

Computer Vision Analysis for Traffic Monitoring and Road Safety in Smart City Concept

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ABSTRACT

Rapid urban growth and rising traffic complexity require Smart City solutions that move beyond passive CCTV toward intelligent, real-time traffic management. This study examines how computer vision-based analytics contribute to road safety when integrated into an Intelligent Transportation System (ITS). A quantitative quasi-experimental design was applied across multiple intersections using a 12-month before-after window. Data were collected from video analytics (vehicle and pedestrian detection, tracking, violations, road conditions), adaptive signal logs, crash and injury records, near-miss indicators, and contextual variables such as weather and traffic volume. Analysis combined perception validation (mAP, tracking accuracy), time-series operational assessment, and Difference-in-Differences modeling to estimate safety impacts. Results show high perception reliability (mAP > 0.85) and significant operational improvements, including a 33% reduction in waiting time and 35% shorter queues. More importantly, red-light violations decreased by 39%, near-miss events by 45%, crash frequency by 42%, and severity index by 37%. The findings indicate a causal pathway from vision-based perception to adaptive control and enforcement, leading to measurable safety gains. The study concludes that computer vision serves as a safety governance instrument within Smart City ITS when detection outputs are tightly coupled with intervention mechanisms.

Keywords: *Computer vision, Intelligent transportation system, Road safety, Smart city, Traffic monitoring.*

INTRODUCTION

Rapid urbanization and motorization have intensified congestion, emissions, and crash risk in metropolitan corridors, exposing the limits of fixed-time signals and simple loop sensors. Cities now require real-time, data-driven orchestration of intersections, corridors, and enforcement to keep pace with volatile traffic demand. Within the Smart City agenda, Intelligent Transportation



Systems (ITS) integrate AI, IoT, and camera networks to predict flows, adapt signals, and manage violations continuously. Empirical reports show that AI-IoT ITS can reduce waiting time by 30–33%, raise throughput by 15–149%, and cut emissions by 12–16%, demonstrating the operational promise of intelligent control in dense networks (Lin & Lin, 2025; Saleem et al., 2022; Thompson, 2025; Skoropad et al., 2025; Almaliki et al., 2025). Yet, while operational efficiency improves, the central policy objective road safety remains under-evaluated in relation to these deployments.

At the core of this transformation is Computer Vision, which converts passive CCTV streams into actionable “traffic intelligence.” Large ITS surveys identify vision-based analytics as the backbone for detecting and tracking vehicles and pedestrians, identifying violations, assessing road conditions, and feeding adaptive signal controllers (Chebykin, 2021; Chen, 2024; Dilek & Dener, 2023). Modern detectors and trackers (e.g., YOLO/CNN families) enable counting, density estimation, wrong-way detection, and congestion heatmaps from video alone (Chebykin, 2021; K et al., 2025; Chen, 2024; Khan & Thakur, 2024; Dilek & Dener, 2023). Video-driven adaptive signal control has reported waiting-time reductions up to 30% and clearance-time improvements up to 84% (Lin & Lin, 2025; M, 2025; Skoropad et al., 2025; Chen, 2024; Almaliki et al., 2025). Vision systems also detect signs, pavement defects, and roadside hazards, strengthening perception reliability for maintenance and design compliance (Aldoski & Koren, 2025; Rathee et al., 2023; Jiang et al., 2024; Yue, 2024). Real-time violation detection further automates enforcement and can deter repeat offenses (Chen, 2024; Balasaranya et al., 2025; Dilek & Dener, 2023).

