



An Intelligent Framework for Smart Traffic Monitoring and Autonomous Enforcement

Divyam Verma¹ , Manish Narwaria²

¹* M.Tech (AI) 4th Semester Student, Department of Artificial Intelligent, IIT Jodhpur, Rajasthan, India

*divyam0216@gmail.com,

²Associate Professor, Department of Electrical Engineering, IIT Jodhpur, Rajasthan, India

narwaria@iitj.ac.in

Abstract

This research investigates an intelligent and integrated traffic monitoring framework which is designed to incorporate conventional surveillance systems. The proposed system considers advanced computer vision and artificial intelligence techniques to perform real-time vehicle, tracking, and analysis using modern deep learning models such as YOLO. The system is capable to identify the various violations like Illegal Parking Detection, Red Light Violation, Wrong way Detection, Traffic Lane violation, Illegal U-turns and Speed violation. The present research study demonstrated various algorithm for such violation.

Keywords : Computer Vision and Intelligent Systems, Intelligent Traffic Management System, Traffic Violation

1. Introduction

The rapid urbanisation, economic-social fibre density growth, outburst of populations in India have led to sudden increase road network and vehicular density in the past decade. According to the Ministry of Road Transport and Highways, in year 2025 [19], India has approximately 4.8 lakh road accidents, resulting in over 1.72 lakh death. Overall Growth of High-Speed Road Network in 2014 was roughly 96,000 km of National Highways, where as economic growth new policies related to connectivity like Bharatmala etc has raised this figure to 1,46,000 KM in 2025. Despite expansion, issues of High accident rates due to over-speeding, Poor lane discipline, Unauthorized access (especially on NHs), limited enforcement in some stretches remains unresolved. Additionally, provisional government data for 2024–2025 show that fatalities have crossed 1.75 lakh annually, confirming the persistent severity of the issue.

Traffic violations remain the prominent cause of road mishaps, with 72.9% of deaths and 67.2% of injuries attributed to violations such as over-speeding, signal jumping, and reckless driving (*latest transportation data, 2025*). This highlights the pressing issue of unsafe driving behaviour [20] as the leading contributor to road accidents in India.

These situations have imposed challenges in traffic management, including congestion, accidents, and violations (*specially wrong side traffic, rash driving and many*). Traditional monitoring systems rely on manual intervened observations and rule-based automation at certain points only. These provisions are limited and unable to handle/regulate the situation in not very effective way. One hand, there is a need of augmenting the technological interventions and

other hand, there is need of optimised utilisation of the existing resources on the road network like speed cameras etc.

With the advent of Artificial Intelligence (AI) with robust deep learning and computer vision algorithms, automated traffic monitoring systems may emerge as a quick response and high yielding solutions. The Present research is an attempt to manifest solutions of the challenges of traffic regulation and safety.

2. Objective

The basis of the proposed system is object detection and tracking techniques such as YOLO8 and OpenCV-based trackers to identify violations like wrong side vehicular movement, etc is the main feature of the project. This proposed project is designed to investigate a video analytics framework system based on computer vision embedded with deep learning and data visualization and followed by video analytics. A video images are fed in a special algorithm using digital signal to perform different types of traffic violation detections discussed in the project.

Further, this paper is related to capture, display and perform interpretation of important data in sights in a video footage. Based on some targeted parameters, data insights are observed by triggering critical events in the video footages which is not dependent of road environment. A simple example of a data insight used in this related to capturing the triggering of critical event like over speeding which can be represented that through graphs/charts variations.

3. Literature Review

Video Analytics and Computer Vision-Based Traffic Monitoring

Intelligent traffic systems (ITS) are based on computer vision techniques for detection of object and spatial tracking. Early models of YOLO and transformer-based architectures are deep learning models which yield higher accuracy and speed. Transformer-based models such as the Vision Transformer [1] and Swin Transformer [2] have attained contextual understanding of traffic scenes.

Today's ITS are capable of identifying vehicles in traffic, pedestrians on pathways, and traffic violations in real time using efficient detection and tracking algorithms such as YOLOv8 [4] and ByteTrack [3]. These developments have significantly enhanced real-time performance. These features may be augmented and may become more predictive if the information on board is captured for decision making. The information on board (telematics) may be gathered from the servers of the vehicle manufacturers which are collected during the journey in real time or through IOT based sensor Networks, installed by regulating agencies on roads. The most existing systems are built on the basis visual data analysis. **There is a need of advanced ITS Framework which integrates Visual Data Analytics and additional contextual information, for enhancing the performance and ensuring safety in complex environments.**

