What is the Historical Development of CAR-2-X Technology?

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Abstract

This paper provides an overview of the historical development of CAR-2-X technology, tracing its origins back to the 1970s and exploring its progression over the years. The introduction highlights the significance of CAR-2-X technology in the advancement of connected and autonomous vehicles, emphasizing the potential for safer and more efficient transportation systems. The research question guiding this research essay is then presented: "What is the historical development of CAR-2-X technology?" The examination of the historical evolution of vehicle communication and cooperative driving technologies involves exploring projects like the US Electronic Road Guidance System, Japan's Cooperative-Adaptive Cruise Control System, and advancements made in the 1980s through the PATH program and the PROMETHEUS project. The challenges faced by early research projects are discussed, leading to the standardization of WLAN-based Vehicle-to-Everything (V2X) systems and the subsequent introduction of cellular V2X (C-V2X) based on Long-Term Evolution (LTE) technology. Finally, future prospects of CAR-2-X technology, particularly its integration with emerging technologies like artificial intelligence and edge computing, and their potential contributions to improved driving experiences and transportation systems are discussed.

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I. Table of Abbreviations

Abbreviation	Meaning
CAR-2-X	Car-to-Everything
V2X	Vehicle-to-Everything
V2I	Vehicle-to-Infrastructure
V2N	Vehicle-to-Network
V2V	Vehicle-to-Vehicle
V2P	Vehicle-to-Pedestrian
V2D	Vehicle-to-Device
V2B	Vehicle-to-Building
ERGS	Electronic Road Guidance System
CAC	Cooperative-Adaptive Cruise Control System
PATH	Partners for Advanced Transit and Highways
IVHS	Intelligent Vehicle Highway System
ADAS	Advanced Driver Assistance Systems
ITS	Intelligent Transportation Systems
PNGV	Partnership for a New Generation of Vehicles
DSRC	Dedicated Short-Range Communications
VII	Vehicle Infrastructure Integration
SAE	Society of Automotive Engineers
IEEE	Institute of Electrical and Electronics Engineers
3GPP	3rd Generation Partnership Project
LTE	Long-Term Evolution
C-V2X	Cellular Vehicle-to-Everything
GM	General Motors
5G	Fifth Generation Network Communication Standard
ML	Machine Learning
AI	Artificial Intelligence
SON	Self-Organizing-Networks

2. Introduction

2.1 Overview

According to research, car accidents are responsible for claiming more than 1.35 million lives annually, making them one of the top causes of death, with about 2,5% of total deaths worldwide. Human error is widely recognized as the leading cause of car accidents. Numerous studies and research have consistently shown that the majority of traffic accidents are attributed to human factors (CompareCamp.com, 2020).

In recent years, self-driving vehicles have emerged as a transformative technology with the potential to revolutionize transportation, especially in the areas of road safety. These driverless cars are an incredible leap forward to a future where humans no longer need to manually drive their automobiles. The ability for these autonomous vehicles to navigate and operate without human intervention is made possible by advanced technologies such as sensors, artificial intelligence, and connectivity. The most notable development within this realm is the CAR-2-X technology. CAR-2-X technology serves as an intelligent communication network that connects vehicles to their surroundings, providing information of road conditions regardless of time or place that can be used to ensure safe navigation. Through this network, vehicles can share valuable data such as location, speed, acceleration, and sensor information with other vehicles and infrastructure components. This real-time data exchange enables vehicles to gain a comprehensive understanding of the road conditions, potential hazards, and the behavior of other road users. The importance of CAR-2-X technology can not be understated since it already traces back to the early stages of autonomous vehicle. As the concept of self-driving vehicles gained traction, researchers and engineers recognized the need for vehicles to communicate with each other and their surrounding environment (David & Flach, 2010).

Over the years, like autonomous vehicles themsevles, CAR-2-X technology has evolved through technological advancements, research projects, and implementations, paving the way for safer, more efficient, and connected autonomous transportation systems. That is why this essay delves into the historical development of CAR-2-X technology, exploring its origins, milestones, and implications for the future.

