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| **Autonomous Traffic Flow Control Through V2X Communication** |

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***Abstract*—** *The development of a cutting-edge Traffic Sign Detector (TSD) system represents a significant stride towards bolstering road safety and traffic management. This system integrates state-of-the-art technology, leveraging a Convolutional Neural Network (CNN) meticulously trained on an extensive dataset of annotated traffic sign images. Its prowess lies in accurately recognizing, categorizing, and localizing traffic signs within images and videos, facilitating better decision-making in road safety and traffic control measures. The system's adaptive learning mechanisms and domain adaptation strategies enable it to generalize effectively across diverse environmental conditions, ensuring consistent performance and reliability in real-time scenarios. Its contribution to road safety and traffic management is substantial, aiding in enhancing driver awareness and compliance while supporting intelligent traffic management systems to minimize accidents and optimize traffic flow. In parallel, the amalgamation of autonomous technologies and Vehicle-to-Everything (V2X) communication emerges as a transformative force in refining traffic flow dynamics. Research endeavours focus on developing robust theoretical models and innovative algorithmic frameworks for autonomous traffic management. The objective is to seamlessly integrate with cutting-edge V2X communication, fostering an environment where vehicles communicate with each other and surrounding infrastructure to enhance traffic coordination, reduce congestion, and improve overall road safety. Meticulous simulation-based analyses assess the adaptability and performance of proposed systems within dynamic traffic scenarios, considering factors like real-time data exchange, predictive analytics, and responsiveness to unforeseen events. Ethical considerations, data privacy intricacies, and broader societal implications are integral components of this research. As vehicles communicate seamlessly with each other and surroundings, addressing ethical and privacy concerns becomes imperative for responsible and secure implementation of these technologies. This research contributes nuanced insights to the ongoing discourse on intelligent traffic control systems, aiming to propel the development and implementation of sophisticated traffic management solutions for a safer, more optimized, and ethically sound urban mobility ecosystem. The ultimate aspiration is to pave the way for a future where autonomous technologies and V2X communication collaboratively redefine the dynamics of urban transportation.*

# I. INTRODUCTION

The development of cutting-edge systems for the automatic identification and categorization of traffic signs from images and videos stands as a monumental leap in computer vision and deep learning technologies. Leveraging state-of-the-art techniques, these systems redefine how we interpret and interact with traffic signs, ultimately impacting road safety and transportation systems. By empowering machines to accurately recognize and classify diverse traffic signs, these systems contribute to mitigating road accidents and optimizing traffic management. The fusion of autonomous vehicles and advanced traffic sign detection systems represents a strategic initiative aimed at addressing the challenges of urbanization. By leveraging technology, communication, and urban planning, cities aspire to create a more sustainable and harmonious urban landscape. The implications are profound, ranging from safer roads and reduced congestion to improved quality of life for residents. As we advance towards this future, collaborative efforts in technology and urban planning converge to shape a more efficient and liveable urban environment. In the face of challenges like congested roads and traffic jams, cities are exploring innovative solutions that combine self-driving cars, smart communication systems, and strategic traffic planning. This vision of the future aims to make city streets less chaotic and more efficient. At its core are self-driving cars, poised to revolutionize transportation in urban environments. Central to enhancing their capabilities is the implementation of Vehicle-to-Everything (V2X) communication, allowing autonomous vehicles to share information with their surroundings, including other vehicles and traffic infrastructure. This cooperative interaction seeks to optimize traffic flow, reduce congestion, and enhance overall transportation efficiency, envisioning a city where vehicles seamlessly navigate through dynamic traffic scenarios, making split-second decisions to optimize traffic flow.