Methodology

The proposed methodology adopts a **modular and integrated approach**, where each functional component agent contributes into development of an intelligent system for traffic monitoring. The proposed methodology uses many advanced AI techniques into an integrated and interconnected framework. Its

key strengths include the following technically robust, practically deployable and socially responsible model. The Prediction through visual data sources through YOLO sources like

- A. Illegal Parking Detection,**
- B. Red Light Violation,**
- C. Wrong way Detection,**
- D. Traffic Lane violation,**
- E. Illegal U-turns,**
- F. Speed violation and monitoring of illegal activities.**

4. The Prediction Model

The first step of the project focuses on development an AI-based video analytics that allows users to input video footage. The step is followed by the study of data insights on the occurrence of critical events and then identification of these insights. The proposed application emphasizes analytics of traffic violations (*A to F of previous Methodology sub-section*) . Figure 1 represents the framework of basic prediction model.

These traffic violation models are programmed to achieve Object detection, its classification, and localization using the ‘open-source deep learning model - YOLO in which Object tracking was achieved through OpenCV's CSRT and DLIB algorithms, figure 2.

The algorithms were implemented in Python for the extraction and visualization of data insights based on specific parameters as mentioned above (A-F).

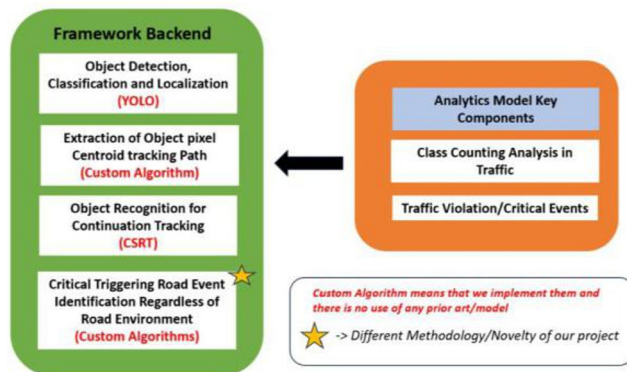


Fig. 1. Framework Back-end for Basic Prediction Model

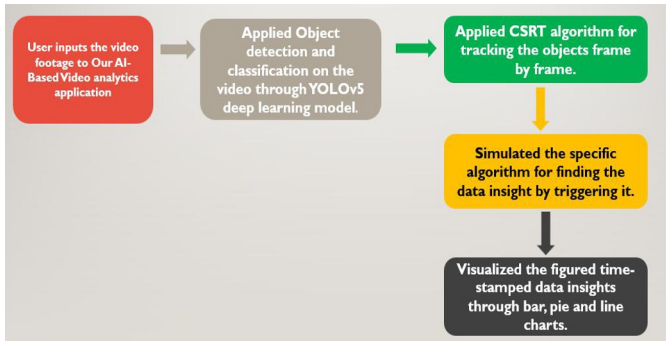


Fig. 2. Process Flow of the Basic Model

5. Algorithms Used for Computer Vision and Deep Learning

A. YOLO V5 :

YOLOv5 (You Only Look Once) is a deep learning object detection and object classification model. It trains on full visual images and directly optimizes detection performance with speed. It sees the entire image during training and test time so it implicitly encodes contextual information about classes as well as their appearance.

B. CSRT algorithm

CSRT (Channel and Spatial Reliability Tracking) tracker has a high chance to identifying objects features, classes and locations as well. Basically, CSRT tracker is C++ implementation of the CSR-DCF (Channel and Spatial Reliability of Discriminative Correlation Filter) tracking algorithm in OpenCV library.

C. Dlib algorithm

Dlib is a object tracker which lets you track the position of an object as it moves from frame to frame in a video sequence. To use it, we give the correlation_tracker the bounding box of the object you want to track in the current video frame. Then it will identify the location of the object in subsequent frames.

6. Designed Algorithm, Results and Analysis for various Violations

6.1 . Red Light Violation Detection Algorithm, (figure 3-6)

1. Select the Region of interest(ROI) where detection is needed to be done.
2. Select another ROI around the red area of traffic light.
3. Draw an offset (Boundary) line at zebra crossing which signifies the threshold of violation.
4. Classify and detect the vehicles using YOLOv5 model frame by frame.
5. Track the vehicles in each frame using CSRT object tracking algorithm.
6. Check every pixel's color of that traffic light ROI.
7. A dataset containing RGB value of different shades of Red, Green and yellow is made for color detection.

