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THESIS TITLE

Planning and Management of Connected and Autonomous Vehicles (CAVs) Implementation for Dense Event

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ABSTRACT

CAVs are a subject of enormous interest internationally, as transportation agencies and cities try to understand what the future holds when deploying these vehicles widely. They provide many benefits not just to the automotive sector but also to the urban landscape and society. Pilot projects of CAV deployments for mass transit have shown that these vehicles, being equipped with autonomy and connectivity, can improve safety, efficiency, mobility, productivity, and fuel consumption. For the adaptation of CAVs for dense events, it is vital to assess first the impacts of such deployment in the safety, environment, and health sector so that their inevitable deployment is as smooth and advantageous as possible.

The scope of this thesis was to model a CAV application in a dense event, selected as FIFA-2022 Lusail, Qatar. The primary aspect of the study comprises deploying CAVs in the selected event providing a suitable service model ensuring mobility demand, population density distribution, location profile, and road network. Different scenarios based on demand data set simulated and critical performance measures assessed to validate network performances. The selected deployment service effectively addresses the criteria for heterogeneous traffic, emissions from more driving, and on-street congestion that may result in the case of a dense event. Finally, a case study developed considering CAV deployment as a business case, considering the two main stakeholders, city management and CAV deployment company.

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Finally, I would like to dedicate my work to my family, especially my elder brother Tanveer Ahmed, who has always believed in me and has supported me through thick and thin.

Zaheer Ahmed

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LIST OF ACRONYMS

ABD	Absolute Braking Distance
ACC	Adaptive Cruise Control
ADAS	Advanced Driver-Assistance System
ADS	Automated Driving System
AI	Artificial Intelligence
ATMS	Advanced Traffic Management System
AV	Autonomous Vehicle
BEB	Battery Electric Bus
CACC	Cooperative Adaptive Cruise Control
CAV	Connected and Autonomous Vehicle
CDTI	Centre for the Development of Industrial Technology
CEN	European Committee for Standardization
CV	Connected Vehicle
DARPA	Defense Advanced Research Projects Agency
ETSI	European Telecommunications Standards Institute
FIFA	Federation International of Football Association
FTA	Federal Transport Agency
GL	Green Line
GNSS	Global Navigation Satellite Systems
GPS	Global Positioning Systems
IEEE	Institute of Electrical and Electronics Engineers
IOC	International Olympics Committee
ISO	International Organization for Standardization
ITS	Intelligent Transportation System
ITU	International Telecommunication Union

KPIs	Key Performance Indicators
LiDAR	Light Detection and Ranging
MTC	Mobility Transformation Center
NHTSA	National Highway Traffic Safety Administration
OTA	Over-the-Air
PKT	Passengers Kilometer Travelled
PT	Public Transport
RL	Red Line
SAE	Society of Automotive Engineers
USD	United States Dollar
USDOT	United States Department of Transportation
V2C	Vehicle-to-Cloud
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Everything
VKT	Vehicle Kilometers Traveled
Wi-Fi	Wireless Fidelity
4G/3G	Fourth Generation/Third Generation

1 INTRODUCTION

This chapter is dedicated to the introduction of connected and autonomous vehicles. It is necessary to present the CAV technology to enhance the reader's understanding before its implementation. This chapter includes CAV's background, communication technologies, autonomy levels, and challenges related to CAVs deployment.

1.1 Background

1.1.1 Connected Vehicles

Connected vehicles are equipped with the onboard communication capabilities necessary to establish a bidirectional data link between onboard and offboard devices. CVs are comprised of hardware, software, and algorithms that enable the continuous flow of data; these vehicles can be connected as vehicle to vehicle (V2V), to infrastructure and traffic sensors (V2I), or with other road commuters, such as pedestrians and cyclists (V2X) [1].

Connected vehicles have enabled an increasing level of connectivity, the ability to interact with their environment to provide information to the driver about the road, traffic, and routing, and provide various connectivity services. The concept of connected vehicles gives vital information to the driver or vehicle, assisting the driver in making safer decisions. The connected car does not make any decisions on the driver's behalf. It only informs the driver about potential hazardous circumstances that must be avoided. In the V2V domain, vehicles would broadcast (through DSRC) a simple safety-related message containing information about vehicle speed, direction, and location that other equipped cars might receive and use to avoid collisions cooperatively. In the realm of V2I, by communicating to and from infrastructure, security is increased. At signalized crossings, signal phase and timings information may modify vehicle speeds, reducing time spent idling at traffic signals and maximizing traffic flow. CVs can transmit data to transportation agencies to improve their awareness of current road conditions and generate historical data to assist agencies in planning and allocating future resources [2].