## II. LITERATURE SURVEY

Traffic sign detection stands as a cornerstone in the evolution of intelligent transportation systems, playing a pivotal role in enhancing road safety and operational efficiency [1]. The precise identification of traffic signs serves as a fundamental conduit for communication between road infrastructure and vehicles, catering to the needs of both human drivers and autonomous vehicles alike [2]. However, the formidable challenges inherent in traffic sign detection, including illumination variations, occlusions, and the dynamic nature of traffic environments, underscore the imperative for the development of robust detection algorithms [3]. This comprehensively explores the evolutionary trajectory of these algorithms, tracing their progression from conventional computer vision methodologies to contemporary deep learning paradigms [4]. Additionally, the survey scrutinizes methodologies related to data augmentation and pre-processing techniques, crucial components aimed at fortifying the resilience of traffic sign detection systems in challenging real-world conditions [5]. Moreover, a meticulous examination of evaluation metrics is undertaken, focusing on parameters such as accuracy, precision, recall, and their practical applicability in real-world scenarios [6]. The integration of traffic sign detection systems into broader intelligent transportation frameworks is scrutinized, shedding light on the symbiotic relationship between traffic sign detection and advanced traffic management strategies [7]. A discerning exploration of the adaptability of traffic sign detection algorithms to diverse environmental conditions is a focal point, examining their ability to generalize across disparate regions and varying traffic scenarios [8]. By providing an intricate and nuanced overview, this literature survey aspires to contribute substantive insights to the collective understanding of traffic sign detection systems [9]. It is poised to serve as a valuable resource for researchers, developers, and practitioners dedicated to the continual refinement and advancement of traffic sign detection technologies. Automatic recognition of traffic signs, exemplified by advanced algorithms like Mask R-CNN, plays a pivotal role in traffic sign detection projects [10]. With an error rate of less than 3% for a comprehensive set of 200 categories, these technologies contribute to the accuracy and reliability of traffic sign detection systems [11]. Moreover, the adaptability of Mask R-CNN to diverse environmental conditions aligns seamlessly with the goals of traffic sign detection projects, ensuring consistent performance in real-world situations [12]. Furthermore, automated traffic sign recognition significantly contributes to the scalability and efficiency of traffic sign detection projects, enabling the processing of large volumes of data in real-time, especially in urban areas with high traffic density [13].The introduction of new data-driven systems in traffic sign recognition represents a transformative advancement [14]. These systems not only recognize all categories of traffic signs but also adopt a comprehensive approach by encompassing both symbol-based and text-based signs within video sequences [15]. By recognizing a diverse range of sign types, including symbols and textual information, these systems exhibit high adaptability crucial for applications in advanced driver assistance systems (ADAS) and autonomous vehicles. They contribute to a more robust and reliable performance, ensuring effective navigation through complex traffic scenarios. In the context of traffic sign detection projects, the integration of such data-driven systems enhances the project's objectives, especially in scenarios where various sign types coexist. This holistic recognition approach not only contributes to the safety of road users but also reinforces the adaptability of traffic sign detection systems in diverse and dynamic traffic conditions. Furthermore, there has been a significant surge in research aimed at advancing the capabilities of autonomous vehicles through innovative technologies and communication systems. Beginning with foundational work on mixed vertical-and-horizontal-text traffic sign detection and recognition for street-level scenes [16], studies have laid the groundwork for enhancing perception systems crucial for safe autonomous vehicle operation in complex urban environments. Further exploration delved into automated vehicle-involved traffic flow studies [17], offering valuable insights into evolving traffic dynamics. Subsequent focus on V2X communication-aided autonomous driving [18] emphasized its pivotal role in achieving safer and more efficient autonomous driving. Meanwhile, investigations into V2X communication challenges [19] and optimization of communication protocols [20] contributed to enhancing communication efficiency. Addressing security concerns, research on jamming attacks in vehicular networks proposed robust security measures [21]. Additionally, the integration of V2X technologies [22] promises transformative potential in creating interconnected transportation networks. Deep learning applications, including semantic segmentation architectures tailored for autonomous driving [23], further enhance vehicle perception capabilities. Optimization-based approaches for resilient traffic control under V2X communication [24] aim to ensure safe intersection operation. Comprehensive surveys on traffic flow studies [25] and the impacts of connected and autonomous vehicles on traffic efficiency [26] provide insights into broader transportation implications. Exploration extends to V2X communication between connected vehicles and unmanned aerial vehicles [27], as well as the design of V2X control architecture [28] essential for autonomous driving systems. Advocacy for enhancing transportation systems through V2X communication [29] underscores its transformative potential, while studies on enabling communication technologies [30] consolidate evolving research landscapes. Critical reviews of the current state of autonomous driving [31] contribute to understanding research progress and identifying future directions. Further research on cooperative control systems [32] leverages deep reinforcement learning to optimize traffic flow, while studies on user privacy perceptions [33] shed light on adoption challenges. Infrastructure-related studies [34] emphasize the importance of reliable communication for intersection traffic control. Investigations into optimization frameworks for traffic efficiency [35], cellular V2X communications [36], and alternative communication protocols [37] further advance communication technologies. Additionally, congestion control methods [38] enhance V2X communication reliability, while cybersecurity solutions [39] fortify autonomous vehicle security. Looking to the future, research on autonomous vehicle impacts [40] and enhancements to V2X communication systems [41] anticipate evolving transportation landscapes. Cooperative autonomous driving [42] aims to optimize traffic flow, while studies on platoon management [43] and heterogeneous traffic stability [44] inform robust traffic management strategies. Finally, research on the stability of heterogeneous traffic [45] explores the impacts of platoon management with multiple time delays, contributing to our understanding of complex traffic dynamics.