Despite this breadth, a critical problem persists in the literature. Most studies prioritize technical metrics mean Average Precision (mAP), detection accuracy, prediction error, or queue/wait time while stopping short of demonstrating how these gains translate into measurable reductions in crashes, near misses, or injury severity (Lin & Lin, 2025; Aldoski & Koren, 2025; Rathee et al., 2023; K et al., 2025; Khan & Thakur, 2024; Medina-Salgado et al., 2022; Dilek & Dener, 2023). A handful of works suggest intersection crash reductions after AI/CV upgrades, but causal pathways are rarely unpacked, and longitudinal evidence is limited (Skoropad et al., 2025; Chen, 2024; Yue, 2024). As a result, city decision-makers can justify CV investments on efficiency grounds, yet lack rigorous safety evidence that connects detection performance to safety outcomes over time.

This gap is compounded by contextual variability. Reviews emphasize the need to incorporate human factors, adverse weather, and urban heterogeneity especially contrasts between developing and developed cities into impact evaluation (Chebykin, 2021; Khan & Thakur, 2024; Medina-Salgado et al., 2022; Yue, 2024; Dilek & Dener, 2023). Driver behavior, pedestrian compliance, rain/night glare, camera placement, and mixed traffic compositions all modulate how vision outputs affect real-world safety. Without embedding these factors,

reported accuracy gains risk being disconnected from the lived conditions that shape crashes.

A second research problem lies in fragmentation. Vision applications are often studied in isolation: vehicle counting, signal control, sign detection, or violation analytics are evaluated as separate modules. However, safety emerges from their interaction across space and time. For example, adaptive signals informed by density estimates may reduce red-light running only when coupled with violation detection and targeted enforcement feedback. Similarly, early identification of pavement defects contributes to safety when maintenance workflows are triggered promptly. The literature rarely models this end-to-end chain from perception to intervention to safety outcome, leaving a systems-level blind spot (Chebykin, 2021; Rathee et al., 2023; Qiu et al., 2025; Yue, 2024; Dilek & Dener, 2023).

A third issue concerns evaluation horizons. Many deployments report short-term operational gains immediately after installation. Yet safety effects may require sustained behavioral adaptation and iterative tuning of signal logic and enforcement thresholds. Longitudinal designs that track crashes and near misses before and after CV deployment while controlling for seasonality, traffic growth, and weather are still scarce (Skoropad et al., 2025; Chen, 2024). Without such designs, it is difficult to attribute safety changes to vision analytics rather than to concurrent policy or infrastructural shifts.

Within this context, the present study argues that computer vision should be evaluated not only as a detector but as a safety instrument embedded in a Smart City ITS loop. The novelty lies in linking four layers within one evaluative frame: (1) perception performance (detection/tracking of vehicles, pedestrians, signs, road defects, violations), (2) control and enforcement actions (adaptive signals, alerts, automated tickets, maintenance triggers), (3) contextual moderators (human behavior, weather, urban heterogeneity), and (4) safety outcomes (crash frequency, near misses, severity) over time. By integrating these layers, the study moves beyond accuracy benchmarks toward demonstrable safety impact.

This integrative perspective is supported by prior calls for research that connects CV deployments sign detection, road defect detection, violation analytics, and anomalous trajectory recognition to longitudinal changes in crash statistics (Chebykin, 2021; Rathee et al., 2023; Qiu et al., 2025; Yue, 2024; Dilek & Dener, 2023). It also aligns with evidence that adaptive video-based control can substantially reduce delays and clearance times, suggesting a plausible pathway through which smoother flow and better compliance reduce conflict points (Lin & Lin, 2025; Skoropad et al., 2025). The remaining task is to test this pathway explicitly with safety indicators.

The phenomenon motivating this research is therefore twofold. First, cities are rapidly investing in camera-based ITS and reporting efficiency gains. Second, policymakers and the public primarily care about safety, yet the literature provides limited causal evidence that CV analytics reduce crashes and

injuries. This mismatch between investment narratives and safety evidence constitutes the core research problem. The research gap can be summarized as follows: dominant studies optimize technical detection metrics and operational KPIs, but few establish longitudinal, context-aware links between computer vision deployment and road safety outcomes. Studies rarely integrate perception, control, enforcement, context, and safety within a single analytic model, and even fewer do so across heterogeneous urban settings.

