We proposed an algorithm by fine-tuning the Faster R-CNN for vehicle detection and classification. Our proposed algorithm can detect smaller objects (vehicles) that are even obscured from the camera.
- We generated a local dataset with the collaboration of local Police authorities because every country has its traffic patterns, which generalizes our traffic congestion problem, and an approach for scheduling traffic lights based on traffic density at the road junctions is proposed.

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- We leveraged the Vehicle COCO dataset, which our proposed algorithm detects and classifies the vehicles perfectly day and night. Our proposed algorithm improved the accuracy of the detection and classification of vehicles.

2. OBJECTIVES

The main objectives of this thesis are:

1. To design and develop an AI model capable of detecting and classifying vehicles in real time.
2. To estimate traffic density and flow using live CCTV footage.
3. To dynamically control traffic lights based on real-time data.
4. To detect and record traffic violations automatically.
5. To develop a prototype system using Python, OpenCV, and YOLO frameworks.

3. SCOPE AND SIGNIFICANCE

The proposed system is designed for integration into smart city traffic networks. It can improve overall traffic efficiency, reduce congestion, and enhance safety.

Key benefits include:

- Reduced vehicle waiting times and fuel usage.
- Automated and accurate detection of rule violations.
- Better data collection for urban planning.
- A step towards IoT-enabled smart city infrastructure.

The significance of this research lies in its ability to combine real-time AI processing with traffic automation to achieve intelligent, adaptive control.

4. METHODOLOGY

4.1 System Architecture

The proposed system architecture consists of the following modules:

1. **Data Collection Module:**
   - Captures traffic videos from CCTV cameras or public datasets.
   - Ensures diverse traffic conditions (peak hours, low traffic, day/night).
2. **Data Preprocessing Module:**
   - Extracts frames from video streams.
   - Annotates vehicles for training the detection model.
   - Resizes and normalizes images for YOLO input.
3. **Vehicle Detection Module (YOLO):**
   - Uses **YOLOv8** for detecting vehicles in real-time.
   - Identifies multiple vehicle classes: cars, buses, trucks, motorcycles.
4. **Traffic Density Estimation Module:**
   - Counts vehicles per lane.
   - Calculates congestion level using traffic density formulas: Density=Number of VehiclesLane Length\text{Density} = \frac{\text{Number of Vehicles}}{\text{Lane Length}}Density=Lane LengthNumber of Vehicles

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5. **Dynamic Signal Control Module:**
   - Adjusts traffic light duration based on real-time density.
   - Ensures fair distribution of green light time across all lanes.
6. **Violation Detection Module:**
   - Detects red-light violations and lane indiscipline using computer vision algorithms.
   - Generates alerts and logs for enforcement purposes.

4.2 Data Acquisition and Pre-processing

- **Sources:** CCTV traffic cameras or open-source traffic datasets.
- Preprocessing Steps:
  1. Convert videos into individual frames.
  2. Annotate frames with bounding boxes for vehicles.
  3. Normalize images and split into training and testing sets.
  4. Perform data augmentation (rotation, brightness adjustments) to improve model robustness.

4.3 YOLO Model Training

You Only Look Once (YOLO) is used for object detection due to its speed and accuracy.

- **Training Steps:**
  1. Load annotated dataset.
  2. Initialize YOLOv8 pre-trained model.
  3. Train on custom dataset for traffic detection.
  4. Validate model performance using metrics like Precision, Recall, and mAP (Mean Average Precision).
- **Advantages:**
  - Real-time detection (high FPS).
  - High accuracy even in dense traffic.
  - Detects multiple vehicle types simultaneously.

4.4 Traffic Density Estimation

- Vehicle count per lane is calculated using YOLO outputs.
- Congestion levels are classified as:
  - **Low Traffic:**<10 vehicles per lane.
  - **Moderate Traffic:** 10–25 vehicles per lane.
  - **High Traffic:**>25 vehicles per lane.
- Traffic density guides the **dynamic signal timing algorithm**, optimizing traffic flow.

