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A Developed Adaptive Modeling Approach to Improve the Traffic Congestion Control in Urban Vehicular Networks

A Thesis
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By

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بسم الله الرحمن الرحيم

﴿وَفَوْقَ كُلِّ ذِي عِلْمٍ عَلِيمٌ﴾

(سورة يوسف 76)

صدق الله العظيم

Supervisor Certification

I certify that the thesis entitled "(A Developed Adaptive Modeling Approach to Improve the Traffic Congestion Control in Urban Vehicular Networks)" was prepared under my supervision at the department of Information Networks / College of Information Technology/ University of Babylon by (Randa Mahdi Kadhim) as partial fulfilment of the requirements of the degree of master in information technology- Information Networks.

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In view of the available recommendations, I forward the thesis entitled "A Developed Adaptive Modeling Approach to Improve the Traffic Congestion Control in Urban Vehicular Networks" for debate by the examination committee.

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Date: / /2023

Dedication

To the one who sows to harvest, but I lack his applause for the joy of my achievement at this moment, you will stay my support and encouragement, you are in my heart

my dear father (may God have mercy on you)

The angel who inspired me with tenderness...my dear mother

I wish to express my gratitude to my beloved husband Laith for your tremendous support and help

To my family my brothers and sisters. Their unwavering belief in my abilities

And to my sons

{Karrar, Zainab and Razan}

With All My Respect and Love…

Randa Mahdi

Acknowledgement

First and foremost, I would like to thank Allah, God, without divine care I could not even have contemplated all the work involved in this study.

I would like to extend my heartfelt thanks to my supervisor, Dr.Saad Talib Hasson, for his unwavering support, expertise, and patience.

Special thanks to Dr.Raaid Al-ubady the one who had the greatest impact on my success, he was a teacher and supporter from the beginning of my studies until I finished this thesis.

My sincere love to my best friend Nibras, she stood with me throughout the study period and her joy matched my joy.

Abstract

Vehicular Ad hoc Networks (VANETs) are a type of wireless communication network that enables vehicles to communicate with each other and with infrastructure components in their vicinity. VANETs form a dynamic and self-organizing network where vehicles act as mobile nodes, exchanging information and cooperating to improve road safety, traffic efficiency, and overall transportation experience. Congestion in transportation systems is usually relates to vehicles passing on a part of roadway at a specific time resulting in slower speeds than "free flow" or normal speeds. Traffic congestion has a negative impact on traffic performance because it increases travel time and air pollution. It represents a significant street traffic problem.

Considering the traffic congestion problem represent a significant part and a way to find a possible solution to facilitate the progress of efficient intelligent transportation systems. Traffic congestion in streets can be happened due to traffic overload, accidents, construction, bad roads, and poor connectivity among other factors. It occurs when the number of vehicles in some road segment is being larger than its capacity. Most of the current traffic light systems are based on fixed time intervals. These fixed time traffic lights are less efficient due to the lacks of the flexibility of modification and adaptation on a real time. In this thesis a proposed adaptive traffic system to real time traffic patterns in order to optimize the traffic flow by dynamically changing the green light timings.

The proposed approach is helping to controlling traffic lights junctions by creating an order to delay the green light times or switches to green in a given direction based on the situation of the emergency vehicles. The other proposed model is to address the congestion problems by predicting the occurrence of congestion based on specific parameters. The simulation results are performed by NetLogo 6.3.0 under different conditions such as different numbers of vehicles, different values of traffic light length, and different flow densities.

The simulation results have proven that the use of these solutions has effectively contributed to reducing congestion and reducing delay time, which leads to more efficient and sustainable urban transport systems.

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CHAPTER ONE

General Introduction

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1.1 Overview

Intelligent Transportation System (ITS) is a technology-based solution that integrates advanced communication and information technologies to improve transportation efficiency, safety, and sustainability in urban environments (Pable, S. N., & Welekar, A., 2014) (Jing, P., Huang, H., & Chen, L., 2017). ITS uses sensors, cameras, communication networks, and algorithms to collect and analyze data about traffic flow, vehicle movement, and weather conditions. It helps reduce congestion, improve mobility, and enhance safety by providing real-time information to drivers, traffic managers, and public transit operators (Mishra, S., Bhattacharya, D., & Gupta, A., 2018). ITS has a wide range of applications in urban environments, such as Traffic Management, Public Transit, Parking Management, Freight Management, Pedestrian Safety, Environmental Sustainability (Wu, L., et. al, 2019). VANET play a vital role in promoting the concept of ITS, use wireless communication between vehicles and infrastructure to enable vehicles to share real-time information with each other and with the surrounding infrastructure. This communication can help improve safety, reduce traffic congestion, and enhance the overall efficiency of the transportation system (Ma, Z., et. al, 2021). The VANETs are a key enabler of some ITS applications, such as Cooperative Adaptive Cruise Control (CACC), Intersection Collision Avoidance, Intelligent Parking, and Emergency Vehicle Priority. However, VANETs are exposed to several challenges and problems that can affect their performance and reliability, such as Connectivity and Communication, Security and Privacy, Scalability and Deployment, Quality of Service, and Energy Efficiency (Lee, W. H., & Chiu, C. Y., 2020) (Ma, Z., Cui, T., Deng, W., Jiang, F., & Zhang, L., 2021).

Urban areas are usually the centers of economic and cultural activity, with higher levels of economic activity, cultural diversity, and social inequality compared to rural areas (Zibo, et. al, 2021). The physical features of urban areas may include tall buildings, transportation infrastructure such as highways, bridges, and public transit systems, public spaces such as parks and plazas, and other amenities such as shopping centers, restaurants, and entertainment venues (Wong R., et. al, 2022).

The growth and expansion of urban areas exert a significant influence on society, economy, and environment. Urbanization could trigger economic growth and advancement; however, it can also lead to socio-economic inequality, environmental degradation, and health issues (Zibo, Tongchao, Wenxing, Fengyao, Liguo., 2021).

To guarantee the sustainable development and progression of urban regions, it is crucial to conduct precise planning and management that consider factors such as land utilization, transportation, housing, public services, and environmental sustainability (Mishra, S., Bhattacharya, D., & Gupta, A., 2018). Urban planning and design aim to create equitable, sustainable, and livable urban surroundings that cater to the needs of all inhabitants and enhance their well-being.Urban areas face an array of challenges that vary depending on their particular context and location. These challenges include issues such as overpopulation, inadequate housing, traffic congestion, transportation issues, environmental degradation, socio-economic inequality, public safety, lack of access to public services, and high crime rates (Aleko, D. R., & Djahel, S., 2020).

Addressing these challenges requires thorough planning, policy development, and investment in urban infrastructure, services, and programs. ITS and VANET offer promising solutions to lessen traffic congestion and enhance transportation in urban areas. These technologies enable real-time traffic management and communication between vehicles and infrastructure, resulting in safer and more efficient transportation. Implementation of these technologies can also help to reduce emissions and improve environmental sustainability in urban areas. By promoting sustainable urban development and decreasing socio-economic inequality, we can create more equitable and livable urban environments for all inhabitants (Cao, M., Shuai, Q., & Li, V. O., 2019, October) (Cao, M., Shuai, Q., & Li, V. O., 2019, October).

1.2 Problem Statement

VANETs and ITS can provide a range of benefits, including improved traffic flow, enhanced safety, and reduced environmental impacts. However, congestion can still be a problem in roads, particularly in urban environments with high volumes of vehicles and limited infrastructure capacity.

In this thesis, a prediction can be proposed to manage or avoid the expected congestion places. Facilitating the traffic flow may help in reducing the delay times of the moving vehicles towards their destinations. Emergency vehicles must be considered as vital case during their moving route, empty their lane is a significant priority. Most of these issues can be improved by adapting the traffic light role to respond to the challenge in time.

1.3 Thesis Aim

The main aim of this thesis is reducing the traffic congestion. This aim can be achieved through addressing the following objectives:

1. Modeling and simulating the vehicle's traffic flow and traffic congestions.
2. Develop prediction models to indicate the congestion states.
3. Proposing an adaptive traffic light at road intersections.
4. Prioritize the pass of the emergency vehicles through the traffic congestion.

1.4 Related Works

There are two proposed model in this thesis to solve the traffic congestion, Adaptive traffic light and congestion prediction:

1.4.1 Adaptive Traffic Light

In traffic congestion, there are multiple types of vehicles must be solved as cases:

a) Normal vehicles

Libing WU, et. al, 2018 proposed a pipeline model for adaptive traffic light scheduling in urban areas based on vehicle-to-infrastructure (V2I) communication. The proposed system uses real-time traffic data from V2I communication to adjust traffic signal timings and optimize traffic flow. The paper concludes that the V2I communication-based pipeline model for adaptive traffic light scheduling can significantly improve traffic flow and reduce congestion in urban areas and the DRL-based traffic signal optimization system can significantly improve traffic flow, reduce travel time, and reduce congestion in urban areas.

Zibo Ma, et. al, at 2021 proposed an adaptive traffic signal optimization system that utilizes deep reinforcement learning (DRL) to optimize traffic signal timing in real-time. The proposed system uses traffic data collected from cameras and loop detectors to learn traffic patterns and make adjustments to traffic signal timings. The paper deals with the main features of the system, including its ability to adapt to changes in traffic patterns and its ability to optimize traffic flow based on different traffic objectives. The authors also discuss the hardware and software components of the system and provide a detailed description of its implementation.

Robert Wong, et. al, at 2022 proposed a system for implementing virtual traffic lights using roadside units (RSUs) and wireless communication in vehicular environments. The proposed system utilizes the IEEE 802.11p standard for wireless access and RSUs placed at intersections to create virtual traffic lights that communicate with equipped vehicles. The RSUs use a control algorithm to determine the appropriate timing for the virtual traffic lights based on traffic flow and pedestrian crossings. The authors also describe the results of their simulations and field tests, which demonstrate the feasibility and effectiveness of the proposed system.

b) Emergency vehicles

Jiangchen Li, et. al, at 2018 proposed a signal priority request delay modeling and mitigation approach for emergency vehicles in a connected vehicle environment. The paper argues that the proposed approach can significantly reduce emergency response times and improve the efficiency of emergency vehicle dispatching. The paper discusses the challenges in providing timely signal priority to emergency vehicles in a connected vehicle environment and proposes a novel solution to mitigate the delay in signal priority requests. The proposed solution includes an adaptive delay threshold algorithm that can adjust the signal priority request delay threshold based on traffic conditions. The approach is adaptable and can adjust to changing traffic conditions in real-time, making it suitable for different traffic scenarios.

Majed Al-qutwani and Xingwei Wang at 2019 proposed a traffic management system that uses Vehicular Named Data Networking (VNDN) to improve the efficiency of traffic lights. VNDN is a communication protocol designed specifically for vehicular networks that can handle large amounts of data traffic. The system uses VNDN to communicate between traffic lights and vehicles to provide real-time traffic updates and control traffic lights. The paper argues that this system can reduce traffic congestion, improve traffic flow, and reduce the time that vehicles spend waiting at traffic lights. The paper concludes that the proposed system has the potential to significantly improve traffic management in urban areas and enhance the overall driving experience for commuter.

Seniman et al., (2020) proposed a traffic light control system that uses GPS tracking and GPRS network to prioritize the passage of emergency vehicles through traffic lights. The system uses GPS tracking to monitor the position of emergency vehicles and communicate with traffic lights through GPRS network to provide real-time control of traffic signals. The paper discusses the implementation of the system in a simulation environment and presents the results of experiments that show the effectiveness of the proposed system. The paper concludes that the proposed system has the potential to make a significant contribution to emergency response times and traffic management in urban areas.

Mohamed Gamal, et. al, (2022) proposed a traffic control system that can detect the presence of an emergency vehicle in traffic and adjust traffic signals to give the emergency vehicle priority. The system uses a combination of cameras, sensors, and communication technology to detect the emergency vehicle's approach and to communicate with traffic signals to make real-time adjustments. The paper concludes that the proposed system has the potential to make a significant contribution to emergency response times and traffic management in urban areas.

1.4.2 Congestion Prediction

Isabel V. Martin-Faus, et. al, at 2018 proposed the use of Markov-Reward Models to analyze and model idle time in VANETs. These models allow for the representation of system states and the associated rewards or costs for transitioning between these states. By applying Markov-Reward Models to VANETs, the researchers aim to gain insights into the idle time behavior and its impact on network performance.

Mahmuda Akhtar and Sara Moridpour at 2021 discussed the importance of traffic congestion prediction and the challenges associated with it, including the dynamic and complex nature of traffic systems. It then reviews the various AI-based approaches that have been used to predict traffic congestion, including machine learning, neural networks, fuzzy logic, and evolutionary algorithms. Also discusses the future directions and challenges in traffic congestion prediction, including the need for more accurate and real-time data, better integration of multiple data sources, and the development of more robust and scalable AI models.

Lokesh Manohar Giripunj, et. al, (2021) proposed a solution called Adaptive Congestion Aware Routing Protocol (ACARP) for VANET that uses a dynamical artificial intelligence (AI) technique to detect congestion and establish safe and reliable routes for data transmission. The simulation results show that ACARP improves QoS performance and reduces CO2 emissions compared to underlying fuzzy-based methods.

Rashmi and Rekha Patil at 2022 proposed CFRS-CP-Congestion free route selection, estimates congestion probability using a technique based on link quality, MAC overhead, neighbor density, and vehicle velocity. This results in congestion-free routing paths, improving end-to-end delay, packet delivery ratio, and throughput compared to existing protocols. The solution can improve the comfort and safely of driving by developing efficient vehicular environment systems using wireless access.

1.5 Organization of the Thesis.

This thesis is organized into five chapters as follow:

Chapter two: This section will detail the research design and methods used to collect and analyze data. This will include a description of the research approach, data collection techniques, and data analysis methods.

