



Adaptive Traffic Flow Management Using YOLO, LSTM, and Q-Learning

P Sandeep Yadav*¹, L Dharma Rao² and Vinuja G

¹ Department of Computer Science and Engineering
Vel Tech Rangarajan Dr Sagunthala R&D Institute of Science and Technology
Chennai, India

*Corresponding author: vtu22178@veltech.edu.in
Emails: vtu22179@veltech.edu.in and vinujag@veltech.edu.in

Abstract. Traffic congestion continues to be a significant problem in Indian cities which grow quickly because of multiple vehicle types and unpredictable traffic patterns and irregular lane usage. Traditional traffic signal operations that depend on fixed schedules and sensors fail to adjust properly to these changing conditions. The current system creates longer wait times which results in inefficient traffic flow. The research presents an AI based traffic signal control system which combines three modern methods through YOLO for vehicle detection and LSTM for traffic prediction and Q-learning for signal timing optimization. The YOLO system operates by using camera footage to detect and count moving vehicles while the LSTM model analyzes recent traffic patterns to predict how congested roads will become. The Q-learning agent uses these predictions to select the best green time distribution that will decrease traffic delays. The system achieved better results through tests with real traffic footage and simulated scenarios which demonstrated a 32-45% reduction in average waiting time and a 28-40% decrease in queue length compared to standard control systems. The system provides emergency vehicle priority and congestion control features which allow it to operate effectively at high-traffic urban intersections.

Keywords: Traffic Management, Intelligent Transportation Systems, YOLO, LSTM, Reinforcement Learning, Q-learning

1 Introduction

The rapid expansion of urban areas has created traffic congestion which stands as their main challenge especially in developing nations like India. The urban road network supports various vehicle types which include cars and two-wheelers and buses and trucks and auto-rickshaws but drivers fail to maintain proper lane positions. The different types of vehicles operating

together create unpredictable traffic patterns which result in regular intersection blockages.

The fixed-time control strategy operates all existing traffic signal systems which operate under current deployment standards. The systems operate with fixed signal timings which ignore actual traffic conditions to produce extended wait periods and underused road capacity. The sensor-based traffic system encounters problems when it tries to operate in urban areas because its vehicle detection system produces incorrect results which result in faulty data collection.

Recent advancements in artificial intelligence have made possible intelligent traffic management systems which adjust their operations based on current road traffic patterns. The combination of machine learning with computer vision systems enables them to identify vehicles while studying traffic patterns which helps them develop real-time signal control systems.

The research presents an adaptive traffic signal control system which unites computer vision technology with predictive learning and reinforcement learning methods. The proposed method unites YOLO for instant vehicle detection with LSTM which forecasts traffic patterns and Q-learning which adjusts traffic light timing. The system uses these methods together to decrease traffic congestion while it shortens driver wait times and boosts traffic movement through busy intersections.

2 Related work

The field of AI-based traffic management systems has received major research attention from scholars. Deep learning models demonstrate strong abilities to predict traffic flow patterns and detect congestion patterns. The research field applies machine learning to analyze urban traffic data which results in the creation of data-driven systems for traffic congestion management.

Public researchers access two main traffic analysis datasets which include the Urban Traffic Congestion Dataset and the IEEE Data Port Indian Vehicle Dataset for their model training activities. These datasets provide useful data about the different types of traffic situations which appear throughout Indian urban areas.

Scientists develop adaptive traffic signal control systems through reinforcement learning which stands as their primary solution. Research shows that reinforcement learning agents develop optimal signal control policies by

actively participating in traffic system environments through their learning process. The systems operate successfully with changing traffic conditions while they progressively boost their traffic flow performance.

Recurrent neural networks including LSTM models demonstrate their strength in short-term traffic prediction because they analyze temporal patterns which exist in sequential time-series data. The combination of these technologies enables researchers to create hybrid systems which improve traffic flow performance.

The proposed work develops an advanced intelligent traffic management system which unites YOLO-based vehicle detection with LSTM-based traffic prediction and Q-learning decision-making optimization.

3 Methodology

3.1 System Architecture

The proposed system links computer vision technology with predictive modeling and reinforcement learning to develop better traffic signal control systems. The entire process consists of several stages which start with data collection and proceed through vehicle identification and traffic forecasting and final signal optimization.

CCTV cameras at intersections capture traffic data through their surveillance system. The video stream undergoes processing by a YOLO-based object detection system which identifies and counts all vehicles that appear in the footage. The data set enables precise measurement of traffic volume along with the length of vehicle queues which appear in each lane.

The research team applies an LSTM model to process vehicle count data which they collect from their monitoring system to study previous traffic patterns and forecast upcoming traffic congestion. The system provides future traffic condition forecasts through its predictive technology.

Finally, a reinforcement learning agent based on Q-learning determines the optimal signal timing strategy by analyzing both real-time traffic data and predicted congestion levels. The agent continuously updates its decision policy based on observed traffic conditions and system rewards.

The overall system architecture is illustrated in Fig. 1.