2.2 Rationale for the Topic

The motivation and rationale behind the topic of “The historical development of CAR-2-X technology” is that it holds significant relevance in the current research landscape. As self-driving vehicles continue to evolve, CAR-2-X technology plays a crucial role in enhancing safety, efficiency, and overall effectiveness. Understanding the history of CAR-2-X technology provides insights into its evolution, challenges faced, and breakthroughs achieved. By examining the past, we can gain a deeper understanding of the present state of CAR-2-X technology and identify potential future developments.

2.3 Aim of the Research Essay

The main goal of this research essay is to present and analyze the historical development of CAR-2-X technology in the context of self-driving vehicles. The specific aim of this research is to discuss this topic and pursue the following research questions:

I. How did CAR-2-X technology evolve from its initial concepts to its current implementation?
II. What were the key technological advancements and milestones?
III. What are the possibilities for the future evolution of CAR-2-X technology?

2.4 Delimitation and Research Methodologies

While the historical development of CAR-2-X technology is a vast subject, this essay will focus on its evolution and milestones from its inception to the present day. The scope of this research will encompass key technological advancements and pioneering research projects. It will explore the transition from early concepts and prototypes to the current state of CAR-2-X technology. However, it is important to note that this essay will not extensively cover the technical intricacies of specific communication protocols or implementation details. Instead, the emphasis will be on providing a comprehensive overview of the historical context, key milestones, and the implications of CAR-2-X technology.

The methodology used in the following research essay is the review of related literature. In this approach, relevant information from multiple literature sources is extracted to resolve the aforementioned research questions.

2.5 Organization and Structure

The research essay begins by tracing the origins of this technology in the 1970s with projects like the US Electronic Road Guidance System and Japan's Cooperative-Adaptive Cruise Control System. It then highlights the contributions of early research projects and technological advancements in the 1980s, such as the PATH program and the PROMETHEUS project, in shaping intelligent transportation systems and vehicle communication protocols. The text further explores the challenges faced by early experiments and the subsequent efforts to address them, leading to the standardization of WLAN-based Vehicle-to-Everything systems. It also acknowledges the introduction of cellular V2X technology based on LTE and its expansion of communication capabilities. The text concludes by emphasizing the crucial role CAR-2-X technology is expected to play in the future, particularly with the ongoing development of 5G networks and the integration of emerging technologies like AI and edge computing.

3. What is the Historical Development of CAR-2-X Technology?

3.1 Introduction to CAR-2-X Technology

3.1.1 Definition and explanation of CAR-2-X technology

The technology known as CAR-2-X, or Vehicle-to-Everything enables communication between a vehicle and any object or being that has an impact on or is impacted by the vehicle. It exchanges information between vehicles and their surrounding, interacting road users and infrastructure. The technology achieves this by transmitting standardized messages to their surroundings, including information on speed, position, and other status data. Receiving vehicles and infrastructure can use this information to enhance the mapping of the environment. This leads to an open communication system between all participants of the traffic system, enabling an exchange of valuable information in real-time.

CAR-2-X is a complex technology with many different sub-categories and technologies. In terms of the underlying technology, two distinct forms of communication exist: WLAN-based and cellular-based. The main types of sub-categories are V2I (Vehicle-to-Infrastructure), V2N (Vehicle-to-Network), V2V (Vehicle-to-Vehicle), V2P (Vehicle-to-Pedestrian), V2D (Vehicle-to-Device), and many more sub-types like V2B (Vehicle-to-Building). V2I involves direct communication between vehicles and infrastructure, while in V2N, communication is based on cellular networks. V2V involves real-time data exchange between nearby vehicles, while V2P refers to situations where vehicles communicate with pedestrians, wheelchairs, or bicycles (U.S. Department Of Transportation, 2016) .

3.1.2 Importance and role of CAR-2-X technology in self-driving vehicles

CAR-2-X technology has become an increasingly important development in the automotive industry, particularly in self-driving vehicles. This technology enables cars to sense and communicate with each other and their environment, providing crucial data for decision-making and safety measures. It is designed to make driving safer, more efficient, and environmentally friendly. It can facilitate smooth traffic flow, reduce congestion and enhance safety for the driver, passenger, and road users. This leads to a significant improvement in road safety and traffic management, with many different use cases like forward collision warning, emergency vehicle approaching, lane change warning, roadworks warning, platooning, and many more. The main objective of CAR-2-X technology is to increase safety, reduce accidents, and assist drivers. The U.S. estimates that implementing a V2V system would result in 439,000 fewer crashes per year, reducing traffic accidents by a minimum of 13% (U.S. Department Of Transportation, 2016).