Chapter three: Exploration of how the technologies can be integrated into a distributed traffic management system. Additionally, this section will examine the potential of VANETs and RSUs in developing new smart mobility solutions such as dynamic ride-sharing and autonomous vehicles.

Chapter four: evaluates the proposed system performance by using Net Logo simulation; Studying the results and analyzing them fully.

Chapter five: includes the thesis conclusion and future work directions.

CHAPTER TWO

Theoretical Background

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2.1 Introduction

This chapter will discuss the background and related literature on the use of VANETs and RSUs for traffic management in urban areas. Also, will discuss the technical aspects of VANETs and RSUs, including their architecture, communication protocols, and data transmission mechanisms. The system structure will be based on the use of VANETs and RSUs to create a distributed traffic management system in urban areas. furthermore, will describe the components of this system, including the vehicles, roadside infrastructure, and centralized traffic management system. It will also discuss how these components interact with each other to facilitate real-time communication and exchange of traffic information. Additionally, the chapter will explore the potential of VANETs and RSUs to enable new smart mobility solutions such as dynamic ride-sharing and autonomous vehicles, and the implications of these developments for traffic management in urban areas.

2.2 Vehicular Ad-hoc Networks (VANETs):

VANETs are a type of wireless ad-hoc network that enables communication between vehicles and between vehicles and infrastructure. VANETs are an emerging technology that is expected to play a major role in improving road safety, traffic efficiency, and passenger comfort (Turan, B., et. al, 2021). Vehicles in a VANET are equipped with wireless communication devices, such as Wi-Fi or Dedicated Short-Range Communications (DSRC) radios, that allow them to communicate with each other and with roadside infrastructure. VANETs use a variety of communication protocols, including IEEE 802.11p and Wireless Access in Vehicular Environments (WAVE), to facilitate communication between vehicles and infrastructure (Jing, P., Huang, H., & Chen, L., 2017). One of the key applications of VANETs is improving road safety. VANETs can be used to provide real-time information about road conditions, such as traffic congestion, accidents, and weather, to drivers. This information can help drivers make informed decisions and avoid potential hazards (Liu, Y., et. al, 2023). VANETs can also be used to provide warnings to drivers about potential collisions or other dangerous situations. Another important application of VANETs is improving traffic efficiency (Pable, S. N., & Welekar, A., 2014). VANETs can be used to provide real-time traffic information to drivers, allowing them to choose the most efficient route. VANETs can also be used to facilitate ITS, which use real-time data to optimize traffic flow and reduce congestion. Figure 2.1 shows the VANETs (Zibo, et. al, 2021).

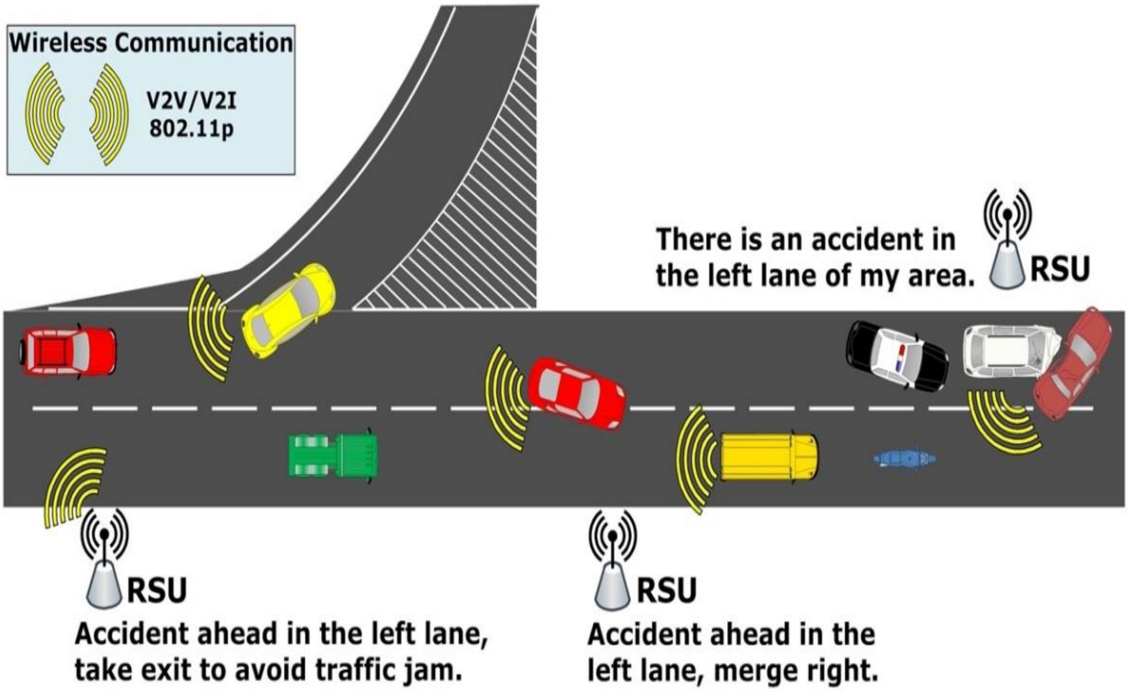

Figure 2.1 VANETs (Hassan, H. A., 2022)

VANETs also have applications in entertainment and passenger comfort. For example, VANETs can be used to provide Wi-Fi hotspots in vehicles, allowing passengers to connect to the internet and stream media (Cao, M., Shuai, Q., & Li, V. O., 2019, October). VANETs face several challenges, including limited bandwidth, high latency, and security issues. VANETs must also address issues related to privacy and data protection, as the communication between vehicles and infrastructure can contain sensitive information. Researchers are actively working on addressing these challenges to ensure the reliable and secure operation of VANETs (Aleko, D. R., & Djahel, S., 2020).

2.2.1 VANET Architectures

VANET is a type of wireless ad hoc network that is specifically designed for communication among vehicles and between vehicles and roadside infrastructure (Pandey, P. K., et. al, 2020). VANETs employ various architectures to facilitate communication among network nodes, including:

- **Centralized architecture**: In this architecture, a central entity (such as a roadside unit) controls the communication between vehicles. The central entity collects information from various vehicles and disseminates it to other vehicles as needed. This architecture is easy to manage but can be a single point of failure (Hassan, H. A. 2022).
- **Decentralized architecture**: In this architecture, there is no central entity controlling communication. Instead, vehicles communicate directly with each other or with roadside infrastructure. This architecture is more robust than the centralized architecture but can be more difficult to manage (Yeferny, T., & Hamad, S., 2021).
- **Hybrid architecture**: This architecture combines the centralized and decentralized architectures. In this architecture, some entities (such as roadside units) act as central controllers, while others (such as vehicles) communicate directly with each other. This architecture aims to provide the benefits of both centralized and decentralized architectures while minimizing their drawbacks (Yeferny, T., & Hamad, S. (2021).
- **Cluster-based architecture**: In this architecture, vehicles are grouped into clusters based on their geographic proximity. Each cluster has a cluster head that is responsible for communication within the cluster and with other clusters. This architecture aims to reduce the amount of communication overhead and increase network efficiency (Yeferny, T., & Hamad, S., 2021).

Each of these architectures has its advantages and disadvantages, and the choice of architecture depends on the specific application and network requirements.

2.2.2 Communication Infrastructure in VANETs

Communication infrastructure is a key component of VANETs that facilitates the exchange of information between vehicles and infrastructure elements. VANETs use different communication models, such as Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), and Hybrid Communications (V2X), each with its own advantages and limitations (Senouci, O., et. al, 2019). The communication infrastructure in VANETs relies on wireless communication technologies, such as Dedicated Short-Range Communications (DSRC), which provide high-velocity data transmission and low-latency communication for safety-critical applications. Efficient communication infrastructure is essential for VANETs to achieve their objectives and provide safe and efficient mobility services to passengers. Figure 2.2 shown the Communication Infrastructure in VANETs (Wu, L., et. al, 2019).

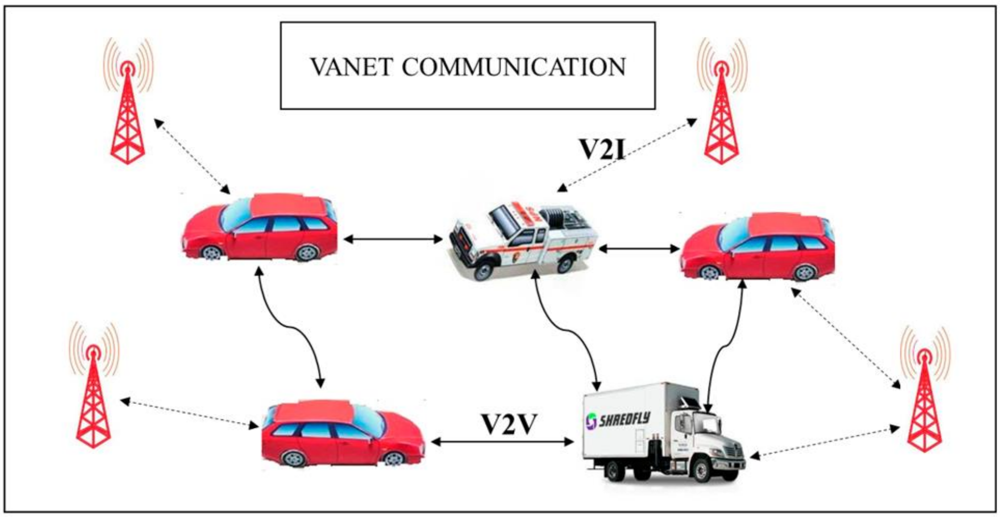

Figure 2.2 Communication Infrastructure in VANETs (Gregurić, M., et. al, 2020)

- **Vehicle-to-Vehicle (V2V) Communications:** In this type of communication, vehicles exchange information with each other, such as location, velocity, direction, and stability, or regarding road accidents. This strategy utilizes Dedicated Short-Range Communications (DSRC) with a range of 300 meters for sending and receiving data between vehicles. V2V communication can help reduce traffic congestion, prevent accidents, and improve road safety. VANET is a specific case of Mobile Ad-hoc Network (MANET) that applies to this type of communication (Yeferny, T., & Hamad, S., 2021).

- **Vehicle-to-Infrastructure (V2I) Communications:** This strategy involves connecting the vehicle to the road through RSUs that are deployed along the road. It includes the exchange of data such as traffic lights, road conditions, routers, Internet connectivity, and more. DSRC is used as a communication model with a range of 300 meters between the vehicle and RSUs. V2I communication provides drivers with accurate and reliable information, and can be used to collect data about vehicles and infrastructure for analysis or forecasting purposes (Karunathilake, T., & Förster, A., 2022).
- **Hybrid Communications (V2X):** Hybrid communication is an integration of V2V and V2I architectures, where nodes communicate directly with each other in hybrid networks (V2V), and at the same time, vehicle communication is conducted through V2I in the areas served by RSUs. This strategy improves connectivity and increases network coverage while minimizing implementation costs. Hybrid communication includes a mixture of several communication technologies (Liu, Y., et. al, 2023).

2.2.3 VANET Characteristics, Challenges and Applications

Despite the numerous benefits offered by VANETs, they also face several challenges, including security threats, scalability, network stability, and data transmission reliability (Hassan, H. A., 2022) (Yeferny, T., & Hamad, S., 2021) (Liu, Y., et. al, 2023).

Characteristics:

- High mobility of nodes (vehicles) that can lead to frequent network topology changes.
- Dynamic and unpredictable network conditions due to the changing environment and traffic conditions.
- Limited communication range of wireless devices in vehicles.
- High data transmission rate requirements for real-time safety applications.
- Limited power supply in vehicles.

Challenges:

- Security and privacy issues due to the sensitive nature of the information exchanged.
- Network congestion due to the limited bandwidth and high data transmission rate requirements.
- Limited coverage in rural areas and tunnels.
- Lack of standardized communication protocols.
- High deployment costs and maintenance expenses.

Applications:

- Safety applications such as collision avoidance, emergency response, and traffic congestion management.
- Traffic efficiency applications such as intelligent navigation, parking management, and eco-driving.
- Infotainment applications such as in-car entertainment and internet access.
- Fleet management applications for commercial vehicles.

2.2.4 Roadside Unit (RSU)

RSU stands for Roadside Unit, which is an important component of ITS that are being developed to improve road safety and traffic management (Wong, R., et. al, 2022). RSUs are wireless communication devices that are installed along the roadsides, and they play a critical role in enabling communication between vehicles and infrastructure. An RSU typically consists of an antenna, a transceiver, and a processing unit that can communicate with vehicles equipped with wireless communication devices, such as Wi-Fi or Dedicated Short-Range Communications (DSRC) radios (Hassan, H. A., 2022). RSUs are usually installed at fixed locations along the roadside, such as traffic lights or road signs, and they can be used to collect and disseminate real-time traffic information to drivers (Karunathilake, T., & Förster, A., 2022). Figure 2.3 shows the Roadside unit to vehicle communication.

One of the primary applications of RSUs is to provide real-time traffic information to drivers. This information can include data on traffic congestion, road accidents, road closures, and weather conditions, and it can be used to help drivers make informed decisions about their route and driving behavior.