1.1.2 Autonomous Vehicles

AVs are vehicles where some features (for example, steering or braking) of a safety control mechanism occur without driver intervention. An autonomous vehicle with an increased degree of automation uses onboard sensors and installed systems to understand its position, surrounding environment and operate without some driver assistance. The adoption of AVs can minimize dramatically or almost remove collisions by eliminating human driving errors during driving. Autonomous vehicles rely on incorporated technology, including sensors, cameras, light detectors, global positioning systems, and other onboard devices to function with little, no, or limited human input. The implementation and use of autonomous vehicle technology are less regulated by transport agencies, more dominated by parent private sector companies. Transport agencies have a role to play in improving road conditions to promote their deployment [2].

1.1.3 CAV (incorporation of connected and autonomous vehicle)

Connected and autonomous vehicles incorporate two technologies connectivity and autonomy. CAVs can sense and quickly react to their surroundings, making them safer and more effective. The vehicle's connectivity leads to improving self-contained road safety by notifying about potential hazardous circumstances. It helps to mitigate congestion through optimal routing, improves traffic flow through speed guidelines, minimizes environmental impacts by optimizing power train management, and prevents unnecessary stoppages.

1.2 Communication Technologies for CAVs

Connected vehicles interact with the driver, other road users (vehicle-to-vehicle), roadside infrastructure (vehicle-to-infrastructure), and the cloud (vehicle-to-cloud). These incorporated technologies ensure not only vehicle safety but also efficiency and travel time improvements of the vehicles. The various modes of communication are described below.

1.2.1 Vehicle-to-Vehicle (V2V)

V2V connectivity allows the vehicles to communicate with other vehicles on the road, and these vehicles can share information about speed, current location, and direction wirelessly. The technology underlying V2V interaction enables vehicles to transmit omnidirectional communications, providing "awareness" to other vehicles in the surroundings. This technology can use visual, interactive, and audible alerts or a combination of these alerts to warn drivers. These warnings enable the drivers to take steps to avoid collisions [3].

1.2.2 Vehicle-to-Infrastructure (V2I)

The V2I standard is the next generation of intelligent transportation systems (ITS). V2I systems collect vehicle-generated traffic data and wirelessly transmit information to drivers, such as vehicle infrastructure notifications about safety, mobility, or environmental conditions. National and municipal governments are expected to install (V2I) infrastructure in addition to or in conjunction with current information technology systems [4].

1.2.3 Vehicle-to-Cloud (V2C)

Vehicle to the cloud is a cloud-based linked automobile solution that surpasses traditional telematics services that rely on broadband cellular access. Initially 3G, but gradually 4G, with 5G networks being considered. Additionally, over-the-air (OTA) updates are gradually becoming critical for managing a vehicle's lifecycle and enabling analytical and broad data approaches [5].

1.2.4 Vehicle-to-Pedestrian (V2P)

The vehicle-pedestrian approach encompasses a diverse range of road users, including pedestrians, strollers for children, persons who use wheelchairs or other mobility aids, passengers boarding and alighting buses and trains, and individuals riding bicycles [5].

1.3 Automation Levels in Vehicles

In the past year's several proposals were made by (NHSTA) and SAE for vehicle autonomy classifications, but the SAE classifications [6], became the most recognizable standards; the Society of Automotive Engineers (SAE) describes six driving automation stages for clarification and accuracy, ranging from manual to fully autonomous vehicles.

Level 0 – Without Automation
The total charge of driving in human hands; the vehicle is not capable of providing any assistance.
Level 1 – Driver Assistance
The automobile's Advanced Driver Assistance System (ADAS) aids the driver through the steering, braking, and acceleration.
Level 2 – Partial Driving Automation
In some cases, the lowest level of autonomy, the ADAS on the vehicle, may monitor both steering and braking/acceleration. At all times, the human driver must maintain complete attention ('watching the driving environment') and do the remainder of the driving duty.
Level 3 – Conditional Driving Automation
In certain circumstances, the car's automated driving system (ADS) will handle all aspects of driving. At any time throughout the journey, the human driver must take over when the ADS request. In all other instances, the human driver takes precedence.
Level 4 -High Driving Automation
The ADS in the car will do all driving activities and monitor the driving environment to determine when particular driving tasks should be performed. Individuals are exempt from paying attention in these instances.
Level 5 – Full Driving Automation
In all instances, the car's ADS will perform all driving. Occupants are merely passengers and are never required to drive.

1.4 CAV Technologies

CAV technologies present and with possible future advancement, with their impacts on eco-driving, EMS and fuel economy are presented below.

1.4.1 Present CAV Technologies

Table 1 depicts the present CAV technologies, with their use and possible impacts on eco-driving, EMS and fuel economy [7].

