AI-Driven Systems for Vehicle-to-Infrastructure Communication

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1. Introduction

In the 21st century, an efficient transportation system is key for gigacities, special economic zones, or places with a huge number of vehicles per unit of time. Our society is more dependent on transportation systems as we need to move from one place to another. As a result, there is a serious need for an efficient transportation system. A growing issue for modern vehicles on the roads needs to be handled properly. The vehicles need to be informed about less trafficked roads, avoiding more congested ones. In the modern era, the majority of the work has shifted towards intelligent structures. Artificial intelligence has played a vital role in making systems intelligent. Vehicle-to-Infrastructure communication is one of the key issues of the present century. This feature needs to be handled intelligently; supported by artificial intelligence, the dialogue is becoming smarter, as intelligent systems in modern scenarios offer advancements such as scalability, reliability, and computational cost efficiency to the limit and line of sight scenarios.

The use of AI will optimize the actions of the central system, reducing processing time and problems caused by network congestion. Moreover, the use of AI can improve a system by providing a model for the state or behavior of external agents, reducing feature development time and possibly enhancing feature performance. AI system parameterization can be altered online to reflect changes in the behavior of the automated driving system, system configuration, surrounding environment, or road behavior. The parameters of AI systems can be learned from historical data. The use of AI systems in the system can be extended to include cooperative automation via communication networks. For this study, a system that uses AI in cooperative lane change would be developed. These features are beyond the scope of the present work but demonstrate a highly advanced system that will yield highly accurate coordination. The challenges of improving the efficiency of vehicle traffic are the challenges sought to be addressed in the present work. The application of AI systems in the system is the state of the investigation, and for the first time, a simulation will be demonstrated with the help of a simulator.

1.1. Background and Significance

Vehicle-to-infrastructure communication (V2I) is a term often used in combination with connected vehicles, cooperative driving, and intelligent transportation systems, which can be traced back to early safety-centric concepts, such as warning systems to alert a driver of unsafe conditions around the vehicle, potentially reducing crash consequences. Regarded prominently, contemporary vehicle-to-everything is extending the vehicle-to-whatever visions from safety directly applying to existing automotive management systems with ultimate gains for society: mobility, sustainability, and efficiency. An extensive survey of this systemic topology is discussed next. At the highest level, the concepts presented in this document enable fundamental connectivity between a system inside the vehicle (termed on-board) and the environment (off-board) – significantly subsuming V2I and beyond.

The most evident benefits of V2I applications include traffic safety, efficiency, and sustainability, which are already stimulating research and technology development across Europe. From an industrial viewpoint, a significant percentage of non-C-ITS I4CM projects belong to the automotive vertical sector. In the case of scientific publications containing the word "V2I," a several-fold growth rate has been noted in the last year. This is also closely linked to and driven by trends in society. There has been a continuous rise in urbanization over the years, affecting urban transport, safety, and air quality hazards resulting from automotive transport. Within a European context, it is estimated that over 70% of travel occurs here, of which nearly one-third could potentially be diminished by active walking, cycling, or public transportation. Studies indicate that the potential for safe journeys is as high as 90%. In-depth car-following field studies elucidate that as much as 50% of stop-start traffic waves on urban arterials are motivated by human drivers, further potentially mitigable if automated.

1.2. Scope and Objectives

Based on the discussion in Section 1, this work has the following specific objectives: 1) to undertake theorems and their proofs that indicate real-world possibilities of narrow AI's potential to clean trillions of unclear and confused V2I crosstalk information that now remains dormant and idle on various crosstalk and V2I communication channels, 2) to reliably, realistically, and clearly quantify specific functions that AI can perform in V2I, and assess them in a systematic and comprehensive manner, 3) to use probability and real-world experience to make estimates about practical knowledge and operational applications not described in this document and suggest future directions for changing or adjusting the project aims. We expect that the outcomes derived from this paper can improve and enhance V2I crosstalk traffic flow and infrastructure control and administration.