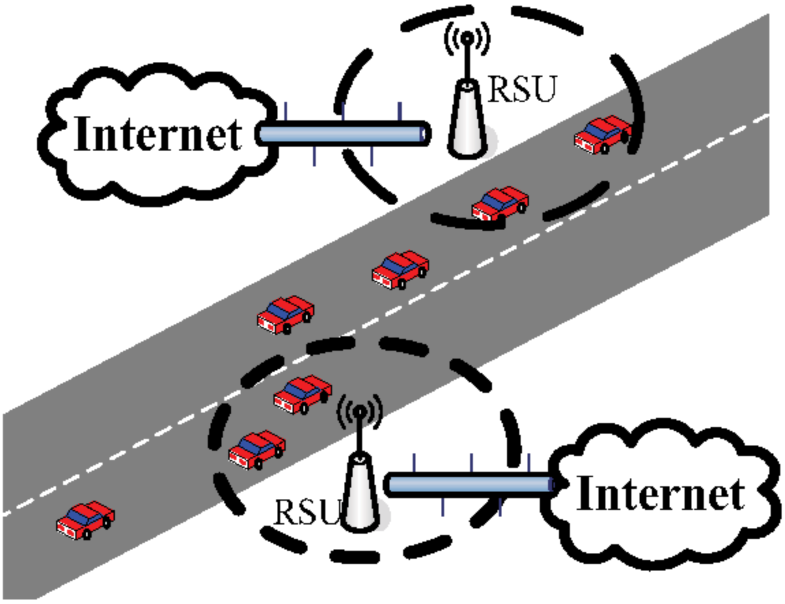

Figure 2.3 Roadside unit to vehicle communication (Hassan, H. A., 2022)

RSUs can also be used to provide warnings to drivers about potential hazards or dangerous situations on the road. Another important application of RSUs is to facilitate ITS (Hassan, H. A., 2022). RSUs can be used to collect real-time data on traffic flow, vehicle velocity, and other parameters, and this data can be used to optimize traffic management and reduce congestion. RSUs can also be used to provide information to drivers about parking availability and other services, such as electric vehicle charging stations. RSUs face several challenges, including limited bandwidth, high latency, and security issues. RSUs must also address issues related to privacy and data protection, as the communication between RSUs and vehicles can contain sensitive information. Researchers are actively working on addressing these challenges to ensure the reliable and secure operation of RSUs (Wong, R., et. al, 2022).

2.2.5 On-Board Units (OBUs):

On-board units (OBUs) are electronic devices installed in vehicles to enable communication with roadside infrastructure, other vehicles, and the internet. OBUs are a critical component of ITS and are commonly used in applications such as electronic toll collection, traffic management, and vehicle-to-vehicle communication (Collodi, G., et. al, 2020). OBUs typically use wireless communication technologies such as dedicated short-range communications (DSRC), Wi-Fi, or cellular networks to communicate with other devices. They may also include GPS receivers to enable location-based services and sensors to collect data about vehicle velocity, acceleration, and other parameters (Sedar, R., et. al, 2021). One of the primary functions of an OBU is to communicate with RSUs to provide and receive real-time traffic information, such as congestion warnings and road condition alerts. OBUs can also communicate with other vehicles to exchange safety-related messages and to support cooperative driving applications. In electronic toll collection systems, OBUs are used to communicate with toll booths or gantries to automatically deduct tolls from a pre-paid account. This helps to reduce traffic congestion and improve travel time for drivers. Figure 2.4 shows the On-board units (OBUs) (Chang, X., et. al, 2019).

OBUs are also used in fleet management systems to track vehicle location and performance, monitor driver behavior, and optimize routing and scheduling. Some of the key challenges in OBU development include ensuring secure and reliable communication, providing accurate location information, and integrating with existing ITS infrastructure (Outay, F., et. al, 2022).

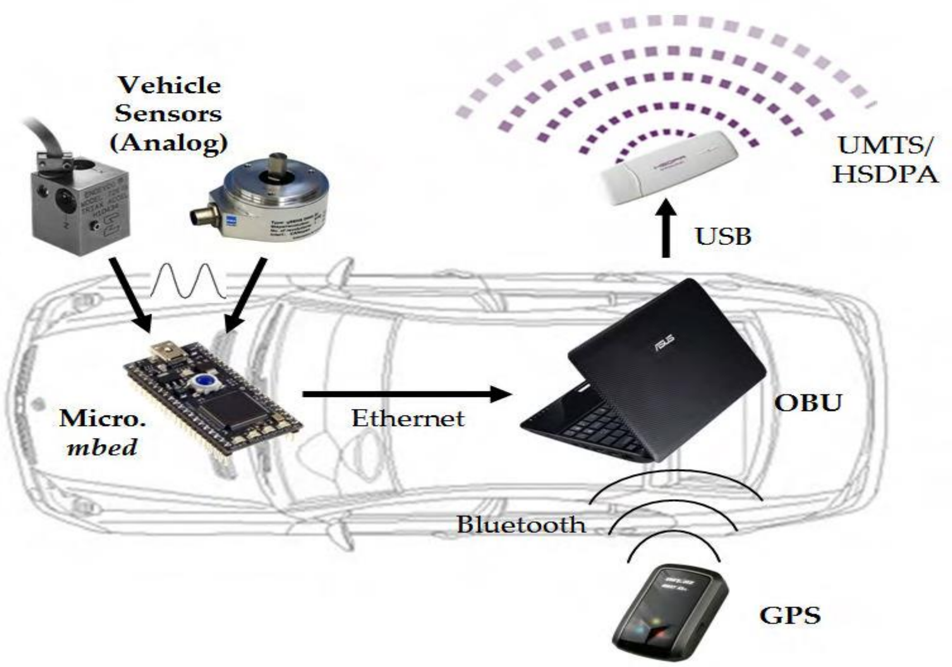

Figure 2.4 OBUs (Zibo, et. al, 2021)

2.3 Intelligent Transportation System (ITS)

ITS is an advanced technological system that enhances transportation efficiency, safety, and sustainability (Wong, R., White, J., Gill, S., & Tayeb, S., 2022). It integrates various technologies, such as communication systems, sensors, and computing systems, to provide real-time traffic information, improve traffic flow, reduce congestion, and enhance safety. The application of ITS is not limited to roadways but extends to other transportation modes such as railways, airways, and waterways (Aleko, D. R., & Djahel, S., 2020). ITS comprises several components, including advanced traffic management systems (ATMS), advanced traveler information systems (ATIS), and advanced vehicle control systems (AVCS). ATMS allows traffic operators to monitor and manage traffic conditions in real-time. It utilizes various technologies, such as CCTV cameras, sensors, and communication systems, to provide accurate and timely information about traffic flow, incidents, and congestion (Zendrato, N., Arisandi, D., & Lubis, F., 2020, June). This information is then used to optimize traffic management strategies, such as signal timing and ramp metering, to improve traffic flow and reduce congestion (Zendrato, N., Arisandi, D., & Lubis, F., 2020, June). Figure 2.5 shows ITS.

Figure 2.5 ITS (Gregurić, M., et. al, 2020)

ATIS provides real-time traffic information to travelers through various technologies, such as dynamic message signs, mobile applications, and websites (Jing, P., Huang, H., & Chen, L., 2017). It gives information about traffic conditions, travel times, and alternative routes, which enables travelers to make informed decisions about their travel plans, such as choosing the best route and mode of transportation. AVCS utilizes various technologies, such as sensors, communication systems, and automated controls, to enhance the safety and efficiency of vehicles. AVCS includes various systems, such as adaptive cruise control, collision avoidance systems, and automated parking systems, which can help reduce accidents, improve fuel efficiency, and enhance mobility (Al-qutwani, M., & Wang, X., 2019).

The implementation of ITS requires substantial investment in infrastructure and technology development. However, the potential benefits of ITS, such as reducing congestion, enhancing safety, and improving sustainability, make it a worthwhile investment. Furthermore, ITS has the potential to stimulate economic growth by improving transportation efficiency and reducing transportation costs (Chentoufi, M. A., & Ellaia, R., 2018, October).

2.3.1 Benefits and Advantages for the Implementation of ITS

1. Saving time by reducing the number of unwanted stops.
2. Ensuring safety through velocity control and driver alerts.
3. Providing entertainment and comfort during travel, effective management of data and traffic.
4. Reducing the impact on various environments.

2.3.2 Planning Strategically for the Implementation of ITS

The overall strategy for implementing ITS is based on three main phases, as illustrated in Figure 2.6, namely: data collection, data transmission, and data analysis (Malik, S., & Sahu, P. K., 2019).

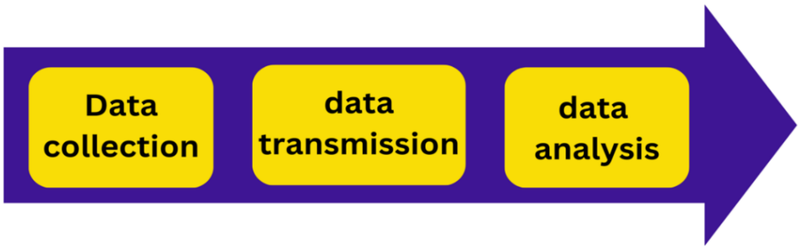

Figure 2.6 data collection, data transmission, and data analysis

- **Data collection**: specialized devices are used to collect real-time and accurate data from transportation systems, including traffic movements, travel velocity and time, vehicle location and weight, delays, and other relevant information. The collected data is then stored in private servers for further analysis and processing (Wong, R., White, J., Gill, S., & Tayeb, S., 2022).
- **Data transmission**: efficient communication mechanisms are established to ensure fast and reliable data transfer between the transportation systems and the Traffic Management Center (TMC). This requires good connectivity and coverage for rapid and real-time information communication (Turan, B., Uyrus, A., Koc, O. N., Kar, E., & Coleri, S., 2021). The data can be transferred via the internet or through units on the transportation vehicles, and different communication methods such as ad hoc short-range communications (DSRC) and continuous medium and long-range air interfaces (CAILM) can be used (Ma, Z., Cui, T., Deng, et. ai, 2021).
- **Data analysis**: takes place in the TMC, where the collected data is processed through stages such as error correction, data synthesis, cleaning, and adaptive logical analysis. Specialized programs are used to identify and correct errors and differences in the data, which is then compiled and sent back to the transportation systems. This processed data can be used to predict traffic scenarios and road problems, providing better services to travelers (Chentoufi, M. A., & Ellaia, R., 2018, October).
- The implementation of ITS involves a complex and dynamic process of data collection, transmission, and analysis, with the ultimate goal of improving transportation systems' efficiency, safety, and reliability (Zendrato, N., Arisandi, D., & Lubis, F., 2020, June).

2.4 Congestion in VANET

In general, there are two types of traffic congestion: recurring and non-recurring congestion. According to general studies, about half of the traffic congestion is the recurring type, which occurs daily and is due to lack of capacity on the road. The other type of congestion, non-recurring and called "temporary disruptions" in travel, such as bad weather or a car collision (Khoza, E., Tu, C., & Owolawi, P. A., 2020).

Within these two types of traffic congestion, there are four more specific categories as following (Akhtar, M., & Moridpour, S., 2021) (Gregurić, M., et. al, 2020):

1. **Environment (non-recurring)**

Traffic collisions increase by about 50 percent during snow, rain, foggy weather, or a severe blizzard that stops drivers in their tracks, even a light rain has an effect if all drivers reduce their velocity together. Weather has an uncontrollable effect on traffic on road conditions as well (Mishra, S., et. al, 2018). In general, bad weather is the main cause of 15% of traffic jams

2. **Mechanical (non-recurring)**

Another factor that can cause traffic congestion is the condition of mechanical failure. Which happens because the driver does not maintain his car and can occur suddenly while driving or mechanical failures can also occur due to external factors such as the presence of a sharp object on the road. These problems require the driver to stay off the road, which can be a difficult task. When other drivers rush to get around the stopped car, it only increases the impact on traffic (Gregurić, M., et. al, 2020).

3. **Human (non-recurring)**

The common cause of traffic is humans. from distracted driving or are ill or drowsy. Here, the traffic jam is caused by the driver making quick decisions and engaging in behaviors such as braking at the last minute. As soon as the driver hits the brakes because he's distracted, a ripple effect begins. Depending on other traffic conditions, this single braking error could slow traffic in that lane and surrounding lanes for hours. This is what is referred to as a phantom traffic jam because when drivers pass the slow spot, it will appear as if nothing at all caused the slowdown (Pable, S. N., & Welekar, A., 2014).

4. **Infrastructure (recurring)**

Another category that is arguably man-made is infrastructure. Although it is very wide but the world around it is changing very quickly, infrastructure is the hidden dwarf that amplifies traffic problems in many urban and suburban areas. Jams alone account for 40% of the causes of traffic congestion (Wu, L., 2019).

2.5 Methods to Avoid Congestion

There are many types to avoid congestion, in this thesis two basic types will be discussed:

2.5.1 Adaptive Traffic Light

Adaptive traffic light is an innovative approach utilized to forecast congestion in transportation systems and adaptively adjust the prediction model to enhance its precision. This model receives inputs from various sources such as traffic cameras, traffic sensors, GPS data, weather reports, and other real-time traffic information sources to generate a congestion prediction for a specific area or route. The prediction model requires adjustment based on the actual traffic conditions to enhance its precision. This can be achieved by comparing the predicted congestion levels with the actual traffic conditions and modifying the model (Jing, P., et. al, 2017). If the predicted congestion level is higher than the actual traffic conditions, the model can be adjusted to reduce the predicted congestion level. By adapting to real-time traffic conditions. The adaptive congestion prediction technique has several benefits, including improved traffic management and reduced travel time for drivers. By accurately predicting congestion levels, transportation authorities can implement proactive measures such as rerouting traffic or adjusting traffic signal timings to prevent congestion from occurring (Jing, P., et. al, 2017) (Pable, S. N., & Welekar, A., 2014). This technique also enables drivers to plan their routes in advance, avoiding congested areas and reducing travel time.

Each vehicle is processed to predict congestion at the moment t. The prediction principle is applied to predict congestion and to estimate the current vehicle congestion probability in the network in time depending on Bandwidth, Link quality, Mobility, Neighbor Density, Vehicle Velocity (Jing, P., et. al, 2017) (Jing, P., et. al, 2017).