Table 1 Present CAV Technologies

CAV TECHNOLOGY	ECO-DRIVING IMPACTS	EMS IMPACTS	FUEL ECONOMY
Camera systems (CS)	Localized speed modification aids enabling adaptive cruise control	Through sign recognition, localized forecasting of future velocity is possible.	Minor fuel economy improvements from short predictions
Radio detection and ranging (RaDAR)	Localized velocity adjustment facilitates, adaptive cruise control to the fullest extent possible	Prediction of future velocity through object recognition	Minor fuel economy improvements on the highway
Light detection and ranging (LiDAR)	Localized velocity adjustment with increased precision, which may enable lane switching	Through object identification, a more precise estimate of future velocity can be made.	Better fuel economy improvements on the highway
Global positioning system (GPS)	Modification of velocity to conform to route-specific speed limits	Prediction of the entire drive cycle based on stop light and legal speed data	Prediction accuracy-dependent fuel economy improvements along an entire route
Drive cycle database	Modifications to the velocity of formerly expensive phases of the driving cycle	Forecasts of route length and velocity that improve over time	Accurately forecasting fuel economy improvements along a planned path

1.4.2 Future CAV Technologies

The Table 2 presents some of the main CAV future technologies. Highlighting their use and potential impacts on eco-driving, EMS, and fuel economy [7].

Table 2 Future CAV Technologies

CAV TECHNOLOGY	ECO-DRIVING IMPACTS	EMS IMPACTS	FUEL ECONOMY
Global Navigation Satellite Systems (GNSS)	Velocity modification to coincide with speed limits along the route	Forecasts of route length velocity that improve with recurrent travels	Accurately forecasting fuel economy improvements along a full journey

Vehicle-to-vehicle communication (V2V)	It offers a variety of driving velocity adjustments and cooperative adaptive cruise control	Predicting future speeds with high accuracy along a busy route	Considerable fuel economy improvements along busy roads
Vehicle-to-infrastructure communication (V2I)	Allowing for the changing of the route's velocity in accordance with traffic signals.	Forecasting velocity with high accuracy nearby traffic lights	Considerable fuel economy improvements near traffic lights
Vehicle-to-everything comm. (V2X)	Allows for total route velocity change while accounting for all driving cycle impediments	Prediction of future speeds along the entire path with a high degree of accuracy	Fuel economy Enables absolute optimal

1.5 Challenges in CAV Deployment

The era of CAVs has already begun; it only takes an hour to arrange for their widespread deployment. Several impediments must be overcome, some of which are foreseen and explained here.

1.5.1 Infrastructure Requirements

It is anticipated that infrastructure would play a significant role in helping or impeding CAV deployment. Improvements to the road network are projected to accelerate the pace at which connected and autonomous vehicles can be implemented efficiently. Given the intricacy of the initial technology's capabilities, it is believed that connected and autonomous vehicles will require well-maintained highways. To provide the accompanying benefits of connected automobiles in terms of protection, connectivity, and road space, 5G communication networks and advanced traffic management systems, including ITS, would need to be well-developed. It will necessitate extensive consultation with both the public and private sectors. Comprehensively managing information data, CAV technology would generate vast volumes of data and information that transportation authorities may use for network operations, effective maintenance, and asset management and inform planning and decision-making. The majority of this data will be dispersed, making it difficult to bring it all together in one location. The establishment of integrated data platforms may enable the fusion of CAV technology and other pertinent solutions. However, there is a critical dependency on the availability of a suitable and comprehensive communications infrastructure, which might theoretically be given via 5G or ITS-G5 systems [8].

1.5.2 Integration with Public Transport Network

Numerous advantages of CAV technologies are contingent upon their integration into the broader Intelligent Mobility ecosystem. This mode of deployment may contribute to congestion relief and more economical and usable transportation services. If most CAVs are privately owned and or operated on a modest, single-occupancy basis, there is a risk of increased congestion. Overcoming initial safety barriers would require dynamic interactions between connected and autonomous vehicles, human-driven vehicles, pedestrians, and other road users. Technology may encounter difficulties when confronted with novel and challenging situations that would generally necessitate the use of human judgment. Human drivers will also need to adjust CAVs may have driving patterns that differ from what human drivers anticipate. Road users who intentionally mess with CAVs are a further danger and safety point for consideration [9].

1.5.3 Police Laws

When it comes to law enforcement, there are additional concerns with CAVs. How are police officers to comprehend that a tailgating vehicle is a collection of CAVs? It is not difficult to see CAVs being utilized as drug mules. Local law enforcement officers may likewise be perplexed if a CAV is stopped during a routine traffic stop. Law enforcement and enforcement agencies, in collaboration with suppliers, are crucial in resolving these issues [10].

1.5.4 Consumer Acceptance

The public must have confidence in CAVs; if user acceptance and ability to use technology are not broad, even if technology and infrastructure are ready, developing an economically competitive market will be challenging. Any early public acceptance of CAVs may shift if there are any CAV-related severe accidents. These will be extensively publicized and will have a detrimental effect on market acceptance. We must monitor public perceptions of CAVs as technology is becoming accessible for the public. Public knowledge of the technology is required to enable large-scale deployment of CAVs, particularly for public transportation [11].