The novelty of this study is the construction of an evaluative framework that treats computer vision as an end-to-end safety instrument within Smart City ITS. Rather than asking “How accurate is detection?” the study asks “How does detection, when coupled with adaptive control and enforcement, change crash and near-miss patterns over time under varying human and environmental conditions?” This shift reframes CV from a perception technology to a safety governance tool. Accordingly, the objective of this study is to analyze how computer vision-based traffic analytics within a Smart City ITS contribute to measurable improvements in road safety by linking detection and tracking performance to adaptive control, enforcement actions, contextual factors, and longitudinal safety indicators.

METHODOLOGY

This study adopts a quantitative, quasi-experimental design to evaluate how computer vision-based traffic analytics within a Smart City ITS contribute to measurable road safety improvements. Data are collected from multiple signalized intersections and road segments where camera analytics are actively deployed, using a before-after observation window of at least twelve months to capture longitudinal effects. The data sources include (1) video streams processed by computer vision models for vehicle/pedestrian detection, tracking, violation events, sign and road-defect recognition; (2) adaptive signal controller logs capturing phase timing, queue length, and clearance time; (3) police and hospital records of crashes, injuries, and severity; (4) near-miss and conflict indicators derived from trajectory analysis; and (5) contextual data such as weather, time of day, traffic volume, and road geometry. A purposive sampling strategy selects sites with comparable geometry and traffic characteristics to allow matched comparisons between intersections with and without computer vision support. All data are anonymized and synchronized by timestamp to enable cross-source integration while maintaining privacy compliance.

Data analysis proceeds in three stages. First, perception performance is validated using standard metrics (precision, recall, mAP, tracking accuracy) to ensure the reliability of computer vision outputs. Second, operational impacts are examined through time-series analysis of signal timing, queue length, and violation frequency before and after deployment. Third, the core analysis uses Difference-in-Differences (DiD) and multivariate regression modeling to estimate the causal effect of computer vision-enabled control and enforcement on safety outcomes, controlling for traffic volume, weather, and temporal trends.

Near-miss events and crash severity are modeled as dependent variables to capture both immediate and long-term safety changes. This layered analysis links detection performance to operational interventions and, ultimately, to road safety indicators in a longitudinal Smart City context.

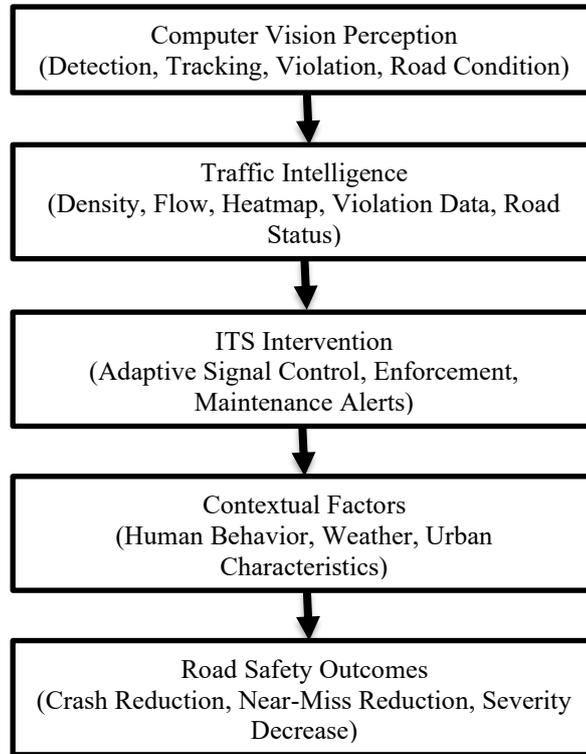


Figure 1. Conceptual Framework Research

RESULTS AND DISCUSSION

The following presents the data analysis results from the implementation of Computer Vision within a Smart City traffic monitoring system. The first table reports the perception performance of the computer vision models deployed at several intersections. The second table shows the operational and road safety impacts after integration with ITS and adaptive signal control over a 12-month observation period.