1. **Bandwidth**

   The accuracy of the prediction model can be affected by the bandwidth of the communication network used to transmit traffic data. A low-bandwidth network may result in delays or data loss, which can have a significant impact on the accuracy of the prediction model.

Compression techniques have been proposed in some studies to reduce the amount of data transmitted over the network while maintaining the accuracy of the prediction model. Bandwidth is a vital standard parameter that helps to estimate how much congestion is currently on the vehicle (Jing, P., et. al, 2017).

It can be calculated by equation 2.1 (Pable, S. N., & Welekar, A., 2014):

$$B^{v} = 1 - \left(\frac{bandwidth\ h(v,t)}{2048}\right) \ldots\ldots\ldots\ldots 2.1$$

Where:

bandwidth h (v, t) is a function returns the bandwidth allocated of vehicle v at time t.

The value (2048 kbps) represents the maximum bandwidth allowed for each vehicle in the network.

The result of $B^{v}$is in the range 0 to 1. Higher available bandwidth will result in lower chances of congestion by v.

2. **Link quality**

Another significant factor that can affect the accuracy of the prediction model is the quality of the traffic data used as input. Link quality refers to the strength and stability of the wireless communication link between two vehicles or between a vehicle and roadside infrastructure (Pable, S. N., & Welekar, A., 2014). Link quality can be affected by various factors such as signal strength, interference, and obstacles. In congestion prediction, link quality can be used to estimate the level of traffic on a specific road segment. Higher link quality indicates lower data traffic density, while lower link quality suggests higher data traffic density (Pable, S. N., & Welekar, A., 2014). To use link quality in congestion prediction, researchers can collect link quality data from vehicles or RSU and analyze it to extract data traffic information. Additionally, link quality can be used to adjust the transmission power of vehicles or RSU to improve communication reliability, which can lead to more accurate congestion prediction (Jing, P., et. al, 2017). can be calculated by equation 2.2 (Zibo, et. al, 2021):

$$LIQ = P_{trans}\left({}^{\omega}/_{4\pi d^{2}}\right) * G_{trans} * G_{recv} \ldots\ldots\ldots\ldots\ldots 2.2$$

Where:

LIQ: Link Quality, which represents the quality or reliability of the wireless link between a transmitter and receiver.

P_{trans}: Transmitter Power, the power level at which the transmitter is operating.

ω: Angular frequency, related to the frequency of the transmitted signal.

d: Distance between the transmitter and receiver.

G_trans: Transmitter Gain, representing the gain or directional property of the transmitter antenna.

G_recv: Receiver Gain, representing the gain or directional property of the receiver antenna.

$\left(\omega/_{4\pi d^2}\right)$: Free space path loss, which accounts for the attenuation of the signal as it propagates through space.

The equation suggests that the link quality (LIQ) is influenced by factors such as transmitter power, distance, antenna gains, and free space path loss. However, it's important to note that this equation represents a simplified model and may not capture all the complexities and factors affecting wireless link quality in practical scenarios. Real-world wireless systems often consider additional parameters, such as interference, fading, modulation schemes, and noise, to accurately assess link quality.

To achieve the reliable solutions, computed the link quality $Q^v$of each vehicle v at MAC layer. It is computed by equation 2.3 (Rashmi and Rekha Patil, 2022):

$$\boldsymbol{Q^v = \frac{recv(v,t-1,t)}{expt(v,t-1,t)} \ \ldots\ldots\ldots\ldots\ldots\ 2.3}$$

Where $recv\ (v,\ t-1,\ t)$ and $expt\ (v,\ t-1,\ t)$ total number of packets received and expected respectively at vehicle v during the time interval $(t-1,\ t)$. Higher Q^v value leads to lower congestion at v.

3. **Mobility**

For VANETs, mobility is an important for estimating the probability of congestion is the velocity of movement of the vehicle. The vehicle's current mobility velocity v in time is estimated by equation 2.4 (Rashmi and Rekha Patil, 2022):

$$M^v = 1 - \left(\frac{mobility\ (v,t)}{200}\right) \ldots\ldots\ldots 2.4$$

Where, $mobility\ (v,\ t)$ is a function returns the current moving velocity of vehicle v at time t. The value 200 km/hr is maximum mobility velocity assumed for each vehicle in network. The outcome of M^v is in range of 0 to 1. Lower M^v value will result in lower chances of congestion of vehicle v.

4. **Neighbor Density:**

Neighbor density refers to the number of nearby vehicles in a certain area. In congestion prediction, neighbor density can be used as an indicator of traffic congestion. High neighbor density indicates high traffic volume, while low neighbor density indicates lower traffic volume.

To use neighbor density in congestion prediction, researchers can collect neighbor information from vehicles or RSU and analyze it to extract traffic information.

The node density is determined by equation 2.5 (Jing, P., et. al, 2017):

$$D = \frac{1}{M} * \sum_{i=1}^{1-M} DIST(i,j) \ldots\ldots\ldots 2.5$$

Where M is the total nodes number and DIST is the distance between the node and its adjacent node.

Therefore, the density of the entire nodes in network is summarized in equation 2.6 (Jing, P., et. al, 2017):

$$ND = \frac{1}{M} * \sum_{i=1}^{N} D(N) \ldots\ldots\ldots 2.6$$

5. **Vehicle Velocity:**

Vehicle velocity refers to the velocity at which a vehicle is moving. In VANETs, nodes usually move at higher velocities, for this reason in congestion prediction, vehicle velocity can be used to estimate the level of traffic congestion. Lower vehicle velocity indicates higher traffic density, while higher vehicle velocity indicates lower traffic density. To use vehicle velocity in congestion prediction.

It can be computed by equation 2.7 (Rashmi and Rekha Patil, 2022):

$$V_{velocity} = \frac{(1+r)^{w} + (V_{prev} * (N-1))}{N} \text{……….2.7}$$

where N represents the control messages received and exchanged during the time interval.

$Vpre$ denotes the previously recorded velocity, r is the relative value between the velocities and the current vehicle velocity observed in the control messages and w is the value of weight.

2.5.2 Congestion Prediction

Congestion prediction in urban areas is an important research area in transportation engineering that aims to forecast traffic congestion in advance using various data sources and prediction models. The main goal of congestion prediction is to provide timely and accurate information to drivers, traffic management centers, and other stakeholders to help them make informed decisions and take appropriate actions to avoid congestion or mitigate its effects (Zibo, et. al, 2021).

There are several techniques and data sources that can be used for congestion prediction, including real-time traffic data from sensors, cameras, and GPS devices, historical traffic data, weather data, social media data, and other relevant information sources. These data sources can be integrated and analyzed using various prediction models, such as statistical models, machine learning models, and artificial neural networks, to generate congestion predictions (Ma, Z., et. al, 2021). The basic principle of congestion prediction is to use past and current traffic data to identify patterns and trends and then use this information to forecast future traffic conditions. Machine learning models and artificial neural networks are particularly effective for this task, as they can learn and adapt to changing traffic patterns and make accurate predictions even under uncertain and dynamic conditions (Jing, P., Huang, H., & Chen, L., 2017).

In addition to providing real-time traffic information to drivers and traffic management centers, congestion prediction can also be used for other applications, such as route planning, intelligent transportation systems, and smart city initiatives. For example, the data generated from congestion prediction can be used to optimize traffic signal timings, improve public transportation services, and reduce greenhouse gas emissions (Pable, S. N., & Welekar, A., 2014). Figure 2.7 explain the traffic predication.

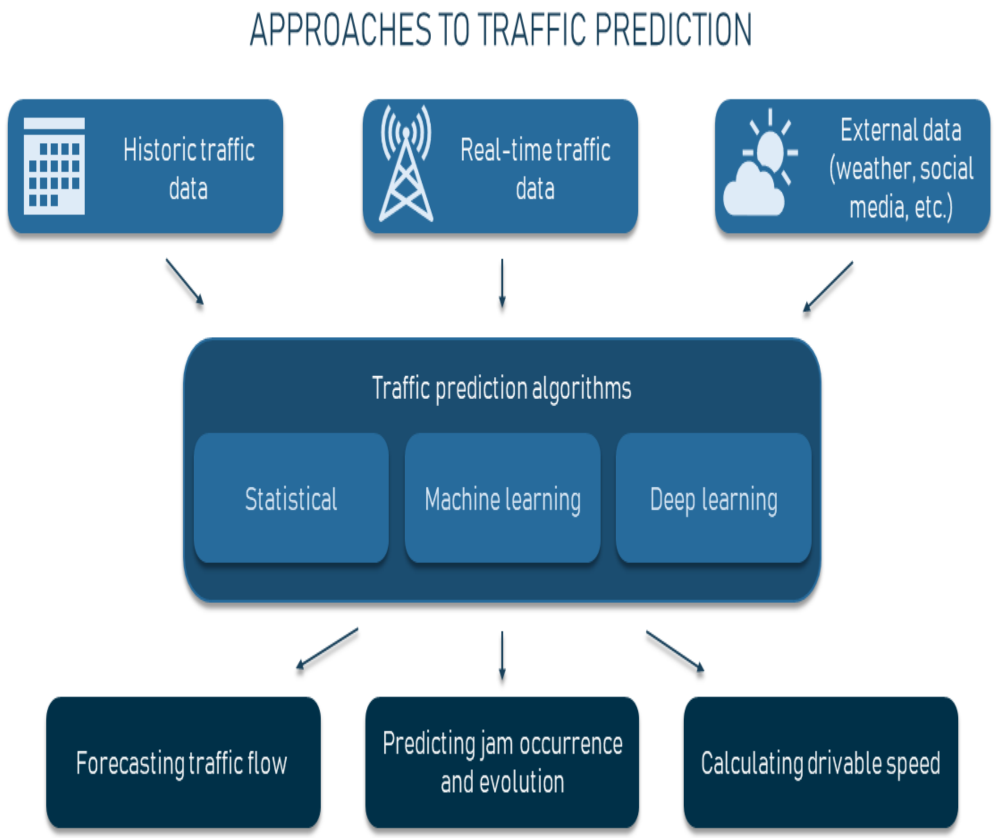

Figure 2.7 Approaches to traffic predication (Gregurić, M., et. al, 2020)

Congestion prediction is a critical issue in urban areas to reduce traffic congestion and improve the transportation system's efficiency. To achieve this, various techniques have been developed, including the use of Link Quality, Neighbor Density, and Vehicle Velocity. These techniques can help in predicting the congestion level in a particular area and aid in making decisions for traffic management. In this context, it is essential to understand how these factors can be utilized and the scientific principles behind their effectiveness (Jing, P., Huang, H., & Chen, L. 2017).

2.6 The Flow Rate of Vehicles

The flow rate for vehicles refers to the number of vehicles passing through a particular point or section of a road within a given time period. It is commonly measured in vehicles per hour (vph) or vehicles per minute (vpm).

The flow rate of vehicles can vary depending on several factors, including road capacity, traffic conditions, speed limits, and the presence of traffic control measures such as signals or roundabouts. It is influenced by factors such as the number of vehicles on the road, the distribution of vehicle types (e.g., cars, trucks), and driver behavior.

in this model traffic is defined by two key variables: traffic density and velocity. Traffic density is the number of vehicles per unit length of the route, whereas traffic velocity is the velocity at which cars move through a certain area of the road. The variables of the conservation equation:

Flow rate = Density * Velocity

$$q = \rho * v \quad \ldots\ldots\ldots\ldots 2.8$$

2.7 Simulators using with VANET

In order to simulate any system, a suitable simulator must be carefully selected and applied. Different network simulators were developed in different features. The most applicable simulators are Net Logo, NS2, OPNET, OMNET, QualNet, NetSim, and J-Sim (Fawziya, 2014). In this simulation study an open-source network Simulator Net Logo was used to program, design, implement, evaluate and test the performance of the proposed systems.

NetLogo is a multi-agent programming language and modeling environment for simulating complex natural and social phenomena. It is particularly well suited for modeling complex systems evolving over time. Modelers can give instructions to hundreds of independent “agents” all operating concurrently. NetLogo enables users to open simulations and “play” with them, exploring their behavior under various conditions. NetLogo is also an authoring environment that is simple enough to enable researchers to create their own models, even if they are not professional programmers. Netlogo can be successfully utilized in the early stages of simulation to identify promising areas to explore with less effort and time.

CHAPTER THREE

The Proposed Model

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The Proposed Model

3.1 Introduction

VANET is one of the important solutions to Improve the ITS. The congestion are the main challenges in VANET with urban environment. To control this challenge, the using of RSU assistant is an appropriate solution. In this thesis experiments, new models are applied in VANET based on a solving congestion problem by type of vehicles. Simulation is a very important tool due to the cost and difficulties of real application in urban scenarios, therefore Netlogo 6.3.0 (as an agent-based modeling approach) has been used in implementing the simulation scenarios.

3.2 The Proposed Model Framework

VANETs and RSUs as a promising solution to address the issue of traffic congestion and emergence supporting in urban areas. VANETs are wireless networks that allow vehicles to communicate with each other and roadside infrastructure, such as traffic lights, parking meters, and other vehicles. This communication enables real-time exchange of traffic information, which can be used to optimize traffic flow, reduce congestion, and improve safety. VANETs use various communication technologies, such as Dedicated Short-Range Communication (DSRC) and Cellular Vehicle-to-Everything (C-V2X), to enable reliable and secure communication between vehicles and infrastructure. RSUs, on the other hand, are low-cost devices that are installed at various locations, such as intersections and parking lots, and provide real-time traffic information to drivers and traffic management systems. RSUs can detect traffic flow, congestion, and accidents and relay this information to the central traffic management system. This enables the model to optimize traffic flow and reduce congestion by providing drivers with real-time traffic information and suggesting alternative routes. The combination of VANETs and RSUs can create a distributed traffic management system that can promptly respond to changing traffic conditions. This approach provides drivers with real-time traffic information, enabling efficient routing and diversion of traffic and improving traffic flow in urban areas. Moreover, the use of VANETs and RSUs can lead to the development of new smart mobility solutions such as dynamic ride-sharing and autonomous vehicles, which optimize road space usage and further reduce congestion. The implementation of VANETs and RSUs in urban areas requires substantial investment in infrastructure and technology development. However, the potential benefits of reducing congestion and improving traffic flow make it a worthwhile investment. Therefore, by prioritizing the solutions provided by the aforementioned technologies, we can effectively tackle the issue of traffic congestion and significantly enhance the efficiency of traffic management in urban areas.

