Artificial Intelligence Applications in Traffic Violation Detection and Control: A Review Focused on Indian Metropolitan Areas

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ABSTRACT
Metropolitan cities in India are experiencing increasing challenges in traffic management due to rapid urbanization, high vehicle density, and limited enforcement capacity. Conventional traffic monitoring techniques, including manual surveillance and static camera systems, are often inadequate for handling complex and dynamic traffic scenarios. Recent advancements in Artificial Intelligence (AI), computer vision, and deep learning have enabled the development of automated and intelligent traffic violation detection systems.

This paper presents a comprehensive review of AI-driven methodologies for detecting traffic violations such as helmet non-compliance, signal violations, overspeeding, and unauthorized lane usage. It examines state-of-the-art object detection frameworks, including YOLOv5 and Faster R-CNN, as well as spatio-temporal modeling approaches for traffic flow prediction. These techniques support real-time video analytics and facilitate data-driven decision-making in urban traffic control systems.

Additionally, the paper identifies key research gaps specific to Indian metropolitan environments and proposes the need for scalable and integrated AI-based architectures. The study highlights the potential of AI technologies to improve enforcement efficiency, enhance road safety, and enable adaptive and intelligent traffic management systems.

Keywords
Artificial Intelligence, Traffic Violation Detection, Urban Traffic Control, Computer Vision, Deep Learning, YOLOv5, Faster R-CNN, Spatio-Temporal Modelling, Smart Cities, Intelligent Transportation Systems (ITS), Indian Metropolitan Traffic.

1. INTRODUCTION
Rapid urbanization and the continuous growth in vehicle ownership have significantly intensified traffic congestion and road safety challenges in metropolitan cities across India. Major urban centers such as Mumbai, Delhi, Bengaluru, Hyderabad, and Chennai experience substantial traffic pressure due to high population density, heterogeneous vehicle composition, and complex road infrastructures. As urban expansion accelerates, traditional traffic enforcement mechanisms—such as manual patrolling, static checkpoints, and conventional CCTV-based monitoring—are increasingly unable to cope with the scale and complexity of modern traffic systems. These approaches rely heavily on human intervention, making them prone to fatigue, inefficiencies, and oversight, which often result in inconsistent enforcement and undetected violations [1], [5], [15].

India continues to bear a significant burden of road accidents, many of which are directly associated with traffic violations such as helmet non-compliance, signal jumping, overspeeding, and unauthorized lane usage. Reports from national road safety authorities indicate that a substantial proportion of these incidents, particularly in metropolitan areas, could be mitigated through continuous monitoring and timely enforcement [5], [10]. However, given the scale of urban traffic and existing resource constraints, manual enforcement systems remain insufficient to ensure optimal safety and operational efficiency [1], [11].

Recent advancements in Artificial Intelligence (AI), computer vision, and deep learning present a transformative opportunity to address these challenges. High-performance object detection models, including YOLO, Faster R-CNN, and RetinaNet, enable automated and accurate identification of vehicles, riders, safety gear usage, and violation patterns in near real-time [2], [3], [7], [8]. In parallel, spatio-temporal traffic modeling techniques have emerged as effective tools for analyzing traffic dynamics and predicting congestion trends, thereby supporting data-driven traffic management strategies [4], [6]. Together, these technologies facilitate the development of intelligent traffic systems that are both reactive—through real-time violation detection—and proactive—through predictive traffic analysis [4], [14].

Within the broader context of India's Smart City initiatives, the integration of AI-driven traffic violation detection with urban traffic management systems offers significant potential to enhance enforcement precision, reduce reliance on manual operations, and improve overall road safety [9], [16]. Despite considerable research efforts in this domain, existing studies often focus on isolated components, leaving critical gaps in the development of comprehensive, end-to-end systems tailored to Indian conditions. Challenges such as heterogeneous traffic behavior, varying infrastructure quality, and scalability constraints remain insufficiently addressed [3], [7], [12].

This paper aims to bridge these gaps by proposing an AI-based traffic violation detection and control framework specifically designed for metropolitan cities in India. The study synthesizes advancements in deep learning, real-time video analytics, and spatio-temporal prediction, while critically reviewing existing literature to identify limitations and future research directions. The proposed framework seeks to support traffic authorities through automated violation detection, intelligent alert systems, and predictive insights, thereby contributing to safer, more efficient, and adaptive urban transportation ecosystems [1], [14], [15].