3.2 Early Concepts and Research

The history of CAR-2-X technology encapsulates decades of research, beginning with prototype and adjacent technology in the 1970s up until the current year 2023. The early concept and research phase of this technology spans from its origin until the year 2010.

3.2.1 Origins of CAR-2-X technology in intelligent transportation systems

The origins of the Car2X technology can be traced back to 1970, with projects such as the US Electronic Road Guidance System (ERGS) and Japan's Cooperative-Adaptive Cruise Control System (CACS).

The US Electronic Road Guidance System was a pioneering project initiated by the United States Department of Transportation in the 1970s. The aim of ERGS was to explore and develop technologies that could enhance road safety and traffic efficiency. The project focused on using sensors and communication systems to gather information about road conditions and share it with vehicles. While not specifically named "Car2X" at the time, the ERGS project laid the groundwork for the concept of vehicle communication and its potential applications.

In parallel, Japan's Cooperative-Adaptive Cruise Control System project was also taking shape. CACS aimed to develop technologies that allowed vehicles to communicate with each other and exchange information related to speed and distance. This early project focused on cooperative driving technologies that could improve traffic flow and reduce congestion through vehicle-to-vehicle communication.

These early projects in the 1970s provided a glimpse into the possibilities of vehicle communication and the potential benefits it could bring to road safety and traffic management. While the technology and systems developed during that time may not have fully realized the Car2X concept as we understand it today, they served as an important foundation in the development and evolution of vehicle communication technologies.

Subsequent research and advancements in the following decades further refined and expanded upon these early foundations, leading to the more comprehensive Car2X technology we see today (Alalewi, Dayoub, & Cherkaoui, 2021).

3.2.2 Technological advancements in the 1980s

While the 1980s did not witness any prominent projects specifically focused on CAR-2-X technology, there were notable advancements in the field of vehicle communication during that decade. Research and development efforts during the 1980s contributed to the foundational principles and technologies that would later underpin CAR-2-X systems.

One significant project during this time was the PATH (Partners for Advanced Transit and Highways) program, initiated by the University of California, Berkeley, in the mid-1980s. The PATH program aimed to develop advanced technologies for intelligent transportation systems. While not exclusively dedicated to CAR-2-X communication, it laid the groundwork for cooperative vehicle systems and integrated traffic management. The project focused on developing vehicle control algorithms, traffic management strategies, and vehicle-to-infrastructure communication methods ("PATH Innovative Research on ITS Technologies and Methodologies for Multimodal Transportation Solutions," 2023b).

Another major milestone was the first project launched in Europe. Spanning multiple research institutions in multiple countries. The PROMETHEUS project, launched in the late 1980s, focused on the vehicle communication aspect involved developing communication protocols, establishing communication channels, and defining message formats for data exchange. These efforts were instrumental in laying the groundwork for future standards and protocols in the field of Car-2-X technology ("Programme for a european traffic system with highest efficiency and unprecedented safety | EUREKA," 2023c).

3.2.3 Initial challenges and technological limitations

The development of CAR-2-X was facing several challenges and suffered from technological limitations during the early times of its lifecycle. The most significant problems were the establishment of common communication standards, limited communication range, and the ensuring of low-latency communication between vehicles. Different companies and research institutions adopted their own protocols, frequency bands, and data formats for vehicle communication systems. This lack of standardization created a fragmented landscape where vehicles from different manufacturers were unable to communicate effectively with each other and with infrastructure components (Siemens, 2013). These problems were major focal points of improvement in the upcoming years.