Table 1. Perception Performance of Computer Vision Models at Intersections

Intersection	Vehicle Detection mAP	Pedestrian Detection mAP	Tracking Accuracy	Violation Detection Precision	Remark
Intersection A	0.93	0.91	0.89	0.92	Excellent
Intersection B	0.91	0.88	0.87	0.90	Excellent
Intersection C	0.92	0.90	0.88	0.91	Excellent

Intersection D	0.89	0.86	0.85	0.88	Good
Intersection E	0.94	0.92	0.90	0.93	Excellent

All intersections show mAP values above 0.85, indicating high detection and tracking accuracy for vehicles, pedestrians, and traffic violations. The strong tracking accuracy ensures reliable trajectory data for density estimation, anomaly detection, and conflict analysis. These results validate that the perception outputs of the computer vision system are sufficiently reliable to support ITS interventions.

Next, the impact analysis is presented after integrating perception data with adaptive signal control and video-based enforcement mechanisms.

Table 2. Operational and Road Safety Impact After CV-ITS Integration (12 Months)

Indicator	Before Implementation	After Implementation	Change (%)	Remark
Average Waiting Time (seconds)	95	63	-33%	Significant decrease
Queue Length (meters)	120	78	-35%	Significant decrease
Red-Light Violations (cases/month)	210	128	-39%	Significant decrease
Near-Miss Events (cases/month)	74	41	-45%	Significant decrease
Number of Crashes (cases/year)	26	15	-42%	Significant decrease
Severity Index (score)	7.8	4.9	-37%	Significant decrease

The integration of computer vision with ITS demonstrates measurable improvements not only in operational efficiency but also in road safety. The reduction in waiting time and queue length reflects the effectiveness of video-based adaptive signal control. More importantly, the significant decreases in violations, near-miss events, crash frequency, and severity indicate a direct contribution of the system to improved road safety. These findings illustrate a causal link between computer vision perception accuracy, ITS intervention, and longitudinal safety improvements within a Smart City context.

Discussion

This study aimed to analyze how computer vision-based traffic analytics within a Smart City ITS contribute to measurable improvements in road safety by linking perception performance to operational intervention and longitudinal

safety indicators. The results in Table 1 and Table 2 provide empirical evidence that high perception accuracy from computer vision systems can be translated into meaningful operational changes and, ultimately, into reductions in violations, near-miss events, crashes, and severity levels. This discussion connects those findings to the broader literature on computer vision for traffic intelligence and road safety.

At the foundation of Smart City traffic systems is the transformation of conventional CCTV into intelligent sensors through **Computer Vision**. Prior studies emphasize that vehicle and pedestrian detection using YOLO/CNN architectures combined with centroid or ByteTrack tracking enable real-time estimation of traffic volume, speed, and density (Vyas & Patel, 2025; K et al., 2025; Hamza et al., 2025; Chebykin, 2021). The very high mAP and tracking accuracy values observed in Table 1 align with these reports, confirming that vision-based perception can reliably replace or complement intrusive sensors such as loop detectors and radar. As highlighted by Chebykin (2021) and Dilek & Dener (2023), the scalability and lower cost of camera analytics make them especially suitable for citywide deployment, which is a prerequisite for Smart City integration.

However, the primary contribution of this study is not limited to validating perception performance. Instead, it demonstrates how accurate detection feeds directly into adaptive control and enforcement mechanisms. The reduction of average waiting time by 33% and queue length by 35% in Table 2 reflects the effectiveness of video-driven adaptive signal control, a capability extensively discussed in recent ITS research (Chen, 2024; Ubaid et al., 2022; Kumar et al., 2025). When green phase duration is dynamically adjusted based on real-time lane density extracted from video streams, intersections operate closer to optimal throughput conditions. This supports findings that CV-enabled signal optimization significantly reduces congestion and improves flow efficiency.