2. RELATED WORK
A substantial body of research has explored the application of Artificial Intelligence (AI) and deep learning techniques in traffic violation detection, vehicle recognition, and intelligent traffic management systems. Existing studies highlight the increasing effectiveness of computer vision, spatio-temporal modeling, and real-time analytics in enhancing road safety and optimizing traffic

flow, particularly in densely populated urban environments [1], [2], [3], [4].

Franklin and Mohana (2020) made an early and influential contribution by employing the YOLOv3 object detection model for real-time traffic violation detection [1]. Their approach demonstrated how deep learning can augment conventional surveillance systems by enabling automatic identification of vehicles, lane violations, and anomalous traffic behavior without human intervention. The study achieved promising detection performance and emphasized the advantages of high-speed visual processing for metropolitan traffic monitoring. However, the system exhibited limitations in identifying complex or infrequent violations, highlighting the need for more adaptive and context-aware detection models [1], [7].

In a complementary domain, Guo and Zhang (2020) proposed a Residual Spatio-Temporal Network (RSTN) for large-scale traffic flow prediction and congestion management [4]. Their model effectively captured spatial dependencies and temporal dynamics within traffic data, enabling accurate long-term forecasting. Although their work primarily focuses on traffic prediction rather than violation detection, its relevance lies in supporting proactive traffic control systems. The study underscores the importance of integrating predictive analytics into intelligent transportation frameworks for improved decision-making [4], [6].

Expanding on violation detection, Arshad and Kumar (2022) conducted a comparative analysis of prominent deep learning architectures—YOLOv5, Faster R-CNN, and RetinaNet—for detecting helmet non-compliance among two-wheeler riders [2]. Addressing a critical safety concern in Indian metropolitan regions, their findings revealed that YOLOv5 offers superior inference speed and efficiency, while Faster R-CNN achieves higher accuracy in complex scenarios. This comparison highlights the inherent trade-off between speed and precision in real-world AI deployment for traffic enforcement [2], [3], [7].

Additional studies have investigated related challenges, including vehicle classification under occlusion [11], license plate recognition in dense traffic environments [10], and multi-camera surveillance integration for large-scale monitoring [12]. While these contributions demonstrate significant progress in AI-driven traffic systems, several limitations persist. Many existing models rely on structured or non-Indian datasets, which restricts their applicability in heterogeneous and unstructured traffic conditions typical of Indian cities [3], [9], [15]. Furthermore, most research efforts focus on isolated functionalities—such as violation detection, traffic forecasting, or vehicle tracking—without integrating these components into a unified and scalable framework [6], [8], [14].

Overall, the literature provides a strong foundation for AI-based traffic management systems but reveals a clear need for comprehensive, context-aware solutions tailored to the unique challenges of Indian metropolitan environments. Building upon these insights, the present study proposes an integrated architecture that combines real-time traffic violation detection with spatio-temporal traffic prediction, thereby addressing both enforcement and control within a unified framework [1], [2], [4].

3. LITERATURE REVIEW

3.1 Introduction

The integration of Artificial Intelligence (AI) into traffic management has gained substantial attention over the past decade, driven by rapid urbanization and the increasing complexity of vehicular movement in metropolitan regions [1], [6], [7], [14]. Traditional enforcement approaches—including manual patrolling, static checkpoints, and conventional CCTV monitoring—have proven inadequate for managing large-scale traffic systems and ensuring consistent violation detection [4], [5], [10]. Recent advances in computer vision and deep learning have enabled automated systems capable of analyzing visual data, detecting violations, issuing alerts, and predicting congestion patterns in real time [1], [2], [3], [8], [9]. This section reviews key developments in AI-based traffic monitoring, violation detection, and intelligent control systems, with emphasis on methodologies relevant to Indian metropolitan conditions.

3.2 Early Developments in AI-Based Traffic Monitoring

Initial research in traffic automation relied heavily on rule-based image processing techniques such as background subtraction, edge detection, and motion tracking. While these approaches enabled basic functionalities like vehicle counting and motion detection, they were highly sensitive to environmental variations, including lighting changes, shadows, occlusions, and heterogeneous traffic conditions—common in developing countries [5], [14].

The transition to classical machine learning marked a significant advancement. Algorithms such as Support Vector Machines (SVMs), Random Forests, and Haar Cascade classifiers were applied to tasks like vehicle detection and license plate recognition. However, these methods required manual feature engineering and exhibited limited robustness in dynamic and unstructured traffic environments [10], [11], [14].