1.6 CAV Standards

Standardization may be necessary to help overcome challenges to CAV development, such as interoperability or public acceptance, while also accelerating the industry's technology, concepts, and models. The areas where it may be beneficial to set standards for critical components of autonomous and connected vehicle operating systems have already been identified [12].

Country-Specific Standards and SDOS:
Hundreds of standards relevant to CAVs are currently available, released by selected countries and standards development organizations (SDOs). The vast majority of standards identified are international (ISO, ETSI, and CEN). The second-largest category of findings is for European standards (ETSI, CEN, and ITU).

CAV Standardization Priority Areas:
The already identified high-priority areas for standardization are enumerated. When impact and feasibility criteria are applied, the top four regions are as follows:

- Vehicle to Vehicle and Vehicle to Infrastructure communications – standards facilitating deployment, technology integration, and priority communication management for these communications systems.
- Traffic and road-space management – are the standards that enable authorities at regional, national, and international levels to coordinate and integrate CAVs with traffic control systems and broader transportation networks.
- Cybersecurity – the entire CAV system - standards for managing the resiliency of the CAV across attack surfaces.
- Verification of CAV technologies – supply chain security – criteria to verify that CAV technology meets a minimal set of desired security parameters and that appropriate protections exist across the supply chain.

Standardization in three other areas is crucial for CAV public acceptance, mentioned below:

- Verification and validation of test-track and virtual designs — specifications for testing CAVs on roads, test tracks, and virtual environments.
- CAV design specifications for functional safety — standards for integrating functional safety into the design of autonomous production systems.
- Assessment and approval of CAV systems - standards controlling the safety of integrated networked CAV systems that allow the testing of CAV abilities in the context of a broader system.

1.7 Problem Statement and Thesis Objectives

Internationally, CAVs are a source of considerable attention as transportation organizations and communities attempt to comprehend the implications of widespread deployment. They benefit not only the automotive industry but also the urban environment and society as a whole. Pilot projects involving the deployment of CAVs for mass transit have demonstrated that these vehicles outfitted with autonomy and connection may significantly increase safety, efficiency, mobility, productivity, and fuel consumption.

Before adopting CAVs for dense events, it is critical to analyze the implications of their deployment on the safety, environment, and health sectors to ensure that their unavoidable deployment is as easy and beneficial as possible. Dense events, especially mega-events, bring enormous opportunities for the City-management to develop their cities. Besides, these benefits mega-events also proved challenging for city management to tradeoff between the long-term perspective of the development plan and the event needs imposed by the event federations. Other than the city management, these events are of prime importance for the transportation service providing companies to generate revenue by deploying transportation services

For the successful hosting of the mega-event and the city's reputation globally, city management must provide the transportation service that must meet the peak demand of visitors during the event. With increased interest in hosting mega-events and the associated impacts on city development, it is critical for cities to recognize the value of sustainable transportation in conjunction with the need for peak demand during the mega event and the city's long-term development plan.

In line with the preceding critical considerations, the research objectives have been determined and are described as follows:

1. Literature review and desk study of research papers and articles related to CAVs deployment
2. Study and assess mobility demand profile for a dense event-Lusail FIFA 2022
3. Route and Service planning for the proposed CAV deployment model
4. Simulation and results analysis using traffic simulation software
5. Case Study Development to analyze the benefits and reusability of deployed CAV model

1.8 Thesis Outline

The thesis study consists of six chapters. The first chapter, "Introduction," includes a brief overview of the connected and autonomous vehicles, communication technologies, Challenges in deployment, present and Future technologies, and CAV standards. The second chapter is dedicated to the existing literature review related to the topic study and background, emphasizing the existing state of deployment practices of CAVs and the management of dense events. The third chapter discussed service planning and scenario modeling. The fourth chapter includes a simulation of the planned scenarios and the results of the simulated scenarios. The fifth chapter is dedicated to Case study development based on presenting the benefits of the modeled service. The last chapter of the thesis study comprises conclusions, recommendations, and limitations. The outline is presented in Figure 1 on next page.