8. A pixel's RGB value is subtracted from the all RGB values in the dataset one by one. The color with the least difference is selected as the closest color.
9. Follow 4th step for every pixels ROI. If number of pixels with red color are higher than number of pixels classified as green and yellow, then traffic light is red.
10. Highlight the vehicles whose centroid is within the virtual boundary for a set time limit which means that vehicle is illegally parked.
11. If the color of the traffic light is red and the vehicle's centroid's y coordinate is less than the y coordinate of the offset line, then that vehicle violated the traffic red light.

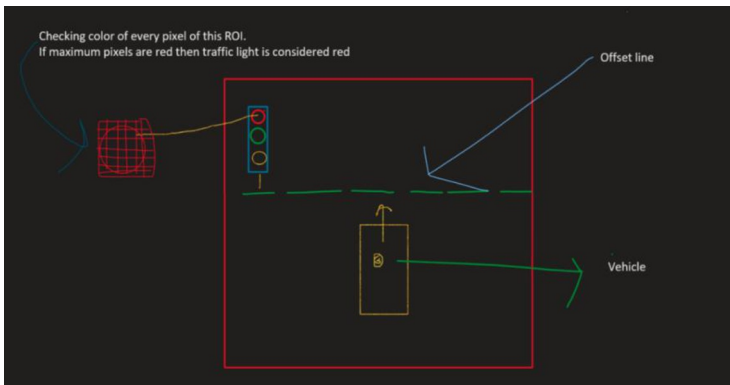


Fig. 3. Schematics of Algorithm (Red Light Violation)