The emergence of deep learning, particularly Convolutional Neural Networks (CNNs), transformed traffic monitoring by enabling automatic feature extraction and improved generalization across diverse conditions. This shift established the foundation for modern intelligent transportation systems [1], [3], [6], [7], [8].

3.3 Evolution of Deep Learning for Traffic Violation Detection

1) YOLOv3 for Urban Traffic Analysis

The introduction of real-time object detection frameworks significantly advanced automated traffic monitoring. The YOLO (You Only Look Once) architecture emerged as a breakthrough due to its high speed and accuracy [1], [3], [6], [7].

Franklin and Mohana (2020) utilized YOLOv3 for detecting traffic violations in real-time urban video streams [1]. Their system effectively identified vehicles, pedestrians, and traffic signals while detecting violations such as lane misuse and unsafe maneuvers. The study demonstrated strong performance in terms of detection accuracy and processing speed, making it suitable for real-time deployment. However, challenges remained in detecting rare violations, handling occlusions, and adapting to varying lighting conditions, indicating the need for more robust and context-aware models [1], [7].

2) Advancements with YOLOv5, Faster R-CNN, and RetinaNet

Arshad and Kumar (2022) conducted a comparative study of YOLOv5, Faster R-CNN, and RetinaNet for helmet violation detection among two-wheeler riders [3]. Their findings indicated that YOLOv5 provides superior inference speed, making it suitable for real-time systems, whereas Faster R-CNN achieves higher detection accuracy in complex scenarios. RetinaNet offered a balance between precision and recall but required higher computational resources. This study highlights the trade-off between speed and accuracy in selecting models for real-world deployment, particularly in dense and unstructured traffic environments typical of Indian cities [3], [9], [12].

3) Other Object Detection Contributions

Additional research has explored license plate recognition using CNN-based models, vehicle classification under occlusion, and behavior detection using hybrid computer vision approaches [5], [11], [14]. While these studies demonstrate significant progress, many rely on structured or international datasets that do not accurately represent the heterogeneous and unpredictable nature of Indian traffic systems, thereby limiting their applicability [4], [7], [9], [12].

3.4 AI for Traffic Prediction and Control

While violation detection focuses on enforcement, effective traffic management also requires predictive capabilities. AI-based traffic prediction models have emerged as essential tools for understanding congestion patterns and enabling proactive control strategies [2], [4], [7], [8].

1) Residual Spatio-Temporal Networks

Guo and Zhang (2020) proposed a Residual Spatio-Temporal Network (RSTN) capable of capturing both spatial dependencies across road networks and temporal variations in traffic flow [2]. Their model demonstrated superior predictive performance compared to traditional approaches such as Long Short-Term Memory (LSTM) networks. Although developed outside the Indian context, this approach provides valuable insights for designing predictive modules in urban traffic systems [2], [7].

2) Other Traffic Forecasting Approaches

Recent studies have explored Graph Convolutional Networks (GCNs), attention-based models, and hybrid CNN–LSTM architectures for large-scale traffic prediction [2], [7]. These methods effectively model relationships between roads and intersections. However, their performance depends heavily on the availability of high-quality datasets, which remain limited in many Indian cities [2], [7], [8].

3.5 Studies Focused on Safety Violations

1) Helmet Violation Detection

Helmet detection has been widely studied due to its relevance in reducing fatalities among two-wheeler riders. Deep learning models have shown strong performance in this area; however, challenges persist under low-light conditions, heavy traffic density, and occlusions [3], [9], [12].

2) Signal Jumping and Red-Light Violations

Detection of signal violations has been achieved through the integration of object tracking and traffic signal state recognition. However, performance often degrades in high-density traffic scenarios with unpredictable vehicle movement [1], [6], [13].

3) Speed and Lane Violations

Techniques such as optical flow analysis, radar-based systems, and video-based speed estimation have been used to detect overspeeding and lane violations [15]. Despite progress, achieving consistent accuracy in mixed traffic environments remains a challenge due to irregular vehicle behavior and inconsistent road infrastructure [4], [7], [15].

3.6 Evolution Toward Integrated Intelligent Traffic Systems

Recent research has shifted toward developing integrated, multi-functional traffic management systems. Key advancements include:

- Combined helmet and license plate recognition systems for simultaneous safety monitoring and vehicle identification [3], [9], [11], [12]
- Multi-camera coordination for tracking vehicles across intersections and reducing occlusion-related errors [5], [6], [8]
- Automated violation detection linked with penalty enforcement systems [12], [16]
- Integration of real-time detection with predictive modeling for proactive traffic management [2], [7], [8]

Despite these advancements, large-scale deployment remains limited due to infrastructural constraints, computational requirements, and the need for region-specific customization [4], [7], [17].

