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Enhancing Road Safety and Traffic Efficiency Through Vehicular Communication Networks

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Dedication

This project is wholeheartedly dedicated to my beloved parents, who have been my source of inspiration and gave me strength when I thought of giving up, they continually provide their moral, spiritual, emotional, and financial support.

To my brother, relatives, friends, and classmates who shared their words of advice and encouragement to finish this study.

And lastly, I dedicated this project to God, thank you for the guidance, strength, power of the mind, protection, and skills.

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I express my special thanks to my thesis supervisor for his advice and support, and Google for always guiding me and helping me know about the subject.

I had made this project from my heart and shown utmost sincerity to complete it. I am very thankful to those who helped and guided me to make such a project. I also thank my parents who have provided me with all the resources to make this happen.

Abstract

Enhancing road safety and traffic through Vehicular Communication Networks (VCNs) addresses the problems in modern cities. Conventional traffic control techniques are inadequate for reacting to real-time variables like accidents, and changing traffic volumes because of their static nature and incapacity to adjust to evolving urban environments. Effective communication channels between infrastructure and cars are essential for sharing critical data to improve safety, traffic efficiency, and route planning to get around these restrictions. To assess VCN responsiveness in emergency scenarios, the detection and response to traffic accidents, and the handling of vehicle problems through a series of meticulously designed simulations employing SUMO, OMNET++, INeT, and Veins. This study's analysis of the data provides insightful information about how VCNs might transform traffic control and road safety. It also has implications for transportation experts, urban planners, and politicians who want to build more modern and integrated transportation systems.

Keywords: VCN, road safety, SUMO, Omnet++, INeT, Veins.

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List of Abbreviations

C-ITS	Cooperative Intelligent Transport Systems
C-V2X	Cellular-V2X
DSRC	Dedicated Short-Range Communication
ETSI	European Telecommunications Standards Institute
GUI	Graphical User Interface
IEEE	Institute of Electrical and Electronics Engineers
INet	Internet Networking
ITS	Intelligent Transportation Systems
MaaS	Mobility-as-a-Service
NED	Network Description
NFV	Network Function Virtualization
MAC	Medium Access Control
OMNeT++	Objective Modular Network Testbed in C++
SAE	Society of Automotive Engineers
SDN	Software-Defined Networking
SUMO	Simulation of Urban MObility
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Everything
VANET	Vehicular Ad hoc NETwork
VCN	Vehicular Communication Network
Veins	Vehicles in Network Simulation
WAVE	Wireless Access in Vehicular Environments

Chapter 1: Introduction

1. Introduction

Vehicles play a necessary part in our day-to-day lives and have transformed the way we live. Vehicles are used to transport goods as well as people across short and long distances for varied purposes. Over time, the number of vehicles around the world has steadily increased. The high frequency of vehicle power leads to a high business demand along highways, which in turn leads to several transportation challenges, including high business traffic, long commutes, and increased threat of accidents. Business traffic has been a major issue several times, particularly in highways and cities such as Beirut, Aley, Tripoli, Zahle, etc.

Traditionally, the result of traffic congestion has been to expand the road network to meet the increased business demand. Nevertheless, this result is becoming unfeasible due to the extraordinary cost of expanding transport structure, and the fact that areas with high population viscosity tend to be clustered around these high-traffic highways, adding to the complexity of planning and structure another capacity. In awkward vehicular business, a significant quantity of road capacity isn't used efficiently. Vehicles tend to travel in free flow mode only in low consistency and when relations between vehicles are rare.

Traffic congestion is the main factor in the increased number of vehicles and high business demand is the increased liability of vehicular collisions and losses. Traffic accidents are among the most critical issues that affect the current transportation system. In addition to injuries and losses, these accidents can damage city structure, produce more business traffic, and lead to action, forfeitures, or other penalties. While individual accidents are caused by a variety of factors such as unanticipated driver behavior, mechanical failures, and distractions on the road, the overall rate of business accidents is frequently a function of further predictable parameters such as time of day, rainfall, and business dynamics.

The increasing frequency of technology has revolutionized travel by supplying drivers with a wealth of information about road conditions and business states using colorful detectors bedded in highways, and data from mobile phones carried by drivers. VCN explores the new possibilities of integrating communication technology into vehicles to ameliorate business safety and effectiveness. VCN uses wireless communication protocols to change information between vehicles and between vehicles and roadside structures. VCNs enable vehicles to anticipate and respond to possible dangers more efficiently by easing real-time data sharing, similar to vehicle position, speed, and business conditions.

This communication network also enables the installation of intelligent transportation technologies similar to business signal optimization and adaptive voyage control, which contribute to lower traffic and better business inflow. likewise, VCNs have the eventuality to play a critical part in allowing intelligent driver backing systems and collaborative collision avoidance, which will minimize accidents and save lives.

2. Background and Context

In recent years, the escalating challenges associated with road safety and traffic congestion have become pressing concerns for urban planners, transportation authorities, and society at large. Traffic accidents, delays, and inefficiencies not only result in economic losses but also pose significant threats to human lives. The advent of VCNs presents a promising avenue for addressing these challenges by enabling vehicles to communicate with each other and with infrastructure components in real-time. This thesis explores the potential of VCNs in enhancing road safety and traffic efficiency, contributing to the broader discourse on intelligent transportation systems.

- VCN in Enhancing Road Safety and Traffic Efficiency:

The concept of VCNs, aimed at enhancing road safety and traffic efficiency, has evolved significantly over the years, reflecting a journey marked by technological advancements, standardization efforts, and real-world testing[1].

In the 1990s, the seeds of VCNs were planted as researchers began exploring the potential benefits of communication between vehicles and infrastructure. The primary objective was to mitigate accidents and improve overall traffic management. However, it wasn't until the 2000s that DSRC technology gained prominence as a dedicated communication standard for V2V and V2I communication. During this era, pilot projects and research initiatives were conducted to test the feasibility and effectiveness of DSRC in real-world scenarios.

The subsequent decade, the 2010s, witnessed a crucial phase in the evolution of VCNs. Standardization bodies, such as the SAE and the IEEE, played pivotal roles in establishing common standards for VCNs. Regulatory initiatives, particularly in North America and Europe, began encouraging the deployment of V2X technologies, creating a foundation for a more standardized and interoperable landscape.

The late 2010s marked the emergence of C-V2X technology, offering an alternative or complementary approach to DSRC. Leveraging cellular networks for V2X communication, C-V2X promised more extensive coverage, improved reliability, and integration with existing cellular infrastructure. This period also saw an increase in pilot programs and field trials globally, aiming to assess the real-world effectiveness of VCNs. These trials were instrumental in testing communication protocols, evaluating system reliability, and gathering data on the impact of VCNs on road safety and traffic efficiency.

As we progress into the present and the future, VCNs are becoming increasingly integral to the development and deployment of autonomous vehicles. Communication among autonomous vehicles, as well as between autonomous vehicles and infrastructure, is critical for safe and efficient navigation in complex traffic scenarios. Ongoing advancements in artificial intelligence and sensor technologies are enhancing the capabilities of VCNs to support autonomous driving.

Looking ahead, there is a growing emphasis on the global deployment and integration of VCNs. The integration with smart city initiatives and the development of comprehensive V2X ecosystems aim to further improve road safety, traffic efficiency, and overall transportation systems. The trajectory from conceptualization and early research to the deployment and integration of standardized communication technologies underscores the ongoing commitment to realizing the full potential of Vehicular Communication Networks.

3. Problem Statement

The traditional method of traffic control emphasizes infrastructure, signage, and static regulations—all of which are frequently unable to change to accommodate the dynamic and unpredictable character of contemporary urban surroundings. In addition to impairing traffic flow efficiency, this lack of adaptability puts safety at risk since it ignores variables that change in real time, such as weather, traffic accidents, and volume fluctuations.

These problems are further exacerbated by the restricted communication capabilities between infrastructure and automobiles. Vehicles operate in isolation when there are insufficiently efficient communication channels available to exchange vital information about possible risks, traffic conditions, and route changes. This raises the risk of accidents and delays in addition to creating inefficiencies in route planning.

Given these difficulties, creative solutions that make use of VCNs' capabilities are desperately needed to build a more dynamic and interconnected transportation environment. To facilitate smooth communication between automobiles, infrastructure components (such as traffic lights and road signs), and centralized control systems, VCNs take advantage of advancements in wireless communication technologies. VCNs can completely change the way traffic is handled and road safety is guaranteed by enabling real-time data interchange and coordination.

Real-time communication between cars and the surrounding infrastructure can be established in a networked environment by integrating VCNs into the current transportation infrastructure. This makes it possible to implement a variety of cutting-edge applications that enhance traffic efficiency and safety on the roads, such as cooperative collision avoidance systems, adaptive signal control, and predictive traffic management.

4. Related Work

A strong foundation for this research is provided by the literature on vehicular communication networks and their effects on traffic efficiency and road safety. Through timely information dissemination and cooperative driving techniques, studies have shown how VCNs can drastically reduce accidents and enhance traffic flow [2]. These projects highlight the value of VCN technologies in resolving issues with contemporary transportation networks.

Additionally, in recent years, research on simulation methodologies for VCNs has become more prominent. Network topologies and communication protocols in VCNs have been extensively modeled using OMNeT++, a discrete event simulation environment [3]. Similar to this, the effects of VCN apps on traffic flow and congestion have been examined using SUMO, a traffic simulation program [4]. These simulation tools give researchers the ability to assess how well VCNs work in different settings and environments.

The intricate relationships between cars, infrastructure, and communication protocols in VCNs are still difficult to adequately predict, though. The main challenges are integrating diverse data sources and expanding simulations to encompass big cities. To solve these issues and assess the performance of VCN apps in various traffic circumstances, recent research has shown how well OMNeT++ and SUMO may be integrated[5].

5. Research Objective

The aim is to make a meaningful contribution to the knowledge of enhancing road safety and traffic efficiency through the exploration of Vehicular Communication Networks. By delving into the intricacies of VCNs and their potential impact on traffic dynamics, safety measures, and overall efficiency.

Aligned with this aim, the objectives of this thesis are delineated as follows:

- Identification of Critical Factors:

The primary objective is to carefully identify and examine the critical elements that are causing traffic inefficiencies and endangering public safety.

- Evaluation of Accident Prevention:

The second objective is a thorough evaluation of VCNs' effectiveness in preventing collisions and reducing collision risks. This study aims to clarify the degree to which VCNs can anticipate possible threats, enable timely warnings, and support adaptive driving practices by examining the fundamental workings of these networks.

- Examination of VCNs' Role in Intelligent Traffic Management:

The third objective is to investigate how important VCNs are to the enhancement of intelligent traffic management systems. This study uses simulation-based studies and empirical research to clarify how VCNs can improve traffic flow efficiency, and resource allocation, and support dynamic routing techniques.

6. Research Questions

- To what extent do Vehicular Communication Networks impact the reduction of business accidents, and what specific communication protocols and technologies contribute most significantly to this effect?
- How do factors similar to structure deployment, standardization, and public acceptance impact the overall effectiveness of Vehicular Communication Networks in mitigating road safety pitfalls and optimizing business inflow?
- In what ways does V2X communication contribute to the integration of independent vehicles into the transportation system, and how does this integration influence overall road safety and business operation?
- How can the interoperability of Vehicular Communication Networks with transportation structures be better, and what part does collaboration between government agencies, assiduity stakeholders, and technology inventors play in this process?

7. Scope

The thesis delves into the multifaceted impact of VCNs on enhancing road safety and optimizing traffic efficiency. Within the scope of this research, key areas include the examination of various V2X technologies, encompassing V2V and V2I communication protocols, and their role in contributing to road safety and traffic efficiency. The study also analyzes the influence of VCNs on accident prevention through early warning systems, collision avoidance, and overall traffic management.

Moreover, it explores the impact of VCNs on traffic flow management, including real-time data exchange, congestion alleviation, and adaptive traffic signal control. The thesis also investigates the role of VCNs in supporting the integration of autonomous vehicles into the transportation system, emphasizing their contribution to safe interactions and traffic optimization. Additionally, it addresses ongoing technological advancements, and standardization efforts, and showcases real-world applications and case studies that highlight successful implementations of VCNs across diverse contexts.

8. Limitations

Despite the comprehensive scope, it is essential to acknowledge certain limitations that may impact the depth and generalizability of the research. First, the rapidly evolving nature of VCN technology poses a challenge, as the thesis may not capture the most recent developments in this dynamic field. Second, regional variances in infrastructure, regulatory frameworks, and public acceptance could influence the effectiveness of VCNs, limiting the generalizability of findings across diverse geographical contexts. Additionally, the success of VCNs often depends on the availability and adequacy of supporting infrastructure, and limitations in infrastructure deployment may affect the broader applicability of the research.

Privacy and security concerns associated with VCNs may not be extensively covered within the thesis, despite their critical importance. Furthermore, economic considerations, including the costs associated with technology implementation, may not be exhaustively explored within the defined scope of the research. Despite these limitations, the thesis aims to provide valuable insights into the impact of Vehicular Communication Networks on road safety and traffic efficiency, offering a foundation for further research and practical applications in the field.