3.3 Methodology

The following sections represent the main steps of the research methodology as presented in Figure 3.1.

Preparing the Environment

- Create Urban Road map with different number of roads
- Setup Roadside Units
- Setup Traffic Light signal
- Setup different number of vehicles
- Move the vehicles in different directions
- Setup time for the traffic light colors

Proposed Models

- Suggest and set the Adaptive Traffic light approach.
- Suggest two Cases for Adaptive Traffic light in Normal and Emergancy vechiles.
- Model the Adaptive Traffic light Control depending on Density, Distance, Speed of vechiles in the suggested approach environment.
- Suggest Congestion Prediction approach.
- Impliment the Regression Mathematical model.
- Model the Congestion Prediction approach depending on Density, Velosity and flow rate of vechiles in the suggested approach environment.

Results Discussions

- Estimate the performance metrics for the Adaptive Traffic light to evaluate the suggested approach.
- Present the comparative results graphically to observe their behaviors.
- Estimate the results of the Congestion Prediction model.
- Calculate the performance metrics of the Congestion Prediction models
- Results evaluation, discussion and Conclusion.

Figure 3.1 The Block diagram for Research Methodology Stages

3.4 Setup Model

In this stage, many steps are performed to prepare and set the requirements for the VANET using Netlogo 6.3.0 simulation environment as an agent-based modeling approach.

3.4.1 Road Map Creation

The environment setup starts with creating a suggested road map segment. The road map segment is designed different number of roads. The RSUs are also created and located along the road segment. An intersection has been created at the intersection of roads. A traffic signal has been added at the intersection to regulate the traffic of cars through the roads, with the addition of the colors of the traffic lights (red, yellow, green) as shown in the Figure 3.2.

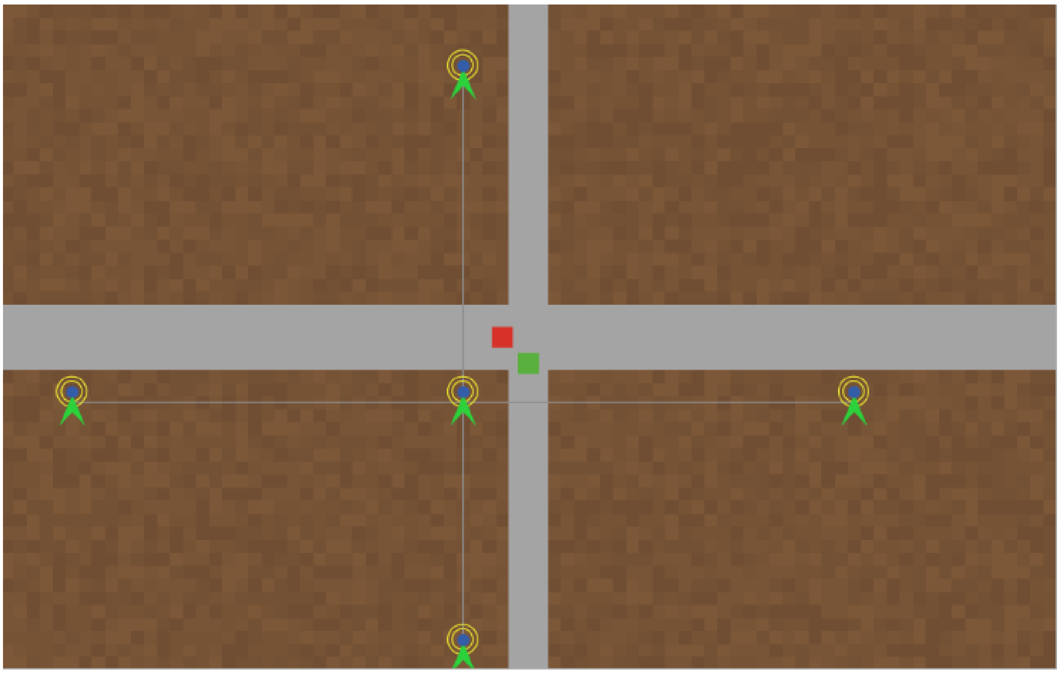


Figure 3.2 Proposed interconnected network

3.4.2 Create and Move the Vehicles

The entrance of vehicles to the road segment is also generated based on a random repeat distribution for each different road. Vehicle velocity is generated randomly and acceleration and deceleration are added to control its movement on the roads and simulate realistic scenarios in organizing vehicle movement as shown in algorithm 3.1.

Algorithm 3. 1 Moving-vehicles

```
Input: velocity, max-velocity, min-velocity, acceleration, deceleration
Output: Moving vehicles in a road segment
Begin
Vehicles generation on road
for each vehicle in road segment
    Indicate and save its vehicle ID
    for vehicle ∈ set of vehicles
        if there is another vehicle in front of vehicle, then
            Indicate and save the ID of this front vehicle
            velocity ← velocity of front vehicle – (deceleration * time)
        else
            velocity← velocity + (acceleration * time)
        end_if
    end_for
end _for
End_Algorithm
```

3.5 Adaptive Traffic Light Congestion Control

One of the simplest methods used to reduce congestion is to use RSU. The main function of an RSU is to enable communication between vehicles and infrastructure components, which can help to improve road safety, reduce congestion, and enhance the overall efficiency of vehicular communication.

3.5.1 Normal Vehicles

Let us denote the density of vehicles in the nearby road by "ρ", the number of vehicles by "N", and the length of the nearby road by "L". The mathematical equation for calculating the density of cars in the nearby road can be expressed as follows equation 3.1:

$$\rho = N/L \quad \text{………………... 3.1}$$

This equation simply divides the number of cars on the near road by the length of the road to get the vehicles density.

Let L =1 km then the equation of density represents:

$$\rho = N \ per \ 1km$$

Minimum number of vehicles in a specific road segment length which resulted in a congestion case can be calculated in a developed equation 3.2.

$$N = [D/(AV + SD)] * NL \quad \ldots\ldots\ldots\ldots 3.2$$

Where:

- AV is the average of vehicles length
- SD is the standard safety distance between two moving successive vehicles.
- NL is the number of road Lanes.

The calculated value of N in equation 2, is used as a threshold in this thesis to indicate the congestion case in each simulation scenario.

As an example:

Let D = 1000 m, AV = 4m, SD = 6m, NL= 2 then:

$N = [1000/(4 + 6)] * 2$ = 200 vehicles in each 1km length.

Controlling the occurrence of congestion in cooperation with the RSUs, where this is done by determining a specific Threshold for the number of vehicles within the specified range, which will be a measure of comparison with the Traffic Flow. Criticize the term Threshold is the maximum number of traffic flow that can be accommodated without causing congestion. This threshold can be set based on factors such as road capacity, vehicle density, and travel velocity.

When the traffic flow can be expressed in terms of vehicles per hour or vehicles per lane per hour. The traffic flow can be measured using traffic sensors or manual traffic counts. Once you have measured traffic flow, one can compare it to the threshold that have already defined. If the traffic flow exceeds the threshold, then congestion is likely to occur. Then the degree of congestion can be determined by how much the traffic flow exceeds the threshold. For example, if the traffic flow is only slightly above the threshold, then congestion may be mild, while a much higher flow would indicate severe congestion. Before comparing traffic flow with threshold value, must note that the range of the RSU is circular, meaning that it can include vehicles in the other direction of the road, not just the desired road. That is why the vehicles must be distributed according to their moving direction or destinations.

Based on what was mentioned, the degrees of congestion are determined according to the number of vehicles in the range of the roadside unit as follows:

- If the number of vehicles greater than or equal to a threshold value within the range of the RSU, then the congestion will be expected.
- Else, If the number of vehicles is smaller than a threshold value within the range of the RSU, the traffic will be normal without any expected congestion.

If the congestion is expected, then an action to alleviate it must be considered. One of the simplest solutions to deal with this situation is to make an adaptive traffic light with the roads traffic flow rates. Utilizing a roadside unit to send an order to increase the crossing time for the busy road direction to reduce congestion and distribute it on the rest of the roads. Figure 3.3, presents a flowchart to show the steps of making the proposed model, while Algorithm 3.2 explains the working mechanism to implement this proposed model.

Algorithm 3.2 congestion for normal vehicles

Input: No. of Vehicles
Output: open or close for traffic light
Begin
Vehicles approaching a traffic light
for each vehicle in road segment
    Indicate and save RSU connected to it
        Count No. of Vehicles in each traffic road
          if No. of Vehicles >= threshold, **then**
              change traffic road to green to open traffic
              change other traffic road to red to closed
        end_if
  end_for
End_Algorithm

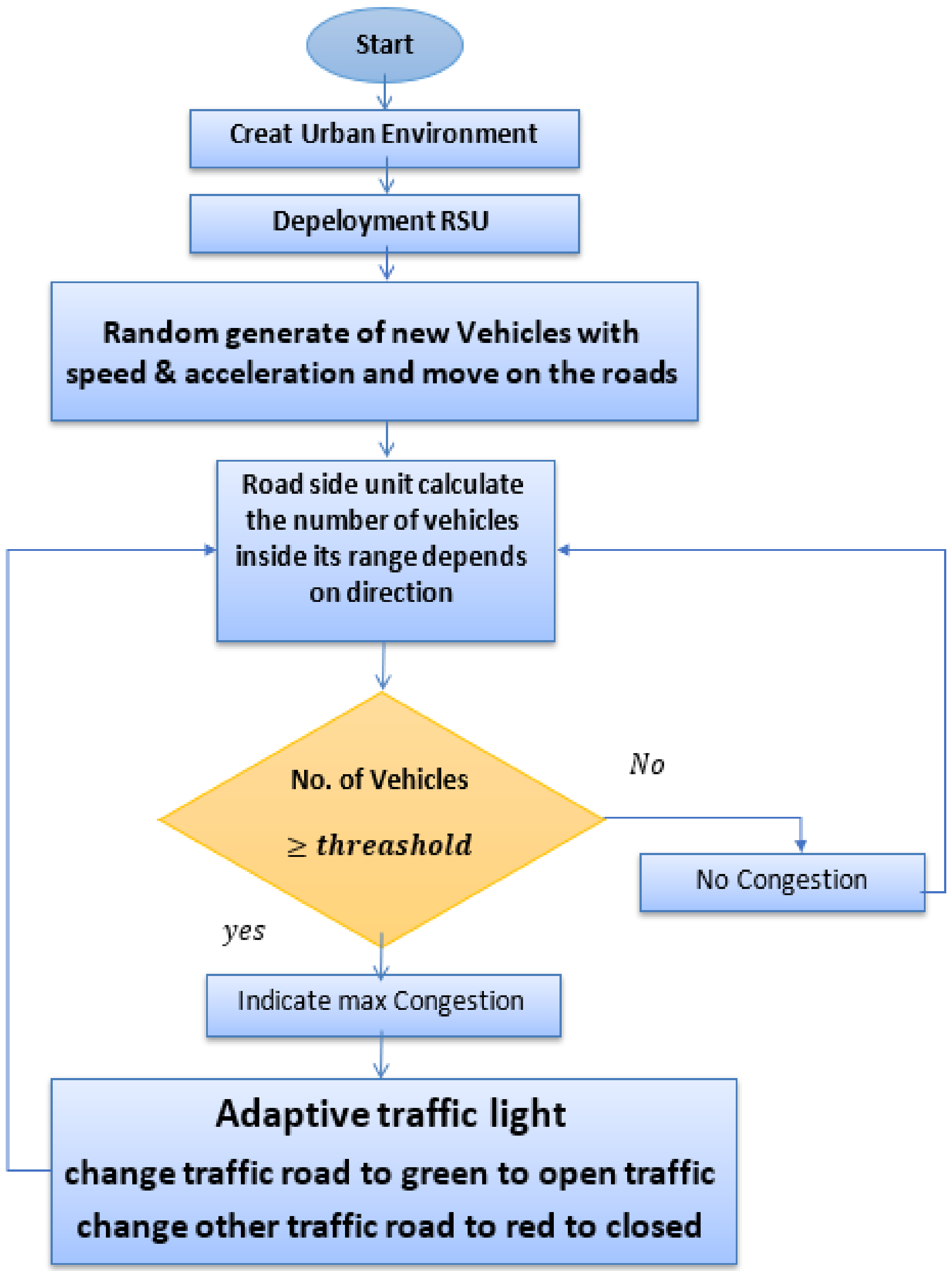


Figure 3.3 flowchart for the proposed model in case of normal vehicles

3.5.2 Emergency Vehicle Traffic Approach

An emergency vehicle is a specialized vehicle used by emergency services such as police, fire, and ambulance to respond to emergencies quickly. These vehicles are equipped with sirens, lights, and other specialized equipment to provide rapid response and save lives.

The importance of reaching emergency vehicles first and not being congestion lies in the critical nature of emergency situations. In many cases, time is of the essence, and delays in emergency response times can have severe consequences, including loss of life. Emergency vehicles need to reach their destination as quickly as possible to provide immediate assistance to those in need.