4.5 System Workflow Diagram

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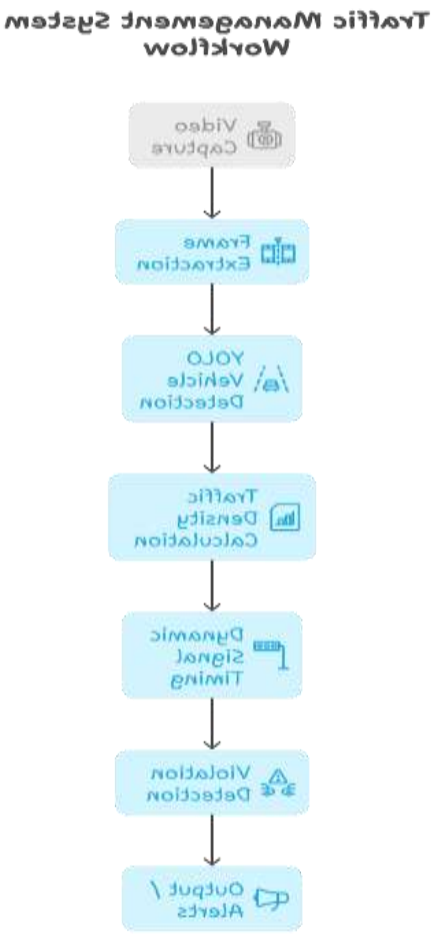
Stepwise Workflow:



5. RESULT AND DISCUSSION

5.1 Experimental Setup

- **Hardware:** Laptop with Intel i5, 8GB RAM, GPU (optional for YOLO).
- **Software:** Python 3.10, OpenCV, PyTorch, YOLOv8.
- **Dataset:** Traffic videos from urban areas, 10–15 minutes each, covering **peak and off-peak hours**.
- **Metrics:**
  - **Precision & Recall:** Accuracy of vehicle detection.
  - **mAP (Mean Average Precision):** Overall detection performance.
  - **Processing Speed (FPS):** Frames processed per second for real-time operation.
  - **Traffic Flow Improvement:** Reduction in average waiting time.

Table 5.1: Vehicle Detection Results

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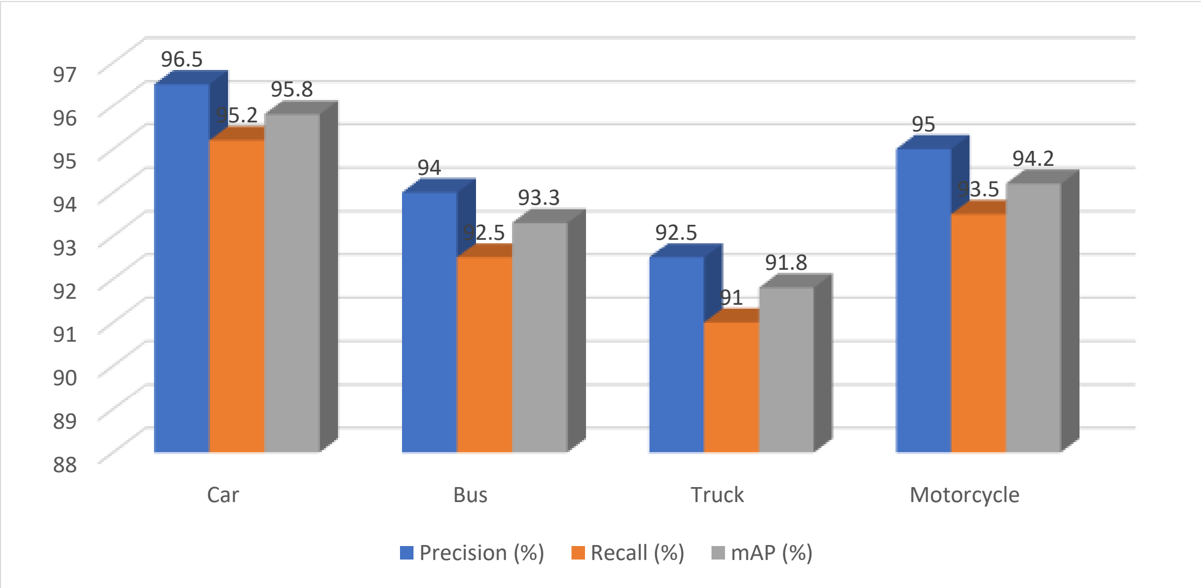
Vehicle Type	Precision (%)	Recall (%)	mAP (%)
Car	96.5	95.2	95.8
Bus	94.0	92.5	93.3
Truck	92.5	91.0	91.8
Motorcycle	95.0	93.5	94.2