9. Significance of the Study

This research is significant for several reasons. originally, it addresses a critical issue that affects the day-to-day lives of individuals and the overall functioning of civic areas. Secondly, the study contributes to the main knowledge of VCNs and their connection in perfecting transportation systems. The findings of this exploration may inform officials, public plans, and researchers in the development of intelligent transportation results.

10.Methodology

The thesis begins with an extensive review of the existing literature on road safety, traffic efficiency, and Vehicular Communication Networks. Following that, essential data on road accidents, traffic patterns, and current VCN implementations are gathered. The collected data is meticulously analyzed to reveal trends, patterns, and correlations, offering a foundational understanding of the current landscape. Following that, simulation tools are used to model prospective outcomes in various traffic scenarios to forecast the impact of VCN deployment. The simulation results are then systematically evaluated, revealing insight into both the predicted benefits and problems of incorporating VCNs into transportation networks.

Chapter 2: Potential and Key Concepts

1. Literature Review

Vehicular communication networks have appeared as a transformative technological result for addressing the complex challenges associated with road safety and traffic efficiency. In recent times, the integration of communication capabilities between vehicles and structures has opened up new possibilities for enhancing the overall dynamics of transportation systems. The exploration of V2X communication networks examines a multifaceted disquisition of their development, operations, and counter accusations for perfecting the safety and effectiveness of road networks.

2. Road Safety and Traffic Efficiency Challenges

Road safety and traffic efficiency are crucial elements of contemporary transportation systems that affect people's lives, communities, and economies all around the world. But even with major advances in infrastructure and technology, many obstacles continue to stand in the way of these vital fields' progression. Addressing these obstacles calls for a thorough understanding and coordinated effort from multiple stakeholders. Pervasive issues like driver behavior and inadequate infrastructure, as well as rising concerns like the integration of technology and environmental sustainability, are just a few examples. Traffic efficiency and road safety are major concerns on a global scale, and both are impacted by a variety of issues[6].

Below is a summary of some of the key challenges:

- Driver Behavior:

Human error remains a leading cause of accidents. Issues such as speeding, distracted driving (e.g., mobile phone usage), driving under the influence of alcohol or drugs, and fatigue contribute significantly to road accidents.

- Infrastructure**:**

Poor road conditions, inadequate signals, lack of proper lighting, and insufficient road markings can contribute to accidents. Additionally, outdated or poorly designed road layouts may not accommodate current traffic volumes efficiently.

- Vehicle Safety**:**

Despite advances in vehicle safety technology, many vehicles on the road lack essential safety features such as airbags, ABS brakes, and stability control systems. Moreover, older vehicles may not meet modern safety standards.

- Pedestrian and Cyclist Safety**:**

Vulnerable road users, such as pedestrians and cyclists, face significant risks from vehicle traffic. Insufficient infrastructure, such as sidewalks, crosswalks, and bike lanes, can increase their vulnerability.

- Traffic Congestion**:**

Urbanization and population growth have led to increased traffic congestion in many cities worldwide. Congestion not only reduces efficiency but also increases the likelihood of accidents due to stop-and-go traffic and frustrated drivers.

- Enforcement**:**

Inadequate enforcement of traffic laws can undermine road safety efforts. This includes issues such as insufficient police presence, lax penalties for traffic violations, and ineffective monitoring of driver behavior.

- Public Awareness and Education**:**

Many road users lack awareness of safe driving practices and the importance of adhering to traffic laws. Education campaigns can help raise awareness and promote safer behaviors among drivers, pedestrians, and cyclists.

- Emergency Response**:**

Prompt emergency response is crucial in reducing the severity of road accidents. However, challenges such as traffic congestion and inadequate emergency services infrastructure can hamper response times.

- Environmental Impact:

Transportation-related emissions contribute to air pollution and climate change. Efforts to improve road safety and traffic efficiency should also consider their environmental impact, such as promoting alternative transportation modes and adopting cleaner vehicle technologies.

Many obstacles stand in the way of road safety and traffic efficiency in Lebanon, such as poor road infrastructure, extreme traffic jams in major cities like Beirut, and a general prevalence of careless driving. Inadequate infrastructure maintenance frequently jeopardizes pedestrian safety, and traffic restrictions are not consistently enforced[7]. Moreover, a significant reliance on private vehicles is a result of the inadequate public transportation infrastructure. These problems are made worse by political and economic volatility, which makes it more difficult to find effective solutions. Lebanon has to make investments in better infrastructure, strengthen enforcement mechanisms, encourage safer driving habits, and create a more dependable public transportation system to increase road safety and traffic efficiency.

3. Vehicular Communication Networks (VCN)

VCNs are computer networks that allow vehicles and roadside equipment to communicate with one another through data exchange. This allows for numerous essential services and applications, including safety-related features and traffic information [8]. Ad hoc networks for vehicles (VANETs) and other short- and medium-range wireless communication systems are used by VCNs to communicate.

Among the many benefits that virtual communication networks offer over traditional communication networks are their infinite transmission capacity, smooth mobility, and wide range of possible uses. VCNs must overcome several obstacles, such as dynamic and frequently fragmented topologies, connectivity restrictions, and strict requirements for dependable and real-time message delivery, to fully realize their potential.

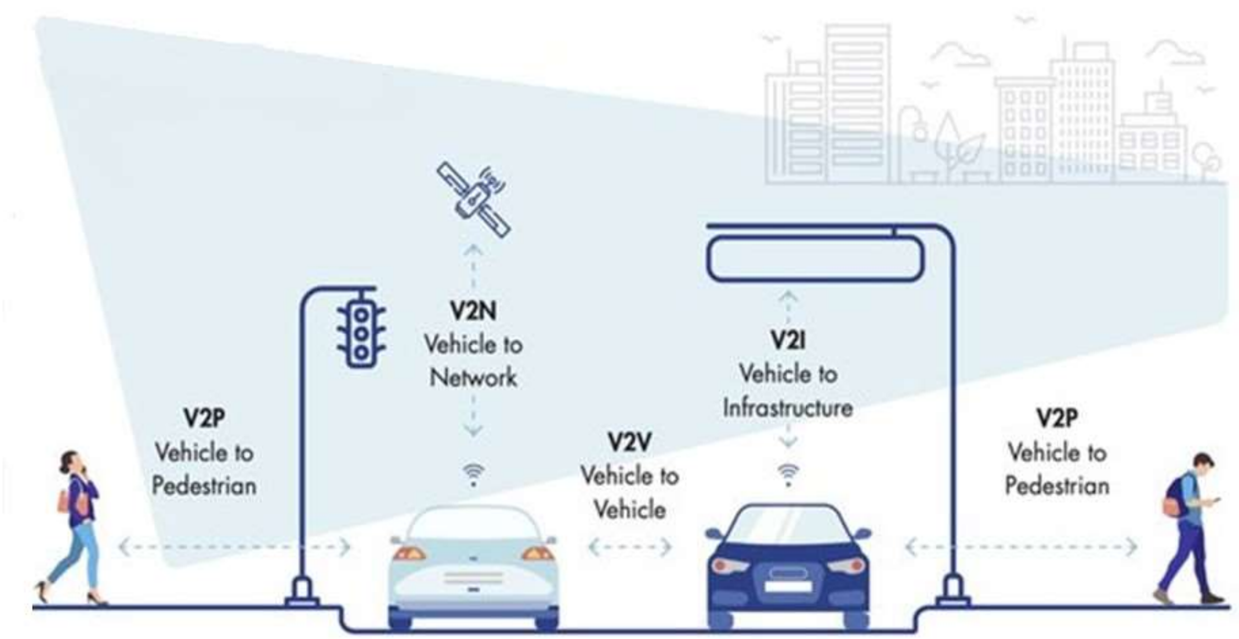

Figure 1: Communication within VCNs.

Technologies facilitating communication within VCNs include:

- Vehicle-to-Vehicle (V2V):

V2V wireless communication allows cars to communicate with one another in real-time, sharing data about their position, velocity, and trajectory [9]. This technology is essential for improving road safety since it increases situational awareness and lowers the chance of accidents.

Beyond safety concerns, V2V communication offers other benefits including efficient traffic management that lowers fuel usage and improves travel convenience. Furthermore, V2V communication has special advantages that cannot be obtained through any other channel.

First of all, since V2V communication is real-time, it allows for quick reactions to shifting traffic situations and information from other cars. The development of creative ITS to raise overall traffic efficiency and safety is facilitated by this real-time interchange.

Secondly, V2V communication is essential to the development of completely autonomous self-driving cars. Comprehensive situational awareness is made possible by the integration of V2V capabilities into autonomous vehicle systems, which make use of data from a variety of sensors, including cameras and LiDAR. This integration offers a comprehensive picture of the environment around the car, which improves passenger convenience while simultaneously enhancing trip safety.

- Vehicle-to-Infrastructure (V2I):

The wireless interchange of data between automobiles and different components of the road infrastructure, such as traffic lights, road signs, and lane markings, is known as V2I [9]. Through the use of a complex system that consists of hardware, software, and firmware, V2I communication is made possible in both directions. This allows vehicles and infrastructure elements to communicate vital information to one another.

By allowing vehicles to give insightful feedback to the infrastructure and receive real-time updates and guidance from infrastructure components, this integrated network improves situational awareness and overall road safety.

Transportation systems can benefit greatly from the incorporation of V2I communication in several ways, including increased safety, more efficient traffic flow, and environmental sustainability. Traffic signal timing can be dynamically adjusted based on current traffic circumstances thanks to V2I communication, which uses real-time data sharing to minimize congestion and maximize travel times. Additionally, V2I communication makes it easier to implement advanced warning systems, which enables drivers to foresee and promptly respond to possible hazards like construction zones or unfavorable weather conditions. This lowers the risk of accidents and improves overall road safety.

- Vehicle-to-Network (V2N):

V2N is a type of C-V2X that allows a car to be connected to other cars, data centers, and road infrastructure. In other words, if a navigation system is having problems with accuracy or changing roads, this effectively turns other drivers into road scouts. Vehicles could speak with pedestrians, traffic signals, street lighting, and other objects by using V2N [10]. When a car is V2N connected, it can talk to other cars to get better and more up-to-date driving directions based on where other drivers are.

With the development of 5G and cellular technology, virtual private networks may eventually materialize. Many features brought forth by 5G technology are necessary for the proper operation of V2N networks. 5G V2N refers to V2N networks that use 5G cellular technology.

- Vehicle-to-Pedestrian (V2P):

To prevent collisions, the V2P network creates direct communication between a car and the pedestrian's mobile device. V2P covers vulnerable road users, such as those who are bicycling, walking, or even getting in and out of public transportation [8]. If these pedestrians are near the car, a signal is sent.

The notifications either notify oncoming pedestrians of the car or warn drivers of oncoming pedestrians. Stable V2P connectivity is impossible without smart road infrastructure (traffic lights, sensors, and cameras).

The goal of Vehicle to Pedestrian is to protect the following categories of people when they are crossing roads: passers-by, Children in strollers, People in wheelchairs, People on bicycles, and people getting into and out of public transportation.

The full details about the vehicle may be included in the standard alerts or safety messages from the viewpoint of the pedestrian. It alerts you to the incoming car's position, speed, and direction. This data can be used to identify and forecast the track of certain vehicles at a given moment. The car can send up to ten notifications per second (at 10 Hz), depending on the frequency of its V2P.

- Vehicle-to-Everything (V2X):

V2X technology is a collection of sensors, cameras, and wireless communication systems intended to allow cars to communicate with other cars as well as with other drivers and their environment[11].