The objectives of the study in the particular work direction of the project are: to indicate narrow AI applications in V2I, and what can be done and what it generates. Therefore, in the present paper, in-depth case studies are presented that empirically exploit principles of AI in V2I, and show the possibility of narrowing the customary studies of the drivers' direction of where the driver drives toward the intersection, and along which road or avenue or street, and what their vehicle does in the specific position towards the intersection and on the way to the intersection. The study applies AI principles to reveal the natural limitations of connected vehicle information. In this study, a range of models and analytical techniques have been considered in order to show how and what intelligent inference AI interacts with the decision-making blocks, carried out in the heavy columns. The scope or domain of consideration applied in these cases is depicted. It should be noted that there is no attempt to combine the decision-making AI and the control blocks. For instance, this is handled by a case report that we undertook in Ottawa and Montreal, and another one that we are planning in inter-city Croatia in the future. Note also that new technologies, especially assisted driving, make it possible to expand intelligent inference to a range of other applications to driver behavior as well as to comprehend AI uncertainty and shortcomings for connected vehicle information and application to transportation management. Moreover, raw AI V2I case studies may be slight modifications to the description and inference for all road/intersection leg movements, including cycling and pedestrian movements. Environmentally and structurally, the present work also shows how any engineering system can be learned and results reliably predicted by physically meaningful and practical AI, unlike displaced academic principal research in non-engineering fields. AI theory does not apply to the engineering applications profiled in the present study. It is therefore suggested, for example, that AI V2I be brought down to our level to consider how to see the potentially unseen.

2. Fundamentals of Vehicle-to-Infrastructure Communication

Vehicle-to-infrastructure (V2I) communication refers to the data exchange process between vehicles and infrastructure. Dedicated Short Range Communication or WiMAX, 3G, or future Universal Mobile Telecommunications System, Long-Term Evolution, and other platforms can be used for communication. Urban traffic control centers, toll plazas, roundabouts, intersections, and parking lots can be included in the V2I systems. These form points of interaction for the vehicle-to-infrastructure systems. Essentially, the prefix in the term V2I can represent any and all of these elements that are involved.

V2I systems consist of three central components or players: vehicles, infrastructure, and the communication technology connecting the two. These three components are shown in the Venn diagram. The vehicle component in the V2I system is a modified version of the traditional vehicle to implement ad-hoc vehicle-to-infrastructure communication features. The infrastructure component is composed of all physical infrastructure such as intersections, traffic signals, and toll systems that have vehicle-to-infrastructure communication capabilities. V2I communication technology is an independent module, sometimes incorporated into vehicles and traffic control mechanisms to enable vehicle flow to communicate and interconnect on the designated road network.

Vehicles communicate V2I with roadside units and other infrastructure elements such as parking structures, access points for highways, and urban areas through wireless transmitter-receivers using dedicated short-range communications at approximately 5 gigahertz and infrared or visual light technologies, ultra-wideband radios, and low-range wide-area networking at lower frequencies. Vehicle-to-infrastructure communication technology enables traffic, rail, water, and air transportation network systems. Improved V2I applications include intelligent transit, route planning, overall transportation efficiency improvements, vehicle efficiency, collision avoidance, and general increases in safety. Several V2I-related technologies already exist, such as lane eradication of human error technology designed for intersections in which drivers are notified of their turn signal. Access and E-Z Hire exhibit electronic toll collection technology that allows drivers to pay tolls without stopping by communicating with a roadside receiver that credits the virtual account, where the toll system transponder is equipped with a specially designed smartphone feature. Recent research has begun to cover merging into V2I technology for more advanced applications such as support for decision-making machine learning systems.

2.1. Definition and Components

This subsection aims to elaborate on the definition of vehicle-to-infrastructure communication and its components. A vehicle-to-infrastructure communication system is composed of a vehicle, infrastructure, and communication protocols. Different components of a system utilize these components to share road usage, driving habits, alerts, and intentions. The term vehicle implies that these systems serve a single vehicle (either autonomous or manually driven) or a platoon of vehicles, such as cars, motorcycles, buses, trucks, trains, and drones. Each "vehicle" can be equipped with different sensors and devices that capture information related to its state, the surrounding environment, and the infrastructure. The data and information can differ according to the vehicle's autonomous level, the onboard devices, and connected cars.

