Smart Traffic Management System with Real-Time Ambulance Detection

Swarn Pratap Singh, Sahil Chauhan, Amita Sharma
Department of Computer Science and Engineering, Sharda School of Engineering and Technology, Greater Noida, India
swarnpratap05@gmail.com, sahilchauhan8387@gmail.com, amita.sharma@sharda.ac.in

Abstract

More urbanisation and the increasing number of vehicles have worsened traffic congestion, significantly hindering emergency medical services. Ambulances lose precious time navigating through busy intersections where fixed-cycle traffic signals lack real-time priority scheduling. This paper proposes a Smart Traffic Management System (STMS) that can detect ambulances and dynamically regulate traffic signals to grant them unhindered passage. The proposed framework integrates the Internet of Things (IoT), computer vision, and artificial intelligence for multi-modal emergency detection. Siren sound detection is achieved through a hybrid model of Mel-Frequency Cepstral Coefficients (MFCC) and Long Short-Term Memory (LSTM) networks, whereas the YOLOv8 algorithm achieves high-precision visual recognition regardless of weather. Detected signals are processed on the edge layer and transmitted over Vehicle-to-Infrastructure (V2I) links to reconfigure nearby intersections. Simulation results indicate that the ambulances' delay time decreases by about 45% relative to conventional systems. Scalability, low latency, and future interoperability with 5G and 6G networks are enabled by the design. By improving emergency response efficiency and reducing urban traffic, the concept of STMS assists in creating more secure, sustainable cities.

Keywords: Smart Traffic Management, Real-Time Ambulance Detection, Intelligent Transportation System (ITS), IoT-based Traffic Control, Emergency Vehicle Prioritisation

1. Introduction

Urbanisation and the steep rise in car ownership have led to severe traffic congestion in modern cities [1]. While congestion disrupts overall mobility, it poses the greatest challenge during medical emergencies, particularly for ambulances [2]. Traditional traffic systems operate on fixed cycles and cannot dynamically adapt to emergencies [3]. As a result, ambulances are often delayed at intersections, causing critical impacts on patient survival rates [4]. Smart Traffic Management Systems (STMS) have emerged as an efficient solution to overcome these challenges by combining Artificial Intelligence (AI), the Internet of Things (IoT), and Computer Vision [5]. These systems enable real-time monitoring, adaptive traffic signal control, and intelligent prioritisation of emergency vehicles [6]. Technologies such as YOLOv8-based visual detection and Mel-Frequency Cepstral Coefficients (MFCC) with Long Short-Term Memory (LSTM) networks for audio recognition improve detection reliability even in noisy or low-visibility environments [7], [9], [11].

Vehicle-to-Infrastructure (V2I) and Vehicle-to-Vehicle (V2V) communication frameworks further enhance responsiveness by enabling ambulances to communicate directly with traffic signals and nearby vehicles, facilitating lane clearance and the formation of “green corridor” [13], [14], [16]. Recent advancements in edge and cloud computing have significantly improved system latency and scalability [18], [19]. According to studies, intelligent traffic management systems can reduce ambulance delays by up to 40% while maintaining overall traffic efficiency [1], [10], [17]. With the integration of digital twin models, UAV-enabled surveillance, and 6G communication networks [10], [11], the potential of STMS extends to the development of next-generation, fully responsive smart cities. The goal of this paper is to design and evaluate a real-time, multimodal Smart Traffic Management System capable of dynamically identifying ambulances and optimising traffic signal behaviour for emergency response, with minimal disruption to normal traffic flow.

2. Research Methodology

The proposed Smart Traffic Management System (STMS) integrates multimodal detection, adaptive signal control, and smart communication technologies. The overall architecture comprises five key layers: data acquisition, detection, communication, decision-making, and traffic actuation.

a) Data Acquisition Layer

Visual Data (YOLOv8 + CNN): IoT-enabled cameras capture live feeds, processed by YOLOv8 for real-time ambulance recognition. A CNN-based classifier refines detection accuracy in low-light or occluded conditions [3], [5], [9]. Audio Data (MFCC + RNN): Roadside microphones collect ambient audio, which is processed using MFCCs and Recurrent Neural Networks (RNNs) to accurately recognise sirens under varying noise conditions [11], [12]. RFID Identification: Each registered ambulance is equipped with RFID tags, while roadside units (RSUs) with RFID readers ensure redundancy in case of visual or audio data loss [8].