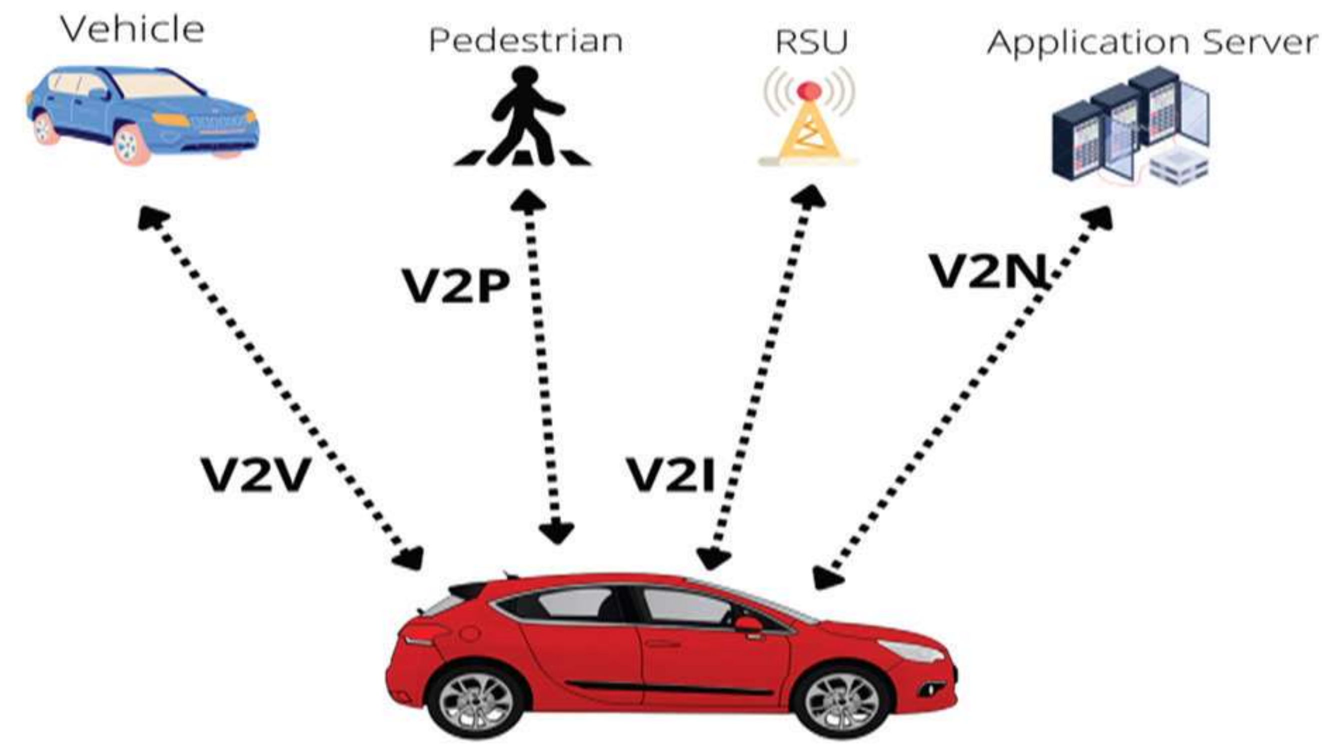

Figure 2. Vehicle-to-Everything (V2X)

However, for V2X technology to be successfully deployed, its many components must be seamlessly integrated and widely adopted. V2X technology is currently plagued by fragmentation since current networks, cameras, and sensors are not fully synchronized to enable effective communication between cars, drivers, and their environment. There are serious problems with this lack of interoperability because many cars can't communicate data unless their model specs are the same.

Large-scale networks like LTE and 5G must be used more widely to fully realize the potential of V2X technology[12]. These cutting-edge networks can cross communication gaps between automobiles, infrastructure, and pedestrians, enabling thorough data exchange and improving road safety in general.

Still, it is unclear how widely these kinds of networks will be adopted in the car business. To fully utilize V2X technology, modern communication networks must be adopted throughout the automobile ecosystem and interoperability issues must be resolved.

4. Applications of V2X Communication

In a car, V2X enables a range of uses, including infotainment and comfort apps, road safety (hazard alerts and driver support), traffic management, and comfort[11]. The applications targeted at improving traffic efficiency and road safety, are:

- Collision Avoidance:

By exchanging data in real-time, cars can predict possible collisions and alert other drivers, giving them time to take evasive action.

- Intersection Safety:

To help ensure safe navigation, automobiles can connect with infrastructure and traffic signals to get information about other vehicles, dangers, and the state of intersections.

- Emergency Vehicle Warning:

To improve access and speed up response times, emergency vehicles alert other cars to their location and condition.

- Pedestrian Safety:

Vehicles that are equipped with pedestrian detection and communication systems can avert collisions and guarantee safe pedestrian crossings.

- Road Condition Monitoring:

Vehicles communicate with each other to transmit information about road conditions, such as construction zones and slick surfaces, which warns drivers of potential hazards.

- Traffic Flow Optimization:

By coordinating lane changes and merging operations, V2X communication helps to reduce congestion and improve traffic flow.

5. Traffic Efficiency Enhancements

Because V2X communication allows real-time data transmission between vehicles and infrastructure, it has a substantial impact on managing traffic congestion and flow[10], [13]. The following are some significant ways that V2X communication affects congestion control and traffic flow:

- Optimized Traffic Signal Control:

V2X communication with infrastructure and traffic lights is made possible by V2X technology. Real-time traffic signal timing optimization can be achieved by cars exchanging information regarding traffic density, speed, and queue lengths. By reducing needless stops and delays, this dynamic change of signal timings improves traffic flow at intersections and on surrounding roads.

- Coordinated Lane Changes and Merging:

Automobiles having V2X communication capabilities can work together to plan coordinated lane changes and merges. Vehicles can seamlessly integrate into traffic by exchanging information about their positions, speeds, and intentions. This lowers traffic congestion and lowers the possibility of accidents resulting from sudden lane changes.

- Early Warning Systems:

Vehicles can communicate with other vehicles via V2X communication to exchange information about traffic conditions, collisions, and other occurrences. By doing this, drivers can minimize the effects of traffic congestion brought on by accidents or road closures by receiving early warnings and modifying their driving habits or routes accordingly.

- Dynamic Route Guidance:

Through V2X connection, cars can get dynamic route guidance that adapts to the flow of traffic in real-time. V2X technology aids in more equitable traffic distribution throughout road networks, easing congestion on highly used routes by offering drivers alternate routes and recommending the best routes.

- Dynamic Speed Harmonization:

Vehicles can modify their speeds to ensure ideal spacing and smooth traffic flow with the use of V2X communication. V2X technology helps avoid traffic jams and bottlenecks by coordinating speed modifications based on the flow of adjacent cars and traffic circumstances.

6. Standards and Regulations for Vehicular Communication Networks

Regulations and standards are essential in determining how VCNs are implemented and function effectively worldwide. the global laws and guidelines controlling virtual community networks, with an emphasis on important protocols like IEEE 802.11p and ETSI ITS-G5[14]. The advantages and challenges of establishing seamless connectivity and collaboration in the transportation industry through exploring the influence of these standards on communication technology in various areas.

A crucial standard for VCNs, IEEE 802.11p, commonly referred to as WAVE, lays out the requirements for the MAC and physical layers of wireless communication in moving vehicles. It allows for low-latency, high-reliability communication between vehicles and infrastructure components while operating in the 5.9 GHz frequency range. The foundation for V2V and V2I communication is provided by IEEE 802.11p, which makes it easier to transmit safety-critical messages and implement cooperative driving applications.

For VCNs, especially in Europe, another crucial standard is ETSI ITS-G5, which was created by the ETSI. For interoperable and secure communication in ITS, ITS-G5 expands on IEEE 802.11p by defining new communication protocols, security measures, and application interfaces. ITS-G5 is a key component of VCN installations in Europe because of its ability to handle a broad range of safety, and traffic management.

The deployment and interoperability of communication technologies in various countries are significantly impacted by the adoption of international standards like IEEE 802.11p and ETSI ITS-G5. Manufacturers, service providers, and regulators can create and implement VCN solutions that are compatible and interoperable across regional boundaries with the help of standardization, which offers a common foundation.

In areas like North America and some parts of Asia where IEEE 802.11p is extensively used, VCN deployments benefited from a developed ecosystem of compliant hardware and software components. This has made it easier for V2V and V2I communication systems to work together, allowing infrastructure components from many vendors and manufacturers to communicate with automobiles smoothly and efficiently.

Regulatory organizations and governmental initiatives have been instrumental in advancing the harmonization and interoperability of communication technologies in Europe, where ETSI ITS-G5 is the primary standard for VCNs. To promote the use of ITS-G5-compliant systems, the European Union's C-ITS platform, for instance, strives to guarantee interoperability and cross-border communication between vehicles and infrastructure throughout Europe.

However, there are obstacles in the way of fully standardizing and interoperating VCNs worldwide. Coordinating and communicating seamlessly between cars and infrastructure parts across multiple locations is hampered by differences in regulatory constraints, spectrum allocation regulations, and technical preferences. To overcome these obstacles and facilitate the global deployment and interoperability of VCNs, cooperation amongst parties, standardization of standards, and alignment of regulatory frameworks are needed.

International VCN interoperability and deployment are significantly influenced by standards and regulations. Globally compatible and interoperable VCN solutions can be developed and implemented by manufacturers, service providers, and regulators using a common framework provided by international standards like IEEE 802.11p and ETSI ITS-G5. The possibilities and difficulties of establishing efficient connectivity and cooperation in the field of transportation by examining how these standards affect communication technologies in various geographic locations. To address these issues and facilitate the global deployment and interoperability of VCNs, stakeholders must work together, harmonize standards, and coordinate regulatory frameworks.

7. Advancements in Vehicular Communication Networks

VCN-related research and development initiatives are essential for fostering innovation and expanding the capabilities of transportation networks. The state of research and development projects in VCNs today, emphasizes advancements in network architectures, ITS, and communication protocols[13], [15]. The state-of-the-art technology and possible future paths in the field of VCNs by looking at recent advances and upcoming trends.

- Innovations in Communication Protocols:

To improve the dependability, effectiveness, and security of wireless communication in automotive settings, recent studies in VCNs have resulted in notable developments in communication protocols. The capabilities of VCNs are being expanded by innovations like C-V2X standards and next-generation protocols based on IEEE 802.11p/WAVE, which allow for larger data speeds, lower latency, and better compatibility[14]. Furthermore, new technologies like NFV and SDN are being used to improve network settings and communication protocols in response to dynamic traffic situations.

- Network Architectures and Infrastructure:

Development efforts in VCNs are concentrating on creating novel network designs and infrastructure solutions to enable the scalability, robustness, and intelligence of transportation systems in tandem with developments in communication protocols[8]. To reduce latency and enhance responsiveness in VCN deployments, researchers are examining edge computing and fog computing paradigms to distribute computational jobs and data processing capabilities closer to the network edge. Furthermore, intelligent decision-making and predictive analytics are made possible by the integration of machine learning and artificial intelligence techniques in VCNs, which improves incident detection, traffic management, and congestion prediction.

- Intelligent Transportation Systems (ITS):

The creation of ITS, which uses cutting-edge technology to increase the sustainability, efficiency, and safety of transportation networks, is being fueled by research and development in VCNs[13]. Applications for cooperative driving—which are made possible by V2V and V2I communication—are being developed to improve the abilities of cooperative merging, platooning, and collision avoidance, which will minimize accidents and improve traffic flow. Moreover, ITS solutions are being implemented to maximize resource use and enhance the general mobility experience for road users. These solutions include automated toll collection, adaptive traffic signal control, and dynamic traffic routing.

8. Integration of VCN with Autonomous and Connected Vehicles

The incorporation of VCNs into connected and autonomous vehicles is a significant development in the transportation sector that has the potential to significantly improve traffic flow and road safety[16]. The incorporation of VCNs with connected and autonomous vehicles has implications, challenges and opportunities for changing the direction of mobility in the future.

- Implications for Road Safety and Traffic Efficiency:

There are significant implications for traffic efficiency and road safety when VCNs are integrated with connected and autonomous vehicles[16]. VCNs improve situational awareness and decision-making skills, lowering the risk of accidents and improving traffic flow by facilitating smooth communication and cooperation between automobiles, infrastructure components, and centralized traffic management systems. Applications for cooperative driving, like intersection coordination, cooperative merging, and platooning, use VCNs to improve traffic management and collision avoidance, hence raising overall road safety and traffic efficiency.

- Challenges in the integration of VCNs:

Although the integration of VCNs with autonomous and connected vehicles has the potential to be revolutionary, several obstacles need to be overcome to fully reap the rewards[17]. Seamless integration is significantly hampered by technical issues such as guaranteeing the interoperability, dependability, and security of communication protocols and infrastructure.

Furthermore, to increase public confidence and acceptance of autonomous and connected vehicle systems, regulatory and legal issues about data privacy, liability, and standardization of VCN technology must be carefully considered. In addition, social issues like equality concerns, behavior adaption, and user acceptability demand a comprehensive approach to address the human elements involved in the adoption of VCN-enabled technology.

- Opportunities for the integration of VCNs:

Despite the difficulties, there are a lot of chances for innovation and cooperation amongst several industry sectors when integrating VCNs with connected and autonomous vehicles. Technological developments in communication, including edge computing, 5G networks, and artificial intelligence, provide new opportunities to improve the functionality and scalability of VCN deployments[15]. Furthermore, cooperation amongst governmental organizations, automakers, telecom providers, and academic institutions can promote the global standardization, interoperability, and harmonization of VCN technology.

Additionally, there are opportunities to optimize resource utilization and reduce environmental impacts by integrating VCNs with emerging mobility services like ride-sharing, car-sharing, and MaaS. This will help to create a transportation ecosystem that is more equitable and sustainable.

The potential for revolutionizing our understanding of, interactions with, and control over transportation systems is enormous when vehicular communication networks are combined with connected and autonomous cars. VCN-enabled technologies hold the potential to transform mobility and elevate the standard of living for both individuals and communities through the improvement of road safety, optimization of traffic efficiency, and facilitation of new mobility services. However, overcoming integration's obstacles—such as technological interoperability, legal compliance, and public acceptance—calls for cooperation and creative thinking from players in many industry sectors. The future of transportation will be shaped by sustained investment in VCN-enabled technology deployment, research, and development of autonomous and connected car benefits that are to be fully realized.