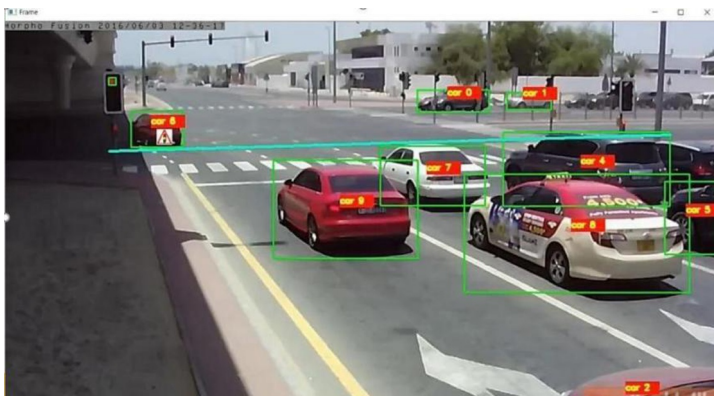


Fig. 4. Results of Red Light Violation

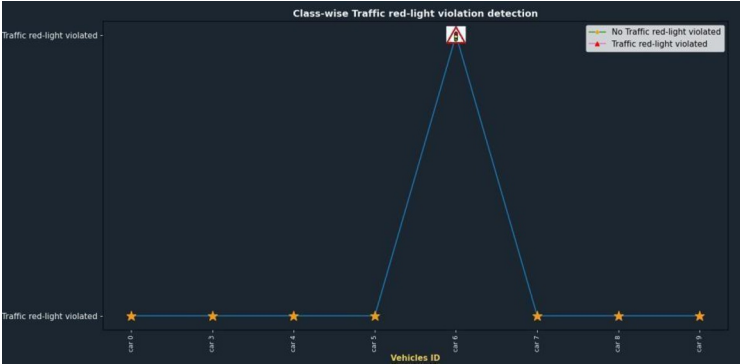


Fig. 5. Result of Red-Light Violation Detection Trough Algorithm

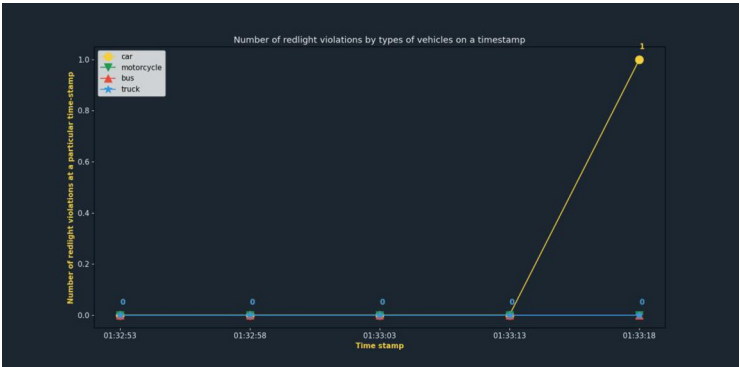


Fig. 6. Result of Red-Light and class of Vehicle Algorithm

6.2. Speed Violation Detection Algorithm, (figure 7-9)

1. Select the Region of interest where detection is needed to be done.
2. Classify and detect the vehicles using YOLOv5 model frame by frame.
3. Track the vehicles in each frame using CSRT object tracking algorithm.
4. Formula for calculating speed = (Distance Travelled) / (Time taken to travel that distance)
5. Distance of the vehicle is calculated by saving the y - coordinate (if the object is moving y-axis)of it's position in frame. For example, if starting y-coord=1 and ending y-coord=10, then distance travelled is 9 units.
6. In reference to the previous example, 9 units is the distance travelled in pixels of the frame of the video. But, real distance is needed to calculate the real speed of the vehicle.
7. If we know how much distance is being covered in a single pixel of the frame, then that value can be multiplied with the distance in pixels in order to calculate the real distance travelled.
8. distance covered in a single pixel =Real length of the road (in meters)/ Height of the frame (in pixels).So, real distance travelled = Distance in pixels * distance covered in a single pixel

9. Time taken can be calculated by saving the timestamp of entry as well as exit of the vehicle.
10. In order to efficiently calculate speed, 3 individual speeds at different intervals of time can be calculated and finally, the average of the 3 individual speeds will be the final speed of the vehicle.
11. Point 7 can be achieved by dividing the frame into 4 horizontal columns named as A,B,C and D. For example, if we have the position and time-stamp of a vehicle at these 4 locations, then:
 12. $\text{speed:1} = (\text{Position at B} - \text{Position at A}) / (\text{Timestamp at B} - \text{Timestamp at A})$.
 13. $\text{speed:2} = (\text{Position at C} - \text{Position at B}) / (\text{Timestamp at C} - \text{Timestamp at B})$.
 14. $\text{speed:3} = (\text{Position at D} - \text{Position at C}) / (\text{Timestamp at D} - \text{Timestamp at C})$.
 15. Final speed of the vehicle = $(\text{speed:1} + \text{speed:2} + \text{speed:3})/3$
 16. If Final speed > speed limit, then that vehicle is violating the speed limit.



Fig. 7. Speed Violation Detection

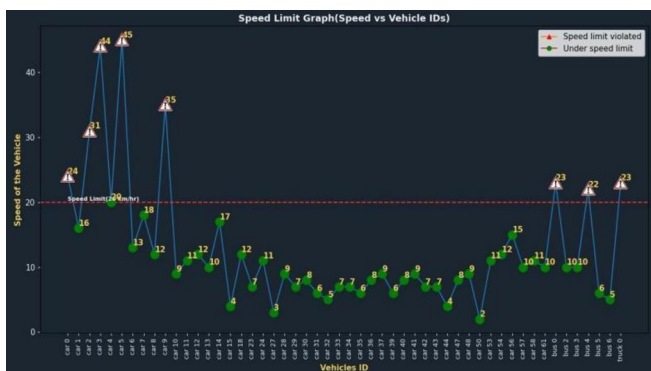


Fig 8. Analysis of Speed Violation Detection

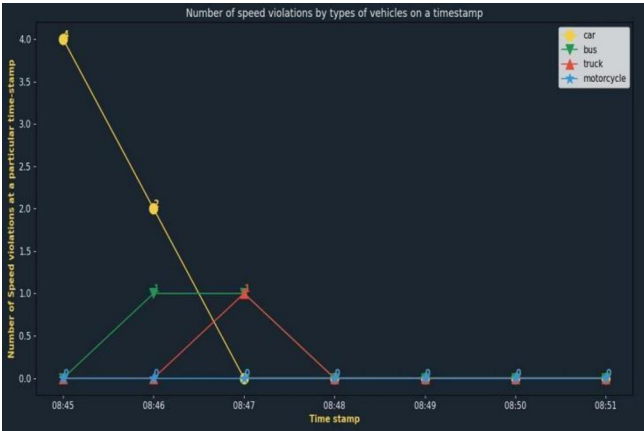


Fig. 9. Time Stamped Analysis Speed Violation

6.3. Class Counting Algorithm, (figure 10-11)

- 1. Select the Region of interest(ROI) where counting is needed to be done.
- 2. Classify and detect the objects (persons+vehicles+others) using YOLOv5 model frame by frame.
- 3. Track the vehicles in each frame using CSRT object tracking algorithm.
- 4. Provide the class-wise IDs to the objects and pick up the highest ID for each class which is the number of objects for that class.
- 5. If a new object gets detected in the frame, increment the ID number of that particular class. For example, Highest ID for class “car” is 45, so the ID is formatted as “car 45”.If another car appears, 45 will be incremented by 1 and the new ID for “class” car is “class 46”.
- 6. On every frame, timestamp is being updated, and on every 60 seconds interval, the number of objects of different class are saved for data visualization.