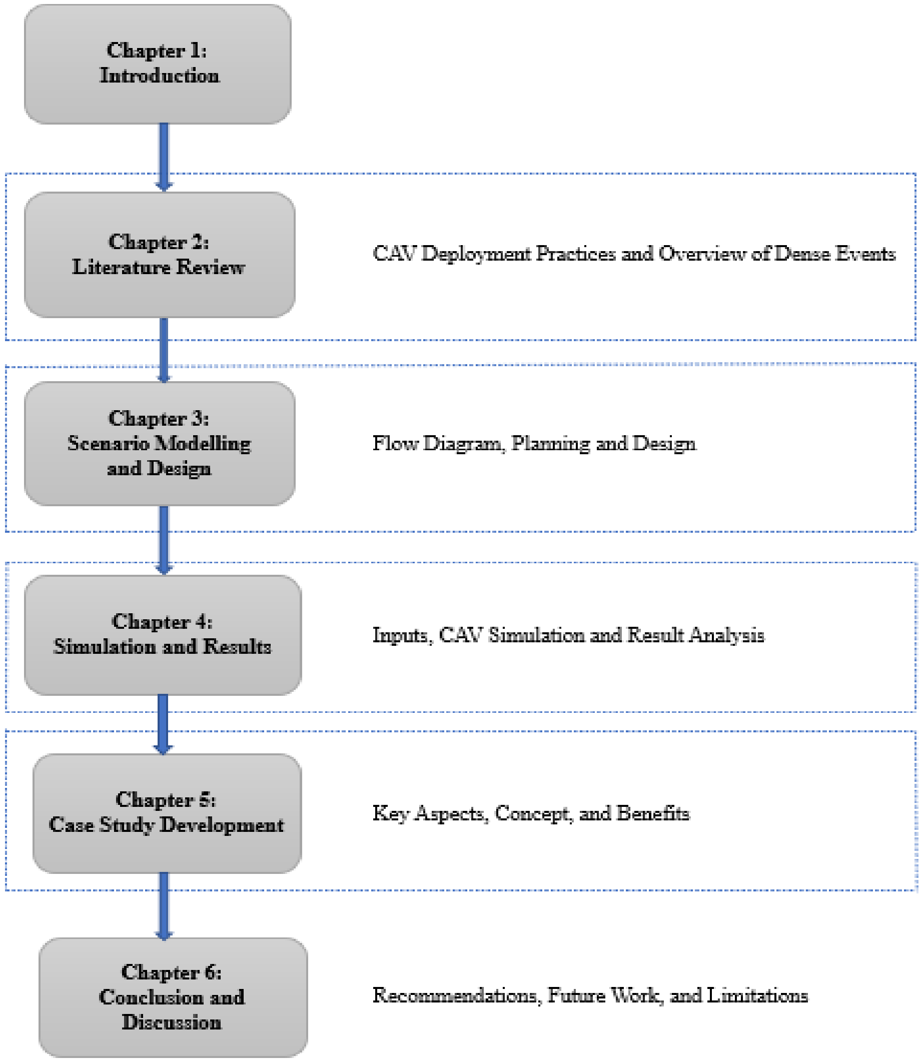

Figure 1 Thesis Outline

2 LITERATURE REVIEW

In this chapter literature review is carried out considering CAV deployment efforts around the globe. Moreover, the effect of CAVs on sustainable mobility, urban mobility, impact on public transport, and integration with the public transport network. Related research papers are read, highlighting the contributions of the efforts in CAV deployments. Interestingly most of the research papers discussed the benefits of CAVs in segregated manners; most of the research work related to AVs only. In the next half of the chapter literature review is presented concerning dense events. The role of the dense events in urban development and planning and management of dense events-related studies are studied.

With the advancement in technology, mobility shifted towards connectivity and autonomy. Various research papers have been written highlighting the benefits of transiting conventional vehicles to autonomous, including safety, reduce emissions, reduce congestion, and cost-effectiveness. Before starting the study's service planning and implementation part, it is essential to present an overview of the CAV technology deployment and dense events. The very brief history of the CAV is presented in the below section.

2.1 CAVs Evolutionary Stages

Efforts for driving vehicles with autonomy belong to the very existence of vehicles. We can categorize the evolutionary stages of CAVs into three main phases.

2.1.1 Introductory Phase

Nearly as long as the automobile business existed, the concept of self-driving automobiles existed in the thoughts of researchers. In 1958, the State of Nebraska and RCA Laboratories conducted a thorough test of an automated highway at the University of Nebraska. By utilizing guidance signal-dependent technology, detector circuits were installed in the pavement to detect the car's speed and relay it to the navigation system [13].

The first genuinely self-contained and autonomous automobiles emerged in the 1980s, with Carnegie Mellon University's Navlab and ALVprojects in 1984 and Mercedes-Benz and the Bundeswehr University Munich's Eureka Prometheus Project in 1987.

2.1.2 Subsequent Phase

This phase dates back to the US research project. The US Defense Advanced Research Projects Agency (DARPA) sponsored three "Grand Challenges" that advanced the development of self-driving technology from 2003 to 2007. The first two Grand Challenges took place in rural areas, while the third took place in urban areas. These impediments pushed university teams to make significant advancements in the field of autonomous vehicle technology. The purpose was to construct an autonomous vehicle capable of moving at high speeds through deserts and along roads; to integrate autonomous cars into the army fleet. This project expanded in scope year after year. With continuous progress to meet new problems, the participants eventually succeeded in developing a car capable of driving itself in urban circumstances on California's roadways [14].

2.1.3 Current Phase

Car manufacturers alongside private firms made tremendous advancements in CAV technologies in the current era. Tesla seized the lead in autonomous vehicles, Waymo, formerly Google's project leading the private firm's autonomy race. Other well-known automakers, such as pony.ai, Volvo, and Audi, continually develop and implement advanced self-driving vehicles. Industry 4.0 and the Internet of things are expanding, and Mobility 4.0 is a component of completely automated mobility.