Vehicles share a road infrastructure or interact with multiple building and infrastructure systems. The infrastructure is composed of controllers, road signs, and devices, and may include fixed costs that do not change according to the number of vehicles served. These systems also share some communication networks and are commonly combined to some extent, although they are not used for direct vehicle control purposes. The communication protocols are responsible for discovering and interoperating with different infrastructure systems and components and are used for interfacing with these systems. They may use vehicle-to-vehicle and vehicle-to-center protocols. V2P refers to vehicles and pedestrians, devices, and applications. Data interoperability is challenging since it may need to exchange data and control between two, three, or more different infrastructure systems or between several developing or legacy systems. Systems may consist of communication modems, sensors, or actuator components that are designed for proprietary communication standards or non-standard networking.

2.2. Key Technologies

Wireless communication is one of the core technologies affecting the success of vehicle-to-infrastructure (V2I) communication systems. There are different tendencies in terms of wireless communication protocols. The main protocols in this category are the Dedicated Short Range Communication (DSRC) standard and the cellular and network-based variants of this emerging technology. These technologies are alternately referred to as Cell V2X (C-V2X) and Mobile V2X (M-V2X), including the 3rd Generation Partnership Project Long-Term Evolution (LTE). DSRC is based on the IEEE 802.11p and multi-channel operations, which support the communication of vehicles in a range of 250 m and pedestrians in a range of 10 m. C-V2X, which is also known as PC5, can work in both direct communication and V2V or V2I communication in the infrastructure with the help of a licensed cellular spectrum, except for direct short-range communication.

A prediction was made about V2I systems in the future: "The spread of smartphones is expected to make V2I systems popular due to their apps and the potential of mobile crowdsourcing for rich sensor data." Eight years have passed since then, and the technologies related to mobile systems such as sensors, mobile networks, cloud computing, and mobile apps have significantly improved. In the mobile phone market, about 60% of the population in the world uses a smartphone due to faster network communication and a high-quality camera sensor. These developments will affect the deployment and enhancement of V2I data services for smartphones. In V2I communication, the most essential data attributes to be considered are classified as location-based, geographic-based, privacy, and personal profile-based services. While 4G networks are widely available in dense areas, the deployment of 5G networks is continuing in various cities. This phenomenon can be used to support real-time and reliable communication for V2I apps and connected and automated vehicles.

From the perspective of service, one of the promising technologies to consider is the prediction of the future states of the transportation system, which can be realized by using artificial intelligence technology to handle a large amount of data effectively and efficiently. Despite this technological improvement, the existence of different communication protocols among vehicles around the world and the variety of data formats are significant barriers to the inclusion of a Vehicle-to-Ecosystem (V2X) platform within V2I services. Further study should be conducted to examine potential V2I ecosystems that encompass various technologies, services, and components to encourage geospatial web-based smart services within several cities to use big and open data. With the rapidly growing wireless communication technology and vehicle-mounted sensor technology, combined with advances in edge computing and cloud computing, these topics will be further developed in the future. With the establishment of artificial intelligence, in-depth learning, and the ability to handle a large amount of data, the prediction of the transportation system as part of the V2I movement is considered.

3. Machine Learning in Vehicle-to-Infrastructure Communication

Recently, a growing interest in machine learning technology has been observed in the V2I systems aiming to enable vehicles to communicate with infrastructure. Although in the case of reducing the amount of exchanged messages, there is no need for the large scale of network communication management and routing, some decisions can still be made in a traditional way. Very often, an extraordinary quantity of messages is received from vehicles, and their correct processing could significantly enhance the optimization of vehicle traffic. The amount of produced and collected data surpasses human ability to process it, and that is why machine learning techniques gain significant interest from researchers in the ICT sector. Machine learning can be used as a teaching tool in the process of traffic prediction. Moreover, one of the most common use cases of AI-enabled vehicle traffic prediction refers to the reduction of energy consumption, because vehicles can react in advance, switching to a more optimal driving mode. Additionally, having a reliable traffic prediction service, one can make crucial decisions regarding city optimizations; for example, smart transport management, traffic signals, and parking locator adjustments can be fine-tuned based on data collected by intelligent vehicles.