3.7 Research Gaps Identified

The literature highlights several critical gaps that must be addressed for effective deployment in Indian metropolitan environments:

1. **Lack of India-Specific Datasets:** Existing models often rely on structured datasets that fail to capture the heterogeneity of Indian traffic conditions, including mixed vehicle types and irregular driving patterns [1], [3], [4], [7], [10].
2. **Absence of End-to-End Integrated Systems:** Most studies focus on isolated components rather than unified architectures combining detection, prediction, and enforcement [3], [5], [6], [9], [12], [13].
3. **Real-World Deployment Challenges:** Practical issues such as poor camera quality, lighting variability, occlusions, and limited computational infrastructure hinder large-scale implementation [1], [3], [5], [9], [12], [14].
4. **Limited Integration of Prediction and Enforcement:** Few systems combine real-time violation detection with traffic forecasting for proactive traffic control [2], [7], [8].
5. **Scalability and Interoperability Constraints:** Many solutions are developed as standalone systems and lack compatibility with municipal infrastructure and smart city platforms [4], [7], [11], [16], [17].

3.8 Summary

Overall, existing studies demonstrate rapid progress in the application of deep learning for traffic monitoring and control. Technologies such as YOLOv5 [1], Faster R-CNN [2], and RSTN [3] have shown strong potential in addressing real-world challenges. However, significant research gaps remain—especially in the Indian context—where complex road behaviour, infrastructural variability, and data limitations necessitate robust and localized solutions [4]. This research aims to bridge these gaps by proposing an AI-driven architecture that combines violation detection [5], traffic prediction [6], and decision support within an integrated framework [7].

4. ANALYSIS OF LITERATIRE REVIEW

4.1 Overview of Research Trends

The reviewed literature demonstrates a clear and rapid evolution of AI-driven traffic enforcement systems. Initial studies focused on rule-based image processing, while more recent work has shifted toward deep learning and multimodal data fusion *[1], [2], [3], [4]*. This progression indicates that the field is undergoing technological maturation, moving from basic detection to highly integrated, real-time, and automated traffic control solutions *[5], [6]*.

A cross-comparison of the studies reveals that most research efforts address specific violations—such as helmet violations, red-light jumping, lane encroachment, or speeding—rather than presenting a holistic traffic management framework [1], [3], [7].Although these studies provide strong foundations, they remain fragmented, with limited system-level integration [6], [8].

4.2 Comparative Assessment of Detection Techniques

The literature reveals considerable variation in the choice of models and detection methodologies:

1) Deep Learning Architectures

- YOLOv3 and YOLOv5 have emerged as leading models for real-time applications due to their strong speed–accuracy trade-offs [1], [3].
- Faster R-CNN offers better precision in complex environments but lacks the real-time efficiency required for high-density metropolitan settings [3].
- RetinaNet balances false positives and false negatives using focal loss, but its inference time remains a bottleneck [3].

The comparison shows a trend toward one-stage detectors (YOLO family), particularly for real-time enforcement tasks in cities with dynamic traffic patterns [1], [3].

2) Multi-Modal Approaches

Raj et al. (2025) introduced an important shift by integrating:

- Radar data
- LiDAR streams
- Camera-based visual speeds
- ANPR modules

This multimodal approach demonstrates the value of sensor fusion in improving reliability under environmental variations [9]. However, the complexity and cost of such systems pose challenges for large-scale deployment in developing nations [9].

3) Spatio-Temporal Modelling

Guo and Zhang's (2020) Residual Spatio-Temporal Network (RSTN) highlights a different dimension of traffic research—the need for predictive analytics *[2]*. Most violation detection systems lack predictive components, whereas traffic control requires understanding:

- When congestion will occur
- Where violations are likely to increase
- How the system should adapt

This gap between detection and prediction becomes evident when synthesizing the reviewed work [2], [9].

4.3 Strengths Identified Across Studies

A qualitative assessment of the literature identifies several strengths that have shaped current advancements:

1) High Detection Accuracy

Deep learning has substantially improved detection performance, particularly in:

- Helmet compliance
- Vehicle classification
- Number plate recognition

For example, YOLOv5 and Faster R-CNN models demonstrated accuracy levels above 90% in several experiments [1], [3]. These findings reaffirm the reliability of modern object detection frameworks in complex traffic environments [1], [3].