9. Objective Modular Network Testbed in C++ (Omnet++)

OMNeT++ is an open-source, modular, extendable, component-based C++ simulation framework and library that is mostly used for creating network simulators. The term "network" refers to a wider range of systems, such as queueing networks, on-chip networks, and wired and wireless communication networks[18]. It offers a platform for simulating complex systems, modeling them, examining their behavior, and testing various protocols and methods. Model frameworks, created as separate projects, offer domain-specific capabilities including support for wireless ad hoc networks, sensor networks, Internet protocols, performance modeling, photonic networks, and so forth.

OMNeT++ has developed a sizable user base despite not being a network simulator per se. It is a widely used network modeling tool in both industrial and scientific contexts. OMNeT++ is a tool used by researchers, academics, and professionals in the industry for a variety of tasks, including modeling communication systems, testing routing protocols, analyzing congestion control techniques, and assessing network performance.

With OMNeT++, programmers can use C++ or its simulation language, NED, to design modular and reusable network models. It provides a wide range of functionalities, such as support for parallel simulation, a graphical user interface for creating and visualizing models, and large libraries for network components and protocols.

A component architecture for models is offered by OMNeT++. A high-level language (NED) is used to build smaller C++-programmed components (called modules) into larger components and models. Model reusability is free of charge. Because of its modular architecture and broad GUI support, OMNeT++ facilitates the easy integration of simulation models and kernels into programs.

10.Internet Networking (INet)

The OMNeT++ simulation environment has an open-source model library called INet Framework[19]. For academics and students working with communication networks, it offers protocols, agents, and other models. INET can be particularly handy when creating and testing new protocols or investigating unusual or novel situations.

Modules that exchange messages through message passing are the foundation of an INet. Components are the representation of agents and network protocols; these can be flexibly combined to create hosts, routers, switches, and other networking devices. The user can create new components, and already-written components are designed to be simple to comprehend and alter.

The infrastructure that OMNeT++ provides is advantageous to INet. This means that models can be developed, assembled, parameterized, run, and their outcomes evaluated from the comfort of the OMNeT++ Simulation IDE or the command line, in addition to utilizing the services offered by the OMNeT++ simulation kernel and library (component model, parameterization, result recording, etc.).

Some features:

- OSI layers implemented (physical, link-layer, network, transport, application)
- Pluggable protocol implementations for various layers
- IPv4/IPv6 network stack (or build your network layer)
- Transport layer protocols: TCP, UDP, SCTP
- Routing protocols (ad-hoc and wired)
- Wired/wireless interfaces (Ethernet, PPP, IEEE 802.11, etc.)
- Physical layer with scalable level of detail (unit disc radio to detailed propagation models, frame level to bit/symbol level representation, etc.)
- Wide range of application models
- Network emulation support
- Mobility support
- Supports the modeling of the physical environment (obstacles for radio propagation, etc.)
- Separation of concerns

- Visualization support

11. Simulation of Urban MObility (SUMO)

Modeling and simulating urban traffic networks are possible with SUMO, an open-source traffic simulation program[20]. It offers a platform for modeling road networks, automobiles, pedestrians, and public transportation systems, among other elements of urban mobility. Numerous auxiliary tools that automate essential processes for the development, implementation, and assessment of traffic simulations—such as network import, route computation, visualization, and emission calculation—come included with SUMO. Custom models can be added to SUMO, which also offers several APIs for remote simulation control.

In addition to accounting for lane changes, acceleration, deceleration, and other aspects of vehicle motion, SUMO also models pedestrian behavior and vehicle-vehicle interactions.

Moreover, it facilitates the modeling of routes, schedules, and passenger behavior for public transportation systems. SUMO makes it easier to adopt and assess different traffic control techniques, like congestion management and optimized signal timing. Users can optimize urban transportation systems and improve mobility and accessibility within cities by analyzing traffic flow, congestion patterns, and vehicle trajectories using its visualization tools.

12. Vehicles in Network Simulation (Veins)

Veins is an open-source system designed to model vehicular communication networks by integrating SUMO and other tools with the discrete event simulation environment OMNeT++. Within the framework of realistic vehicle traffic scenarios, researchers and developers can model and assess communication protocols and applications by using Veins[21].

SUMO integration facilitates realistic vehicular mobility scenarios, which is one of its primary characteristics. This allows for the simulation of intricate road networks and traffic patterns. To accurately simulate different vehicular communication technologies, Veins offers a full suite of communication models. This enables the simulation of V2V and V2I communication.

Researchers and developers can access and optimize communication protocols and applications in the context of dynamic vehicular environments thanks to Veins, which also supports the simulation of communication protocol stacks and offers tools for analyzing network connectivity, message propagation, and communication performance metrics.

Chapter 3: Methodology

1. Methodology

In this chapter, the approach is intended to methodically observe how the VCNs can improve traffic efficiency and road safety. The methodology entails obtaining vital information on traffic flow, road accidents, and the use of VCNs at the moment, then carefully analyzing the data to identify trends, patterns, and correlations. After that, probable results under different traffic scenarios are modeled using simulation tools, which offer insights into the possible impact of VCN deployment.

2. Research Design

To thoroughly evaluate the effectiveness and usefulness of VCNs in improving traffic efficiency and road safety, extensive simulations will be conducted. A carefully designed collection of four simulations has been developed to mimic a wide range of situations and scenarios. These simulations are essential resources for examining the potential and capabilities of VCNs in practical settings. Every simulation scenario is created to examine various facets of VCN impact and performance:

- Emergency Response Scenario Simulation:

In this simulation, the responsiveness of VCNs in emergency scenarios—especially while an ambulance is approaching—will be assessed. The system's capacity to efficiently alert and manage traffic movement will be examined by emulating situations in which an ambulance is near other cars. The main goal is to evaluate how VCNs expedite emergency vehicles' passage, which could shorten response times and improve emergency management effectiveness overall.

- Accident Notification and Traffic Rerouting Simulation:

The primary objective of this simulation is to evaluate VCNs' ability to recognize and react to traffic accidents. When a car has an accident, alerts will go on, causing other cars in the vicinity to divert and stay away from the scene. The purpose of the simulation is to evaluate how well VCNs, which dynamically reroute traffic flow in response to incidents, reduce traffic congestion and the likelihood of secondary accidents.

- Vehicle Malfunction Alert Simulation:

This simulation scenario aims to investigate how VCNs respond to vehicle problems, such as an electrical system failure or running out of fuel. Vehicles nearby will receive notifications about the malfunctioning car, enabling proactive avoidance and traffic control. This scenario will be simulated to assess how well VCNs work at quickly recognizing and resolving possible traffic hazards.

3. Simulation Model Development

The simulation model development will use a variety of sophisticated simulation tools and platforms, each with specific features designed to address various aspects of vehicular communication scenarios. The following are these tools:

- Simulation of Urban MObility (SUMO):

SUMO, which is well-known for its capacity to simulate traffic on roads, will be used mostly for creating varied road networks in the simulation. Because of its advanced characteristics, realistic road designs, crossings, and traffic flow patterns can be created, giving simulations a strong basis for simulating real-world events.

- Objective Modular Network Testbed in C++ (Omnet++):

OMNeT++, the simulation environment's framework, offers a strong platform for simulating intricate network systems and protocols. Its flexible structure and modular architecture make it perfect for combining multiple simulation components, enabling smooth interaction between objects like traffic control systems, communication hubs, and automobiles.

- Vehicles in Network Simulation (Veins):

Veins is an expert in simulating networked vehicle communication systems and their interactions. Veins makes it possible to create realistic communication scenarios, such as V2V and V2I communication, by utilizing the features of OMNeT++. Evaluate the effectiveness of VCNs, also makes the modeling of wireless communication protocols and channel parameters easier.

- Internet Networking (INet):

INet enhances the simulation environment by offering network coding features that are necessary for modeling data transfer and communication protocols inside VCNs. The realistic modeling of communication channels, creating packets, packet routing, and data exchange procedures is made possible by its extensive library of network protocols and services. INet and OMNeT++ integration improves the simulation environment's capacity to model intricate network scenarios and assess VCN performance under various operating environments.

4. Data Collection Methods

Advanced simulation platforms and tools, including SUMO, OMNeT++, Veins, and INeT, will be used to collect data for this thesis. When simulating different vehicular communication settings and gathering relevant data, these technologies offer realistic surroundings. Critical VCN factors such as reaction time, traffic flow optimization, accident mitigation, and emergency vehicle prioritizing will be analyzed through the simulation method.

The simulations will be meticulously designed to imitate actual traffic conditions and emergency circumstances, allowing for a thorough assessment of VCN functionalities. Practical road networks and traffic situations will be simulated with SUMO, and the simulation of vehicular communication systems and interactions in a network environment will be made easier with the help of Veins and OMNeT++. Furthermore, INeT will be used to provide network coding capabilities that are necessary to replicate data transmission and communication protocols inside VCNs.

The simulation-generated data will undergo thorough analysis to evaluate the efficacy and performance of VCNs in accomplishing the study's objectives. Methods of statistical analysis will be used to measure how much VCNs affect traffic efficiency and road safety. Through the utilization of these modeling tools and platforms, this research endeavors to offer significant perspectives on the possible advantages and difficulties linked to the incorporation of VCNs into current transportation systems.

5. Scenario Design

To fully investigate the capabilities and efficacy of Vehicular Communication Networks in improving traffic efficiency and road safety, four different scenarios will be simulated. These carefully crafted scenarios replicate a variety of actual traffic conditions and emergency circumstances, offering insightful information about the capabilities of VCNs in diverse settings.

Among the scenarios are:

- Emergency Response Scenario Simulation:

To simulate actual situations, the simulation will be run on a two-lane, straight road. When an emergency vehicle, such as an ambulance, approaches, the VCN will actively notify all other vehicles. Those who are in the same lane as the emergency vehicle will then move to the adjacent lane, clearing the way for the emergency vehicle to pass. With this dynamic maneuver, traffic flow is optimized and emergency vehicle response times are prioritized. This could result in faster emergency response times and more effective emergency management procedures.

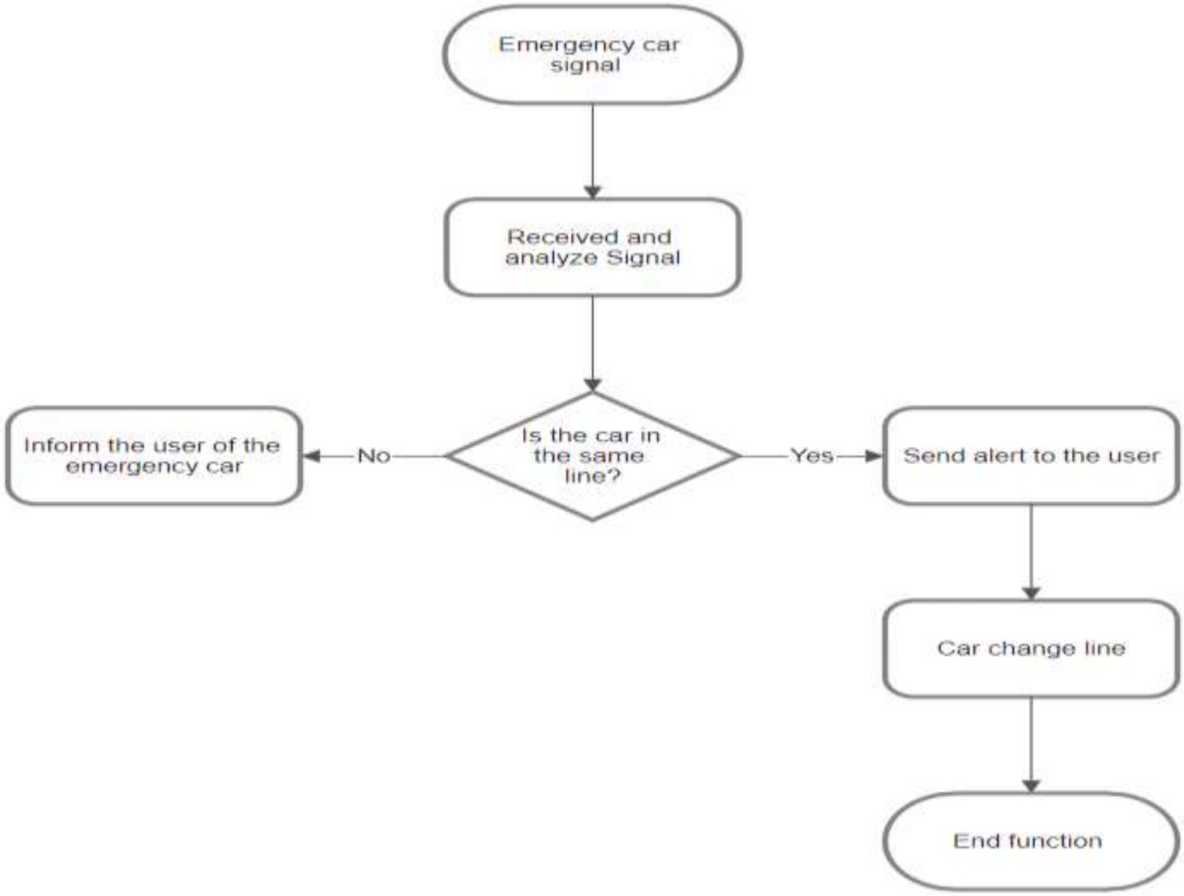

Figure 3: Flowchart for the Emergency Response Scenario Simulation.