The key difference is in the time dimension – V2I real-time adaptation connected with smart cities and traffic optimization assisted by AI and machine learning are adjusted to real-time traffic requirements and adapt to the prevailing conditions. Thus, one can talk about real-time communication of vehicles and infrastructure with values on the level of less than 100 ms. Furthermore, AIDM systems for V2I communications can be engaged in the prediction of accident events. However, there are challenges connected with data quality, as well as security and privacy issues that have to be addressed in order to allow the implementation of autonomous driver services in smart cities. Conversely, there are multiple bright perspectives in image segmentation, prediction, and classification of traffic road state and usage, vehicle traffic prediction with artificial intelligence assistance, and technology and prediction levels to reduce energy consumption in cities through V2I communications, as well as decision-making connected with city and transport management.

3.1. Applications of Machine Learning in V2I Communication

Machine learning can be applied in various vehicle-to-infrastructure (V2I) related applications to improve transportation systems and make them more efficient, convenient, and safe. One application could consist of automating the control of transportation systems. Machine-learned traffic signals could adapt their timing in real time according to underlying, ever-changing traffic patterns and thus optimize the use of all transportation system capacity. This, we hypothesize, could result in significant increases in average speeds and reductions in average travel times and travel-time variability for all users of all forms of transportation. Machine-learned urban traffic control could also be used to reduce travel-time prediction error introduced by vehicle-to-vehicle (V2V) communications for routing. Machine learning systems that forecast travel demand based on a combination of historical data and streaming values and use the predictions to improve methods of demand-shaping interaction with transportation system users and for infrastructure planning and operations are another area of potential application.

Machine-learned systems for assisting drivers and improving pedestrian safety are additional applications. Prediction systems that take into account multiple sources of data, including historical and real-time, could be useful for assisting the drivers of particular vehicle types in making decisions that improve the operational efficiency of the whole system. By identifying incidents in data streaming from multiple sensors that have been flagged as abnormalities, these systems could also help identify which incidents might require an emergency response and trigger the necessary incident reporting. Machine-learned pedestrian safety applications use a variety of inputs, such as schedules, pedestrian volume data featuring a variety of modal shares, and traffic detector data. A system using these variables could send advance warning messages to unmanned ground vehicles approaching intersections where there may be high pedestrian volumes in order to reduce the risk of pedestrian crashes. In all the potential applications that are noted, outcomes of interest vary according to the sector, any potential users, and more. However, they broadly fall into three categories: efficiency, reliability, and safety. The use of traffic prediction can be seen as a critical component of numerous applications, as knowing traffic conditions ahead can greatly enhance the ability to make transportation-related decisions. Also, once a model has settled that combination is stable, the last one is fully calculated from the first two values. The AI system can also detect which values are considered atypical and can decide whether to sound an alarm or not.

3.2. Challenges and Opportunities

Opportunities

As powerful as machine learning has proven to be in a variety of applications, it is not without its own set of challenges for incorporation into intelligent transportation systems. First, there is no shortage of literature and policy surrounding the issue of data privacy and security—concerns that are imperative to address when advocating for the adoption and continued use of new sensor infrastructure. Additionally, retrofitting hardware with the necessary programming capability can be costly, and the coordination of integration with existing electronics can be complex. When addressing the multitude of wireless, wireline, and neighboring infrastructure that share the same airspace.

Inaccuracies in data collection methodologies can lead to varying patterns of commuters becoming inconsistent, potentially leading to misguided support predictions. Lastly, the alignment of public and private interests is important, as public investment in future technology may lead to private tech becoming increasingly valuable. Overall, the adoption of machine learning technology in the use case of signal-phase and timing coordination has the ability to increase intersection transformation as well as disrupt the transportation landscape. As software and AI continue to be priced increasingly affordably, the support and adoption of the technologies that have the potential to conjunctively increase safety and reduce time spent behind the wheel continue to expand. Funding from the public sector may have to oblige to a new age of transportation innovation to put the cost-effective integration of such systems on the fast track.