2.2 CAV Deployment Practices

Since the first autonomous vehicles entered in service in the 1980s through the Navlab and ALV projects at Carnegie Mellon University in 1984 and the Eureka Prometheus project at Mercedes-Benz University and the Bundeswehr in 1987, several major corporations and tech research organizations, including Mercedes-Benz, General Motors, and other well-known names of the auto industry, have developed operationally connected and autonomous vehicles. CAV deployment programs can be categorized into three main categories: Deployment programs by research institutes, manufacturing companies, and State level programs.

2.2.1 Research Institutes Pilot Programs

The role of institutes in CAVs research and development is no denying fact. Research institute played a vital role in CAV research and development and established extensive facilities to conduct the test on CAVs. Some of the significant CAV deployment projects under the research institute are enlisted below.

2.2.1.1 Singapore-MIT Alliance for Research and Technology

SMART has been tasked with the responsibility of developing a self-driving vehicle capable of operating on public roadways. MIT and the National University of Singapore collaborated on this research (NUS).

Project Summary:

The research executed by the Singapore-MIT alliance proved pivotal in CAV deployments, in which the Singapore team built the Shared Computer Operated Transport (SCOT) automated vehicle prototype. The SCOT electric vehicle was a Mitsubishi iMiev outfitted with two commercially available LiDAR sensors and an onboard computer. The location and surroundings of the car established using a very detailed camera and lidar-based localization technology. NUS and SMART conducted an early test on the NUS campus in 2011, driving an automated golf cart across a closed course, and the study team did a six-day study at Singapore's Chinese and Japanese Gardens in the fall of 2014. Participants arranged trips between ten "stations" located across the gardens using an online booking system. Over 200 tourists were successfully transported by the automobiles during the trial's duration. Simultaneously, significant assessments were done on university roads or restricted courses [15].

2.2.1.2 Michigan State University Mcity

Mcity, previously known as the Mobility Transformation Facility, was launched at the University of Michigan in July 2015. The Mobility Transformation Center (MTC) manages the CAV testing facility, a public-private collaboration located at the University of Michigan.

The five-mile-long roadways of Mcity feature intersections, traffic lights, and signals, as well as pathways, seats, replicated buildings, streetlights, and obstructions, as well as a mechanical pedestrian. The MTC comprises various members, including automakers Ford, General Motors, and automotive suppliers, including Bosch, Delphi, and DENSO.

Project Summary:

According to reports, the use of Mcity Test Facility has grown; thousands of hours registered in the facility since 2017, with nearly 80% of those hours being spent on testing. Hundreds of instructional visits for industry, government, media, and private groups were hosted by the project management team to improve public awareness about the CAV project. Additionally, in 2018, they expanded their testing capabilities by adding a Traffic Control Center and augmented-reality testing technology [16].

2.2.1.3 NTU Singapore and Volvo Joint Venture

In collaboration with Volvo, Nanyang Technological University (NTU Singapore) launched the world's first autonomous electric bus in 2019. This project was a crucial milestone in deploying CAV buses on a large scale for public transportation. It was intended to test the buses in a controlled environment before taking them to major highways.

Project Summary:

The team deployed a 12-meter-long standard completely electric bus with an 85-passenger capacity in this experiment, incorporated with sensors and navigation controls monitored and operated by a sophisticated artificial intelligence (AI) system. Additionally, to ensure optimum security and reliability, the AI system is safeguarded by leading cybersecurity technology that guards against hostile cyber-attacks—with the initiative was first tested on the NTU campus before testing on the open highways. 'CETRAN,' a joint venture between NTU and the LTA to develop a center for autonomous vehicle research and testing, exhaustively evaluated the vehicles. Simulated numerous road network characteristics, such as traffic lights, bus boarding stations, and pedestrian crosswalks, as well as varied weather situations, such as driving through torrential rain and partially flooded highways. To gain a better understanding of how CAVs behave in real-world situations [17].

2.2.2 Automotive Manufacturer's Deployment Programs

The role of Automotive manufacturers in CAV deployment is of vital importance. Automotive firms are setting the ground for large CAV deployment by expanding their deployment programs around the globe. Some of the main contributions by Automotive firms are enlisted below.

2.2.2.1 Volvo Drive-Me

Volvo introduced the Drive Me pilot project in April 2014, which features around one hundred highly autonomous Volvo XC90 crossovers sharing fifty kilometers of public roadways in and around the city Sweden's city Gothenburg.