III. PROPOSED METHOD

A diagram of a software development process

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Fig.1. Modular Sequencing for TSD

A diagram of a process flow

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Fig.2. System architecture for TSD

**A diagram of a flowchart

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Fig.3. Modular Sequencing for V2X System

**A diagram of a traffic signal

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Fig.4. System Architecture for V2X System

1. *Outline*

The objective of this project is to develop a robust Traffic Sign Recognition Model to enhance road safety by accurately identifying and classifying traffic signs. The project encompasses various stages, including data acquisition, pre-processing, model architecture design, compilation, training, evaluation, hyperparameter tuning, interpretability analysis, testing, performance metrics evaluation, results visualization, and potentially deployment. These stages involve meticulous attention to detail, from acquiring diverse datasets and optimizing model architecture to fine-tuning parameters and ensuring interpretability. Through comprehensive documentation and reflection on outcomes, the project aims to advance road safety through innovative technological solutions.

1. *Assumptions*

The assumptions underlying our research are vital for contextualizing the proposed autonomous traffic management system within realistic parameters:

* Reliable V2X Communication: Assumes dependable Vehicle-to-Everything (V2X) communication infrastructure for seamless data exchange.
* Vehicle Compliance: Assumes vehicles comply with communication protocols and traffic regulations for effective coordination.
* Accurate Sensor Data: Relies on precise sensor data, assuming it is reliable and free from significant errors.
* Realistic Traffic Scenarios: Analyses assume realistic traffic scenarios for accurate evaluation of system adaptability.
* Responsive Infrastructure: Assumes surrounding infrastructure, like traffic signals, responds promptly to exchanged data for dynamic traffic management.
* Ethical and Privacy Compliance: Assumes ethical and privacy considerations are responsibly addressed for secure technology implementation.
* Scalability: Implies the system can handle varying scales of urban traffic without significant performance degradation.

1. *System Architecture*

The system architecture, as delineated in Fig. 1 and Fig. 2, embodies the Traffic Sign Detection (TSD) system, while Fig. 3 and Fig. 4 illustrate a sophisticated V2X ecosystem, integrating vehicular interactions, traffic signal dynamics, and safety protocols into urban mobility seamlessly. Operating as a continuous loop orchestrating vehicle movements, it dynamically adapts to inputs from sensors, ensuring efficient traffic flow and safety. The modular design encompasses various components, including Initialization, Continuous Monitoring and Update Loop, Obstruction Detection and Traffic Signal Control, Multi-Agent Traffic Interaction, Real-time Visualization and User Interaction, Enhanced Signalling, and Adaptation to Real-life Sensors and Networks, reflecting a holistic approach towards intelligent transportation systems.

1. *Design of Modules*

Embedded within the dynamic urban landscape, the system embodies a comprehensive V2X framework orchestrating vehicular interactions, traffic signals, and potential road obstructions. Its functionality revolves around distinct modules:

* Initialization: Essential parameters are meticulously defined to establish the simulation framework.
* Continuous Monitoring and Update Loop: Vehicles continuously monitor their positions via sensors, facilitating real-time updates.
* Obstruction Detection and Traffic Signal Control: Utilizes vehicle sensors to identify potential hazards, prompting halts and signalling traffic lights.
* Multi-Agent Traffic Interaction: Seamlessly integrates additional vehicles into traffic flow, showcasing complex interaction dynamics.
* Real-time Visualization and User Interaction: Presents real-time data on vehicle positions, traffic signals, and obstructions through a user-friendly graphical interface.
* Enhanced Signalling: Provides additional visual cues, such as a green arrow upon transitioning to red, improving overall signal comprehension and adherence.
* Adaptation to Real-life Sensors and Networks: Ensures seamless integration with physical sensors, actuators, and communication networks in real urban settings, aligning with practical infrastructure capabilities and constraints.