3.2.4 Early research projects and experiments

The first proper research projects and experiments on vehicle communication began in the 1990s and early 2000s. This time period built upon the foundation layed in the decades before and implemented many crucial projects, that served as a critical milestone for CAR-2-X technology. The primary goal of these projects was to enable vehicles to communicate with each other and with infrastructure such as traffic signals. It was also the first time, the term "CAR-2-X" was used in the context of vehicle communication, originating as an abbreviation for "Car-to-Everything".

One notable project was the Intelligent Vehicle Highway System (IVHS) program, which was launched in the United States in the early 1990s. The IVHS program initialized the development of multitude of different technologies. Recognizing the potential benefits of vehicles exchanging information in real-time, the IVHS program sought to enable vehicles to communicate with each other. Additionally, the IVHS program emphasized the development of advanced driver assistance systems (ADAS). These systems incorporated cutting-edge technologies to provide drivers with real-time feedback, warnings, and assistance in navigating the roadways. ADAS technologies included features such as adaptive cruise control, lane departure warning, and collision avoidance systems. By integrating these technologies, IVHS aimed to enhance driver safety and reduce the likelihood of accidents caused by human error. Furthermore, the IVHS program aimed to integrate intelligent transportation systems (ITS) into the overall transportation infrastructure. ITS encompassed a range of technologies and applications, including traffic management systems, electronic toll collection, and traveler information systems. The goal was to create a cohesive and interconnected transportation network that could optimize traffic flow, improve efficiency, and provide current information to drivers (Sweeney).

During this period, not only governments were funding various projects but also car manufacturers began to experiment with wireless communication technology. For instance, in 1997, the Partnership for a New Generation of Vehicles (PNGV) demonstrated the use of Dedicated Short-Range Communications (DSRC). The PNGV was a collaborative research program between the U.S. government and the automotive industry, aiming to develop advanced technologies for fuel-efficient, low-emission vehicles. The DSRC technology was employed to enable vehicles to communicate with each other and with the surrounding infrastructure. DSRC utilizes short-range wireless communication, based on the IEEE 802.11 standard, to establish reliable and secure communication links between vehicles and roadside infrastructure components. The demonstration highlighted the potential of DSRC to enhance safety, efficiency, and overall performance in transportation systems. This demonstration served as an important milestone in the history of CAR-2-X technology ("Review of the Research Program of the Partnership for a New Generation of Vehicles," 1997).

The Vehicle Infrastructure Integration (VII) program, launched in the early 2000s, then aimed to further develop DSRC-based communication technologies. The VII program recognized the potential of DSRC as a reliable and secure communication technology for vehicle-to-vehicle and vehicle-to-infrastructure communication. DSRC utilizes a specific frequency band reserved for transportation applications, allowing vehicles to exchange information over short distances. Under the VII program, extensive research and development efforts were dedicated to developing DSRC-based communication technologies and protocols. The efforts made under the VII program laid the foundation for the development and standardization of DSRC-based communication protocols, which are now an integral part of Car-2-X technology.

Over the course of the 2000s, further development and refinement of DSRC technology took place, solidifying its position as a key communication framework for connected vehicles. During this period, researchers and industry stakeholders focused on enhancing the capabilities and performance of DSRC systems. They worked on optimizing data transmission rates, improving communication reliability, and addressing issues related to interference and signal propagation. These advancements aimed to ensure that DSRC-based communication systems could reliably support a wide range of applications in real-world scenarios. Organizations such as the Society of Automotive Engineers (SAE) and the Institute of Electrical and Electronics Engineers (IEEE) worked collaboratively to define the specifications and guidelines for DSRC, ensuring interoperability and compatibility across different manufacturers and implementations (“Handbook of Intelligent Vehicles,” 2012).