The figure above illustrates the flowchart that explains how the emergency vehicle simulation runs. The system instantly allows the ambulance to signal its approach to nearby vehicles. Every vehicle analyzes its position concerning the emergency vehicle's trajectory after getting the signal. When a car is in the same lane as the emergency vehicle, the driver instantly receives an alert telling them to switch lanes. On the other hand, a car in the adjacent lane gets a notification informing the driver that there is an emergency car in the other lane. This careful planning guarantees quick and effective traffic control, allowing emergency vehicles to pass through unobstructed and improving road safety in emergency circumstances.

- Accident Notification and Traffic Rerouting Simulation:

The simulation will take place inside a road map located in the Ashrafie region to faithfully replicate real-world conditions. To simulate an accident, two cars will collide in this simulation scenario. As soon as the collision occurs, a message alerting surrounding cars to the accident and advising them to adjust their course will be sent out. The goal of this dynamic response mechanism is to mimic the unplanned changes that drivers make in reaction to unanticipated traffic situations. The study aims to capture the unique characteristics of traffic behavior and evaluate the usefulness of VCNs in enabling prompt responses to accidents by simulating such scenarios within a particular geographic area. This will ultimately improve road safety and traffic efficiency in real-world contexts.

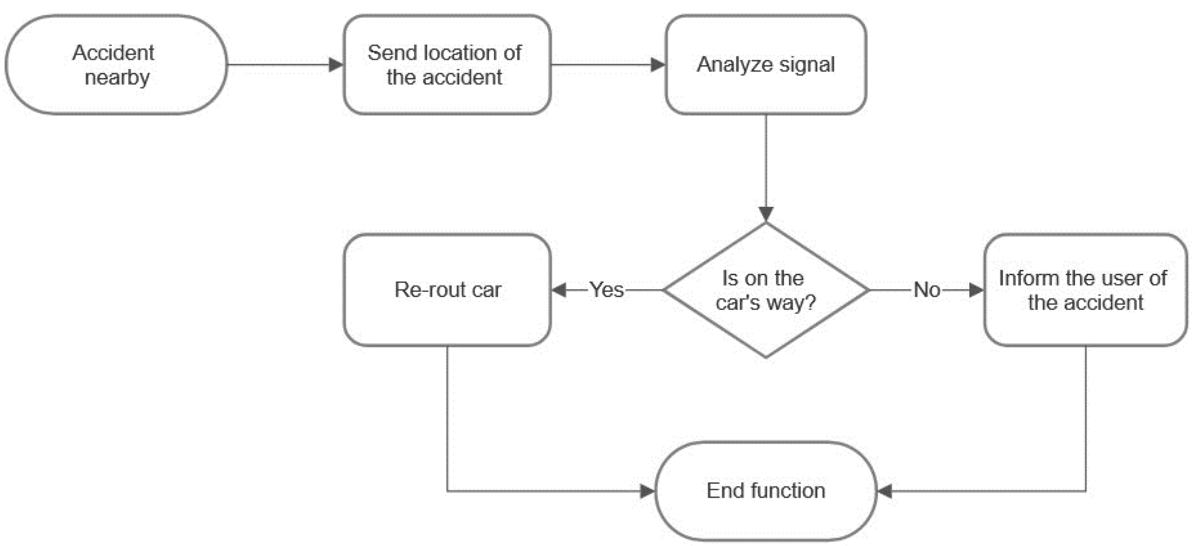

Figure 4: Flowchart for Accident Notification and Traffic Rerouting Simulation.

The figure above illustrates the flowchart detailing the process of the accident notification simulation. When an accident happens in the area in this case, the system quickly notifies all of the close vehicles with the exact position of the occurrence. Once these vital details are received, every car starts rerouting to avoid the impacted area. Vehicles may quickly modify their routes thanks to this dynamic reaction technology, which helps them avoid congestion and accident site hazards. On the other hand, the cars that are in the area but the accident is not in their way, will receive the notification with the location of the accident. To improve road safety and traffic flow optimization, the study simulates this scenario to assess how well VCNs distribute timely information and enable effective traffic management in response to unforeseen events.

- Vehicle Malfunction Alert Simulation:

The simulation will be run on a road map in the Mar Mikhael area to mimic real-world circumstances. Cars will break down in this simulation, mimicking situations when they run out of fuel or have electrical problems. Notifications about the faulty vehicles will be sent to neighboring vehicles in real time, at the same moment these incidents occur. Vehicles will dynamically modify their routes to avoid the impacted region in response to these notifications. The purpose of this proactive rerouting system is to reduce the possibility of delays in traffic and accidents brought on by broken vehicles.

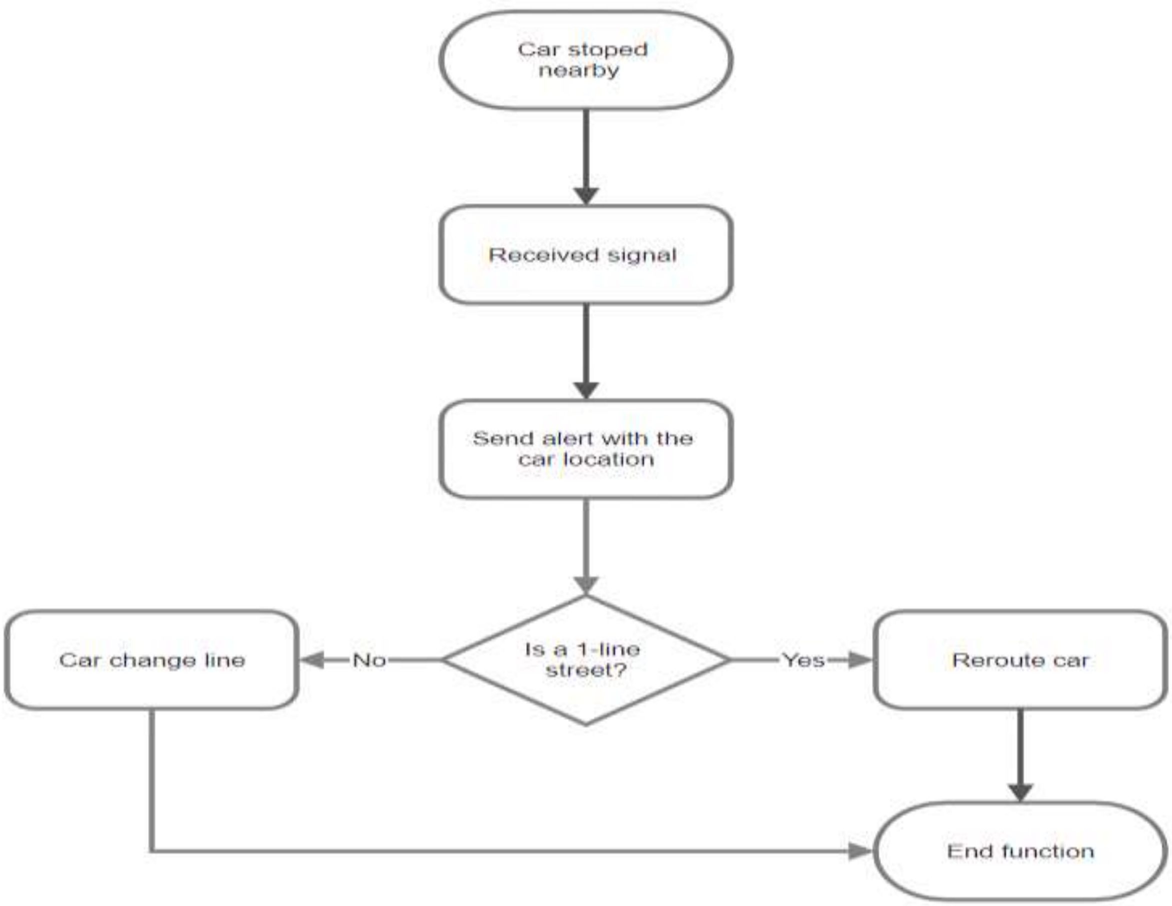

Figure 5: Flowchart for the Vehicle Malfunction Alert Simulation.

The figure above illustrates the flowchart depicting the process of the malfunctioning car notification simulation. In this scenario, when a car breaks down close by, the system instantly notifies all the other cars around it, including the exact location of the broken-down vehicle. Vehicles are instructed to reroute to avoid the malfunctioning area if the road is single-lane. On multi-lane roads, on the other hand, cars can choose to reroute but can also pass through the region if they so want. The objective of this adaptive response mechanism is to minimize possible risks and maintain traffic flow, all the while giving drivers freedom.

6. Data Analysis Techniques

The information generated by the simulations will be carefully examined to assess VCNs' efficacy and performance concerning the objectives outlined in this thesis. Numerous important parameters will be covered by this comprehensive research, such as response time, traffic flow optimization, accident mitigation, and emergency vehicle prioritizing. The study intends to get insight into the observable advantages and operational effectiveness of VCNs in actual traffic conditions by closely examining these parameters.

Moreover, it is essential to emphasize the critical role that C++ programming had in the creation and modification of the simulation framework. Because of its efficiency and versatility, C++ is a programming language that is both powerful and adaptable. As such, it is a great option for combining different simulation components and constructing complex simulation algorithms. By taking advantage of C++'s features, the chosen simulation tools—SUMO, OMNeT++, Veins, and INet—can be easily combined and tailored to accurately replicate real-world vehicular communication scenarios.

Essentially, this study aims to give a thorough and empirically supported evaluation of Vehicular Communication Networks' effects on road safety and traffic efficiency by combining rigorous data analysis methodologies with the powerful programming capabilities of C++. This research intends to contribute to the improvement of transportation systems that are focused on improving public safety and mobility by clarifying the complex interactions between VCN deployment tactics, traffic management protocols, and safety outcomes.

7. Evaluation Criteria

To evaluate the efficacy of vehicle response simulations in the context of VCNs, a wide range of metrics covering different facets of system performance have been used to create assessment criteria. Several key metrics will be employed to evaluate the effectiveness of the emergency response simulations:

1. Response Time:

This metric calculates how long it takes vehicles to move through traffic-simulation scenarios. A more effective emergency response system is indicated by a quicker reaction time.

2. Traffic Flow Optimization:

The influence of emergency response methods on overall traffic flow within the simulated environment will be evaluated through the analysis of traffic flow parameters, including average vehicle speed and levels of congestion.

3. Accident Mitigation:

To assess how well emergency response plans mitigate accidents and lessen their influence on traffic flow, the simulation will monitor the severity of incidents that occur inside the simulated environment.

4. Emergency Vehicle Prioritization:

This indicator assesses how well the simulation model can prioritize emergency vehicles' passage through busy intersections and locations, speeding up response times and enhancing the effectiveness of emergency management.

- Justification for Chosen Evaluation Criteria

These evaluation criteria were chosen because they were pertinent to the research’s objectives and might offer insightful information about how emergency response simulations operated in vehicular communication networks. In emergencies, response time is a crucial component that directly affects the efficacy of emergency response operations and the results for those in need of aid. Metrics related to traffic flow optimization offer valuable perspectives on the wider effects of emergency response procedures on traffic patterns and traffic congestion. Furthermore, measures related to accident mitigation and emergency vehicle prioritization provide important information on how well emergency response plans work to lower the number and severity of accidents as well as enhance emergency vehicle access in scenarios with heavy traffic.

All things considered, the evaluation criteria that have been selected offer an extensive framework that can be used to evaluate emergency response simulations in the context of vehicular communication networks and to inform evidence-based decisions about how best to improve traffic safety and emergency management procedures.

8. Ethical Considerations

The simulation study replicates real-world traffic conditions and emergency events within VCNs by utilizing cutting-edge simulation tools and platforms. Consequently, several ethical issues come up, such as participant consent, data privacy, and the research's possible effects on the community.

Ensuring the privacy and secrecy of the data generated by the simulations is a crucial ethical consideration. Sensitive data will be protected, and data protection laws will be followed, even though the acquired data is anonymized and aggregated. Furthermore, the design of the simulation situations will limit the possibility of injury or inconvenience to participants and stakeholders.

To ensure that results are appropriately reported and understood, the study will also place a high priority on transparency and integrity in its research procedures. All biases and conflicts of interest will be declared and measures will be taken to lessen their impact on the findings of the study. Furthermore, the research would comply with the ethical principles and standards established by regulatory organizations and institutional review boards.

- Steps Taken to Ensure Ethical Conduct:

There will be multiple measures implemented to guarantee ethical behavior during the research procedure. First, to protect the authenticity and integrity of the research findings. This entails using strict data management procedures to ensure the privacy of data as well as performing in-depth data analysis to guarantee accurate and dependable outcomes.