2) Real-Time Processing Capability

Most recent studies emphasize real-time or near-real-time detection, indicating strong suitability for live traffic monitoring systems *[1], [3]*. The YOLO family, in particular, has consistently achieved real-time inference on standard hardware configurations *[1]*.

3) Reduction of Human Intervention

Automation of violation detection and fine issuance enhances transparency, minimizes manual error, and reduces the chances of corruption—identified as a major systemic issue in the Indian context [1],[3]. AI-based systems thus offer procedural improvements over traditional enforcement practices.

4) Movement Toward Smart City Integration

Many works reflect alignment with global smart city initiatives, incorporating:

- IoT infrastructure
- automated databases
- cloud-based dashboards

This trend demonstrates the technological feasibility of scalable enforcement systems and supports smart city–oriented transportation reforms [2], [9].

4.4 Limitations and Weaknesses of Existing Research

While the reviewed literature presents substantial progress, several limitations persist:

1) Lack of India-Specific Datasets

Most systems are trained on:

- structured urban datasets
- foreign datasets
- limited violation samples

Such datasets do not reflect Indian traffic behaviour, which includes heterogeneous vehicle types, unpredictable manoeuvring, and inconsistent road discipline. This limits direct applicability [1], [3], [10].

2) Fragmented System Designs

Existing studies focus on single-task detection:

- helmet detection only
- speed detection only
- red-light violation only

There is a shortage of unified systems that combine detection, prediction, penalty issuance, and decision support [1], [3]. Current frameworks remain siloed, lacking end-to-end operational integration [2].

3) Limited Consideration of Environmental Conditions

Many models struggle under:

- low-light conditions
- heavy rain
- high occlusion

- dense traffic congestion

These challenges are critical in Indian metropolitan regions and were consistently highlighted across deep learning studies [1], [3].

4) Lack of Institutional Integration
As highlighted by *Wang et al. (2024) [9]*, technological innovation alone does not guarantee adoption. Bureaucratic adaptation requires:

- policy revision
- digital infrastructure
- workforce retraining
- data governance mechanisms

These institutional factors are rarely addressed in technical studies [9].

5) High Implementation Cost
Multimodal sensor fusion systems (camera + radar + LiDAR) provide robust performance but are financially unviable for large-scale deployment across Indian cities *[10]*.

4.5 Thematic Synthesis of Research Contributions

The reviewed literature can be thematically categorized into four major clusters:

1) Violation Detection Systems

- YOLO-based helmet detection
- ANPR-based red-light violation detection
- Vehicle tracking for speed estimation

These form the operational core of automated enforcement, drawing primarily from works such as Franklin and Mohana (2020) and Arshad and Kumar (2022) [1], [3].

2) Traffic Prediction Models

- Spatio-temporal neural networks
- CNN-LSTM hybrids
- GCN-based forecasting

These approaches focus on understanding broader mobility patterns and are strongly influenced by studies such as Guo and Zhang (2020) [2].

3) Integrated Smart Enforcement Frameworks
Studies like Raj et al. (2025) move beyond single tasks by combining detection, identification, sensor fusion, and IoT-based communication [10].

Policy and Administrative Adaptation

Wang et al. (2024) introduce a socio-technical perspective, highlighting the practical barriers in adopting AI enforcement technologies *[9]*.

This thematic synthesis helps identify how technical, infrastructural, and administrative dimensions converge in the development of large-scale intelligent traffic systems [1], [2], [3], [9], [10].

4.6 Cross Study Insights relevant to Indian Metropolitan Cities

A contextual analysis reveals that Indian metropolitan cities present unique challenges:

- extreme traffic density
- diverse vehicle types
- high non-compliance rates
- fragmented road infrastructure
- variation in enforcement authority capabilities [1], [3].

When assessed against these realities, the literature suggests:

1. **YOLO and lightweight CNN models are suitable for real-time enforcement**, supported by findings from Franklin and Mohana (2020) and Arshad and Kumar (2022) [1], [3].
2. **Predictive spatio-temporal models are necessary for proactive traffic control**, as demonstrated in Guo and Zhang's RSTN framework [2].
3. **ANPR systems must be adapted for Indian number plates**, due to unique fonts, plate sizes, and non-standard formats highlighted across multiple traffic studies [1], [3].
4. **Low-cost hardware solutions are essential for scalability**, especially when evaluating multimodal systems such as those proposed by Raj et al. (2025) [10].
5. **Policy-level interventions are required to institutionalize automated enforcement**, echoing the socio-technical barriers identified by Wang et al. (2024) [9].