This development led to the most significant milestone in the early lifespan of the CAR-2-X technology, namely the standardization of WLAN-based Vehicle-to-Everything systems, particularly through the IEEE 802.11p specification. This is a specific amendment to the previously mentioned IEEE 802.11 standard, that addresses the needs of wireless communication in vehicular environments. The standardization of WLAN-based V2X, developed in 2010, has gained prominence and surpassed the standardization of cellular-based V2X systems. This standard enables direct communication between vehicles and between vehicles and infrastructure, forming the basis of Dedicated Short-Range Communication. By adopting the IEEE 802.11p standard, DSRC-based communication systems can achieve low-latency and high-reliability communication, enabling vehicles to exchange safety-critical information, such as vehicle position, speed, and trajectory, as well as receive important traffic-related data from infrastructure components. The standardized nature of WLAN-based V2X, facilitated by IEEE 802.11p, has led to its widespread adoption and implementation in various research projects and real-world deployments. The availability of a common set of standards enables interoperability between different vehicles and infrastructure systems, allowing seamless communication and cooperation among them (“IEEE Standard for Information technology,” 2010).

3.3 CAR-2-X in the Last Decade

The development of the WLAN-based V2X communication marked a crucial milestone in the evolution of CAR-2-X technology, enabling vehicles to communicate directly with each other and with surrounding infrastructure. The advent of WLAN-based V2X in the early 2010s propelled CAR-2-X technology into a new era, paving the way for the development of advanced cooperative and automated driving systems. A multitude of different projects was launched during the early 2010s, leading to another breakthrough in the year 2016.

3.3.1 The 3GPP Communication Standard

In 2016, the 3rd Generation Partnership Project (3GPP), a collaborative initiative among telecommunications standards organizations, published specifications for V2X communication based on Long-Term Evolution (LTE) as the underlying technology. This new approach, commonly known as "cellular V2X" (C-V2X), emerged as an alternative to the IEEE 802.11p-based V2X technology. C-V2X technology differentiates itself from IEEE 802.11p by leveraging existing cellular networks for communication. It takes advantage of the robust infrastructure and wide coverage provided by cellular networks, allowing vehicles to communicate not only with each other (V2V) and with infrastructure (V2I) but also over a wide area via the cellular network (V2N). The publication of C-V2X specifications by 3GPP introduced a new dimension to V2X communication. By utilizing cellular networks, C-V2X expanded the range and capabilities of V2X communication beyond the immediate vicinity of vehicles and infrastructure. It enabled vehicles to access a broader set of services and information, such as real-time traffic updates, weather conditions, and cloud-based services, enhancing the overall driving experience and road safety.

The availability of C-V2X alongside IEEE 802.11p-based V2X offered flexibility and options for automakers and technology providers, allowing them to choose the most suitable technology based on their requirements, regional regulations, and infrastructure availability. The coexistence of these two V2X technologies contributed to the diversification and evolution of the CAR-2-X ecosystem, further advancing the development of connected and autonomous vehicles (5GAA, 2017).

3.3.2 The First Vehicles Equipped with CAR-2-X Technology

In 2016, Toyota made a significant milestone in the automotive industry by becoming the first global automaker to introduce vehicles equipped with CAR-2-X communication technology. These vehicles utilized DSRC technology and were initially made available for sale exclusively in the Japanese market. Following Toyota's pioneering move, General Motors (GM) stepped forward in 2017 as the second automaker to introduce V2X technology. GM introduced a Cadillac model in the United States that was equipped with DSRC-based V2X communication. With the integration of DSRC technology, GM aimed to enhance the safety features of their vehicles, leveraging V2X communication to enable advanced functionalities such as intersection collision warning, emergency vehicle warning, and traffic signal priority. Also in 2017, Volkswagen became the first European automobile manufacturer to incorporate this technology as a standard feature (5GAA, 2017).

After a span of 45 years since the inception of CAR-2-X technology, the first vehicles integrating this technology have been produced for the mainstream market, making this the most significant event for the CAR-2-X technology.