The researcher will also keep a close eye on any ethical issues that may surface during the trial and take appropriate action. The establishment of transparent ways to interact will enable the reporting of ethical issues or concerns, and prompt and transparent action will be taken to resolve them.

Overall, the study aims to uphold the highest standards of integrity and professionalism in its research practices and contribute to the advancement of knowledge in the field of vehicular communication networks while guaranteeing the safety and well-being of all involved parties by proactively addressing ethical considerations and adhering to ethical guidelines and standards.

Chapter 4: System Design and Implementation.

1. System Design and Implementation

To fully evaluate the usefulness and efficacy of VCNs in improving road safety and traffic efficiency. To replicate a broad range of circumstances, three precisely constructed simulations have been created, offering insightful information about the capabilities and effectiveness of VCNs in real-world settings. By simulating a wide range of real-world scenarios, these simulations seek to bring some insight into the capabilities and efficacy of VCNs in diverse scenarios.

Every simulation scenario is designed to investigate particular facets of VCN effectiveness and influence. Emergency response, accident reporting, traffic rerouting, and alerts of vehicle malfunctions are some of these characteristics. The simulations evaluate the speed and efficacy with which VCNs can speed up communication between emergency services and cars in the context of emergency response, potentially cutting response times and enhancing results. The emphasis in accident reporting is on assessing the dependability and promptness of VCNs in reporting incidents, which can improve emergency responders' and other drivers' situational awareness and lower the risk of secondary collisions.

Regarding traffic rerouting, the simulations examine VCNs' capacity to reroute traffic dynamically in response to various interruptions such as road closures, congestion, or other events. Reduced travel times and better traffic flow may result from this capacity. Furthermore, the element pertaining to vehicle malfunction notifications examines how VCNs might promptly alert neighboring vehicles on vehicle defects, thereby mitigating the risk of collisions and enabling prompt assistance.

A variety of cutting-edge platforms and technologies, such as OMNeT++, Veins, SUMO, and INeT, will be used to build these simulation models. SUMO offers comprehensive modeling of traffic patterns, vehicle movements, and road networks. OMNeT++ is a C++ simulation toolkit and framework that is modular, extensible, and component-based. It is mostly used for creating network simulators. An open-source framework called Veins combines network and road traffic modeling to create vehicular network simulations. Within the OMNeT++ simulation environment, INeT provides components and protocols for wired, wireless, and mobile networks.

Through the utilization of these instruments, scholars can produce incredibly intricate and lifelike virtual worlds that precisely mirror the intricacies of actual vehicle communication networks. Critical information and insights will be made available by the simulation results, allowing for a comprehensive assessment of the effect of VCNs on traffic efficiency and road safety. Future advancements and applications of VCN technologies in urban and highway environments can benefit from this as well.

2. Emergency Response Scenario Simulation:

The emergency vehicle will drive on a two-lane straight road in this simulation. Notifications about the emergency vehicle's arrival will be sent to nearby automobiles as it approaches them. This notification system functions as a component of the VCN, rapidly informing drivers in the vicinity. When an automobile receives a notification, it will proceed to change lanes if it is in the same lane as the emergency vehicle that is approaching. This will guarantee that the emergency vehicle has an unobstructed path. Cars in the other lane will continue to drive in the same direction, assisting the emergency vehicle's safe passage while also improving traffic flow overall.

Table 1: Parameters for Emergency Response Scenario Simulation.

Parameter	Description
Road Layout	A single straight line with two lanes, each 600 meters in length.
No. of Vehicles	Six vehicles.
Vehicle Types	One emergency vehicle, five passenger cars.
Left Lane Vehicles	Two passenger cars.
Right Lane Vehicles	One emergency vehicle, three passenger cars.

The road construction for this simulation is a single straight line with two lanes, each measuring 600 meters in length, that is generated using SUMO. Six vehicles are added in this simulated environment: one emergency vehicle and five passenger cars. According to the arrangement, two passenger cars use the left side of the road, while the emergency car and three other passenger cars travel on the right. To facilitate the evaluation of vehicle communication and traffic management tactics inside a simulated urban context, this setup attempts to replicate real-world driving situations. A thorough examination of VCNs and their effects on traffic flow and emergency response procedures is made possible by the simulation's exact replication of road dynamics, vehicle movements, and lane-based behaviors thanks to the integration of SUMO's capabilities.

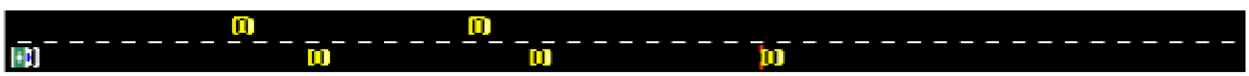

Figure 6: SUMO Map for Emergency Response Scenario Simulation.

The road structure generated by SUMO, including the lane configuration and car placement in the simulation, is depicted in the above figure. Because of SUMO's simulation capabilities, it is possible to create realistic road networks by precisely simulating vehicle movements and lane configurations. In the example, passenger cars and an emergency vehicle are dynamically organized along the assigned lanes using SUMO. This graphic gives a thorough picture of the traffic scenario under simulation and offers insightful information about the spatial distribution of traffic and vehicle interactions.

Figure 7: Omnet++ and SUMO Simulation for Emergency Response Scenario Simulation.

The scenario for the Emergency Response Scenario Simulation generated with OMNeT++ is visualized in the figure above. The six cars engaged in this situation are represented by nodes, with node [5] acting as the emergency vehicle. Nodes in networked systems such as VCNs can be created and managed using OMNeT++, which is well-known for its independent event simulation capabilities. The simulation accurately represents each vehicle's unique behaviors, interactions, and network connectivity by giving each its unique node. This visualization makes it easier for researchers to assess emergency response procedures and the efficiency of VCNs in reducing traffic incidents and improving road safety by allowing them to see the dynamic movement and communication patterns of the cars.

3. Accident Notification and Traffic Rerouting Simulation:

In this simulated scenario, two automobiles will collide, which will cause all neighboring cars to automatically receive a message. This notification system is built into the VCN and serves to rapidly notify other vehicles about an accident that is taking place. Vehicles involved in the collision will dynamically modify their routes in reaction to the warning, veering away from the collision scene to prevent additional disturbance and potential risks. In the interim, unaffected vehicles will continue their usual itineraries, guaranteeing continuous travel along their allocated pathways.

Table 2: Parameters for Accident Notification and Traffic Rerouting Simulation.

Parameter	Description
Road Map	Section of the Ashrafie road map.
No. of Vehicles	Seventeen vehicles.
Vehicle Types	Passenger cars.
Time of the accident	Thirty-three seconds.

A section of the Ashrafie road map is replicated in the road structure created for this simulation using SUMO. This portion of the road plan represents the virtual landscape the 17 vehicles will drive across. Because of SUMO's capabilities, the specified Ashrafie region can accurately depict road configurations, traffic patterns, and vehicle movements. With 17 vehicles operating in this simulated environment, researchers can obtain important information on traffic dynamics.

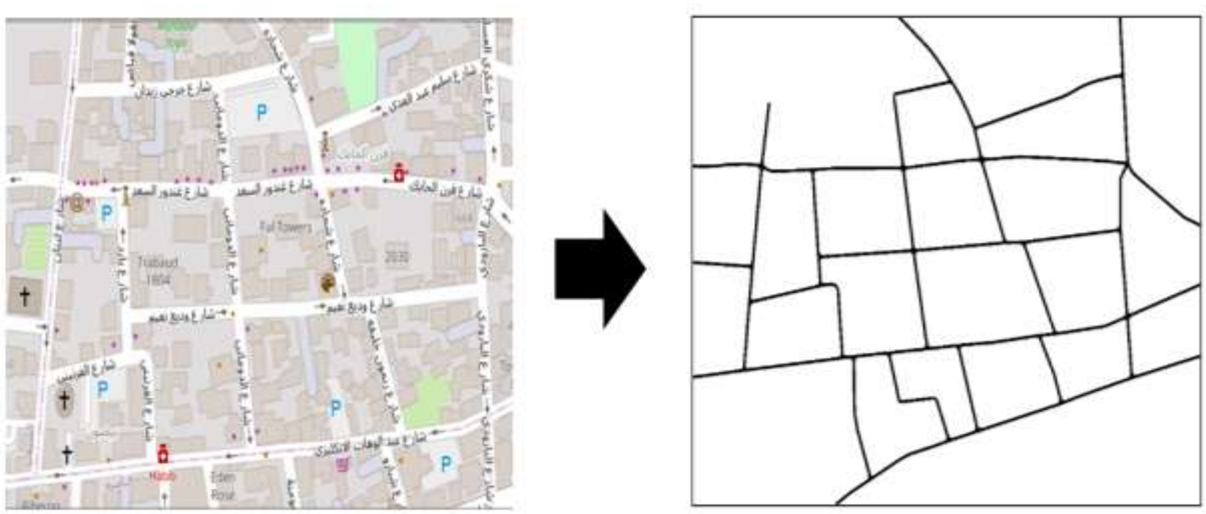

Figure 8: Ashrafie Map Made into SUMO Map for Accident Notification and Traffic Rerouting Simulation.

The Ashrafie map and its SUMO representation are seen in the above image. SUMO faithfully recreates Ashrafie's intricate geography and characteristics in the simulation environment. It is possible to see how the road network is converted into a digital format through SUMO's visualization, which enables an in-depth examination of traffic flow. An improved comprehension of how SUMO mimics actual road settings is made possible by this side-by-side comparison, which also makes it easier to assess the efficacy of VCN and traffic control techniques in Ashrafie's urban environment.

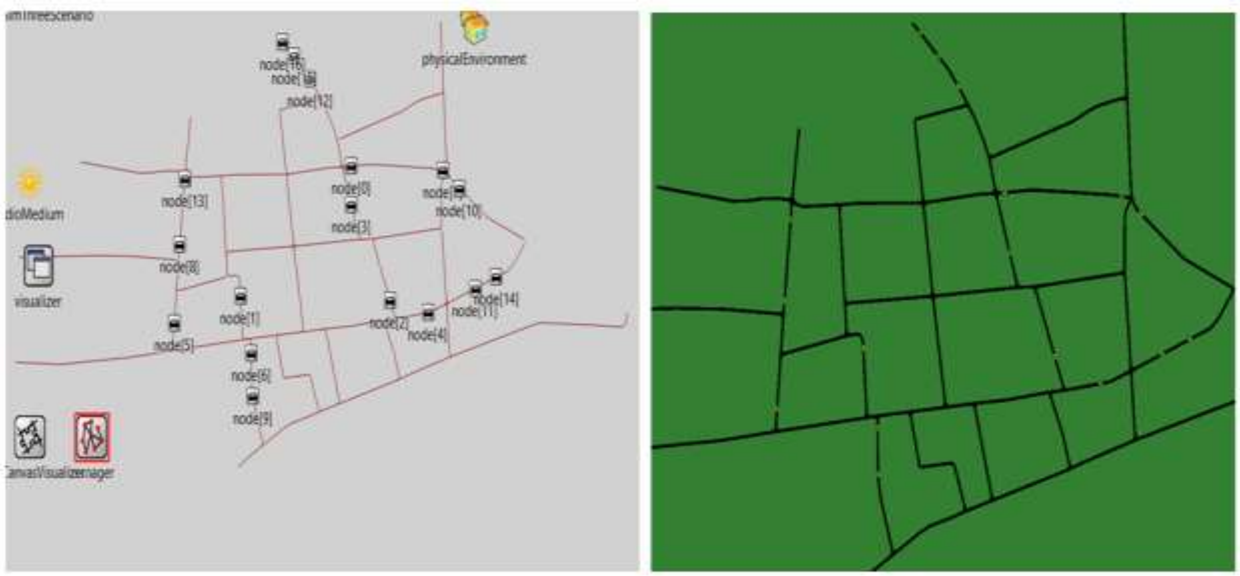

Figure 9:Omnet++ and SUMO Simulation for Accident Notification and Traffic Rerouting Simulation.

The scenario created with OMNeT++ for the Accident Notification and Traffic Rerouting Simulation is shown in the above figure. It has a representation of the Asrafie map with nodes standing in for the 17 cars that are involved. Additionally, nodes are assigned to every car to mimic how they travel and communicate inside the network. To be more precise, nodes node [2] and node [3] are set up to collide at 33 seconds to simulate a car crash. Researchers may dynamically model such occurrences and assess their impact on traffic flow and the efficacy of traffic rerouting schemes by using OMNeT++'s discrete event simulation capabilities.

4. Vehicle Malfunction Alert Simulation:

Two different scenarios will be investigated in this simulation to assess how well VCNs handle vehicle breakdowns and reroute traffic appropriately. At the 15-second mark in Case 1, a car will break down. All surrounding cars will receive messages every 10 seconds, alerting them to the problem and directing them to take alternative routes. There will be a 15-second pause before the car moves forward again. On the other hand, in Case 2, a breakdown happens at the 40-second point, and neighboring trucks receive instant information, causing rerouting actions. In both scenarios, the VCN enables efficient coordination of rerouting measures to reduce traffic congestion and minimize delays resulting from malfunctioning vehicles by facilitating real-time communication between vehicles.