Fig 10. Analysis of Algorithm (Animated Video Clip screen Shot)



Fig. 11. Analysis of Class of Vehicle

6.4. Illegal Parking Detection Algorithm, (figure 12-13)

1. Select the Region of interest where detection is needed to be done.
2. Classify and detect the vehicles using YOLOv5 model frame by frame.
3. Track the vehicles in each frame using CSRT object tracking algorithm.
4. Set a virtual boundary of certain limit around the centroid of bounding boxes of tracked vehicles.
5. Highlight the vehicles whose centroid is within the virtual boundary for a set time limit which means that vehicle is illegally parked.

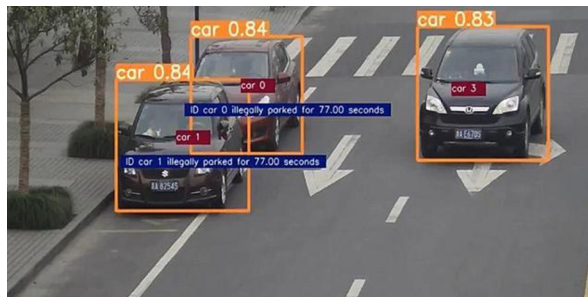


Fig. 12. Result of Illegal Parking



Fig. 13. Illegal Parking Analysis

6.5 Wrong way detection Algorithm, (figure 14-16)

1. Select the Region of interest(ROI) where detection is needed to be done.
2. Draw the lane division point.

- 3. Classify and detect the vehicles using YOLO model frame by frame.
- 4. Track the vehicles in each frame using CSRT object tracking algorithm.
- 5. Calculate the direction(up or down) of vehicle.
- 6. if the vehicle is on the left side and vehicle's direction is down, then vehicle is moving in a wrong way
- 7. if the vehicle is on the right side and vehicle's direction is up, then vehicle is moving in a wrong way.
- 8. Blink the traffic sign when the vehicle is violating the rule.