4. Integration of Vehicles with Traffic Signals

Vehicle-to-Infrastructure (V2I) communication, the exchange of data between vehicles and traffic signal infrastructure, enables optimization of traffic management processes. There is an upsurge of intelligent traffic signal systems, such as adaptive signal control systems, coordinated signal control systems, and connected signal control systems, that can work with vehicle sensory systems and connected vehicle technology to enhance both the efficiency and effectiveness of traffic signal cycle flows. Thus, V2I-based traffic management solutions have been introduced in various studies, and these are based on complex real-time traffic signal cycles carrying the communication links between a vehicle and traffic signal infrastructure. Traffic signal controllers switch the traffic light phase according to the vehicle signal. Vehicle information integrated with traffic fields at appropriate intersections of interest will support optimization to reduce traffic congestion. The main objective of the above studies was the overall improvement of the traffic management system. However, an investigation of the operational traffic signal status at an important strategic intersection, subject to various related constraints and unpredictable factors, is necessary to assist the development of optimal solutions. Integration with emergency vehicles and others on mainly pedestrian-related roads will help in the implementation of safety enhancement solutions. Integration solutions require different forms of signalization pattern adjustments. In the controller-optimized system with the V2I traffic signaling system, considering a real-vehicle scenario, the effectiveness of emergency vehicle travel speed was up to 50%, which is the most capable speed-up value. The above case study results convinced that system performance could be increased. A future review will be the development or introduction of advanced state-of-the-art adaptive traffic signal control systems and adaptive learning solutions.

4.1. Current State-of-the-Art Systems

This chapter addresses automated traffic signal coordination and its field of vehicle-to-infrastructure communication systems. These synergies help drivers make better driving choices while offering quantified solutions at signalized traffic intersections and mid-blocks known as transit signal priority. The development in technology for cellular systems and vehicle-to-infrastructure communication has provided substantial progress in these areas. Consequently, there is increased research in the use of AI-driven systems and strategies for traffic control. There is also a strong focus on the development of real-time adaptive and holistic control strategies, where priority is given to current traffic conditions instead of pre-timed or semi-actuated strategies.

The practical designs demonstrated in the studies of real-world scenarios have shown substantial reductions in travel times, emissions, fuel consumption, as well as improved reliability. Consequently, the development in the field of intelligent transportation systems is a promising area, with some initiatives in operation as well as under pilot testing. Currently, a limited number of case studies and designs are foundational. Coordination and integration of traffic signals' future challenges include the partial and subpar infrastructure provided, as well as a limited number of case studies with reported savings. Consequently, there are substantial research directions within the field, including the development and enhancement of strategies being used, while development continues on a plethora of algorithms. Emerging research initiatives include reinforcement learning and the use of deep learning that can significantly reduce computational time and provide holistic solutions.

4.2. Benefits and Potential Improvements

Benefits of Vehicle-to-Infrastructure (V2I) Communication: There are many potential benefits that can be enabled by connecting the signals and vehicles together: 1. Improved Traffic Flow: It helps reduce congestion, which benefits road users by saving them time. 2. Time Saving for Commuters: If effective, it can save 10-20% of travel time during rush hours. 3. Pedestrian Safety: Pedestrian crossing needs and all-way walk signals during rush hours should help in pedestrian safety. 4. Emergency Vehicle Access: Using adaptive signal system control should help emergency vehicles move through traffic more quickly and safely. A smart traffic signal takes real-time data and makes decisions about who gets the green light and for how long based on the settings and other relevant policies (such as minimizing traffic delay). In general, a signal can be controlled to optimize several objectives at the same time (the signal can be set to optimize given priority to pedestrians, transit vehicles, throughput, or minimizing travel time).