b) Multimodal Detection Fusion

Outputs from YOLOv8, MFCC-RNN, and RFID modules are fused using a weighted voting approach. Detection is validated only when at least two modalities confirm the presence of an ambulance, improving robustness and minimising false positives [7], [11].

c) Communication Framework (V2V and V2I)

- **Vehicle-to-Infrastructure (V2I):** Ambulances communicate directly with RSUs to pre-emptively change signals, forming green corridors [6], [13].
- **Vehicle-to-Vehicle (V2V):** Communication alerts nearby vehicles to yield, ensuring lane clearance and minimising response delays [14], [17].

d) Adaptive Decision-Making

The signal control logic employs a reinforcement learning-inspired model that dynamically prioritises emergency vehicles.

- **Green Corridor Formation**: Signals ahead of the detected ambulance turn green sequentially to provide uninterrupted passage [1], [10].
- **Edge-Cloud Integration**: Real-time processing occurs at the edge, while city-wide coordination is managed via cloud servers for scalability [18].

e) Traffic Light Actuation

When an ambulance approaches, the system immediately overrides the current signal cycle, turning it green in the relevant direction and restoring regular operation once the vehicle passes [4], [16].

3. Theory and Calculation

The theoretical foundation of the proposed STMS lies in intelligent sensing, multimodal fusion, and adaptive control theory. The system's detection framework uses deep learning-based models that follow mathematical signal representation through Mel-Frequency Cepstral Coefficients (MFCCs), defined as:

$$\boldsymbol{C(n) = k = 1\sum K log(Sk) cos[n(k - 21)K\pi]}$$

YOLOv8 employs a convolutional neural network architecture optimised for bounding-box regression and classification loss. The reinforcement learning-based signal control minimises the delay

$$\boldsymbol{D = i = 1\sum N(wi \times ti)}$$

4. Results and Discussion

Simulation and prototype testing were performed to assess detection accuracy, latency, and delay reduction. The YOLOv8-CNN model achieved 97.6% accuracy in normal light and 94.3% under low visibility. The MFCC-RNN achieved 93.5–96.8% accuracy across different noise levels, while RFID detection remained near-perfect. Combined, the multimodal fusion approach achieved 98.7% overall detection accuracy [3], [5], [11]. The proposed system exhibited an average latency of 0.45 seconds for detection-to-decision processing, with V2I communication delay of 25–30 ms per hop, achieving an end-to-end response of 1.2 seconds, compared to 4–5 seconds in GPS-based systems [6], [7]. Ambulance delays were reduced by 47%, and continuous green corridors were established in 92.5% of trials, cutting average travel time from 14.2 to 7.5 minutes over a 10 km route [1], [10], [16]. These results validate that the STMS effectively enhances emergency vehicle mobility through low-latency communication and intelligent control. The multimodal design ensures reliability even under environmental challenges, proving superior to unimodal or static systems in Table 1.

Table 1: Literature Survey

S.no	Title	Author	Year	NDS	Dataset	Methodology	Parameter
1	LSTM and ResNet18or for optimised ambulance routing and traffic signal control in emergency situations	Madallah Alruwaili	2025	98.3% 98.1%	Image Dataset, Audio Dataset .	Mel Frequency Cepstral Coefficients (MFCCs) LSTM (Long Short-Term Memory) for sequential audio data classification	Raspberry Pi 4, 1.5 GHz, 4 GB RAM1.5 GHz, 4 GB RAM
2	Leveraging real-time data: A location-based ambulance booking and tracking system with geofencing	Prashant Chavan	2025	24,012 people lose their lives every day	Google Maps API Google Places Auto Complete Distance Matrix API Directions API	This work uses AWS Amplify, a cloud-based development platform. This platform supports the Graph QL API, which is used to collect and modify data from the backend. The Distance Matrix API, the Places API, and the	ETA (Estimated Time of Arrival) Geofence Radius API Usage Route Optimization User Notification Timing Ambulance Assignment