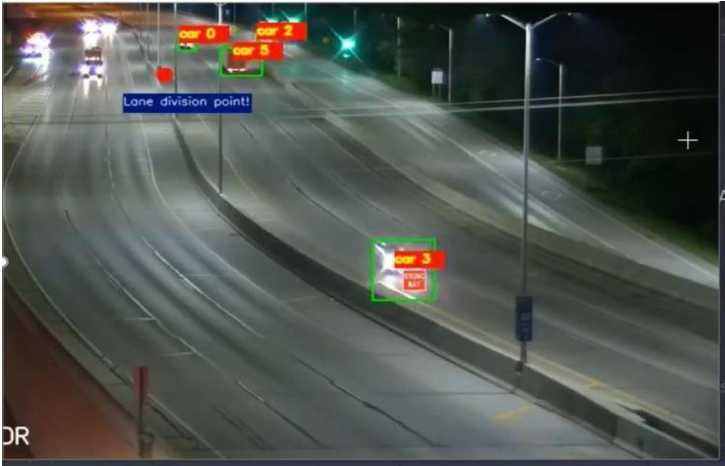


Fig. 14. Wrong Way Detection

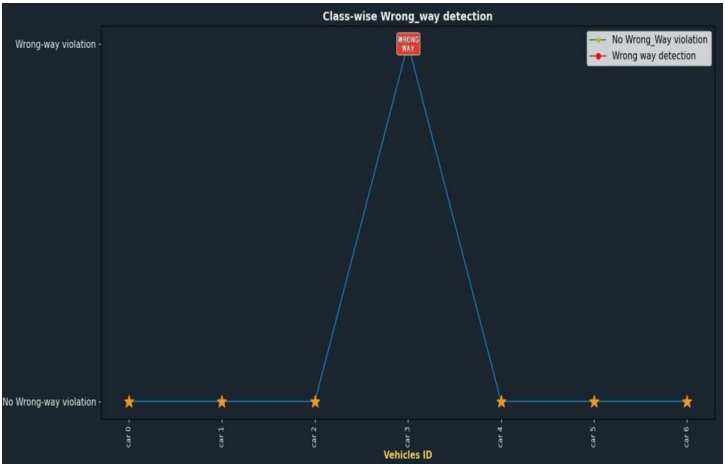


Fig .15. Wrong way Identification algorithm

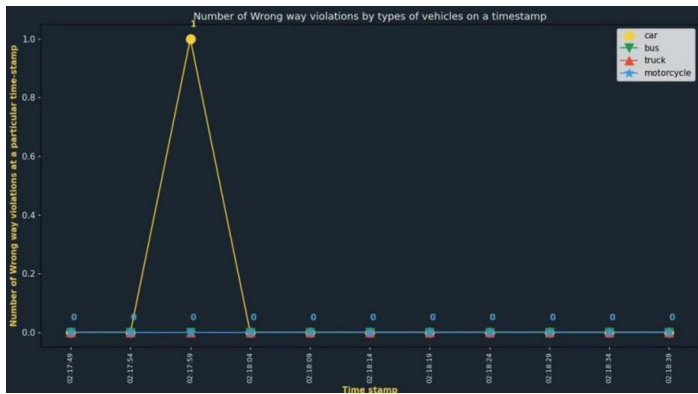


Fig. 16. Time Stamped Analysis of Wrong Way

6.6. Traffic lane violation detection Algorithm, (figure 17-19)

1. Select the Region of interest(ROI) where detection is needed to be done.
2. Draw 4 offset vertical lines which divide the lanes.
3. Classify and detect the vehicles using YOLOv5 model frame by frame.
4. Track the vehicles in each frame using CSRT object tracking algorithm.
5. A particular vehicle class is allowed to move on a particular lane.
6. If a particular vehicle class is not allowed to move on a particular lane and if its still moving on that lane, then that vehicle is violation the traffic lane.
7. This is checked by calculating point of intersection b/w vehicle's centroid's horizontal line (across the width of the frame) and lane's left and right line

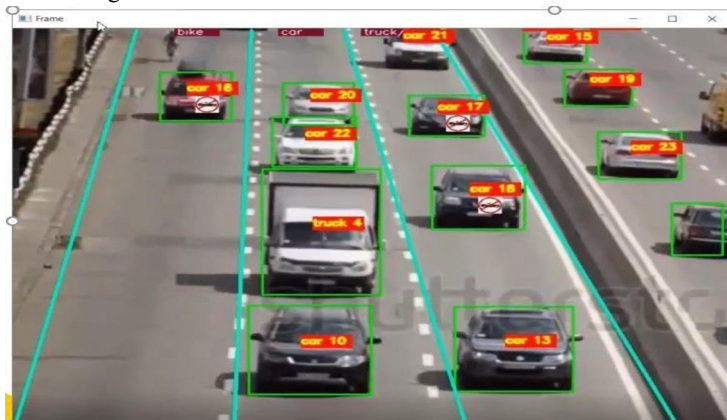


Fig. 17. Traffic Lane Violation Results



Fig. 18. Traffic Lane Violation Detection

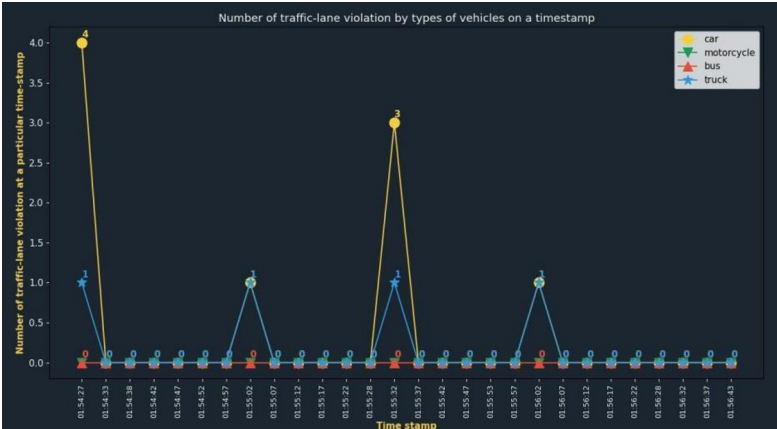


Fig. 19. Time Stamped Analysis of Traffic Lane

6.7 Illegal U-Turn detection Algorithm, (figure 20-22)

1. Select the Region of interest(ROI) where detection is needed to be done.
2. Draw the offset line at the end of the lane.
3. Draw the lane division point.
4. Classify and detect the vehicles using YOLO model frame by frame.
5. Track the vehicles in each frame using CSRT object tracking algorithm.
6. if y coordinate of the vehicle > y coordinate of the offset line, this means vehicle is initially below offset line.
7. If vehicle is initially below line and if y coordinate of the vehicle < y coordinate of the offset line, this means the vehicle has crossed the offset line.
8. If vehicle was initially below offset line and if vehicle has crossed the offset line and if y coordinate of the vehicle > y coordinate of the offset line and if, initially (vehicle initial position) the difference between x coordinate of the vehicle and x coordinate of the lane division point is not same with the new difference(new position of vehicle), then vehicle is Illegally taking U turn.