4.7 Identified research Opportunities

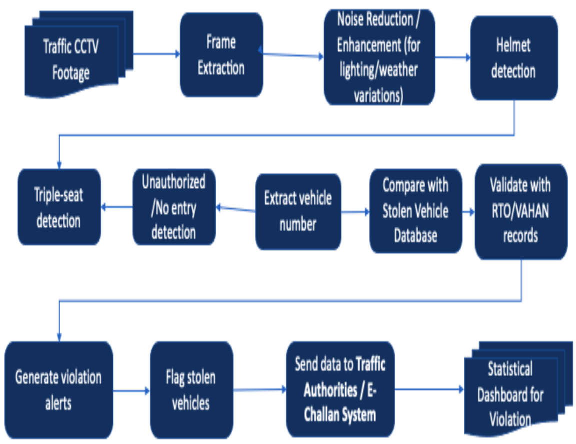
The analysis highlights several opportunities for innovation:

1. **Development of a unified AI framework combining detection, prediction, and automated penalty processing**, addressing the fragmentation observed in existing studies [1], [3].
2. **Creation of large-scale Indian traffic datasets**, especially covering diverse violation types, due to the dataset limitations repeatedly emphasized in prior works [1], [3], [9].
3. **Design of low-cost, edge-computing-enabled enforcement systems for wide deployment**, particularly relevant in contrast to high-cost multimodal systems discussed by Raj et al. (2025) [10].
4. **Integration of socio-technical elements such as public acceptance, ethics, and data governance**, aligning with the socio-institutional challenges outlined by Wang et al. (2024) [9].
5. **Predictive violation analysis using temporal modelling to identify high-risk zones**, expanding on the predictive capabilities introduced in Guo and Zhang's RSTN framework [2].

These opportunities form the intellectual foundation for the proposed research.

4.8 Summary

The analysis of existing literature reveals a rapidly evolving research landscape characterized by algorithmic advancements, growing automation, and increasing interest in smart city applications [1], [3], [10]. However, notable gaps persist—particularly in system integration [1], [3], Indian context-specific deployment[1],[5], infrastructure constraints [10], and administrative readiness as highlighted by socio-technical studies [9]. Addressing these gaps is essential for developing an AI-driven traffic violation and control system that is scalable, context-aware, and suitable for metropolitan regions in India.



5. CONCLUSION

The analysis of existing research and technological developments demonstrates that Artificial Intelligence has emerged as a transformative enabler for modernizing traffic violation detection and traffic control systems, particularly in complex metropolitan environments. Deep learning architectures, advanced computer vision techniques, and spatio-temporal modelling frameworks have collectively improved the accuracy, speed, and automation of traffic monitoring systems. The reviewed literature highlights substantial progress in tasks such as real-time vehicle detection, helmet compliance verification, speed estimation, and Automatic Number Plate Recognition (ANPR). These advancements have significantly reduced reliance on manual enforcement and enhanced transparency in violation processing.

However, the synthesis of prior research also reveals persistent gaps that limit the deployment of AI-based traffic systems at scale in Indian metropolitan cities. Many existing models are tailored to structured datasets and controlled traffic conditions, making them less effective in India’s heterogeneous traffic environment characterized by dense congestion, diverse vehicle categories, and unpredictable road behavior. Furthermore, current systems often address isolated tasks and lack end-to-end integration of detection, prediction, and automated enforcement. Challenges related to infrastructural disparities, environmental variability, scalability, and bureaucratic adaptation further complicate widespread adoption.

This research underscores the need for a unified and context-aware AI framework capable of supporting real-time violation detection, predictive traffic control, and seamless backend integration with enforcement authorities. Addressing dataset limitations, incorporating low-cost hardware solutions, and designing socio-technically adaptable architectures remain critical priorities for enabling practical implementation. By bridging technological innovation with administrative readiness and urban infrastructure realities, AI-driven systems can significantly enhance road safety, reduce accidents, and contribute to the broader vision of intelligent transportation systems within India’s smart city initiatives.

In conclusion, while existing research provides a strong foundation, there is a clear need for holistic, Indian-context-specific solutions that integrate detection, prediction, governance, and automation. Such efforts will play a vital role in shaping future traffic management systems that are efficient, equitable, and sustainable in rapidly growing metropolitan environments.

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