IV. METHOD EVALUATION

In this module evaluation, we undertake a comprehensive exploration of the development and optimization processes inherent in the creation of a V2X Traffic Sign Detection System, integrating MATLAB. This system represents a critical component in the advancement of intelligent transportation systems, aiming to enhance road safety, traffic efficiency, and overall urban mobility. Throughout the evaluation, we adhere to IEEE standards of scientific rigor and methodology, ensuring robustness and reliability in our findings.

1. *Development and Optimization of V2X Traffic Sign Detection System*

The journey begins with an exhaustive examination of the development and optimization of the V2X Traffic Sign Detection System. We meticulously align system objectives with sustainability goals, leveraging state-of-the-art edge computing principles to optimize system efficiency and performance. Additionally, stringent cybersecurity protocols are implemented to safeguard data integrity and ensure system reliability. Furthermore, the integration of the IEEE 802.11p protocol facilitates seamless communication within the V2X ecosystem, enhancing situational awareness and enabling real-time decision-making capabilities.

1. *Model Training, Evaluation, and Deployment*

Moving forward, we delve into the critical phase of model training, evaluation, and deployment. This phase entails rigorous assessment of the trained model on separate validation sets, employing a suite of performance metrics including accuracy, precision, recall, and F1 score. Techniques such as learning rate scheduling and hyperparameter tuning are meticulously applied to optimize model performance, achieving remarkable results. Various visualization techniques, conforming to IEEE standards, are employed to effectively communicate model performance and facilitate comprehensive understanding and interpretation. Furthermore, integration with real traffic data enhances simulation accuracy, aligning it closely with real-world traffic conditions for robust deployment.

1. *Broader Considerations for Real-World Application*

In addition to technical aspects, we delve into broader considerations crucial for the practical application of the V2X Traffic Sign Detection System. We meticulously analyse and define simulation parameters to create a realistic environment that accurately mirrors real-world conditions, emphasizing safety, adaptability, scalability, and environmental sustainability. Thoughtful discussions on energy consumption and edge computing principles enrich participants' understanding of system efficiency and reliability in diverse urban settings, ensuring comprehensive preparation for real-world implementation challenges.

V. RESULTS AND DISCUSSION

**A diagram of a confused matrix

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Fig.1. Confusion matrix for TSD

A comparison of a graph

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Fig.2. Accuracy and loss for TSD

**A graph with a line going up

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Fig.3. Car Position over time graph for V2X System

A graph with a line and numbers

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Fig.4. Obstruction Detection for V2X System

A graph with a green line

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Fig.5. Change of traffic light for V2X System

A graph with a line

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Fig.6. Delay Time In Sending Obstruction Detected Message for V2X System

A graph of a car signal

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Fig.7. Multiple Cars Position Over Time for V2X System

In this section, we present a meticulous examination of simulated V2X traffic dynamics, encompassing the performance evaluation of the Traffic Sign Detector (TSD) system, assessment of adaptive learning mechanisms, considerations for scope and compliance, and implications for real-world applications. With the rapid advancements in intelligent transportation systems, V2X technologies have emerged as key enablers for enhancing road safety, optimizing traffic flow, and mitigating congestion. The development and optimization of robust traffic sign detection systems play a pivotal role in realizing the full potential of V2X applications, ensuring accurate interpretation of traffic regulations and timely decision-making by autonomous vehicles and intelligent transportation systems. In this context, our study endeavours to evaluate the effectiveness of the TSD system, explore adaptive learning mechanisms for enhancing system robustness, and discuss broader considerations for deployment and future enhancements.

1. *Performance Evaluation of the Traffic Sign Detector (TSD) System*

The evaluation of the TSD system involves meticulous testing procedures to gauge its accuracy and precision in detecting and categorizing traffic signs. Through extensive data acquisition and annotation efforts, a diverse dataset of annotated traffic sign images is gathered to train and validate the TSD system. Various metrics such as detection accuracy, classification precision, recall rates, and F1 scores are computed to assess the system's performance comprehensively. Furthermore, the effectiveness of pre-processing techniques, data augmentation strategies, and model optimization approaches are analysed to ensure robust performance across different environmental conditions and lighting scenarios. The success of the TSD system in accurately identifying regulatory, warning, and informational signs contributes significantly to enhancing road safety and facilitating efficient traffic management.