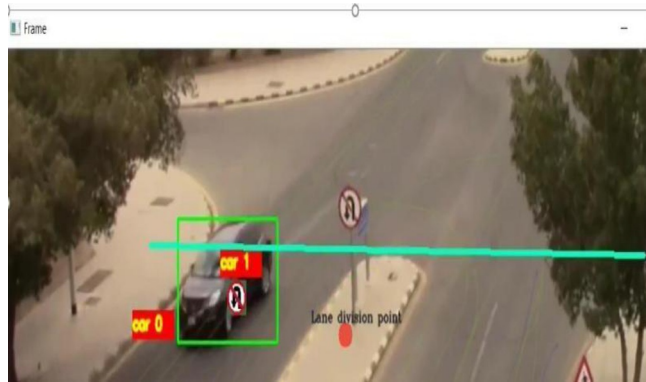


Fig. 20. Illegal U-turn Detection



Fig. 21. Analysis of Illegal U-Turn Detection

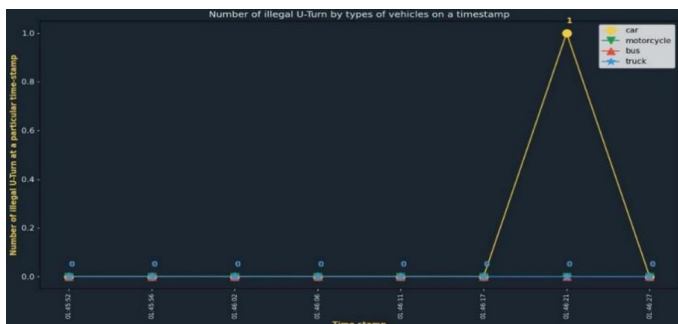


Fig. 22. Time Stamped Analysis of Illegal U-Turn

7. Discussion

This study introduced visual prediction model in the our system, we yield better results in comparison violation detection through visual data. Better prediction and better enforcement of the violation were achieved. The Fusion Model was trained on various data sets. Finally the results for evaluation of our model is shown in the figure 23, 24 in which clearly growth in precision and accuracy in comparison of visual data sets responses. The system demonstrates improved accuracy and scalability for smart traffic enforcement.

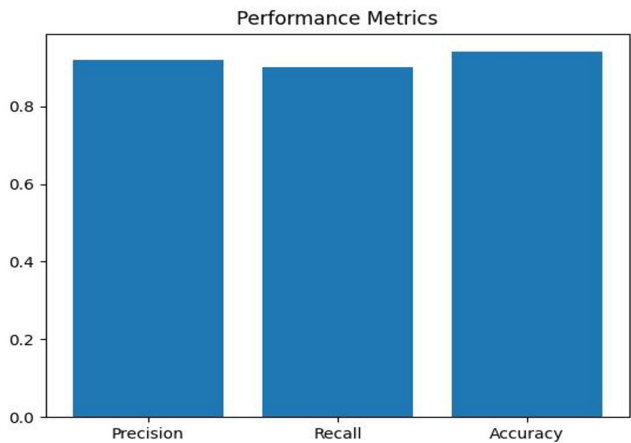


Fig. 23 Performance Metrics of Data Fusion Model

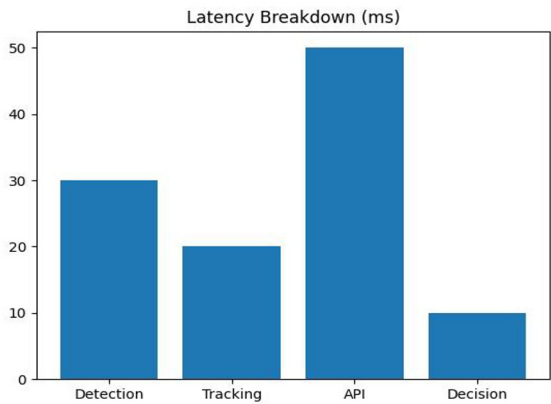


Fig. 24. Latency Breakdown after Intermediately Fusion

8. CONCLUSION

The proposed model proposes a comprehensive and robust framework for intelligent traffic monitoring. This model addresses the limitations of existing systems. The proposed model is a effort to make the reactive traffic management scenario toward a proactive traffic management predictive framework.

The proposed system not only deals with real-time detection of traffic violations but also introduces predictive capabilities [20], It offers scalable, intelligent, and adaptive solution for modern traffic challenges. Anticipating certain challenges and limitation such as augmentation of computing infrastructure computational complexity, data privacy, and model generalization, the propose model provides a foundation for future advancements in intelligent transportation systems. The outcomes of this work will have the potential to significantly enhance road safety, reduce congestion, and support data-driven decision-making in urban environments while using capability of each vehicle in decision make and law enforcement.