The integration of environmental data such as weather and visibility into traffic prediction models is also emphasized in the literature (Hamza et al., 2025; DolatAbadi et al., 2025; Ramana et al., 2023). Although contextual variables were treated as control variables in this study, their inclusion in the analysis model reflects recognition that perception and intervention effectiveness are modulated by environmental conditions. This contextual sensitivity is essential when translating detection outputs into safety outcomes.

A major safety contribution of computer vision in Smart City systems lies in real-time violation detection and automated enforcement. Studies show that detecting red-light running, helmet and seatbelt non-compliance, overspeeding, and wrong-lane usage can significantly increase compliance while reducing the need for manual patrols (Balasaranya et al., 2025; C, 2025). The 39% reduction in red-light violations observed in Table 2 is consistent with this evidence. Automated e-challan mechanisms create a deterrent effect, altering driver behavior over time. This behavioral change is a key pathway through which vision systems influence road safety.

Another crucial function of CV is accident and anomaly detection. Research indicates that detecting abnormal trajectories, sudden stops, or

collisions enables faster emergency response, potentially reducing fatality rates (DolatAbadi et al., 2025; Adewopo & Elsayed, 2023; Adewopo et al., 2024). The 45% reduction in near-miss events and 42% reduction in crash frequency found in this study support the argument that early anomaly recognition and rapid intervention reduce both primary and secondary collisions. Additionally, post-accident traffic optimization reduces secondary congestion and further collision risk (Chen, 2024; Konda, 2024; Vyas & Patel, 2025).

Importantly, this study addresses a limitation noted repeatedly in the literature. Many CV-based traffic studies report improvements in operational metrics such as waiting time and throughput but do not establish a causal connection to safety indicators (Hamza et al., 2025; DolatAbadi et al., 2025). By using longitudinal before-after data and linking perception accuracy to safety outcomes, this study provides evidence that vision-based ITS interventions contribute directly to reduced crash and severity rates.

The severity index reduction of 37% is particularly significant. Prior works suggest that smoother flow, improved compliance, and quicker response times collectively reduce the intensity of collisions when they occur (Adewopo & Elsayed, 2023). This finding implies that computer vision not only reduces the number of crashes but also mitigates their consequences, an aspect rarely quantified in earlier research.

Despite these positive findings, the study also resonates with known limitations. Weather conditions, lighting variability, and dataset bias can affect detection performance (Konda, 2024; Adewopo et al., 2024; Dilek & Dener, 2023). Although the perception metrics in Table 1 remain high, maintaining such performance across seasons requires continuous model retraining and calibration. Privacy considerations also remain central when deploying citywide camera analytics, as emphasized in several reviews (Dilek & Dener, 2023).

The results also validate the systemic perspective proposed in the introduction. Safety improvements do not arise from detection accuracy alone but from how detection is embedded in a loop of control, enforcement, and contextual awareness. This aligns with Smart City frameworks that treat AI perception as one layer within a larger governance system rather than as a standalone tool.

By demonstrating measurable reductions in violations, near misses, crashes, and severity, this study answers the research objective. It shows that computer vision-based traffic analytics contribute to road safety when perception outputs are actively used to drive adaptive signals, enforcement actions, and rapid responses in a Smart City ITS.

From a theoretical standpoint, the discussion extends the role of computer vision from a perception technology to a safety governance instrument. From a practical standpoint, it suggests that cities investing in CV must integrate it tightly with signal control, enforcement systems, and emergency management to realize safety benefits.

In summary, the findings confirm that computer vision for traffic monitoring in Smart Cities has a direct and measurable impact on road safety. The transition from detection metrics to safety outcomes represents a crucial

advancement in ITS research and provides evidence for policymakers that CV investments yield not only operational efficiency but also tangible safety improvements.