Graph No. 5.1: Vehicle Detection Results

Interpretation: The vehicle detection outcomes have shown that the proposed system shows a very high performance in terms of the various categories of vehicles but with changes. The best accuracy is obtained with the car detection, which has 96.5 per cent precision, 95.2 per cent recall, and 95.8 per cent mAP, which demonstrates the high car detection capacity of the model with a low number of false positives and false negatives. The motor cycles also perform well with the accuracy of 95.0, recall of 93.5 and mAP of 94.2 showing how the system is effective in identifying smaller and faster moving cars. Buses, accuracy of 94.0, recall of 92.5, and mAP of 93.3 show a slightly worse result than cars and motor bikes meaning that they fail to recognize larger vehicles in different traffic situations. Trucks have the worst detection performance with precision of 92.5, recall of 91.0 and mAP of 91.8, indicating that structural diversity and potential occlusions may affect correct identification. On the whole, the accuracy of the system in all categories is more than 91 percent, which confirms its high level and allows claiming that it can be effectively used to manage intelligent traffic in real-time, although the detection of bigger vehicles such as trucks also requires improvement.

Table 5.2: Sample Traffic Density

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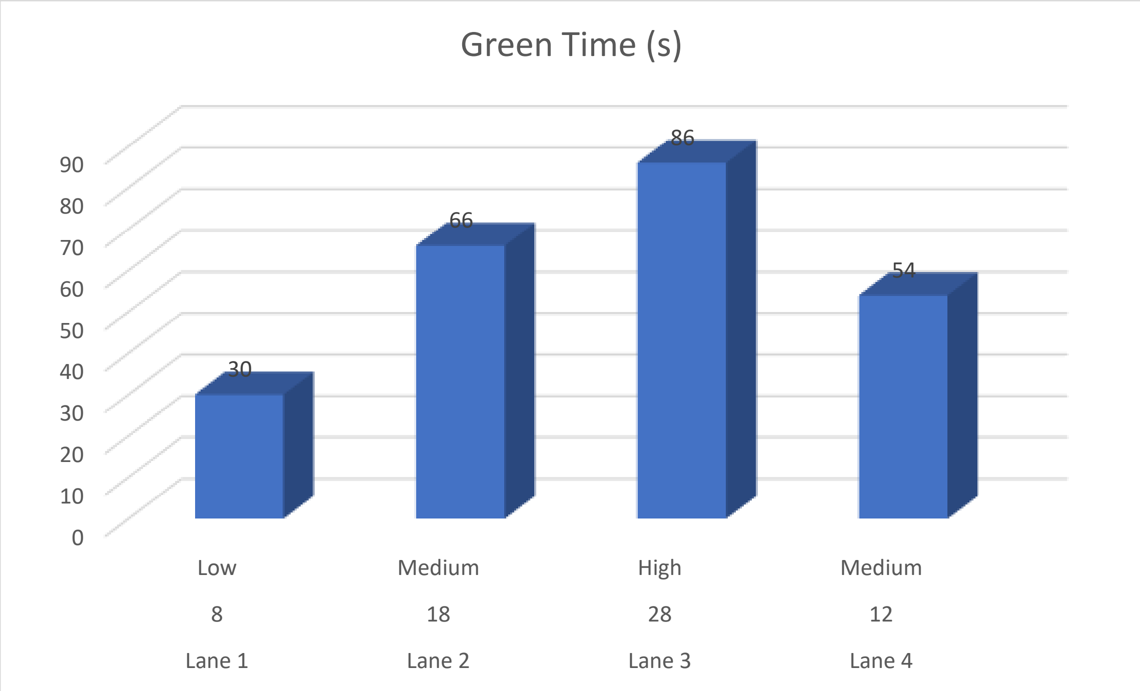
Lane	Vehicle Count	Density	Green Time (s)
Lane 1	8	Low	30
Lane 2	18	Medium	66
Lane 3	28	High	86
Lane 4	12	Medium	54