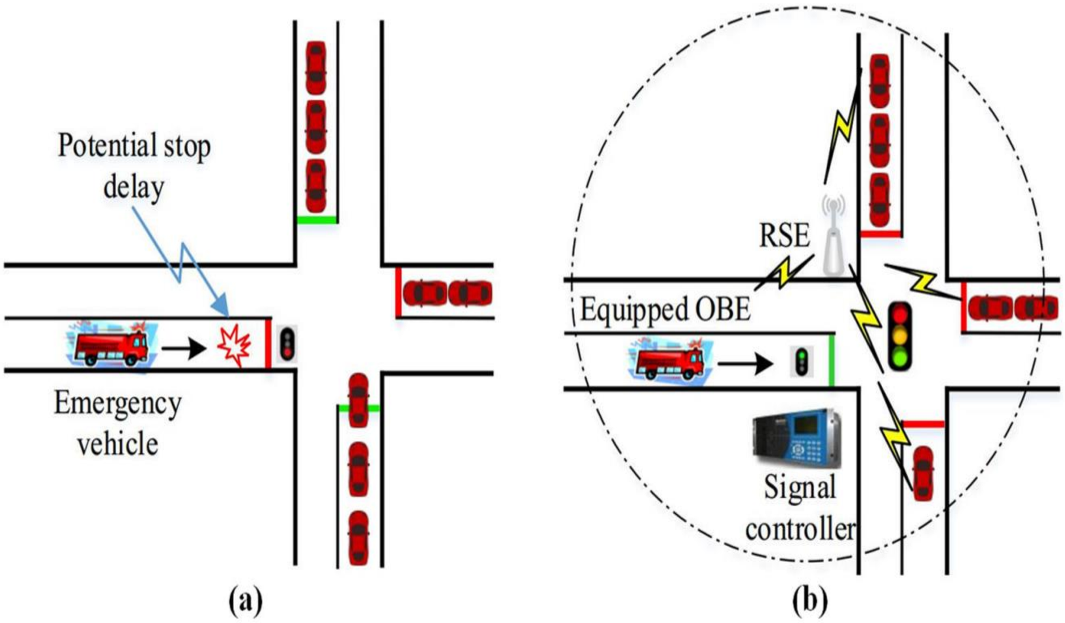


Figure 3.4 Delay illustration for emergency vehicle's response time: (a) typical stop delay for emergency vehicle (3); (b) a representative CV-based preemption system with communication delay (Zibo, et. al, 2021)

As shown in Figure 3.4 if emergency vehicles are over congestion or delayed due to traffic congestion, their ability to respond to emergencies is severely hampered. In such cases, a few extra minutes can make a significant difference in the outcome of an emergency situation. Prioritizing emergency vehicles' passage through traffic lights and ensuring they have clear roads can reduce response times and improve the chances of saving lives. Hence, it is crucial to manage traffic flow efficiently and prioritize emergency vehicles' passage to ensure the fastest response times possible.

Emergency vehicles such as ambulances, fire engines, and police cars require the use of traffic lights in urban environments to ensure they can quickly and safely reach their destination. In most countries, emergency vehicles are equipped with sirens and flashing lights that are used to alert drivers and other pedestrians of their presence. When an emergency vehicle approaches an intersection, they usually activate sirens and flashing lights to notify other drivers that they need to go through the intersection. Traffic lights are designed to help manage traffic flow and keep drivers and pedestrians safe. If an emergency vehicle is present, traffic lights can be temporarily bypassed or altered to ensure that the vehicle passes safely through the intersection. To solve this problem, suggested preparing the roads, especially near and before the traffic lights, according to the ring, with RSUs, which can communicate with the vehicle at a distance of 1 km. When the emergency vehicle approaches an intersection, it sends a signal to the roadside unit located in the road, which in turn determines its location and velocity. The distance between the vehicle and the RSU is calculated instantly by the distance law:

$$\boldsymbol{d} = \sqrt{(\boldsymbol{x_2} - \boldsymbol{x_1})^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. 3.3$$

Where:

d: is the distance between the vehicle and the traffic light
Then can derive the equation of time as follows:

$$\boldsymbol{t} = \frac{\boldsymbol{d}}{\boldsymbol{v}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. 3.4$$

Where the RSU is able to turn on the signal a minute before the time of the arrival of the emergency, so that the street is completely empty when the emergency vehicle arrives, so that it turns green for emergency vehicles and red for other vehicles. This helps clear the intersection and ensures that the emergency vehicle passes safely.

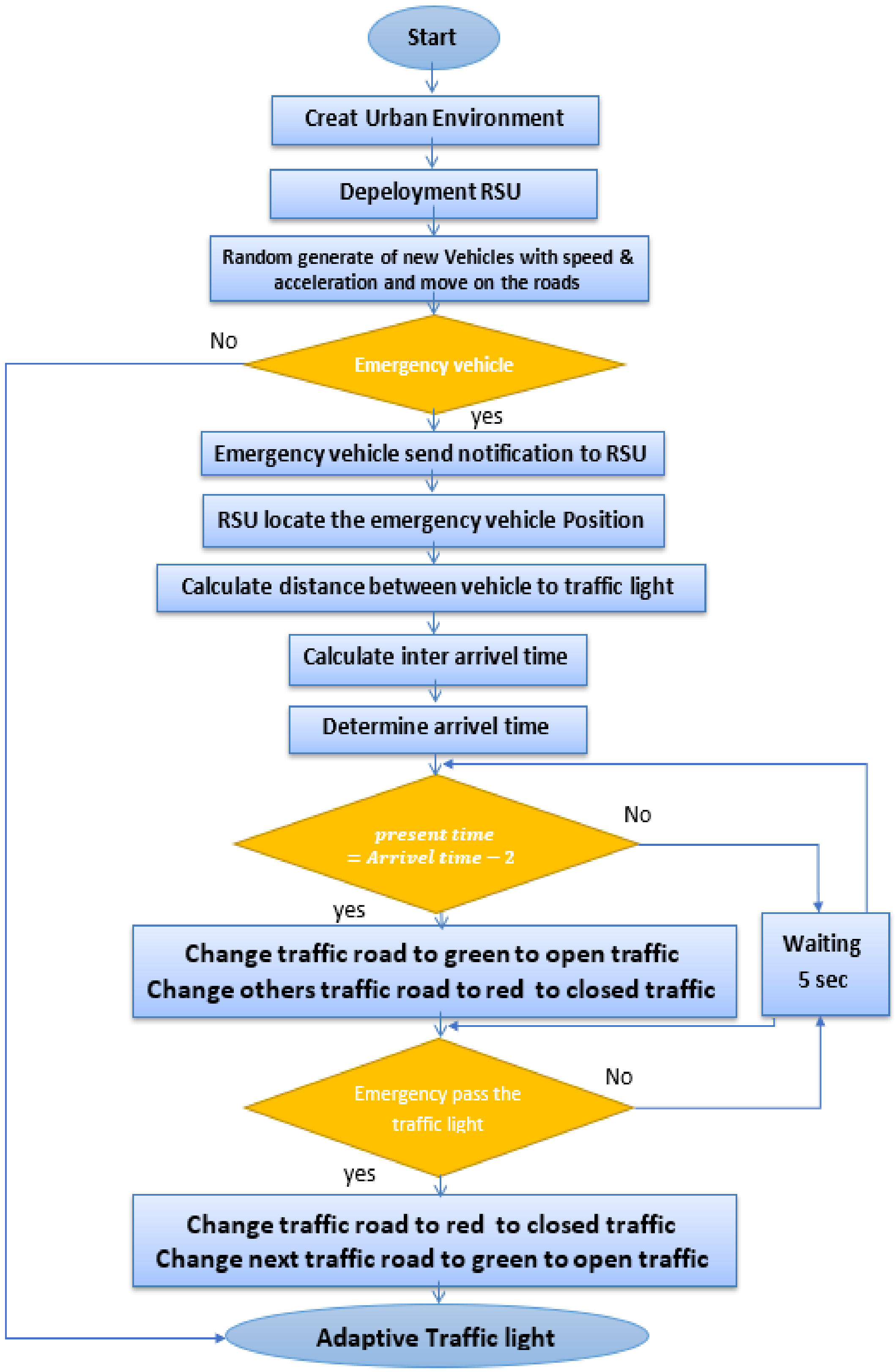


Figure 3.5 flowchart for the proposed model in case of emergency vehicles

3.6 Prediction of Congestion

The model architecture of the solution proposed involves the use of two key components VANETs and RSUs. Together, VANETs and RSUs create a distributed traffic management system that can promptly respond to changing traffic conditions. This approach provides drivers with real-time traffic information, enabling efficient routing and diversion of traffic and improving traffic flow in urban areas. VANETs and RSUs can work together to create a more efficient traffic management system by transmitting real-time traffic information to drivers and traffic management systems. This information can then be used to adjust traffic signal timing, redirect traffic flow, and notify drivers of alternative routes. The model architecture also includes the use of smart mobility solutions such as dynamic ride-sharing and autonomous vehicles.

These technologies optimize road space usage and further reduce congestion. The use of autonomous vehicles in particular can lead to a significant reduction in traffic congestion, as these vehicles can communicate with each other and with the surrounding infrastructure to optimize traffic flow. The implementation of VANETs and RSUs in urban areas requires substantial investment in infrastructure and technology development. However, the potential benefits of reducing congestion and improving traffic flow make it a worthwhile investment. By prioritizing the solutions provided by the aforementioned technologies, we can effectively tackle the issue of traffic congestion and significantly enhance the efficiency of traffic management in urban areas.

The prediction of congestion occurrence can be made by analyzing the density and velocity of nearby vehicles, which are important indicators of traffic flow:

1. **Density**: Density refers to the number of vehicles per unit length of the road. The neighbor density of vehicles can be calculated by dividing the number of vehicles in a specific section of the road by the length of that section. The formula for calculating density is:

   $$Density = Number\ of\ Vehicles / Length\ of\ Sectioflown \text{ ....3.5}$$

   For example, if you count 30 vehicles passing through a section of road that is 100 meters long, the density of vehicles would be:

   Density = 30 / 100

Density = 0.3 vehicles/meter

Calculating the neighbor density vehicles is an important step in analyzing traffic flow and predicting congestion. It can provide insights into the level of demand for transportation on a specific section of the road and help identify areas where congestion is likely to occur.

2. **Velocity**: velocity is an important indicator of traffic flow, as slow-moving vehicles tend to cause congestion. calculate the velocity of nearby vehicles by measuring the time it takes for vehicles to pass through two or more RSUs that are placed at a known distance from each other. This data can be used to analyze traffic flow and make informed decisions about traffic management and infrastructure improvements.

   Here's how to calculate the velocity of nearby vehicles using RSUs:

   Calculate the velocity of nearby vehicles: The velocity of a vehicle can be calculated using the following formula:

$$velocity = Distance/Time \quad \ldots\ldots\ldots\ldots 3.6$$

   Where distance is the distance between the two RSUs, and time is the time it takes for the vehicle to pass through both RSUs.

   For example, if the distance between two RSUs is 100 meters and it takes a vehicle 5 seconds to pass through both RSUs, the velocity of the vehicle can be calculated as follows:

   Velocity = 100 / 5

   Velocity = 20 meters per second

   This can be converted to kilometers per hour by multiplying by 3.6:

   Velocity = 20 * 3.6

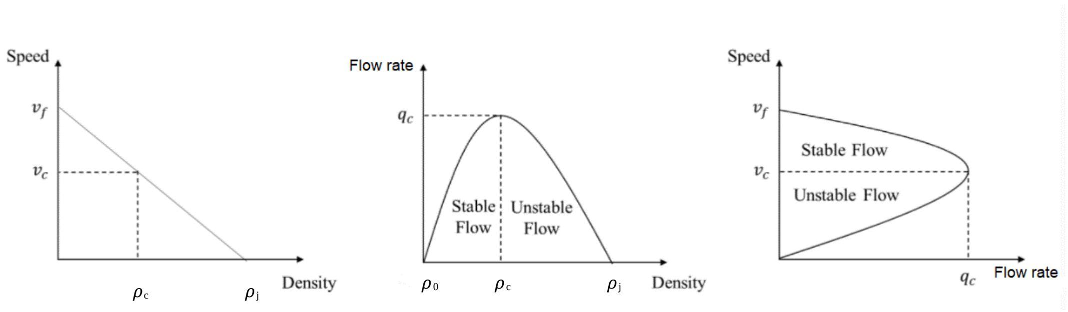
   Velocity = 72 km/h

The density and velocity are using to calculate the flow rate for vehicles by the equation:

Flow rate = Density * Velocity

$$q = \rho * v$$

The model describes the relationship between velocity (v) and density (ρ) of vehicles as being negatively correlated with density increasing with the decrease in velocity as shown in Fig (3.6), Where V_f is the free flow velocity when density is zero. vehicles can move freely as there are no or very few vehicles on the road. As the density of vehicles increases the speed decreases till density reaches the maximum which is referred to as jam density or (ρ_j) at which point the velocity becomes zero and vehicles are stuck in a jam. In the figure 3.6 (ρ_m) and (V_m) are the optimal density and velocity respectively which allows the traffic to progress at the optimum rate of flow.



a-The Relation between Density and Speed

b-The Relation between Density and Flow Rate

c-The Relation between Flow Rate and Speed

Figure 3.6 The Model prediction of Congestion

CHAPTER FOUR

Results and Discussions

Chapter Four
Results and Discussions

4.1 Introduction

This chapter aims to investigate the results of the proposed model on avoiding congestion at traffic lights in the urban environment. The navigation model approach was designed and implemented using Netlogo 6.3.0 simulation. The obtained results are discussed to show the parameters that have an impact on the results of the traffic light congestion reduction model and its proposed prediction and network performance measures.

4.2 Environment Creation

After designing and running the proposed model approach according to the simulation environment, the results were collected and presented using the Netlogo results viewer. The suggested simulation environment is presented in Table 4.1.