1. *Assessment of Adaptive Learning Mechanisms and System Robustness*

In addition to performance evaluation, our assessment delves into the integration of adaptive learning mechanisms and domain adaptation strategies to enhance the robustness and real-time performance of the TSD system. By incorporating techniques such as transfer learning, fine-tuning, and ensemble methods, the system demonstrates improved generalization capabilities, enabling it to adapt to dynamic traffic scenarios and varying road conditions. Moreover, the implementation of reinforcement learning algorithms allows the TSD system to continuously learn and refine its detection capabilities based on feedback from real-world interactions. Through rigorous testing and validation procedures, the system's reliability and responsiveness are evaluated, paving the way for more effective traffic management solutions in urban environments.

1. *Considerations for Scope and Compliance*

A comprehensive analysis of the project's scope encompasses various aspects such as legal and safety compliance, data management protocols, integration requirements, and scalability considerations. Furthermore, discussions on testing and validation protocols highlight the importance of ensuring the TSD system's accuracy and reliability in real-world deployment scenarios. Addressing maintenance and support needs, training requirements for end-users, documentation standards, and cost analysis provide stakeholders with a holistic understanding of the project's implementation challenges and resource implications. Additionally, insights into future implications explore the potential integration of advanced machine learning techniques, optimization of communication protocols, and considerations for scalability and environmental sustainability. By addressing these factors, the TSD system holds promise for revolutionizing road safety and traffic management practices, ushering in a new era of intelligent transportation systems.

VI. CONCLUSION AND FUTURE ENHANCEMENS

1. *Conclusion*

The V2X MATLAB project and the development of the Traffic Sign Detector (TSD) system represent significant advancements in the realms of connected vehicle simulations and traffic sign recognition technology, respectively. Leveraging state-of-the-art technologies and methodologies, both projects have demonstrated their potential to enhance road safety, optimize traffic management, and contribute to the efficiency of transportation systems. The V2X MATLAB project showcases the efficacy of connected vehicle simulations in advancing road safety and optimizing traffic management. Through meticulous representation of urban traffic dynamics, the project has emerged as a valuable tool for comprehending and analysing connected vehicle technologies. Future enhancements, such as dynamic traffic flow optimization algorithms and integration of advanced detection methods, promise to further enhance the project's utility in addressing complex urban mobility challenges. Similarly, the development and implementation of the TSD system mark a significant milestone in traffic sign recognition technology. By leveraging cutting-edge technologies like Convolutional Neural Networks (CNNs) and adaptive learning mechanisms, the TSD system achieved remarkable accuracy and adaptability in identifying and categorizing traffic signs.

1. *Future Enhancements*

Both projects have laid a robust groundwork for future advancements in their fields, including Vehicle-to-Everything (V2X) communication. Through meticulous analyses and thorough examinations, they have identified key challenges and opportunities, paving the way for strategic solutions. Emphasis on compliance and integration needs underscores their commitment to seamless incorporation into existing systems and frameworks, ensuring compatibility and interoperability with V2X networks. Rigorous testing and validation processes instil confidence in the reliability and efficacy of their solutions, validating their potential impact in real-world scenarios. Moreover, the dedication to continuous maintenance and support signifies a long-term commitment to sustainability and evolution, acknowledging the dynamic nature of their respective environments and V2X ecosystems. The adaptability demonstrated by the Traffic Sign Detection (TSD) system across diverse environmental conditions, coupled with its consistent real-time performance, not only underscores its significance in enhancing road safety but also highlights its potential to revolutionize transportation systems by integrating seamlessly with V2X communication networks. As these projects continue to evolve and refine their approaches, they are poised to make significant contributions to their fields, driving innovation and shaping the future of intelligent transportation systems in tandem with V2X technologies.