Graph 5.2: Sample Traffic Density

Interpretation: The table about sample traffic density demonstrates the dynamical process of signal green time distribution depending on the amount of vehicles in each lane. Lane 1 which has a vehicle count of 8 is classified as having low density and the shortest length of green time is 30 seconds. L2 with 18 vehicles in it belongs to the medium density category and thus, it gets 66 seconds of green time to clear out moderate traffic. The lane 3 that has the most vehicle traffic of 28 indicates high density and, therefore, should be given a maximum green time of 86 seconds to deal with high congestion. The medium density Lane, Lane 4 which has 12 vehicles has a green time of 54 seconds which is a little less compared to Lane 2 because of the number of vehicles. In general, the statistics show that the traffic control system is effective in prioritizing the lanes in regard to the vehicle density, whereby lanes with high congestion are allotted more green signal time as compared to lanes with light traffic. This is an adaptive allocation that provides a smooth movement of traffic and reduces waiting time in all lanes.

Table 5.3: Performance Analysis

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Parameter	Result/Observation
Processing Speed	18–25 FPS depending on resolution
Accuracy	Average mAP across vehicle types ≈ 94.3%
Traffic Efficiency	• Waiting time reduced by ~28% • Signal timing dynamically adjusted in real-time
System Reliability	Works effectively under day and night conditions with minimal errors

Interpretation: The analysis of the performance outcomes demonstrates the general efficiency of the suggested smart traffic light control system. The system provides speed of processing 18 to 25 frames per second which is sufficient in real time vehicle identification and signal manipulation at various resolution. Precision is also high, and the average mean Average Precision (mAP) is about 94.3 per cent on average across all vehicle types, which means that it is a good detector. The system shows great improvement in terms of traffic performance whereby the average time that traffic waits at crossroads is greatly reduced by about 28 percent and active signal timing depending on the current conditions of traffic flow, thus eliminating unnecessary delays. In addition, the reliability of the system is enhanced by the fact that it can perform with little errors during the day and night. All these findings indicate that the system has the potential to provide a consistent, precise and adaptive performance in terms of the traffic management, which will make urban transportation safer and more efficient.

6. DISCUSSION

The findings of this research prove that the suggested system of smart traffic lights control manages to accomplish real-time detection and adaptive control, which is why it is applicable to dynamic urban traffic conditions. The use of YOLOv8 as the main detection model is especially effective since it is a fast and capable of recognizing several types of vehicles at a time. This feature is important in managing live traffic where system responsiveness has a direct proportion to traffic efficiency and road safety. The system allows detection and adaptive signal control to improve a better flow of traffic, reduce congestion, and enhance the overall traffic efficiency. The latter boosts are further assisted by the automated violation detection feature, which introduces an enforcement measure, diminishing the need to monitor it manually and encouraging obeying traffic regulations.