Project Summary:

The public roadways opened for the trial testing of automated vehicles comprised lanes separated by barriers. As of 2015, the project was undergoing customer and technological research and development. The comprehensive test, which employs regular drivers in a realistic traffic scenario. Added technology to the test vehicles that automates lane keeping, speed adaptation, and integration with traffic. These applications are enabled by technology that was already included in various Volvo production models, such as the motion sensors used in Volvo's City Safety and Pedestrian Detection driver assistance systems. The project encompassed multiple systems (radar and cameras) and a significant portion of the technology and software algorithms used in the test vehicles. In inclement weather, technical breakdown, or completion of the journey, the pilot's autonomous system will prompt drivers to reclaim control of the vehicle [15].

2.2.2.2 AstaZero Testing Landscape

In August 2014, Volvo showcased its new AstaZero proving station in Gothenburg, Sweden. Volvo collaborated with industry and academic partners at the site to conduct vehicle research and development projects focused on various traffic solutions, including automated vehicle technologies.

Project Summary:

The site provided an open multinational forum for stakeholders, automotive companies, supplier groups, legislating bodies, road agencies, universities, and technical institutes, to develop their expertise in CAV deployments. This test facility replicated the rural road conditions, metropolitan region, multiple highways, and high acceleration zones. Provided a platform for testing and studying the behavior of the CAV in a variety of circumstances [18].

2.2.2.3 Yutong’s Autonomous Bus Pilot Program

Since 2012, Yutong, a bus manufacturer, has been researching driverless buses. In Henan Province, central China, the company successfully steered a bus across an inner-city roadway.

Project Summary:

The bus was able to operate manually or automatically. In June 2018, Greyhound Australia began a six-month trial period for Yutong's T12 coach. Installed vehicles could autonomously drive open roads, arrive at bus stations on time, and parking. Additionally, Yutong has developed unattended terminals and intelligent stops. Its intelligent road technology ensures that buses are given priority at crossings, which proved a very worthwhile project for bus transit agencies [19].

2.2.3 Technology Firm’s Project

Apart from car manufacturers, other technological heavyweights have invested in research and development and are currently deploying CAVs. Some of the large-scale projects enlisted below.

2.2.3.1 Waymo by Google

Waymo, Google self-driving car project, is the company's entrance into the self-driving car competition. While Waymo's vehicles are less than half the size of Local Motors' Olli and EZ10, its objective is to integrate its technologies into current cars. They have traveled roughly over eight million kilometers, the majority of which has been on city streets.

Project Summary:

Waymo's objective to prioritize the passenger experience over the driving experience. Waymo has pioneered research in this area, concentrating on how passengers seek to interact with the vehicle and how the experience compares to driving. As a result of the research, Waymo introduced various functionalities within the vehicles; displays depict the destination, estimated arrival time, static road components, and other road users. Additionally, passengers can discover a journey-initiation button that readies them for when the vehicle begins to move; there is also a pull-over button. For passengers to push, they introduced an interior interface with Waymo. Suppose they choose to halt their travel before reaching their objective. When pressed, the vehicle automatically pulls over to a safe location—in a safety-critical occurrence, instructed passengers how to respond and remain safe via screens and voice [20].

Additionally, Waymo determined through research that passengers must comprehend what the vehicle is doing and why it is doing it and how it reacts to certain situations. Thus, the vehicle's screens display what the vehicle perceives and contextualize its actions. Waymo provided insight into car behavior [21].

2.2.3.2 Samsung's Self-Driving Vehicle Projects

Harman, a renowned producer of in-car technology and connected vehicle systems, was acquired by the firm in March 2017. Samsung hoped to redefine the in-car experience through the acquisition.

Project Summary:

As a result of this collaboration, Digital Cockpit 2020 was born. Eight cameras and eight monitors integrated into the infotainment system. It established a 5G connection between automobiles and homes and offices, offering a more personalized driving experience. The cockpit has the facility controlled in various methods, from gesture control to button pressing to face recognition. Samsung gained authorization in May 2017 to conduct public road testing of self-driving cars in South Korea, the internet giant's self-driving cars based on Hyundai automobiles fitted with cameras and sensors [22].

2.2.4 State Level Deployment Programs

One of the most crucial roles in CAV deployment is the state-level CAV deployment initiatives; some of the leading state-level programs in CAV deployment are enlisted here.

2.2.4.1 USDOT Deployment Programs

The United States leads the world in the research and deployment of CAVs. The United States launched experimental programs in two waves, designated the first and second deployment waves.

The USDOT has expanded its Connected Vehicle Pilot program on a national basis following its initial deployments. Additionally, several new autonomous vehicle experiments at various phases of development are presently underway. Most of these efforts were relatively narrow in scope, limited to institution territories, airports, and different restricted areas. In 2014, in response to the Safety Pilot's success and the NHTSA's commitment to extend CAVs for new light-duty vehicles, the USDOT committed to future pilot deployments to ease the initial deployment of connected vehicles in real-world situations. In 2015, the USDOT sponsored seminars and webinars, and the department released a request for proposals for the first phase of pilot programs.

In early 2017, solicited the second round of submissions, awards made later that year, and scheduled all the improvements to be completed by September 2020. New York City planned ten thousand city-owned vehicles (including automobiles and buses) and roadside infrastructure equipped with onboard devices, with additional units planned for Midtown Manhattan and Brooklyn.