REFERENCES

1. H. Luo, Y. Yang, B. Tong, F. Wu, and B. Fan "Traffic Sign Recognition Using a Multi-Task Convolutional Neural Network," in IEEE Transactions on Intelligent Transportation Systems, vol. 19, no. 4, pp. 1100-1111, April 2018, doi: 10.1109/TITS.2017.2714691.
2. Z. Liu, J. Du, F. Tian, and J. Wen, "MR-CNN: A Multi-Scale Region-Based Convolutional Neural Network for Small Traffic Sign Recognition," in IEEE Access, vol. 7, pp. 57120-57128, 2019, doi: 10.1109/ACCESS.2019.2913882.
3. X. Bangquan and Xiao Xiong, "Real-Time Embedded Traffic Sign Recognition Using Efficient Convolutional Neural Network," in IEEE Access, vol. 7, pp. 53330-53346, 2019, doi: 10.1109/ACCESS.2019.2912311.
4. R. Chen, L. Hei and Y. Lai, "Image Recognition and Safety Risk Assessment of Traffic Sign Based on Deep Convolution Neural Network," in IEEE Access, vol. 8, pp. 201799-201805, 2020, doi: 10.1109/ACCESS.2020.3032581.
5. Gámez Serna and Y. Ruichek, "Traffic Signs Detection and Classification for European Urban Environments," in IEEE Transactions on Intelligent Transportation Systems, vol. 21, no. 10, pp. 4388- 4399, Oct. 2020, doi: 10.1109/TITS.2019.2941081.
6. Z. Zhao, X. Li, H. Liu and C. Xu, “Improved Target Detection Algorithm Based on Libra R-CNN,” in IEEE Access, vol. 8, pp. 114044-114056, 2020, doi: 10.1109/ACCESS.2020.3002860.
7. A. Avramović, D. Sluga, D. Tabernik, D. Skočaj, V. Stojnić and N. Ilc, “Neural- Network-Based Traffic Sign Detection and Recognition in High-Definition Images Using Region Focusing and Parallelization,” in IEEE Access, vol. 8, pp. 189855-189868, 2020, doi: 10.1109/ACCESS.2020.3031191.
8. D. Tabernik and D. Skočaj, “Deep Learning for Large-Scale Traffic-Sign Detection and Recognition,” in IEEE Transactions on Intelligent Transportation Systems, vol. 21, no. 4, pp. 1427-1440, April 2020, doi: 10.1109/TITS.2019.2913588.
9. S. He et al. , “Automatic Recognition of Traffic Signs Based on Visual Inspection,” in IEEE Access, vol. 9, pp. 43253-43261, 2021, doi: 10.1109/ACCESS.2021.3059052.
10. Taylor de O. Antes, Ana L.C. Bazzan, and Anderson Rocha Tavares Taylor de O. Antes, Ana L.C. Bazzan, Anderson Rocha Tavares, Information upwards, recommendation downwards: reinforcement learning with hierarchy for traffic signal control, Procedia Computer Science, Volume 201, 2022, Pages 24-31, ISSN 1877- 0509, <https://doi.org/10.1016/j.procs.2022.03.006>.
11. J. Kim, J. -K. Kang, and Y. Kim, “A Low-Cost Fully Integer-Based CNN Accelerator on FPGA for Real-Time Traffic Sign Recognition,” in IEEE Access, vol. 10, pp. 84626-84634, 2022, doi: 10.1109/ACCESS.2022.3197906.
12. Z. Zhao, X. Li, H. Liu and C. Xu, “Improved Target Detection Algorithm Based on Libra R-CNN,” in IEEE Access, vol. 8, pp. 114044-114056, 2020, doi: 10.1109/ACCESS.2020.3002860.
13. Zheng Wu, Sheng Ren, “GRTR: Gradient Rebalanced Traffic Sign Recognition for Autonomous Vehicles," in IEEE Transactions on Automation Science and Engineering, doi: 10.1109/TASE.2023.3270202.
14. G. Yildiz, A. Ulu, B. Dızdaroğlu, and D. Yildiz, "Hybrid Image Improving and CNN (HIICNN) Stacking Ensemble Method for Traffic Sign Recognition," in IEEE Access, vol. 11, pp. 69536-69552, 2023, doi: 10.1109/ACCESS.2023.3292955.2023
15. R. Valiente et al. "Robust Perception and Visual Understanding of Traffic Signs in the Wild," in IEEE Open Journal of Intelligent Transportation Systems, vol. 4, pp. 611-625, 2023, doi: 10.1109/OJITS.2023.3298031.
16. J. Guo, R. You and L. Huang, Mixed Vertical-and-Horizontal-Text Traffic Sign Detection and Recognition for Street-Level Scene, in IEEE Access, vol. 8, pp. 69413-69425, 2020, <https://doi:10.1109/ACCESS.2020.2986500>.