Table 4.1 Simulation Environment

Simulator	Netlogo 6.3.0
Simulation Ticks	500 ticks
RSU coverage Range	2 km (diagonally)
Arrival rate	10, 50, 80, 100 Vehicles
Velocity distribution	Exponential
Acceleration	variable m/s^2
Deceleration	variable m/s^2
Period of open traffic for EV	2 min
Scenario	Urban
Street length	5 km
Number of roads	4

4.3 Scenarios to Simulate Proposed Approach

After applying the proposed model using Net Logo 6.3.0 Simulation on the virtual urban map that was designed to simulate this thesis proposals. Represented by two direction roads (one lane) with an intersection.

4.3.1 Adaptive Traffic Light Congestion Control Results

To apply the adaptive traffic light, will be taken in two cases

a) Case of normal vehicles

After simulating the proposed model and calculating the congestion based on the developed equations with several simulation runs, the results are presented in Table 4.2.

Table 4.2 Results from simulations for the proposed model in case of normal vehicles

Threshold in simulation =10			
Simulation Time (ticks)	Congestion in North	Congestion in East	Traffic open for
30	14	10	North
42	11	6	North
60	7	12	East
91	11	17	East
115	11	8	North
160	12	16	East
172	15	9	North
250	15	5	North
310	3	9	East
326	8	6	North

Table 4.2 shows that the congestion was more frequent on the road heading north than east. Which indicates that the density of vehicles passing through this road is more than that of the other road.

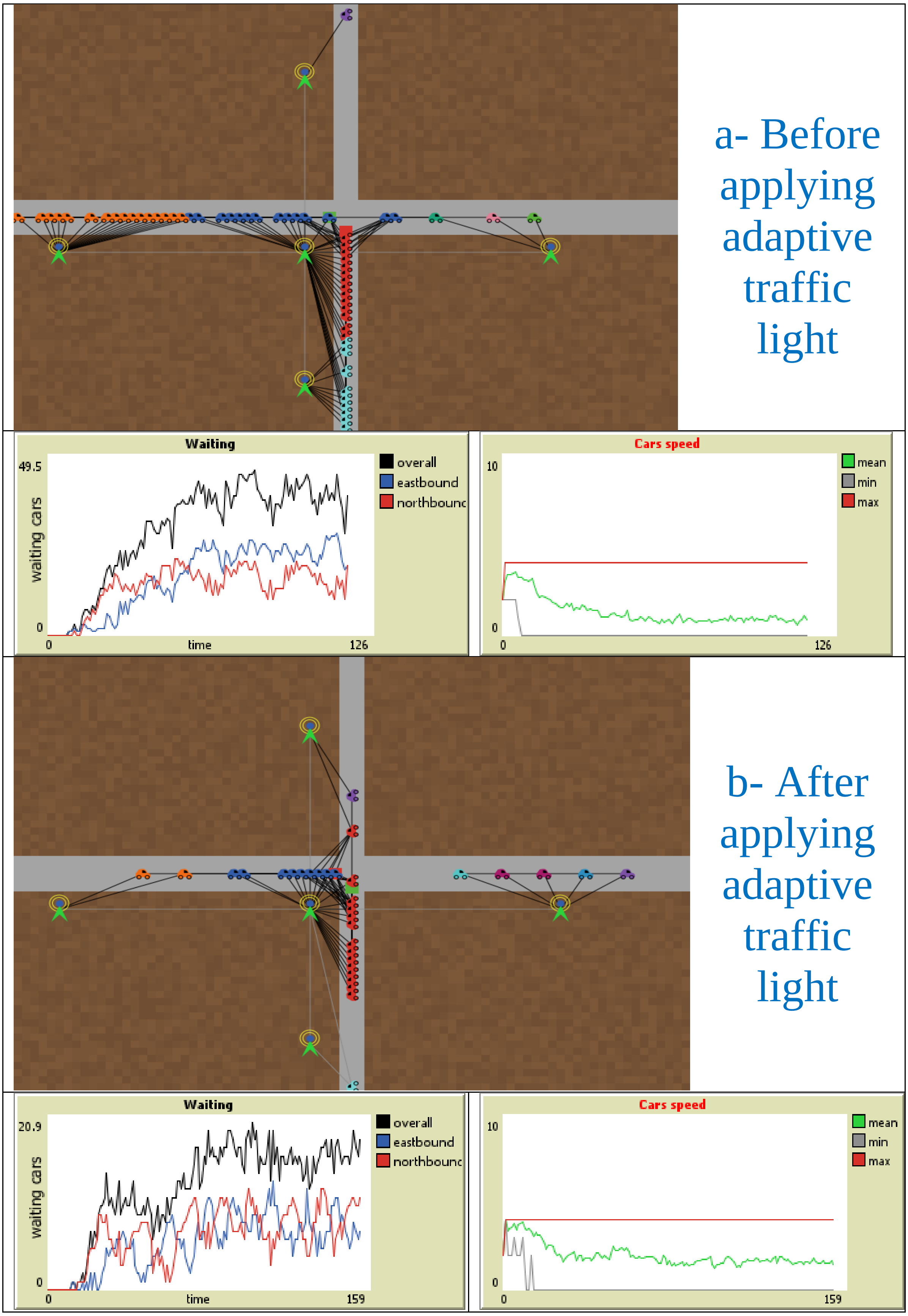


Figure 4.1 Simulation for Adaptive Traffic for in case of normal vehicles

Figure 4.1 (a) shows the performance of the normal traffic light before applying the adaptive, where the total waiting time for the vehicles is more, while Figure 4.2 (b) shows the performance of the traffic light adapted to a large density of vehicles to prevent the occurrence of congestion, where the total waiting time for vehicles is less. The graphic results show the waiting time and the mean, min, and max for vehicles on all roads, in general.

b) Case of Emergency vehicles

After simulating the proposed model and calculating the developed equations with several simulation runs, as shown in Figure 4.2, the scenario begins with several vehicles entering the roads, including an ambulance. The ambulance moves on the road with constant contact with the RSUs, and when the ambulance arrives at the roadside unit that precedes the roadside unit connected to the traffic light, the roadside unit sends a notification to the roadside unit connected to the traffic light to open the traffic signal before (5 Ticks) The arrival of the ambulance. The continuous arrival time is calculated by the previously proposed equations. After the ambulance has passed, the traffic light will return to normal operation. Thus, ambulances avoid traffic jams and arrive as quickly as possible.

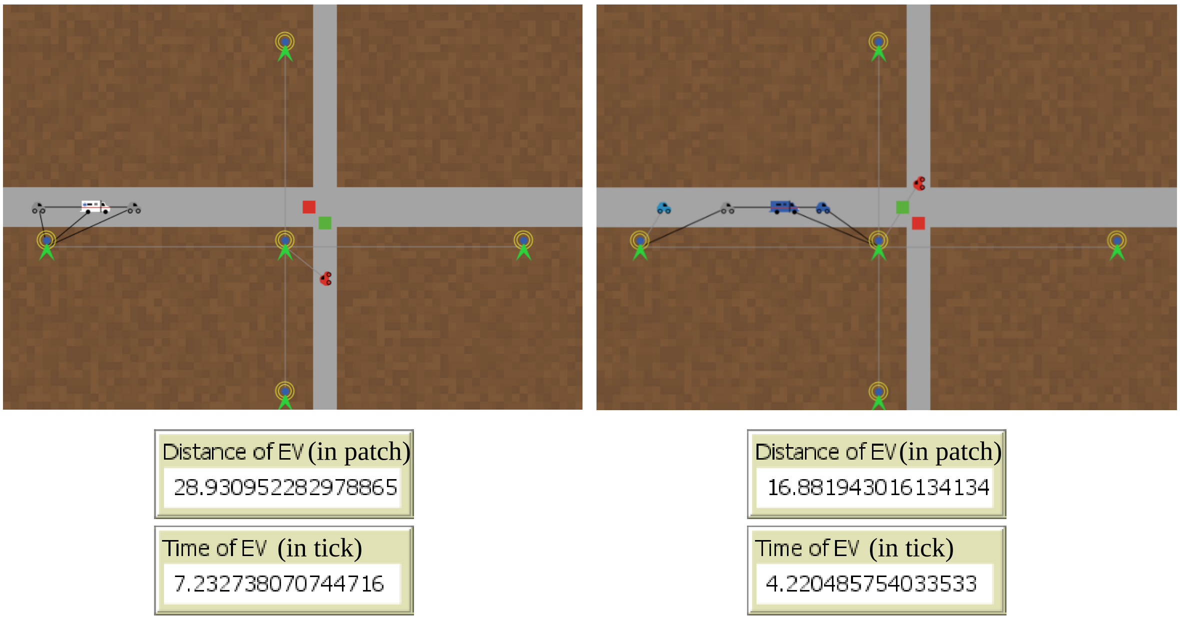
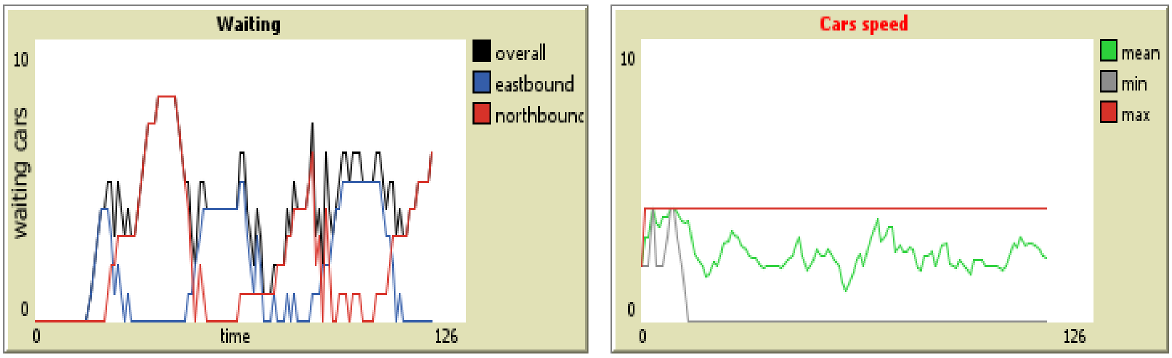


Figure 4.2 Simulation for Adaptive Traffic for in case of emergency vehicles

Figure 4.3 (a) shows a schematic diagram showing the vehicles that wait at the traffic lights. Opening the emergency vehicle's traffic light increases the waiting time for the rest of the vehicles in other directions of the vehicle, but the total average waiting time indicates that it does not significantly affect the model. This means the stability of the model. While Figure 4.3 (b) shows an analysis of the general car speed on the map in terms of the average, the highest and lowest speed value. Calculating the mean speed of vehicles is necessary to find out the time required to open the parking lot before the emergency vehicle reaches the traffic light, so that all vehicles stopped in the traffic light can pass before the arrival of the emergency vehicle.



(a) Waiting for vehicles (b) Mean, Max and Min of Cars Velocity

Figure 4.3 schematic diagram

4.3.2 Analysis Result for Adaptive Traffic Light

After analyzing the results shown in Table 4.2, one can notice that by using the adaptive traffic model, congestion was gradually reduced. as shown in the curvature in Figure 4.4, as the congestion rate began to gradually increase and decrease in harmony between the two roads until more stable and less congested roads are obtained. It is noteworthy to note that the previous results can help in predicting which streets are the most crowded in the city based on the information of the RSU analysis model extracted from the logs sent by the vehicles. Which helps to build a clear perception of whether the congestion is accidental and can occur at peak times only, or that it is permanent, since this road leads to vital centers in cities.

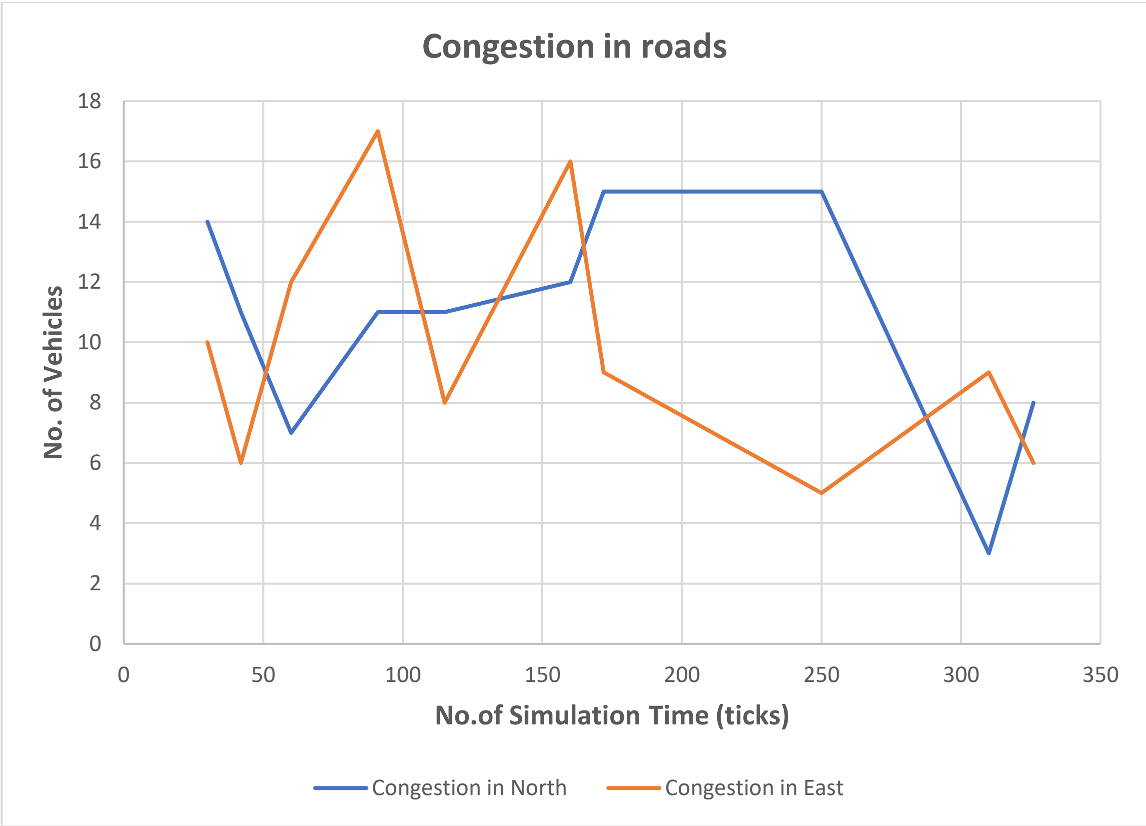


Figure 4.4 Analysis the results in Simulation for Adaptive traffic in normal case

4.3.3 Congestion Prediction Results

After simulating the proposed model and calculating the developed equations with several simulation runs, the results are presented in Table 4.3.