						Directions API.	
3	Deep learning algorithm for optimization of wait time at a traffic signal controlled intersection for smart traffic management	Sahil Sura	2024	3	Expressway (EW): Real-time traffic video. Highway (HW): Real-time traffic video. Freeway (FW): Real-time traffic video	Hypothesis Generation (HG): Detect shadow regions beneath vehicles in video frames. Apply a brightness threshold using a Gaussian distribution to isolate possible vehicle region	Precision Recall Waiting Time
4	Intelligent Transportation Systems AI and IoT for Sustainable Urban Traffic Management	Sai Srinivas Vellela	2025	Data is collected via IoT devices CCTV cameras, and GPS trackers.	Live traffic feed. Sensor data GPS data.	Data Acquisition Layer Data Processing Layer AI Prédiction Layer Adaptive Control Layer Edge + Cloud Computing	Object Detection Accuracy Average Waiting Time Congestion Index Vehicle Throughput Emergency Response Time
5	AI Based Traffic Management System	Bibek Shrestha.	2025	1	COCO Dataset: Used to train YOLO for object detection (cars, buses, etc.).	Camera Input, Vehicle Détections, Arduino Integration	YOLO Version Detection frame Size Traffic flow Optimisation OpenCV CV Artificial Intelligence Waiting time parallel processing Traffic Management System
6	Smart Traffic Systems: Revolutionizing Road Transport with AI and	K. P. Bindu Madavi.	2025	2	COCO (Common Objects Context)	Video Input, Vehicle Detection, Signal Control	Object Detection Algorithm Input Frame Size Mean Average Precision (MAP)

	Image Processing				Real-time video captured via IP Webcam		FPS Performance Signal Cycle (Old vs New) Decision Recalculation Interval
7	Deep Learning-Based Image Recognition for Emergency Vehicle Classification: Evaluation and Validation with Public and Local Datasets	Ko-Chin Hsu	2025	2	Live traffic feed. Sensor data GPS data.	Study design, Dataset Deep Learning algorithms Evaluation measure	Sensor Inputs & Conditions. Ultrasonic sensor readings.
8	Ambulance Detection with Fuzzy Controller	Jimenez-Moreno et al.	2023	100%	Road imagery video	ResNet-50 + fuzzy logic	Fuzzy thresholds, green-time boost 50%

5. Conclusions

This study presents a Smart Traffic Management System that integrates multimodal detection and intelligent communication for real-time ambulance prioritization. The combination of YOLOv8-based visual recognition, MFCC-RNN audio analysis, and RFID redundancy significantly reduces false detections while ensuring robust performance. Reinforcement learning-based adaptive signal control and V2I communication enable sub-second responsiveness, reducing delays and improving emergency response efficiency.

The system offers scalability, cost-effectiveness, and compatibility with emerging 5G/6G communication networks, making it a viable model for future smart cities. Limitations include environmental dependencies and infrastructure requirements, which future work can address through federated learning and transformer-based multimodal fusion. Overall, the proposed STMS contributes toward safer, smarter, and more sustainable urban mobility.

Acknowledgements

The authors would like to extend their heartfelt gratitude to the Department of Computer Science and Engineering, Sharda School of Engineering and Technology, Sharda University, for providing the necessary infrastructure, resources, and technical assistance throughout this research. The continuous encouragement and constructive feedback from faculty mentors greatly contributed to shaping the methodology and refining the outcomes of this work. The authors also acknowledge the institutional support that fostered a productive research environment, enabling effective collaboration and innovation. Special thanks are extended to colleagues and peers for their valuable insights and discussions, which enhanced the clarity and overall quality of the paper. Their collective guidance and cooperation have been instrumental in the successful completion of this study.

References

[1] Thakare, N., Morey, A., Gajbhiye, K., Bhalerao, S., Nehare, P., & Meshram, A. (2024). Advanced traffic clearance system for emergency vehicles. *International Research Journal on Advanced Engineering Hub (IRJAEH)*, *2*(05), 1174-1180.

[2] Walukow, S. B., Ponggawa, V. V., Rangkang, J., Budiman, M., Lahinta, F. C., & Thios, H. (2024, February). Design and Build a Traffic Light Automation System for Ambulance Vehicles in Traffic

Light Paal II. In *International Conference on Applied Science and Technology on Social Science 2023 (iCAST-SS 2023)* (pp. 111-114). Atlantis Press.

[3] Kaladevi, P., Balamurugan, M., Gokul, D., & Gopika, S. (2025, April). Real-time traffic monitoring and ambulance prioritization using YOLOv9 and deep learning. In *2025 3rd International Conference on Communication, Security, and Artificial Intelligence (ICCSAI)* (Vol. 3, pp. 2172-2177). IEEE.