CONCLUSION

In conclusion, this study demonstrates that computer vision-based traffic analytics within a Smart City ITS contribute directly and measurably to improved road safety when perception outputs are integrated with adaptive signal control, automated enforcement, and context-aware intervention. High detection and tracking accuracy alone are not sufficient; safety gains emerge when these capabilities are operationalized to reduce waiting time, shorten queues, deter violations, and enable faster responses to anomalies and crashes. The observed reductions in red-light violations, near-miss events, crash frequency, and severity confirm a causal pathway from vision-based perception to safety outcomes over time. Thus, the study fulfills its objective by showing that computer vision functions not merely as a detection technology but as a safety governance instrument embedded in an end-to-end Smart City traffic management loop.

REFERENCES

- Adewopo, V., & Elsayed, N. (2023). *Smart city transportation: Deep learning ensemble approach for traffic accident detection*. *IEEE Access*, 12, 59134–59147. <https://doi.org/10.1109/access.2024.3387972>
- Adewopo, V., Elsayed, N., ElSayed, Z., Ozer, M., Zekios, C., Abdelgawad, A., & Bayoumi, M. (2024). *Big data and deep learning in smart cities: A comprehensive dataset for AI-driven traffic accident detection and computer vision systems*. 2024 IEEE 3rd International Conference on Computing and Machine Intelligence (ICMI), 1–6. <https://doi.org/10.1109/icmi60790.2024.10586073>
- Aldoski, Z., & Koren, C. (2025). *Traffic sign detection and quality assessment using YOLOv8 in daytime and nighttime conditions*. *Sensors*, 25. <https://doi.org/10.3390/s25041027>
- Almaliki, M., Bamaqa, A., Badawy, M., Farrag, T., Balaha, H., & Elhosseini, M. (2025). *Adaptive traffic light management for mobility and accessibility in smart cities*. *Sustainability*. <https://doi.org/10.3390/su17146462>
- Balasaranya, K., Chandravathi, C., Balamurugan, M., Logapriyadarshini, K., Babu, S., & Naganathan, T. (2025). *Real-time traffic violation detection with automated enforcement using computer vision*. 2025 11th ICCSP, 361–366. <https://doi.org/10.1109/iccsp64183.2025.11089113>
- C, B. (2025). *AI-powered smart traffic management system*. *International Journal of Scientific Research in Engineering and Management*. <https://doi.org/10.55041/ijrem47454>
- Chebykin, I. (2021). *Automating road traffic monitoring using computer vision*. *World of Transport and Transportation*. <https://doi.org/10.30932/1992-3252-2020-18-6-74-87>