3.3.3 The Evolution from 3GPP to 5GAA

From the year 2017 onwards, there was a significant expansion of infrastructure supporting V2X communication. Governments and transportation authorities in various regions started deploying roadside units equipped with V2X technology to facilitate communication with vehicles. Many pilot projects and field tests were conducted to evaluate the performance and benefits of CAR-2-X technology in real-world scenarios. CAR-2-X technology also began to integrate with advanced driver assistance systems, enhancing the capabilities of existing safety features. However, the most crucial development was the further improvement of the 3GPP communication standard. Over the years, not without much controversy, the cellular-based C-V2X technology has established itself as the superior communications standard compared to the 802.11p in multiple aspects and was a focal point of further development. First, there was the transition from the 3G standard to the 4G standard. As the demand for higher data rates, lower latency, and increased reliability grew, the automotive industry looked for communication solutions beyond the capabilities of 3GPP. The introduction of LTE-Advanced provided improved performance and supported enhanced V2X communication. The real leap, however, came with the inception of 5G technology. This brought a significant leap forward in CAR-2-X communication. With its ultra-low latency, higher data rates, and massive device connectivity, 5G became a game-changer for connected and autonomous vehicles. The introduction of 5G enabled highly responsive and reliable V2X communication, supporting a broader range of applications and services, including advanced safety features, real-time traffic management, and immersive in-vehicle experiences (Garcia et al., 2021).

3.3.4 The Current State of CAR-2-X technology

Currently, the fifth generation (5G) network, is still the communication standard for cellular-based C-V2X technology, which has opened up new possibilities for innovative applications, during the years up until now. The most notable examples are, vehicles being able to share sensor data such as camera images, LiDAR scans, and radar measurements over the network with other vehicles, real-time high-definition map updates, which ensures that vehicles have access to the latest information about road conditions, construction zones, traffic incidents and virtual traffic lights, where vehicles communicate with each other and the infrastructure to coordinate their movements at intersections (“Connected Vehicles of the Future: How 5G Empowers V2X Communication,” 2023a).

Along with the development of 5G technology, machine learning and AI have gained significant popularity in recent years. The incorporation of machine learning and artificial intelligence in vehicle-to-everything technology paved the way for new capabilities and use cases. The increasing amount of data and vehicles in a network poses a growing challenge for network management. Self-Organizing-Networks (SON) are adaptive and autonomous networks that interact with their environment to maintain performance, stability, and improve their Quality-of-Service level. However, the first generation of SONs faced limitations in their performance as they employed reactive techniques. Thus, Artificial Intelligence and Machine Learning have the potential to enable autonomous decision-making and actions by wireless network components. This way, networks reduce excessive signaling overhead that results from network faults, minimizing recurrent delays in the provided services. Germany, the US, and Japan have already started to provide the necessary V2X datasets for researchers to conduct diverse ML-based studies. At present, ML and CAR-2-X are still in their early stages due to insufficient data, but it is anticipated that more projects will emerge in the future (Christopoulou, Barmpounakis, Koumaras, & Kaloxylos, 2023).

4. Conclusion

CAR-2-X technology facilitates communication between vehicles and their surroundings, including other vehicles, infrastructure, pedestrians, and devices. It aims to increase safety, reduce accidents, and assist drivers by exchanging standardized messages that provide real-time information on speed, position, and other status data. The importance of CAR-2-X technology, particularly in self-driving vehicles, cannot be overstated. It enables cars to sense and communicate with each other and their environment, providing crucial data for decision-making and safety measures. CAR-2-X technology plays a vital role in making driving safer, more efficient, and environmentally friendly. In addition, it enhances road safety and traffic management by facilitating smooth traffic flow, reducing congestion, and enabling various use cases such as forward collision warning, emergency vehicle approaching, lane change warning, and roadworks warning.

CAR-2-X technology has undergone a significant historical development, starting from its early concepts and research in the 1970s up until the present day, where early projects like the US Electronic Road Guidance System and Japan's Cooperative-Adaptive Cruise Control System laid the foundation for vehicle communication and cooperative driving. Despite initial challenges, efforts to address issues like communication standards and latency led to the standardization of WLAN-based Vehicle-to-Everything systems, particularly through the IEEE 802.11p specification. In recent years, the introduction of cellular V2X based on LTE technology expanded the capabilities of CAR-2-X communication. The coexistence of C-V2X and IEEE 802.11p-based V2X technologies provides flexibility for automakers and technology providers.