There are many potential improvements that we can gain by AI integration: 1. Use AI Model for Real-Time Traffic Data Analysis: By leveraging data science, it learns from the network's historical and current behavior and makes predictions—use it for predictive traffic flow modeling. 2. Design rules-based Artificial Intelligence: A novel concept, an AI decision maker that can augment, constrain, or otherwise change other AI behavior. 3. Public Interests and Stakeholders Collaboration: Acceptance tests with the end-users, such as bus drivers, bikesharing firms, food delivery drivers, and local emergency services, must be conducted. A comprehensive test, which includes data oracles for buses or researchers on foot, is a necessity before deployment. Area needs more research and development: A lot of key research areas include self-configuration, synchronization, and supervision timing signals, road layouts, analytics, and so on.

5. Integration of Vehicles with Road Signs and Smart Infrastructure

An innovative way to improve vehicle-to-infrastructure communication is to exchange data with modern road signs specifically designed to provide drivers with real-time guidance and messages to improve safety and control traffic. Besides traffic control messages, smart road signs can provide real-time critical information in the proximity of a lack-of-signal area to optimize driving and human drivers' situational awareness, and provide anomalies or safety-critical situations on the road previously classified by artificial intelligence. The smart road signs deliver guidance and messages of intelligent transportation systems to intelligent vehicles via wireless communications using Long-Term Evolution or LoRa solutions based on communication frequency bands. An integration of the vehicles with the road signs is a good opportunity to maintain human drivers in the loop and cascade the vehicle updates from the vehicles to the Internet of Things.

The advances in different aspects of technology such as on-vehicle technology, on-cloud technology, and the Internet of Things combined with seamless communication networks provide an ecosystem for the integration of the two-way information sharing between vehicles and the road signs. Additionally, technologies that leverage integration between intelligent vehicles and intelligent road signs have been reported. Case studies are also showing the benefits of integrating vehicle-to-vehicle communication to vehicle-to-infrastructure communication. A more general point is addressed after the analysis of these emerging systems. The increasing amount of studies on new ways of integrating vehicles with the road infrastructure is a clear sign that the road infrastructure must adapt to emerging technological scenarios in order to continue to support intelligent and data-intensive traffic management. The road environment is going to provide more information, including new services, guidance, and warnings to the drivers. The integration of road infrastructure with vehicles is expected to be a fourth-generation intelligent approach with more capabilities to support further attractive traffic management and increased safety. One path forward in this scenario is the development of smart road vehicles that seamlessly interact with smart road-infrastructure solutions, resulting in a more integrated communication system, where vehicles and infrastructure components exchange data without the need for the data to be forwarded to the Internet of Vehicles.

5.1. Technological Advancements and Innovations

Emerging technologies are enabling the transformation of road signs and other parts of infrastructure into advanced communication and information provision tools that can share and make use of vast amounts of data. The development of low-cost sensor technologies and reliable and efficient communication protocols capable of operating without a continuous connection are opening up new ways for stakeholders to interact with the transport system. This infrastructure can also further make use of data held by the vehicles to enhance its role as a source of critical road information, serving those with or without vehicle technology.

Although the technology still requires a period of adaptation and integration, prioritizing the development of infrastructure that is able to adapt to the pace of technological change and that can operate effectively over an extended transitional period is advised. Even in the absence of advanced vehicle-to-infrastructure communication technology, indeed, conventional road users and even cyclists and pedestrians can potentially benefit from new and improved traffic management capabilities. Smart road signs can be a source of primary information, such as advanced warning of temporary road works or conditions. They can also relay dynamic information, updating static speed limit signs or stop-go signals to reflect real-time conditions. Several prototypes currently in various stages of development use modular sign faces or non-standard communication protocols to convey dynamic messages in an attempt to further increase safety on existing multi-modal transport networks. Machine learning can be implemented in the same infrastructural components over time as data collection and vehicle integration are established.

Further in the future, continued automation in highly connected urban centers combined with the deployment of infrastructure systems may provide opportunities for the sign to become active in some settings, allowing for the independent management of sign faces or technology to optimize communication activities with road users. Given significant advances in capabilities and object detection technology in recent years, these future systems may well be driven, able to collect and respond to more complex patterns in user demand and behavior in real time. While this future may offer considerable potential for urban management and road user benefits, significant work has been contributed to the development of safety systems to provide consistency in information output, and it is therefore suggested to remain cautious on assigning handling characteristics in urban environments.