17. Haiyang Yu, Rui Jiang, Zhengbing He, Zuduo Zheng, Li Li, Runkun Liu, Xiqun Chen, Automated vehicle-involved traffic flow studies: A survey of assumptions, models, speculations, and perspectives, Transportation Research Part C: Emerging Technologies, Volume 127, 2021, 103101, ISSN 0968-090X, https://doi.org/10.1016/j.trc.2021.103101
18. Jung C, Lee D, Lee S, Shim DH. V2X-Communication-Aided Autonomous Driving: System Design and Experimental Validation. *Sensors*. 2020; 20(10):2903. <https://doi.org/10.3390/s20102903>.
19. Xun Yang, Yunyang Shi, Jiping Xing, Zhiyuan Liu, Autonomous driving under V2X environment: state-of-the-art survey and challenges, Intelligent Transportation Infrastructure, Volume 1, 2022, liac020. <https://doi.org/10.1093/iti/liac020>.
20. Xiaoyun Xie, Yahya Dorostkar Navaei, Sajad Einy, "A Clustering-Based Routing Protocol Using Path Pattern Discovery Method to Minimize Delay in VANET", *Wireless Communications and Mobile Computing*, vol. 2023, Article ID 3776815, 18 pages,2023. <https://doi.org/10.1155/2023/3776815>
21. Anh Tuan Giang, Hoang Tung Tran, Huu Ton Le, Nhat Quang Doan, Minh Huong Nguyen, "Jamming Attack in Vehicular Networks: Adaptively Probabilistic Channel Surfing Scheme", *Wireless Communications and Mobile Computing*, vol. 2022, Article ID 3884761, 8 pages, 2022. <https://doi.org/10.1155/2022/3884761>
22. Znh Tuan Giang, Hoang Tung Tran Huu Ton LeNhat Quang Doan Minh Huong Nguyen, “VEHICLE TO EVERYTHING (V2X) COMMUNICATIONS TECHNOLOGY FOR SMART MOBILITY” <https://doi.org/10.35741/issn.0258-2724.56.4.47>
23. Sharjeel Masood, Fawad Ahmed, Suliman A. Alsuhibany, Yazeed Yasin Ghadi, M. Y. Siyal, Harish Kumar, Khyber Khan, Jawad Ahmad, "A Deep Learning-Based Semantic Segmentation Architecture for Autonomous Driving Applications", *Wireless Communications and Mobile Computing*, vol. 2022, Article ID 8684138, 12 pages, 2022. <https://doi.org/10.1155/2022/8684138>
24. Lu, Qiang & Jung, Hojin & Kim, Kyoung-Dae. (2021). An Optimization-based Approach for Resilient Connected and Autonomous Intersection Crossing Traffic Control under V2X Communication. IEEE Transactions on Intelligent Vehicles. 7. 1-1. 10.1109/TIV.2021.3133841.
25. Haiyang Yu, Rui Jiang, Zhengbing He, Zuduo Zheng, Li Li, Runkun Liu, Xiqun Chen, Automated vehicle-involved traffic flow studies: A survey of assumptions, models, speculations, and perspectives, Transportation Research Part C: Emerging Technologies, Volume 127, 2021, 103101, ISSN 0968-090X, <https://doi.org/10.1016/j.trc.2021.103101>
26. Jung C, Lee D, Lee S, Shim DH. V2X-Communication-Aided Autonomous Driving: System Design and Experimental Validation. *Sensors*. 2020; 20(10):2903. <https://doi.org/10.3390/s20102903>
27. Zyed Adnan Yusuf Arshad Khan Riad Souissi, “Vehicle-to-Everything (V2X) Communication Approach Towards Advanced Intelligent Transportation”. <https://doi.org/10.35741/issn.0258-2724.56.4.47>
28. Haokun Song, Fuquan Zhao, Guangyu Zhu, Zongwei Liu, "Impacts of Connected and Autonomous Vehicles with Level 2 Automation on Traffic Efficiency and Energy Consumption", *Journal of Advanced Transportation*, vol. 2023, Article ID 6348778, 2023. <https://doi.org/10.1155/2023/6348778>
29. Kavas-Torris O, Gelbal SY, Cantas MR, Aksun Guvenc B, Guvenc L. V2X Communication between Connected and Automated Vehicles (CAVs) and Unmanned Aerial Vehicles (UAVs). *Sensors (Basel)*. 2022;22(22):8941. Published 2022 Nov 18. <https://doi:10.3390/s22228941>
30. Dhawankar P, Agrawal P, Abderezzak B, Kaiwartya O, Busawon K, Raboacă MS. Design and Numerical Implementation of V2X Control Architecture for Autonomous Driving Vehicles. *Mathematics*. 2021; 9(14):1696. <https://doi.org/10.3390/math9141696>
31. Guilherme Carrenho, “Enhancing Transportation with Vehicle-to-Everything (V2X) Communication”. Innovation Expert at Encora.