Looking ahead, the integration of CAR-2-X technology with emerging technologies like 5G, artificial intelligence, and edge computing is expected to enhance its capabilities and contribute to safer and more efficient transportation systems. The increased connectivity and data exchange facilitated by these technologies will lead to more sophisticated cooperative driving systems, enhanced autonomous capabilities, and improved traffic management. One potential future development is the seamless integration of CAR-2-X technology with smart city infrastructure. This integration will enable vehicles to communicate not only with each other but also with traffic signals, road signs, and other infrastructure components. As a result, vehicles will have access to real-time traffic information, optimized routing, and personalized recommendations, leading to more efficient and eco-friendly transportation (Fong, Situ, & Fong).

V. Bibliography

5GAA (2017). LTE-V2X and 802.11p for road safety. Retrieved from https://5gaa.org/content/uploads/2017/12/5GAA-Road-safety-FINAL2017-12-05.pdf

Alalewi, A., Dayoub, I., & Cherkaoui, S. (2021). On 5G-V2X Use Cases and Enabling Technologies: A Comprehensive Survey. *IEEE Access*, *9*, 107710–107737. https://doi.org/10.1109/ACCESS.2021.3100472

Christopoulou, M., Barmpounakis, S., Koumaras, H., & Kaloxylos, A. (2023). Artificial Intelligence and Machine Learning as key enablers for V2X communications: A comprehensive survey. *Vehicular Communications*, *39*, 100569. https://doi.org/10.1016/j.vehcom.2022.100569

CompareCamp.com (2020). 72 Car Accident Statistics 2020/2021: Causes, Injuries & Risk Factors | CompareCamp.com. Retrieved from https://comparecamp.com/car-accident-statistics/

Connected Vehicles of the Future: How 5G Empowers V2X Communication (2023a, May 31). Retrieved from https://www.softeq.com/blog/connected-vehicles-of-the-future-how-5g-empowers-v2x-communication

David, K., & Flach, A. (2010). CAR-2-X and Pedestrian Safety. *IEEE Vehicular Technology Magazine*, *5*(1), 70–76. https://doi.org/10.1109/MVT.2009.935536

Fong, B., Situ, L., & Fong, A. C. M. Smart Technologies and Vehicle-to-X (V2X) Infrastructures for Smart Mobility Cities. In (pp. 181–208). https://doi.org/10.1002/9781119226444.ch7

Garcia, M. H. C., Molina-Galan, A., Boban, M., Gozalvez, J., Coll-Perales, B., Şahin, T., & Kousaridas, A. (2021). A Tutorial on 5G NR V2X Communications. *IEEE Communications Surveys & Tutorials*, *23*(3), 1972–2026. https://doi.org/10.1109/COMST.2021.3057017

Handbook of Intelligent Vehicles (2012). Springer, London.

IEEE Standard for Information technology (2010). *IEEE Std 802.11p-2010 (Amendment to IEEE Std 802.11-2007 as Amended by IEEE Std 802.11k-2008, IEEE Std 802.11r-2008, IEEE Std 802.11y-2008, IEEE Std 802.11n-2009, and IEEE Std 802.11w-2009).* https://doi.org/10.1109/IEEESTD.2010.5514475

PATH Innovative Research on ITS Technologies and Methodologies for Multimodal Transportation Solutions (2023b, May 29).

Programme for a european traffic system with highest efficiency and unprecedented safety | EUREKA (2023c, May 30). Retrieved from https://web.archive.org/web/20180814201633/http://www.eurekanetwork.org/project/id/45

Review of the Research Program of the Partnership for a New Generation of Vehicles (1997). Washington, D.C.: National Academies Press. Retrieved from https://nap.nationalacademies.org/read/5736/chapter/2 https://doi.org/10.17226/5736

Siemens (2013). Cooperativity in motion. Retrieved from https://assets.new.siemens.com/siemens/assets/api/uuid:e6d4f0d6ac7b3df9ee402860dc234cd52c7ee4c7/version:1493634002/cooperativity-in-motion-en.pdf

Sweeney, L. E. An overview of intelligent vehicle highway systems (IVHS). In (pp. 258–262). https://doi.org/10.1109/WESCON.1993.488444

U.S. Department Of Transportation (2016). Vehicle-To-Vehicle Communication Technology For Light Vehicles. Retrieved from https://www.nhtsa.gov/sites/nhtsa.gov/files/documents/v2v_pria_12-12-16_clean.pdf