Calculating the maximum flow rate that represents the Threshold, in simulation threshold equals 4 which is the largest number of vehicles that can flow smoothly through the same point per unit of time. When the flow rate exceeds this threshold, it indicates that possibility of congestion for thus congestion indication is equal 1, and if it is less than this limit, this means that it is a good indication that congestion does not occur for thus congestion indication is equal 0.

Table 4.3 Results from simulations for the proposed model in congestion prediction

Threshold in simulation = 4				
Simulation Time (ticks)	**Velocity patch/tick**	**Density Veh/patch**	**Flow Rate Veh/tick**	**Congestion**
160	**6**	**0.3**	**1.79**	**0**
183	**13**	**0.5**	**6.93**	**1**
220	**4**	**0.53**	**2.13**	**0**
247	**6**	**0.36**	**2.19**	**0**
260	**9**	**0.6**	**5.399**	**1**
270	**1**	**0.43**	**1.43**	**0**

4.3.4 Analysis Result for Congestion Prediction

After analyzing the results shown in Table 4.3, Figure 4.5 shows the value of flow rate resulting after applying its mathematical equation. As for Figure 4.6, it shows the congestion value that was predicted according to the Threshold value.

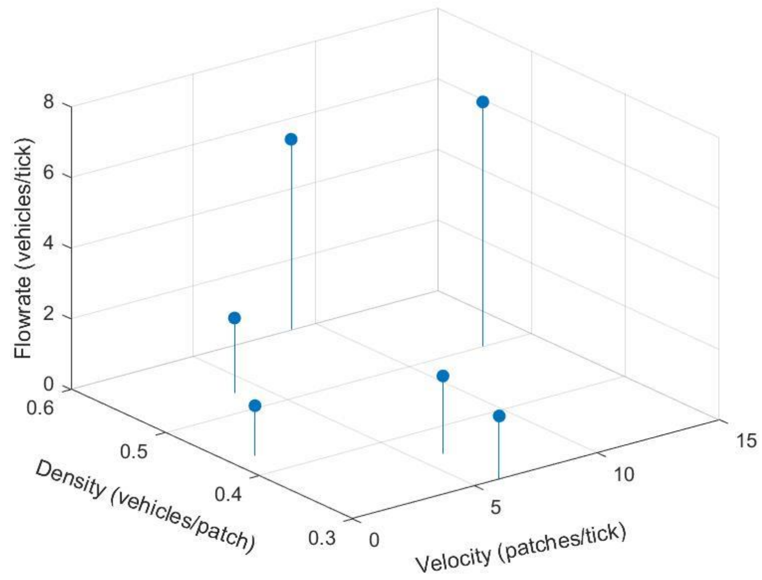


Figure 4.5 Analysis the results for flow rate in Simulation

Figure 4.5 (a-b) explain the amount of flow rate change depending on the values of vehicle density and speed, which are variable from time to time depending on the measured time or region.

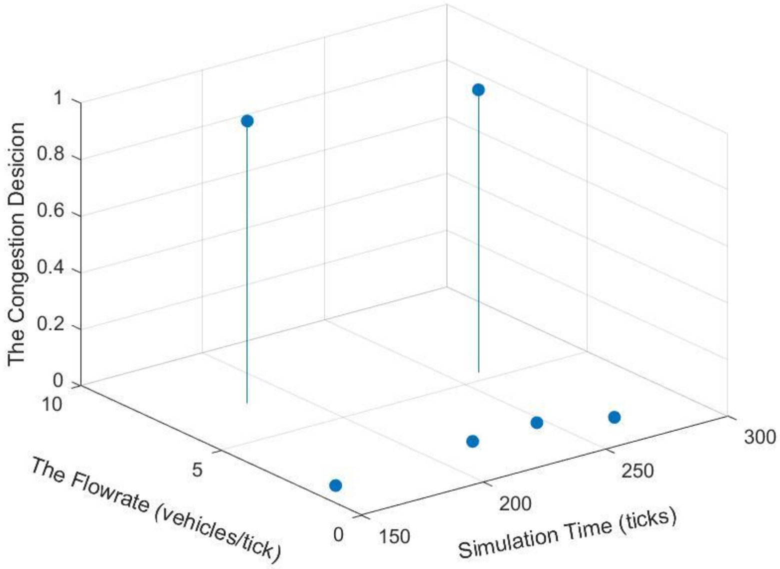


Figure 4.6 Analysis the results for congestion in Simulation

Figure 4.6 explain the congestion value corresponding to the flow rate values. When the vehicle flow rate is less than the capacity of the road or transportation system, the traffic tends to flow smoothly and the congestion is minimal, that is, there is no congestion and is represented by the value 0. But when the flow rate approaches or exceeds the capacity, congestion begins to occur and is represented by the value 1, which means that the relationship between them is an inverse relationship.

4.4 Evaluation for the Proposed Model

The distance between two RSUs is calculated in simulation by 30 patches. This means that in the case of calculating the amount of delay time for the emergency vehicle, it must be taken into account that it will send a notification to the RSU before the traffic, which means a distance of 45 patch to inform it of its arrival on this road.

The time required for the emergency vehicle to reach the traffic light is calculated, and check whether the signal is red or green at that time, and there will be more than one case for calculating the delay time (Note that the time to open the traffic light in green is 5 ticks), as follows:

First Case:

Emergency vehicle velocity = 9 patch/ tick

Which means that the emergency vehicle will arrive after 5 ticks to the traffic light, and we will have two cases for the delay time account

If the signal is just green, there will be a delay of 10 ticks

If the north signal is just green, there will be a delay of 5 ticks

Second Case:

Emergency vehicle velocity = 5 patch/ tick

Which means that the emergency vehicle will arrive after 9 ticks to the traffic light, and we will have two cases for the delay time account

If the signal is just green, there will be a delay of 10 ticks

If the north signal is just green, there will be no delay

Third Case:

Emergency vehicle velocity = 3 patch/ tick

Which means that the emergency vehicle will arrive after 15 ticks to traffic light and we will have two cases for the delay time account

If the signal is just green, there will be a delay of 5 ticks

If the north signal is just green, there will be no delay.

After apply the proposed approach, notice there is no delay for the emergency vehicles in the traffic light.

It's clear from the simulation results when applying the proposed approach model in the case of emergency vehicles for deferent traffic state that the proposed model obtained an improvement performance represented by the decreasing the delay time in the traffic light.

Actually, there is no delay for emergency vehicles when applying the proposed model.

CHAPTER FIVE

Conclusions and Future Works

Chapter Five
Conclusions and Future Works

5.1 Conclusions

In the proposed model, two proposed methods were presented to avoid congestion on traffic light, the following are the conclusions of each method:

5.1.1 Adaptive Traffic Light Congestion Control

In this method, it was applied to all types of vehicles, then emergency vehicles were taken as a special case to deal with, and the following conclusions were obtained:

- **For Normal Vehicles**

In this model, an adaptive traffic control model was proposed. This model, was implemented, and evaluated in different simulation runs. It helped in overcoming the congestion problems caused by the traditional traffic system. By calculating the traffic density through the number of vehicles on the road. Threshold was given to estimate the occurrence of congestion based on several factors, including RSU coverage and the number of cars within this coverage. A model was built through an algorithm that works on estimating the occurrence of congestion through the Threshold and working on opening the traffic light for the busy road and closing the traffic light for other roads. In the event that the roads are not exposed to congestion, the traffic lights return to their traditional work. The results obtained from the simulation, when analyzed, showed that the proposed model regulates the traffic of vehicles and reduces congestion, which makes the movement of vehicles at intersections in urban environments more stable.

- **For Emergency Vehicles**

Emergency vehicles play a crucial role in saving lives and protecting property during emergency situations. They are specially designed and equipped to provide rapid response and immediate assistance in emergencies, such as fires, accidents, and medical emergencies. The importance of emergency vehicles lies in their ability to respond quickly and efficiently to emergencies. Their specialized equipment and highly trained personnel can provide critical care and support to those in need. Emergency vehicles can transport patients to hospitals, rescue individuals from dangerous situations, and provide on-site medical treatment to injured people. Furthermore, emergency vehicles also play a critical role in managing disasters and emergencies that affect communities, such as natural disasters and terrorist attacks. They help to evacuate people from dangerous areas, provide search and rescue operations, and deliver essential supplies and equipment to affected areas. In this research, a proposed model was discussed to solve the problem of congestion of the emergency vehicle and to connect it as quickly as possible through adaptive traffic light using the assistance of the RSU, and the ambulance was taken as an example for applying the proposed model. The results showed that the model is effective in reducing congestion significantly for emergency vehicles. This approach is adaptive and can adapt to changing traffic conditions in real time, which makes it suitable for different traffic scenarios.

5.1.2 Congestion Prediction

predicting various aspects in VANETs is an important research area that holds significant potential for overall communication in intelligent transportation systems. prediction can be made based on monitoring the flow rate of vehicles within the network that helps to reduce traffic congestion, Safety and collision avoidance, assessing the stability of the VANET network and road network planning in future.

5.2 Future Works

- The ability of connecting vehicles to the Internet via a vehicle sim vehicle with 5G and thus obtaining information directly from the source such as a street map and thus sending and receiving data through a dedicated platform.
- Internet of Vehicle (IoV), which is a new concept that has entered the world of vehicle networks, experimented with the proposed approach, whether through communication operations, data dissemination, or the use of applications.
- Modifying the proposed approach by the concept of priority can be applied when more than one emergency vehicle approaches the same intersection at the same velocity.

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الخلاصة

الشبكات المخصصة للمركبات (VANETs) هي نوع من شبكات الاتصالات اللاسلكية التي تمكن المركبات من التواصل مع بعضها البعض ومع مكونات البنية التحتية في المناطق المجاورة لها. تشكل VANET شبكة ديناميكية وذاتية التنظيم حيث تعمل المركبات كعقد متنقلة ، وتتبادل المعلومات وتتعاون لتحسين السلامة على الطرق ، وكفاءة حركة المرور ، وتجربة النقل الشاملة. عادة ما يتعلق الازدحام في أنظمة النقل بالمركبات التي تمر على جزء من الطريق في وقت محدد مما يؤدي إلى سرعات أبطأ من "floe rate" أو السرعات العادية. الازدحام المروري له تأثير سلبي على الأداء المروري لأنه يزيد من وقت السفر ويلوث الهواء. إنه يمثل مشكلة مرور كبيرة في الشوارع.

تمثل مشكلة الازدحام المروري جزءًا مهمًا وطريقة لإيجاد حل ممكن لتسهيل تقدم أنظمة النقل الذكية الفعالة. يمكن أن يحدث الازدحام المروري في الشوارع بسبب الازدحام المروري والحوادث والبناء والطرق السيئة وضعف الاتصال من بين عوامل أخرى. يحدث عندما يكون عدد المركبات في بعض أجزاء الطريق أكبر من سعتها. تعتمد معظم أنظمة إشارات المرور الحالية على فترات زمنية ثابتة. تعد إشارات المرور الثابتة هذه أقل كفاءة بسبب نقص مرونة التعديل والتكيف في الوقت الفعلي. في هذه الأطروحة ، تم اقتراح نظام حركة متكيف مع أنماط حركة المرور في الوقت الفعلي من أجل تحسين تدفق حركة المرور عن طريق تغيير توقيتات الضوء الأخضر ديناميكيًا.

يساعد النهج المقترح في التحكم في تقاطعات إشارات المرور من خلال إنشاء أمر بتأخير أوقات الضوء الأخضر أو التبديل إلى اللون الأخضر في اتجاه معين بناءً على حالة سيارات الطوارئ. النموذج الآخر المقترح هو معالجة مشاكل الازدحام من خلال التنبؤ بحدوث الازدحام بناءً على معايير محددة. يتم تنفيذ نتائج المحاكاة بواسطة NetLogo 6.3.0 في ظل ظروف مختلفة مثل أعداد المركبات المختلفة ، والقيم المختلفة لطول إشارة المرور ، وكثافات التدفق المختلفة.

أثبتت نتائج المحاكاة أن استخدام هذه الحلول قد ساهم بشكل فعال في تقليل الازدحام وتقليل وقت التأخير ، مما يؤدي إلى أنظمة نقل حضرية أكثر كفاءة واستدامة.

جمهورية العراق
وزارة التعليم العالي والبحث العلمي
جامعة بابل
كلية تكنولوجيا المعلومات
قسم شبكات المعلومات

طريقة نمذجة متكيفة مطورة لتحسين التحكم بالازدحام المروري لشبكات المركبات في المناطق الحضرية

رسالة

مقدمة إلى مجلس كلية تكنولوجيا المعلومات في جامعة بابل كجزء من متطلبات نيل درجة الماجستير في تكنولوجيا المعلومات – شبكات المعلومات

مقدمة من قبل

رنده مهدي كاظم سلمان

باشراف

أ.د. سعد طالب حسون الجبوري

١٤٤٤ هـ **٢٠٢٣م**