Table 3: Parameters for Vehicle Malfunction Alert Simulation.

Parameter	**Description**
Road Map	Section of the Mar Mikhael road map.
No. of Vehicles	Twenty-five vehicles.
Vehicle Types	Passenger cars.
Time of the accident	Fifteen seconds and forty seconds

For this simulation, a portion of the road map in Mar Mikhael is replicated using SUMO to construct the road structure. Within this simulated environment, 25 vehicles will traverse the designated area. SUMO's capabilities allow for the accurate representation of road layouts and traffic dynamics. With 25 vehicles navigating through the simulated road network, it can gather valuable insights into traffic patterns.

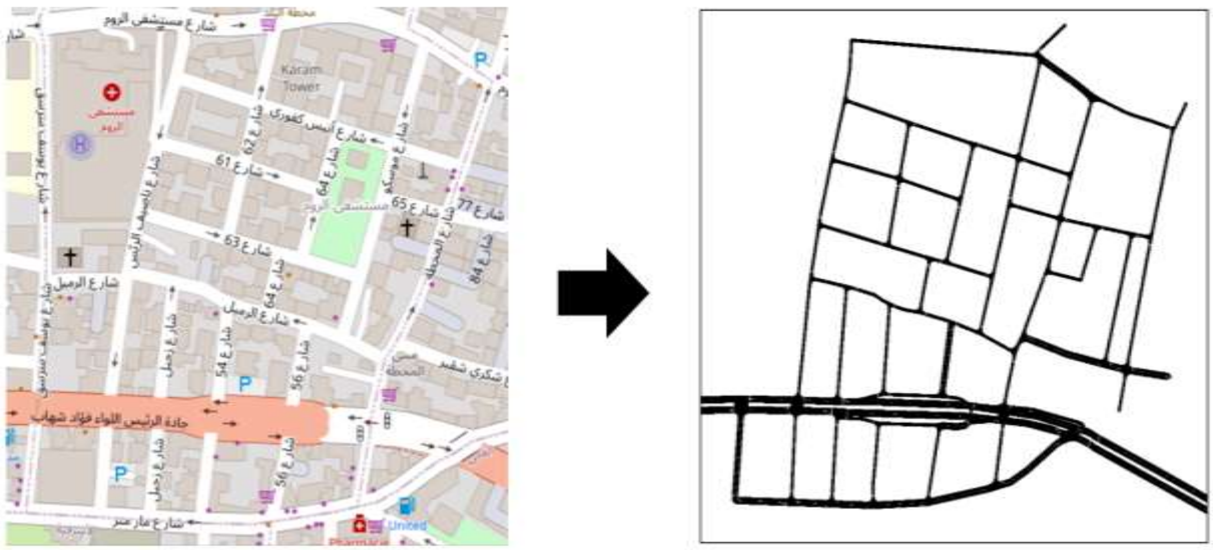

Figure 10: Mar Mikhael Map Made into SUMO Map for Vehicle Malfunction Alert Simulation.

The figure above provides a visual comparison between the Mar Mikhael map and its representation within SUMO. SUMO accurately recreates the road network of Mar Mikhael, capturing its layout and features within the simulation environment. This side-by-side depiction allows the observation of how the real-world map translates into a digital format in SUMO, providing insights into traffic patterns and congestion dynamics. By comparing the two versions, analysts can better understand how SUMO simulates real-world scenarios, facilitating the evaluation of traffic management strategies and the effectiveness of VCN within the Mar Mikhael urban area.

Figure 11: Omnet++ and SUMO Simulation for Vehicle Malfunction Alert Simulation.

The figure above provides an overview of the scenario generated by OMNeT++ for the Vehicle Malfunction Alert Simulation, which includes a representation of the Mar Mikhael map and nodes corresponding to the 25 cars involved. Within this simulation, specific nodes are programmed to simulate vehicle malfunctions, enhancing the realism of the scenario. Notably, node [2] is programmed to halt its movement at the 15-second mark before resuming at the 30-second mark, while node [0] is set to stop at the 40-second mark. These simulated malfunctions enable researchers to evaluate the effectiveness of VCNs in promptly detecting and disseminating alerts about vehicle malfunctions to nearby vehicles.

5. Results of Emergency Response Scenario Simulation

When the SUMO map was incorporated into the Veins system, an important feature was added: the emergency vehicle would send out a message to every nearby vehicle in the area alerting them to its location. If a nearby car happens to be in the same lane as the emergency vehicle, this early warning system is meant to warn it and tell the other driver to move. Through the use of the Veins architecture, which enables realistic vehicular communication simulations, this feature improves the simulation's realism by simulating actual situations in which emergency vehicles announce their presence to oncoming traffic.

Figure 12: Emergency Car Sending Signal to Cars Nearby.

The system by which the emergency car broadcasts messages to every other vehicle nearby is shown in the above figure. The emergency vehicle connects to all other vehicles through a fully connected topology, guaranteeing that its alert message is distributed throughout the whole network. Because every vehicle in this topology is directly connected to every other vehicle, dependable and effective communication is possible without the use of intermediate nodes. By using this method, the emergency vehicle can quickly broadcast its message to all other vehicles in the area, causing them to change lanes to make room for it to pass.

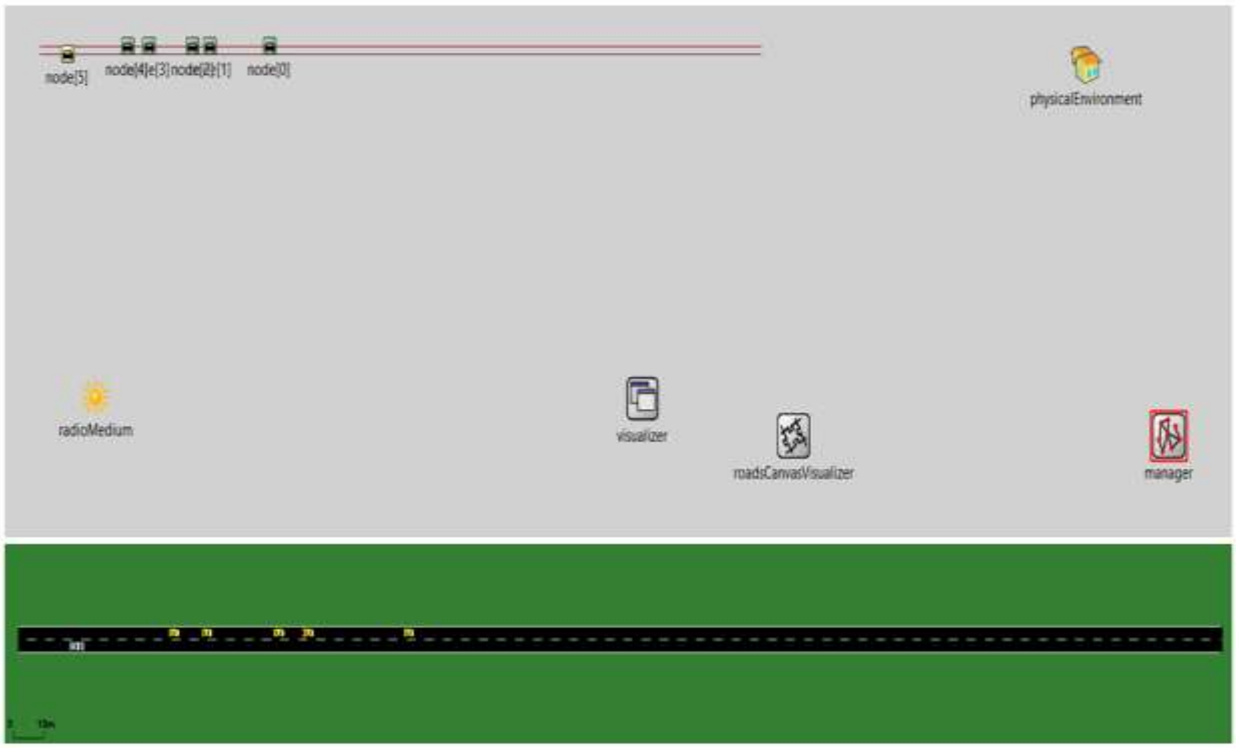

Figure 13: Cars Received Signal and Made Way to the Emergency Car.

The reaction of the cars to the message they receive and the following processing is shown in the above figure. Two cars that were not initially in the same lane as the emergency vehicle kept their lane positions without changing lines after the emergency car's message was received and processed, according to the simulation. On the other hand, the simulation shows that the other three cars, which were initially in the same lane as the emergency vehicle, quickly changed lanes. This graphic depiction offers important new information about the dynamics of driver behavior and vehicle communication in emergency scenarios.

6. Results of Accident Notification and Traffic Rerouting Simulation

After Ashrafie's SUMO map was incorporated into the Veins framework, two nodes—node [2] and node [3]—were configured to mimic a collision that happened 33 seconds in. Following that, a warning message indicating the accident's location was sent to every car nearby. Early response from surrounding vehicles was made possible by this proactive alerting system, which caused them to reroute their paths to avoid the accident scene. Using the Veins framework's realistic vehicular communication simulation capabilities, this capability imitated real-world situations where traffic incidents lead to rerouting actions that reduce congestion and guarantee road safety.

Figure 14: Cars Crashed and Sending Signal to Cars Nearby.

The situation where nodes [2] and [3] have collided, mimicking a car accident, is shown in the above figure. After the collision, both automobiles use a fully connected topology to quickly send messages to every other car around. Because every vehicle in this topology is immediately connected to every other vehicle, the accident location information is sent throughout the whole fleet. The vehicles involved in the collision allow other motorists to quickly reroute and avoid traffic around the scene by broadcasting their whereabouts to all adjacent cars. This graphic illustrates the effective communication that VCNs provide in accident scenarios, allowing for quick action and improving traffic safety in metropolitan settings.

Figure 15: Cars Re-Rout After Receiving Signal.

The reaction of the cars after they received and processed the accident notification message is seen in the above figure. Additionally, nodes [12], [15], and [16] are seen to change their paths to avoid the accident site when an accident alert is received. On the other hand, since the accident does not directly affect their intended itineraries, other vehicles in the simulation stay on their original routes. The dynamic decision-making processes driven by VCNs in reaction to on-the-road events in real time are highlighted by this visual portrayal. With well-informed decision-making, these simulations help to improve traffic management tactics and road safety standards.

7. Results of Vehicle Malfunction Alert Simulation

Two different situations were simulated once the Veins framework was integrated with Mar Mikhael's SUMO map. In Case 1, node [2] was designed to malfunction and keep sending out a message to cars in the area. The goal of this simulation scenario was to imitate a situation in which a vehicle malfunctions and continuously generates warnings to alert other vehicles. On the other hand, node [0] in Case 2 was designed to malfunction without initiating a comparable message repetition process. So, it can be evaluated on how well VCNs identify and handle vehicle faults, as well as the effects of continuous message broadcasts on communication dependability and traffic flow, by simulating these scenarios.

- Case 1:

In Case 1 of the simulation, node [2] was purposefully set up to malfunction at the 15-second interval, starting a loop of alert messages being transmitted every 10 seconds. The purpose of this malfunction simulation was to imitate a situation in which a vehicle has a problem and keeps alerting other cars to its whereabouts. As soon as the malfunction is located, the nearby cars are alerted to the location of the problematic vehicle and are prompted to reroute to minimize any possible interruptions to traffic. The 30-second stage is when node [2] returns to regular operation and when the alert message transmission stops.

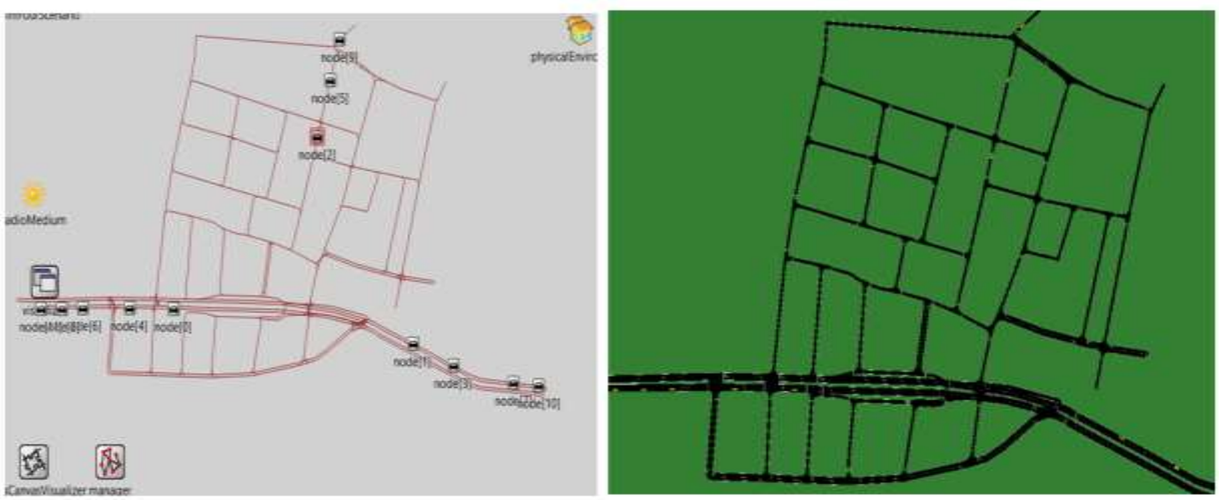

Figure 16: Car Malfunctioning and Sending Signal to Cars Nearby.