Although the proposed system offers significant advancements in traffic management system, there are several challenges [18] and limitations that we foresee.

The use of surveillance data, especially video issues related to data privacy and security. The model in working on various AI models and their interconnections, there is requirement of substantial computational resources. All highways will need to be equipped with high speed data network and require high computing infrastructure between two starch of road Network. This will lead to ensure low-latency processing for real-time applications. Handling high-resolution video streams and multiple data sources simultaneously is being seen as a big challenge.

As a limitation of AI models, the model will be trained on specific datasets which may not perform well in different environments like varying lighting conditions, weather, or road structures. Crowd data source and continuous learning and adaptation will be essential.

REFERENCES

1. A. Dosovitskiy *et al.*, "An Image is Worth 16×16 Words: Transformers for Image Recognition at Scale," in *Proc. Int. Conf. Learning Representations (ICLR)*, 2021.
2. Liu *et al.*, "Swin Transformer: Hierarchical Vision Transformer Using Shifted Windows," *Int. J. Comput. Vis.*, vol. 130, no. 7, pp. 1725–1741, 2022.
3. Y. Zhang *et al.*, "ByteTrack: Multi-Object Tracking by Associating Every Detection Box," in *Proc. Eur. Conf. Comput. Vis. (ECCV)*, 2022.
4. Z. Ge *et al.*, "YOLOv8: Real-Time Object Detection and Tracking Advances," *Ultralytics Tech. Rep.*, 2023.
5. Z. Wu *et al.*, "A Comprehensive Survey on Graph Neural Networks," *IEEE Trans. Neural Netw. Learn. Syst.*, 2023.
6. L. Chen *et al.*, "Multi-Modal Traffic Flow Prediction Using Deep Learning Techniques," *Transp. Res. Part C: Emerg. Technol.*, vol. 147, p. 103981, 2023.
7. X. Wang *et al.*, "Deep Learning-Based Traffic Behavior Analysis and Anomaly Detection in Intelligent Transportation Systems," *IEEE Access*, vol. 12, 2024.
8. J. Ngiam *et al.*, "Multimodal Deep Learning: A Survey," *J. Mach. Learn. Res.*, 2022.
9. H. Wei *et al.*, "IntelliLight: A Reinforcement Learning Approach for Intelligent Traffic Signal Control," in *Proc. ACM SIGKDD*, 2019.
10. M. T. Ribeiro, S. Singh, and C. Guestrin, "Why Should I Trust You? Explaining the Predictions of Any Classifier," in *Proc. ACM SIGKDD*, 2016.
11. S. M. Lundberg and S.-I. Lee, "A Unified Approach to Interpreting Model Predictions," in *Adv. Neural Inf. Process. Syst. (NeurIPS)*, 2017.
12. W. Jiang, J. Luo, and H. Xiong, "Traffic Prediction Using Spatio-Temporal Graph Neural Networks: A Survey," *IEEE Intell. Transp. Syst. Mag.*, 2024.
13. H. Zhou *et al.*, "Informer: Beyond Efficient Transformer for Long Sequence Time-Series Forecasting," in *Proc. AAAI Conf. Artif. Intell.*, 2024.

14. A. Kumar, R. Singh, and S. Gupta, "AI-Based Traffic Congestion Prediction in Smart Cities: Real-Time Data Integration and Machine Learning Approaches," *J. Smart City Syst.*, 2025.
15. Y. Li, R. Yu, C. Shahabi, and Y. Liu, "Diffusion Convolutional Recurrent Neural Network for Traffic Forecasting," in *Proc. Int. Conf. Learning Representations (ICLR)*, 2023.
16. Z. Zhao *et al.*, "LSTM Network: A Deep Learning Approach for Short-Term Traffic Forecasting," *IEEE Trans. Intell. Transp. Syst.*, 2023.
17. J. Gao, J. Wang, and M. Liu, "Digital Twin-Based Traffic Simulation and Optimization Using Reinforcement Learning," *Simul. Model. Pract. Theory*, 2025.
18. M. Rahman, M. Hasan, and S. Islam, "Explainable AI in Intelligent Transportation Systems: Challenges and Opportunities," *Elsevier AI Applications*, 2024.
19. Ministry of Road Transport and Highways, Government of India, *Road Accidents in India*, 2023–2025.
20. T. Toledo, H. N. Koutsopoulos, and M. E. Ben-Akiva, "Integrated Driving Behavior Modeling," *Transp. Res. Part C: Emerg. Technol.*, vol. 15, no. 2, pp. 96–112, 2007.

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