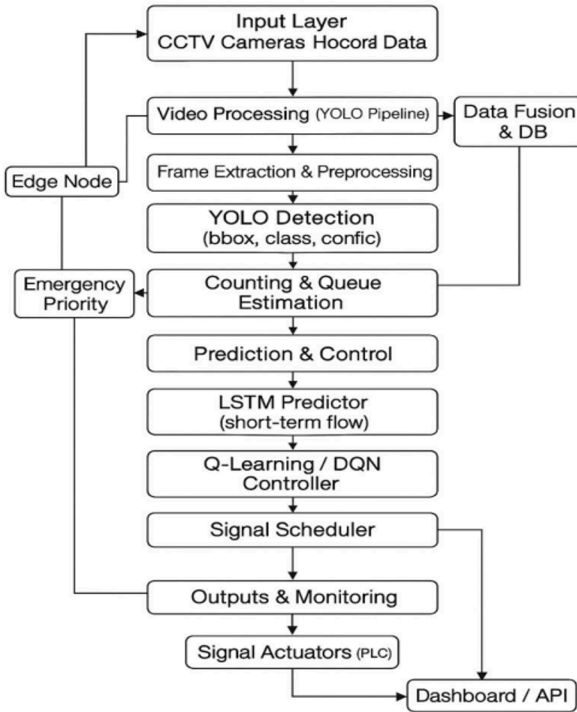


Figure 1. System architecture of the adaptive traffic signal system.

3.2 Hybrid Traffic Optimization Algorithm

The system follows the following algorithm:

1. Initialize Q-learning parameters and LSTM prediction model.
2. Capture real-time traffic frames from CCTV cameras.
3. Detect vehicles using the YOLO object detection model.
4. Calculate vehicle count, density, and queue length.
5. Predict short-term traffic flow using the LSTM model.
6. Form the system state based on current and predicted traffic conditions.
7. Select signal timing action using an epsilon-greedy policy.
8. Execute the selected signal timing.
9. Observe new traffic conditions and compute reward.
10. Update Q-learning values based on reward and next state.

11. Repeat the process continuously.

The workflow of the proposed algorithm is shown in Fig. 2.

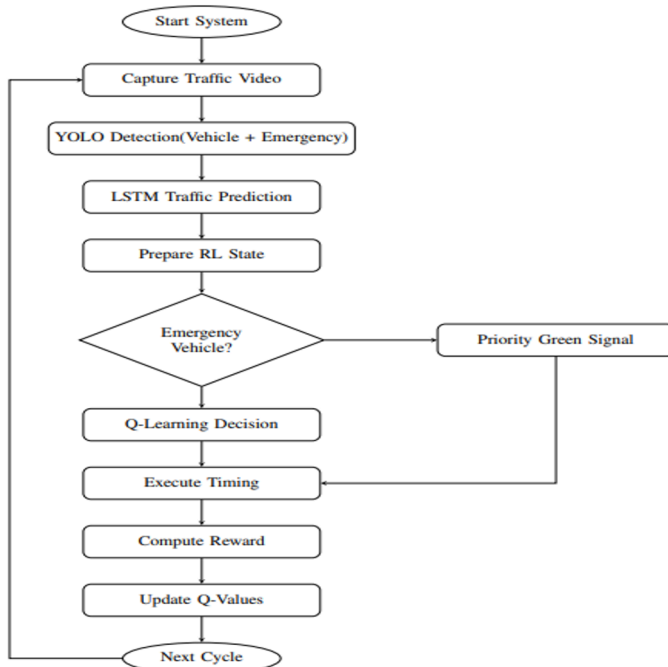


Figure 2. Flowchart of the AI-based adaptive traffic signal system.

4 System Implementation

4.1 Development Platform

Python-based machine learning frameworks and cloud computing platforms served as the foundation for the system which the proposal presented. Google Colab served as the main development platform because it provided GPU access and users could work through its notebook interface which made their work more efficient.

4.2 Object Detection

Vehicle detection was performed using the YOLOv8 model. The model was trained using traffic video data containing various vehicle categories such as cars, buses, trucks, and motorcycles.

4.3 Traffic Prediction

Traffic prediction was performed using a two-layer LSTM neural network. The model analyzed time-series traffic data to forecast short-term traffic flow variations.

4.4 Reinforcement Learning Controller

The signal control system was implemented using a Q-learning agent. The agent learned optimal signal timing policies through continuous interaction with the traffic environment.

5 Experimental Setup and Results

5.1 Simulation Environment

SUMO traffic simulation platform served as the evaluation system for this research. The researchers built a four-way intersection model which they used to study different types of traffic that people see in Indian cities.

The YOLO detection system generated vehicle density data which the LSTM model used to forecast future traffic congestion patterns. The Q-learning agent used real-time traffic data together with forecasted traffic information to modify traffic signal timings at all times.

5.2 Performance Metrics

The system was evaluated using the following performance indicators:

- Average waiting time
- Queue length
- Traffic throughput
- Emergency response time

Experimental results demonstrated significant improvement over conventional fixed-time traffic control systems.

The performance comparison between the traditional system and the proposed AI-based system is presented in Table 1.

Metric	Fixed time system	Proposed AI system	Improvement
Average time	45 sec	30 sec	32-45%
Queue length	26 vehicles	15 vehicles	28-40%
Traffic throughput	60 veh/min	80 veh/min	19%
Emergency response time	120 sec	72 sec	40%

These results indicate substantial improvements in traffic efficiency and congestion reduction.

6 Conclusion

The research developed an AI-based traffic signal control system which combines YOLO vehicle detection with LSTM traffic prediction and Q-learning signal optimization methods. The system operates through its ability to change traffic signal schedules when it receives current data and forecasted traffic information for better traffic management.

The simulation results showed that traffic performance became better through decreased wait times and reduced vehicle backup and improved vehicle movement compared to standard fixed-time traffic signal systems.

The upcoming research period will expand the current system to operate across various intersections through multi-agent reinforcement learning systems. Smart city infrastructures need better system accuracy through IoT sensors which should operate together with real-time CCTV camera footage to support their deployment across extensive urban areas.

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