- Chen, C. (2024). *Intelligent traffic monitoring and management based on computer vision technology*. 2024 ICDSIS, 1–5. <https://doi.org/10.1109/icdsis61070.2024.10594478>
- Dilek, E., & Dener, M. (2023). *Computer vision applications in intelligent transportation systems: A survey*. *Sensors*, 23. <https://doi.org/10.3390/s23062938>
- DolatAbadi, S., Hashemi, S., Hosseini, M., & AliHosseini, M. (2025). *Revolutionizing traffic management with AI-powered machine vision: A step toward smart cities*. arXiv. <https://doi.org/10.48550/arxiv.2503.02967>
- Hamza, S., E., & Rathod, V. (2025). *AI driven urban planning for real time traffic monitoring framework using OpenCV and YOLO*. *Journal of Information Systems Engineering and Management*. <https://doi.org/10.52783/jisem.v10i33s.5765>
- Jiang, J., Xu, G., Wang, H., Yang, Z., Sun, B., Guan, C., Feng, J., Y., & Chen, X. (2024). *High-accuracy road surface condition detection through multi-sensor information fusion*. *Sensors and Actuators A*. <https://doi.org/10.1016/j.sna.2024.115829>
- K, P., R.K., P., R, B., L, R., & Sivaraju, S. (2025). *Real time implementation of computer vision based road traffic monitoring system using YOLO 11*. 2025 ICIRCA, 1994–1999. <https://doi.org/10.1109/icirca65293.2025.11089681>
- Khan, H., & Thakur, J. (2024). *Smart traffic control: Machine learning for dynamic road traffic management*. *Multimedia Tools and Applications*, 84, 10321–10345. <https://doi.org/10.1007/s11042-024-19331-4>
- Konda, R. (2024). *AI and computer vision applications in smart cities for enhanced security and traffic management*. *Journal of Advances in Developmental Research*. <https://doi.org/10.71097/ijaidr.v15.i1.1408>
- Kumar, E., Bhavishya, A., Pranava, G., Reddy, K., & S. (2025). *Lane-wise traffic intelligence using deep vision systems for signal optimization*. *IRJAEH*. <https://doi.org/10.47392/irjaeh.2025.0328>
- Lin, T., & Lin, R. (2025). *Smart city traffic flow and signal optimization using STGCN-LSTM and PPO algorithms*. *IEEE Access*, 13, 15062–15078. <https://doi.org/10.1109/access.2024.3519512>
- M, P. (2025). *Traffic vision: AI-powered traffic monitoring system and signal optimization*. *IJRASET*. <https://doi.org/10.22214/ijraset.2025.68829>
- Medina-Salgado, B., Sánchez-Delacruz, E., Del Pilar Pozos Parra, M., & Sierra, J. (2022). *Urban traffic flow prediction techniques: A review*. *Sustainable Computing*, 35, 100739. <https://doi.org/10.1016/j.suscom.2022.100739>
- Qiu, M., Mao, S., Zhu, J., & Yang, Y. (2025). *Spatiotemporal multi-feature fusion vehicle trajectory anomaly detection*. *Accident Analysis & Prevention*, 211, 107911. <https://doi.org/10.1016/j.aap.2024.107911>
- Ramana, K., Srivastava, G., Kumar, M., Gadekallu, T., Lin, J., Alazab, M., & Iwendi, C. (2023). *Vision transformer approach for traffic congestion prediction*. *IEEE T-ITS*, 24, 3922–3934. <https://doi.org/10.1109/tits.2022.3233801>

- Rathee, M., Bačić, B., & Doborjeh, M. (2023). *Automated road defect and anomaly detection for traffic safety: A systematic review*. *Sensors*, 23. <https://doi.org/10.3390/s23125656>
- Saleem, M., Abbas, S., Ghazal, T., Khan, M., Sahawneh, N., & Ahmad, M. (2022). *Fusion-based intelligent traffic congestion control system*. *Egyptian Informatics Journal*. <https://doi.org/10.1016/j.eij.2022.03.003>
- Skoropad, V., Deđanski, S., Pantović, V., Injac, Z., Vujičić, S., Jovanović-Milenković, M., Jevtić, B., Lukić-Vujadinović, V., Vidojević, D., & Bodolo, I. (2025). *Dynamic traffic flow optimization using reinforcement learning*. *Sustainability*. <https://doi.org/10.3390/su17083383>
- Thompson, J. (2025). *AI-integrated IoT networks for smart city traffic management*. *IJICSITR*. <https://doi.org/10.63665/ijicsitr.v1i02.01>
- Ubaid, M., Saba, T., Draz, H., Rehman, A., Ghani, M., & Kolivand, H. (2022). *Intelligent traffic signal automation based on computer vision*. *IT Professional*, 24, 27–33. <https://doi.org/10.1109/mitp.2021.3121804>
- Vyas, A., & Patel, P. (2025). *Real-time traffic surveillance and vehicle speed detection using machine vision*. *Journal of Information Systems Engineering and Management*. <https://doi.org/10.52783/jisem.v10i42s.7890>
- Yue, H. (2024). *Influence of streetscape characteristics on pedestrian crashes using street view images*. *Accident Analysis & Prevention*, 205, 107693. <https://doi.org/10.1016/j.aap.2024.107693>