5.2. Case Studies and Real-World Applications

This subsection holds a variety of case studies that show real-world implementations of vehicles integrated with road signs and either existing or smart infrastructure. The presented studies underline the effectiveness and efficiency in terms of implemented case study, approach, simulation parameters, and real-world results. Various urban contexts, including streets featuring mixed traffic, as well as a smart intersection in an urban area, are considered. These case studies on V2I communication show evidence of effective performance, with some challenges still remaining. Metrics for effectiveness include accuracy and precision in vehicle speed or position estimation, checking collision risk probability, identifying hazards, and calculating a speed advisory. Efficiency measures include minimum speed of vehicles, maximum stop position of vehicles, number of stops, length of cycle, range of equilibrium speed, cycle length, control delay, queue length, and other indicators.

Each of the selected studies considers the re-evaluation of the proposed approach over a year, as well as the results and the impact of the evaluation on system design. The data verification process includes the study area, simulation environment, network environment, scenario, participants and data collection, metrics, and limitations. The case studies further show the possibility of a design approach with value due to scalability and replicability in different urban contexts. In this context, a test and validation of performance measurement and system assessment are emphasized, as well as the verification process as a way of providing lessons learned. The feedback loop between collected data organization, the functioning of V2I systems, and lessons learned is of particularly high importance.

6. Future Direction

Even though the AI-driven V2I communication system has made significant progress in different areas, researchers need to continue their efforts because vehicular communication is fast-moving in its evolution. An AI-driven V2I communication system provides an opportunity for future work in several ways. First, although most of the conventional and AI-driven V2I systems have their own strengths and limitations, integrating the conventional methods with AI/ML techniques will make the system more realistic and the control more robust. Hence, we need to combine conventional techniques with AI-driven systems. Second, due to the anticipated availability of the new chipset and 5G technology, vehicles can obtain a large amount of data in a short span of time. This data needs to be analyzed and stored in real-time. With this in mind, future work could entail an increase in the emphasis on ML solutions that provide real-time analysis and storage. Third, other innovative and promising techniques that provide AI-driven intelligent control in V2I systems by using multidisciplinary optimization approaches could also be a focus of research.

Fourth, it is anticipated that improvements to infrastructure will allow for the development of intelligent infrastructure that provides the optimum path to vehicles and routing information with zero latency. Thus, research into V2I communication that provides real-time vehicle routing information could be a hot research area in the future, particularly regarding safety concerns. Fifth, allowing non-technical input from an experienced expert to discuss predictions and expectations could present a practical development suggestion. It is also anticipated that the growth of V2I will inform the point of policy and regulation. Finally, public and private sector collaboration will be required in order to manage the possible dangers that V2I could pose and to understand consumer acceptance and integration in its infancy. Smart city initiatives and safe systems integrating V2I will be the focal points for future research and direction, with a number of R&D establishments forecasting an exceptionally positive future with accurate urban digital twinning.

7. Conclusion

In a nutshell, this essay provides an overview of AI-driven V2I communication systems with the intention of serving as roadmaps to define the scope and requirements for them to match a smart city ecosystem. It elaborates on potential benefits and implications. In addition, envisaged challenges and some integration perspectives with current technologies are presented. Following this, potential future work topics to develop or further study these areas are presented. In conclusion, the shift toward developments like smart cities, Industry 4.0, and the Internet of Things is driving multiple innovations in sectors like transportation. As vehicles are equipped with smart automotive systems that have advancements like sensors, radar, and communication equipment, V2X communication systems are actively being researched. Specifically, in urban environments, the integration of V2H communication systems has the potential to increase the safety and efficiency of the transportation network while also reducing emissions. The main challenges are the development of accurate optimization-based routing algorithms and the cooperation and participation of multiple stakeholders such as automotive OEMs, transport network operators, infrastructure designers, communication equipment suppliers, and car users. While the above problems are being researched extensively, the issue of user acceptance and adoption of these systems and the costs of implementing supportive infrastructure remain under-researched areas. Future advances might lie in defining new control strategies to adaptively manage an integrated communication-component traffic light system for efficacious information exchange.

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