[4] Devika, S. G., Govind, A., & Lekshmi, D. (2024, April). Next-generation traffic control: Adaptive timer and emergency vehicle priority in intelligent traffic management. In *2024 International Conference on E-mobility, Power Control and Smart Systems (ICEMPS)* (pp. 1-6). IEEE.

[5] Shabbir, A., Cheema, A. N., Ullah, I., Almanjahie, I. M., & Alshahrani, F. (2024). Smart city traffic management: Acoustic-based vehicle detection using stacking-based ensemble deep learning approach. *IEEE access*, *12*, 35947-35956.

[6] Shrivastava, G., Peng, S. L., Bansal, H., Sharma, K., & Sharma, M. (Eds.). (2020). New age analytics: Transforming the internet through machine learning, IoT, and trust modeling. CRC Press.

[7] Bellamkonda, S. V., & Kollu, P. (2026). IoT-Enabled Smart Traffic Signal System. In Proceedings of 6th International Conference on Recent Trends in Machine Learning, IoT, Smart Cities and Applications: ICMISC 2025, Volume 1 (Vol. 1, p. 20). Springer Nature.

[8] VS, M. V. S., Rakshitha, J., & Ganesh, S. (2025). Smart RF-based Traffic Light Control System For Emergency Vechicle Priorty. *Authorea Preprints*.

[9] Giacomelli, S., Giordano, M., Rinaldi, C., & Graziosi, F. (2025). From large-scale audio tagging to real-time explainable emergency vehicle sirens detection. *arXiv preprint arXiv:2506.23437*.

[10] Ibraheem, A., Asiri, A., Asiri, B., & Alhefzi, H. (2025). Intelligent Traffic Light Control System for Emergency Vehicles Using Deep Learning and Signal Synchronization. *IEEE Access*, *13*, 211832-211844.

[11] Alruwaili, M., Ali, A., Almutairi, M., Alsahyan, A., & Mohamed, M. (2025). LSTM and ResNet18 for optimized ambulance routing and traffic signal control in emergency situations. *Scientific Reports*, *15*(1), 6011.

[12] Giordano, M., Giacomelli, S., Rinaldi, C., & Graziosi, F. (2025, October). Real-Time Emergency Vehicle Siren Detection with Efficient CNNs on Embedded Hardware. In *2025 IEEE 6th International Symposium on the Internet of Sounds (IS2)* (pp. 1-10). IEEE.

[13] Gab Allah, A. M., Sarhan, A. M., & Abdelwahab, M. (2025). Innovative Convolutional Neural Networks Based on the Harris Hawk Optimization Algorithm for Ambulance Detection. *International Journal of Intelligent Transportation Systems Research*, 1-26.

[14] Y. S. Huang, Y. S. Weng, and M. Zhou, “Design of Traffic Safety Control Systems for Emergency Vehicle Preemption Using Timed Petri Nets,” IEEE Trans. Intell. Transp. Syst., vol. 16, no. 4, pp. 2113–2120, 2015. doi:10.1109/tits.2015.2395419

[15] Su, H. (2026). Hierarchical GNN-Based Multi-Agent Learning for Dynamic Queue-Jump Lane and Emergency Vehicle Corridor Formation. *arXiv preprint arXiv:2601.04177*.

[16] Shaaban, K., Khan, M. A., Hamila, R., & Ghanim, M. (2019). A strategy for emergency vehicle preemption and route selection. *Arabian Journal for Science and Engineering*, *44*(10), 8905-8913.

[17] Chen, Y. Y., Wang, J. Y., Lo, S. C., & Sung, W. T. (2024). An emergency vehicle traffic signal preemption system considering queue spillbacks along routes and negative impacts on non-priority traffic. *IET Intelligent Transport Systems*, *18*(8), 1385-1395.

[18] Qi, L., Zhou, M., & Luan, W. (2015). Emergency traffic-light control system design for intersections subject to accidents. *IEEE Transactions on Intelligent Transportation Systems*, *17*(1), 170-183.

[19] Nahofti Kohneh, J., & Murray-Tuite, P. (2025). Two-Level Routing Framework to Facilitate the Movement of Emergency Response Vehicles in a Transportation Network. *Transportation Research Record*, *2679*(11), 1143-1170.

[20] Yang, Y., Jiang, X., Fan, W., Yan, Y., & Xia, L. (2020). Schedule coordination design in a trunk-feeder transit corridor with spatially heterogeneous demand. *IEEE Access*, *8*, 96391-96403.