The scenario where node [2] malfunctions is illustrated visually in the figure above, which shows how the impacted vehicle broadcasts its location to all nearby cars. Making use of a fully connected topology, the failing node starts sending alert messages to all other nearby vehicles. Because every vehicle in this topology is physically connected to every other vehicle, the malfunction location information is widely disseminated. The failing node allows other cars to know where it is and can change their routes to avoid the impacted region by broadcasting its location to all other cars nearby. This graphic illustrates how effective VCNs are in communicating important information and enabling synchronized reactions to unforeseen occurrences while driving.

Figure 17: Cars That Received Signal Re-Routing.

The reaction of the cars after they received and processed the alert message about the malfunctioning car is seen in the above figure. Notably, nodes [5] and [9] are seen to modify their routes in reaction to the warning to steer clear of the afflicted area. On the other hand, other cars in the simulation stick to their normal routes, undisturbed by the broken-down vehicle. This graphic depiction emphasizes how VCNs dynamically alter decision-making processes in reaction to on-the-road events occurring in real-time.

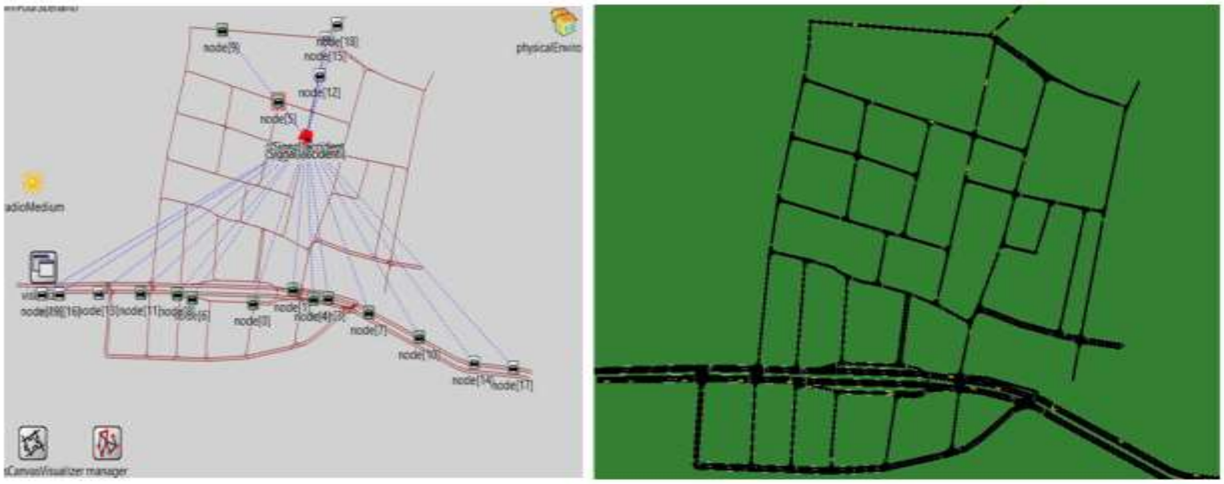

Figure 18: Malfunctioning Car Sending Again the Signal.

The case where node [2] experiences a problem is illustrated in the above picture, which shows how this vehicle resends its position message to all nearby automobiles after a 10-second interval. Functioning in a fully connected topology, the failing node reliably sends warning signals to all other vehicles nearby. Because every car in this system is immediately connected to every other one, the location data is distributed throughout the whole fleet. The faulty node keeps surrounding cars informed by resending its message regularly, enabling them to modify their routes accordingly.

Figure 19: New Cars That Received Signal Re-Routing

The response of automobiles after they have received and processed the repeated alert message is shown in the above figure. notably, nodes [12], [15], and [18] are seen to alter their paths in reaction to the repeated message, to avoid the region that is impacted by the broken car. On the other hand, other cars in the simulation stick to their previous itineraries despite the issue. The dynamic decision-making processes driven by VCNs in reaction to on-the-road events in real time are highlighted by this visual portrayal.

- Case 2:

Node [0] was purposefully engineered to malfunction at the 40-second point in Case 2 of the simulation. A warning message indicating the position of the faulty car was then sent to all the nearby vehicles. This proactive alerting system made it easier for surrounding cars to react quickly, directing them to avoid possible traffic problems brought on by the issue. Through this integration, information about how well VCNs function in handling unforeseen circumstances and enhancing traffic control plans in urban settings may be obtained.

Figure 20: Car Malfunctioning and Sending Signal to Cars Nearby.

The scenario when node [0] malfunctions is depicted visually in the above figure, which also shows how this vehicle broadcasts its location to all nearby cars. Making use of a fully connected topology, the failing node starts sending warning messages to all other vehicles in its neighborhood. Because every vehicle in this topology is truly connected to every other vehicle, the malfunction location information is widely disseminated. The failing node allows other cars to know where it is and can change their routes to avoid the impacted region by broadcasting its location to all other cars nearby. This graphic demonstrates how effective VCNs are in communicating important information and enabling coordinated reactions to unforeseen incidents while driving.

Figure 21:CarsRe-Routing After the Signal was Received.

The figure above illustrates how the cars behaved after receiving and interpreting the alert message about the malfunctioning car. Notably, nodes [6,], [8,], [11], and [16] are seen to modify their routes in reaction to the warning to steer clear of the afflicted area. On the other hand, since the malfunction does not directly impact their intended itineraries, other cars in the simulation remain on their original routes. The dynamic decision-making processes driven by VCNs in reaction to on-the-road events in real time are highlighted by this visual portrayal.

Chapter 5: Conclusion and Future Recommendations

1. Conclusion

Due to the escalating problems of traffic congestion, accidents, and the shortcomings of conventional infrastructure-centric methods, the transportation scene is changing quickly. The potential of VCNs as a game-changing solution to these urgent problems. Through the incorporation of advanced communication technology into infrastructure and vehicles, VCNs provide a dynamic, networked transportation environment that can improve road safety and traffic efficiency.

The efficacy and use of VCNs in diverse settings have been shown by this thesis through a sequence of well-crafted simulations. VCNs have demonstrated their capacity to adjust to changing circumstances and maximize traffic flow in a variety of situations. These include rerouting traffic around accidents and expediting emergency responses.

The findings of the thesis highlight how important VCNs are to changing the way we think about transportation management. VCNs facilitate more efficient risk anticipation and response in automobiles by utilizing sophisticated data exchange mechanisms and wireless communication protocols. By taking preventative measures, traffic congestion is lessened and the chance of accidents is decreased, which ultimately saves lives and enhances the quality of transportation.

Moreover, incorporating VCNs into the current infrastructure offers a viable method to create a transportation network that is more intelligent and resilient. Innovative applications like cooperative collision avoidance systems and adaptive signal control are made possible by VCNs, which enable smooth communication between cars, traffic lights, and centralized control systems. These developments could bring in a new era of safer, more effective, and environmentally friendly mobility by completely changing the way we view and engage with transportation networks.

In conclusion, this thesis's research demonstrates how VCNs have the ability to drastically alter the way that transportation is going to be in the future. By utilizing VCNs' capabilities, we can build a transportation ecosystem that is safer, more adaptable, and able to withstand the demands of the modern world. We get closer to achieving the goal of genuinely intelligent, connected, and sustainable mobility as we keep innovating and incorporating VCNs into our transportation infrastructure.

2. Future Recommendation

The integration of Vehicle Communication Networks into real-world transportation systems has a clear way ahead, based on the insights acquired from the simulations undertaken in this thesis. In order to facilitate the change, the following suggestions are made:

- Integration of Smart Vehicle Technology:

Developing and implementing smart vehicle technology is one of the most promising ways to integrate VCNs into practical situations. To do this, cars must be outfitted with a variety of sensors, radars, cameras, and communication modules that allow them to exchange data in real-time with other cars and infrastructure elements. These sensors can be cameras for image identification, radar sensors for spotting nearby objects and cars, and LiDAR (Light Detection and Ranging) sensors for accurate distance measurement. Through the utilization of these cutting-edge technologies, automobiles are able to interact with one another and the environment in an efficient manner, improving situational awareness and permitting preemptive reactions to possible dangers.

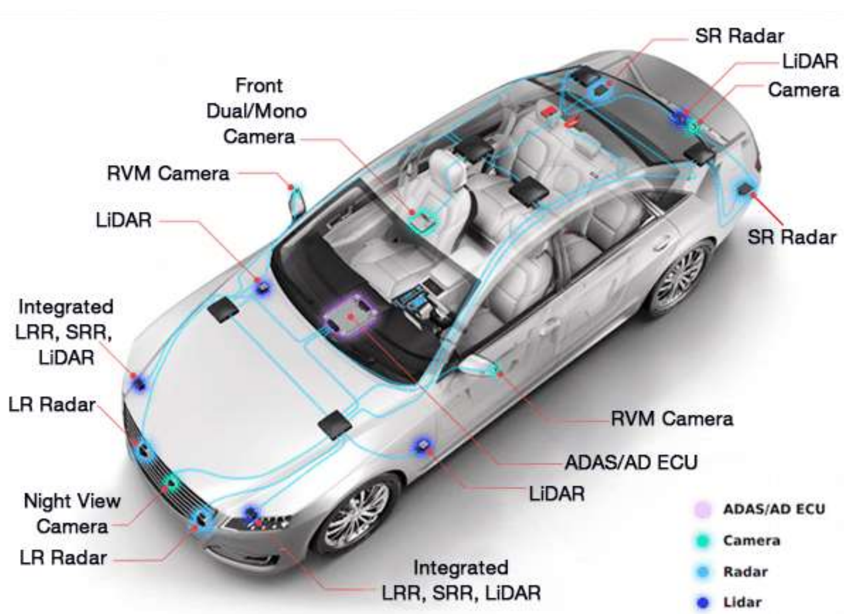

Figure 22. Components of a smart vehicle.

The figure shows the standard smart car equipment, which includes a variety of sensors and systems for autonomous driving (AD) and advanced driver assistance systems (ADAS). In order to obtain high-resolution images, these include front dual/mono, RVM (rearview mirror), and night view cameras; LiDAR sensors on the front, sides, and back for making 3D maps of the environment; short-range (SR) and long-range (LR) radars for detecting objects at different distances; and an integrated system that combines LiDAR, short-range radar, and long-range radar. All of these sensors provide data to the ADAS/AD Electronic Control Unit (ECU), which analyzes it and makes judgments in real time for things like adaptive cruise control, lane-keeping, collision avoidance, blind-spot recognition, and parking assistance.

In order to improve safety and automate driving chores, these components also support the Vehicle Communication Network (VCN), which facilitates smooth data flow across systems.

- Standardization and Interoperability:

Setting up industry standards and communication and interoperability protocols is crucial to guarantee the smooth integration of VCNs into actual transportation networks. This will make it easier for various infrastructure providers and automakers to design hardware and software solutions that work together, creating a more integrated and coherent transportation environment. These standards will contribute to every element in the network that can successfully communicate and function as a whole by fostering a more cohesive and integrated transportation environment.

It is recommended that standardization efforts concentrate on establishing shared data formats, communication protocols, and security measures to enable dependable and secure data transfer between infrastructure elements and cars. Transportation systems that are more coordinated and efficient can be achieved by industry stakeholders by giving priority to these areas, which will also improve the safety and dependability of VCNs.

- Infrastructure Upgrades and Deployment:

It is equally vital to upgrade the current infrastructure to support VCN-enabled communication as it is to equip vehicles with VCN technology. This could involve updating traffic lights and signage with hardware compatible with VCN, putting in place roadside units (RSUs) with sensors and communication modules, and incorporating VCN technology into already-in-use transportation management systems. With these improvements, the infrastructure will be able to connect with VCN-capable cars more easily, allowing for the smooth operation of the transportation system.

Transportation organizations can realize major benefits in traffic efficiency and safety by fully utilizing VCN technology and updating their infrastructure to allow VCN communication. Enhanced coordination between cars and infrastructure, real-time data interchange, and better traffic management are all made possible by fully leveraging VCN technology. By taking a comprehensive strategy, we can maximize the potential of VCN technology and create a transportation system that is safer and more efficient.

In summary, a concerted effort involving car manufacturers, infrastructure providers, governmental organizations, and other stakeholders is necessary for the successful integration of VCNs into actual transportation networks. By adopting smart car technologies, harmonizing communication protocols, and modernizing infrastructure, we can leverage VCNs' transformative potential to build a future transportation network that is safer, more effective, and more integrated.

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