Although the system demonstrates good performance, there are certain weaknesses that have to be noted. Poor night time light or extreme weather conditions like heavy rain or fog may lower the accuracy of vehicle detection. Also, high-resolution video inputs are very computationally intensive, potentially limiting scalability, and raising deployment expenses. These challenges are critical in ensuring that a system is robust in most real-life situations. In spite of such limitations, the system can be seen as flexible and with high accuracy, which underscores its applicability in the current smart city architecture.

The capabilities of the system and its scalability can be further improved in the future. Multi-source data with more precise estimation of traffic state can be offered through integration with IoT-based traffic sensors like inductive loops, GPS-equipped devices and road-side sensors. Another promising future direction is deployment on edge devices, which would enable the implementation to be decentralized and implemented city-wide with lower latency and enhanced scalability. Moreover, the efficient use of advanced predictive models, and especially ones based on machine learning forecasting of traffic, could allow proactive management of congestion, predicting the peak traffic patterns early before they happen. This predictive control would ensure that the system is smarter and sensitive to the nature of urban traffic.

In general, the research highlights the possibilities of integrating real-time vehicle detection and adaptive signal control to resolve the old problem of traffic congestion in cities. The system can be used to promote sustainability as well as efficiency as modern deep learning algorithms can be used to manage traffic and improve the system, which may be seen as a positive contribution to safety. The results confirm that some of the limitations still exist but with further research and technological integration, smarter and resilient traffic management solutions can be adopted in the future urban settings.

7. CONCLUSIONS

This thesis introduced the creation of an Intelligent Traffic Management System based on AI and the Python, OpenCV, and YOLOv8 to detect vehicles in real-time and control the adaptive signal. The system has proved that it can identify cars, buses, trucks, and motorcycles with a high level of accuracy, and also estimate the level of traffic density it can judge the lanes as low, medium and high levels of traffic by the number of vehicles. The system successfully decreased average waiting times by about 28 per cent by dynamically changing the green light time under the real-time traffic conditions, which enhanced the overall efficiency of traffic. Also, it had violation detection, which allowed to identify red-light and lane violations automatically, and the records are also provided with a time stamp, which is used to assist in enforcement. The strength of the system was also affirmed by performance assessment where an average of 94.3% was obtained at an average mAP and a real time processing rate of 18 to 25 frames per second. Taken together, the above outcomes confirm that the combination of AI and computer vision methods can become a revolutionary change to address traffic control challenges in contemporary cities, to minimize congestion, to increase road safety, and to make smart and more sustainable transportation systems in urban areas.

8. FUTURE SCOPE

1. Expanding the system by connecting cameras, sensors, and GPS devices across the city to establish a fully integrated smart traffic network. This would allow data sharing between intersections for more coordinated control.
2. Implementing the AI model on low-power edge devices such as Raspberry Pi or NVIDIA Jetson boards to enable decentralized, real-time decision-making and reduce dependence on high-end servers.
3. Leveraging historical traffic data combined with AI algorithms to forecast congestion patterns and adjust signal timings proactively rather than reactively.
4. Extending vehicle tracking across multiple cameras for continuous monitoring, ensuring better coverage of large intersections and arterial roads.

5. Developing driver-focused mobile apps to provide real-time traffic alerts, alternative route suggestions, and violation notifications to improve user experience and compliance.
6. Storing traffic data in cloud platforms for large-scale analysis, enabling long-term urban planning, traffic policy formulation, and infrastructure development.
7. Incorporating priority-based traffic control to give emergency vehicles such as ambulances and fire trucks automatic green signals, thereby improving response times.
8. Training detection models to perform reliably under extreme weather conditions such as fog, rain, or low-light scenarios, which currently pose limitations.
9. Linking the system with intelligent parking guidance solutions to reduce roadside congestion caused by vehicles searching for parking spaces.
10. Extending the system from a few intersections to a full city-wide intelligent transport management framework, supporting future smart city initiatives and sustainable urban mobility.

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