32. Guo, Jiaying & Cheng, Long & Wang, Shen. (2023). CoTV: Cooperative Control for Traffic Light Signals and Connected Autonomous Vehicles Using Deep Reinforcement Learning. IEEE Transactions on Intelligent Transportation Systems. PP. 1-12. 10.1109/TITS.2023.3276416.
33. Ahangar MN, Ahmed QZ, Khan FA, Hafeez M. A Survey of Autonomous Vehicles: Enabling Communication Technologies and Challenges. *Sensors*. 2021; 21(3):706. <https://doi.org/10.3390/s21030706>
34. Manzoor Ahmed Khan, Hesham El Sayed, Sumbal Malik, Talha Zia, Jalal Khan, Najla Alkaabi, and Henry Ignatious. 2022. Level-5 Autonomous Driving—Are We There Yet? A Review of Research Literature. ACM Comput. Surv. 55, 2, Article 27 (February 2023), 38 pages. https://[doi.org/10.1145/3485767](https://doi.org/10.1145/3485767)
35. Zekun Cai and Aiping Xiong. 2023. Understand users' privacy perception and decision of V2X communication in connected autonomous vehicles. In Proceedings of the 32nd USENIX Conference on Security Symposium (SEC '23). USENIX Association, USA, Article 167, 2975–2992.
36. I. Finkelberg et al., "The Effects of Vehicle-to-Infrastructure Communication Reliability on Performance of Signalized Intersection Traffic Control," [https://doi: 10.1109/TITS.2022.3140767.](https://doi:%2010.1109/TITS.2022.3140767.)
37. Backfrieder, C. (2018). *Traffic efficiency optimization through V2X communication* [Dissertation, Technische Universität Wien]. reposiTUm. <https://doi.org/10.34726/hss.2018.54646>
38. Movil, Kathrein, Mavenir (2018). “Cellular V2X Communications Towards 5G”. 5G Americas.
39. Cheung, Y., Qiu, M., Liu, M. (2019). Autonomous Vehicle Communication in V2X Network with LoRa Protocol. In: Qiu, M. (eds) Smart Computing and Communication. SmartCom 2019. Lecture Notes in Computer Science(), vol 11910. Springer, Cham. <https://doi.org/10.1007/978-3-030-34139-8_40>
40. Natsuki UEHARA, Kenya SATO (2022). V2X Communication Congestion Control Method based on Vehicle Flow Management. Computer and Information Science, Graduate School of Science and Engineering, Doshisha University, Kyoto, Japan. [https://doi.org/ 10.14988/00028928](https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwi5wOOku9KDAxXnR2wGHTqZD-sQFnoECBEQAQ&url=https%3A%2F%2Fdoshisha.repo.nii.ac.jp%2Frecord%2F28936%2Ffiles%2F023063010007.pdf&usg=AOvVaw1b4APTiW2c9Zx9Sn2aaBKV&opi=89978449)
41. G. Bendiab, A. Hameurlaine, G. Germanos, N. Kolokotronis and S. Shiaeles, "Autonomous Vehicles Security: Challenges and Solutions Using Blockchain and Artificial Intelligence," in IEEE Transactions on Intelligent Transportation Systems, vol. 24, no. 4, pp. 3614-3637, April 2023, [https://doi: 10.1109/TITS.2023.3236274.](https://doi:%2010.1109/TITS.2023.3236274)
42. Al-Turki M, Ratrout NT, Rahman SM, Reza I. Impacts of Autonomous Vehicles on Traffic Flow Characteristics under Mixed Traffic Environment: Future Perspectives. *Sustainability*. 2021; 13(19):11052. <https://doi.org/10.3390/su131911052>
43. Hobert, Laurens & Festag, Andreas & Llatser, Ignacio & Altomare, Luciano & Visintainer, Filippo & Kovacs, Andras. (2015). Enhancements of V2X Communication in Support of Cooperative Autonomous Driving. IEEE Communications Magazine. 53. 64-70. 10.1109/MCOM.2015.7355568.
44. Dai, Y., Yang, Y., & Zhong, H. (2023). Impact of Platoon Management on Heterogeneous Traffic under V2X Communication Limitation. *Transportation Research Record*, *2677*(5), 1100 1119.  <https://doi.org/10.1177/03611981221140365>
45. Tiancheng Ruan, Linjie Zhou, Hao Wang, Stability of heterogeneous traffic considering impacts of platoon management with multiple time delays, Physica A: Statistical Mechanics and its Applications, Volume 583, 2021, 126294, ISSN 0378-4371, <https://doi.org/10.1016/j.physa.2021.126294>