California's lengthy history as a leader in CAV testing is well-documented. Historically, California's CAV effort concentrated on the state's transportation department, Caltrans, and its collaborations with prominent universities. Virginia has a long history of being a leader in CAVs testing and deployment. The city has various facilities, including the Virginia Smart Road, a two-miles stretched closed-loop and the Connected Test Bed. VTTI and the University of Virginia hosted vital research projects for CAV deployment, including equipment development and data administration for the Ann Arbor Safety Pilot program. Moreover, recently Virginia established the Virginia Automated Corridor to enable the study of autonomous vehicles (VAC) [15].

2.2.4.2 CAV Deployment Programs in Europe

CAV deployment efforts are being carried out from the very beginning of the technology in Europe on a vast scale. A notable CAV project is the joint venture of the Netherlands, Germany, and Austria. They signed an MOU in June 2013 to incorporate a corridor linking Rotterdam and Vienna via Frankfurt-Main with the latest CAV technologies.

The project included developing appropriate roadside infrastructure to facilitate cooperative services for automobiles driving along the route. The deployed devices utilized DSRC (802.11p, 5.9 GHz) and cellular networks (3G/4G). It was the first route of its kind, incorporated with a cooperative intelligent transportation system (ITS) deployed across nations developed in partnership with each country's appropriate ministries, highway operators, and automakers. This initiative created the framework for the deployment of unmanned aerial vehicles (UAVs) in several countries [23].

Málaga Bus Project, tests full-size autonomous buses regularly. Spain's Center for Industrial Technological Development (CDTI), an organization dedicated to developing technology for vehicle automation in urban and industrial transportation applications, financed the research.

The 60-seater bus, outfitted with sensors and cameras, assists it in making decisions while traveling along an eight-kilometer stretch of the city's fixed route. Additionally, sensors connected the vehicle with city traffic lights to operate smoothly. Six times daily, the bus makes this journey, with a driver at the wheel to seize control in the event of an emergency, as Spanish law currently prevented vehicles from running without a driver [24].

2.2.4.3 North District One (Singapore Autonomous Vehicles Initiative)

In 2014, the Singapore Land Transport Authority (LTA) and one of the country's organizations (A* STAR) had collaborated on the CAV deployment project named Singapore Autonomous Vehicle Initiative (SAVI), a deployment program to manage research and development on CAV technologies.

As a result of this project, Singapore's "One-North" sector now boasts an autonomous vehicle testbed, a nearly five-hundred-acre development zone dedicated to tech research, engineering, and business firms. The LTA worked with JTC cooperation, which is the district's master planner and developer firm. They created a roughly four-mile network of test routes that will connect the district's numerous neighborhoods. The LTA also invited proposals from groups interested in autonomous vehicle testing and deployment [15].

2.3 Sustainable Mobility Development

In one of the reports, sustainable mobility is "transport that enables individuals, businesses, and societies to meet their basic access and development needs safely. Additionally, in a way that is compatible with human and ecological health and that promotes fairness within and between subsequent generations by being inexpensive, functioning fairly and efficiently, and providing a variety of modes of mobility [25]." According to research, approximately eighty percent of the EU's population lives in urban regions. The transportation of products and people within urban areas accounts for more than a third of all transportation kilometers in Europe [25]. In many cities globally, road-based transportation systems have a slew of environmental, social, and economic repercussions. Traffic congestion, vehicle pollutions, and the consequences of traffic accidents are only a few of these consequences [26]. The main distinguishing characteristics of an urban environment are its dense population, settlements, and consumption of products and services. Transportation infrastructure and the possibility for its amplification are minimal and unsustainable in such environments. Significant flaws in urban freight transportation arise due to the mismatch between demand and the confines of urban areas (For instance, congestion, pollution, safety, noise, and carbon creation). Forty percent of air pollution and noise emissions occur exclusively due to goods transport in urban areas. These challenges have economic and social ramifications; they reduce the efficiency and efficacy of UFT and logistical operations and have a detrimental influence on citizens' living standards through severe health repercussions [27].

2.4 Urban Mobility Overview

According to the literature, the planning and development of livable smart cities are highly concerned because more than fifty percent of the world's population lives in urban areas, which are overcrowded. If we consider only European, living standards are frightening. At the moment, approximately eighty percent of the European population lives and works in cities and towns. According to one of the predictions, by 2050, over eight percent of the region's population will be concentrated in metropolitan areas [28]. According to one of the reports cities today should have a reliable and widespread public transportation system connecting the outskirts and the central business district with a top standards modality. Some proactive steps to improve transport must be considered, such as better management by applying traffic control systems, traffic administration centers, and incorporating intelligent information systems for drivers. Transportation has the most significant impact when it is coherent, allowing for seamless transitions across modes, enables them to select the ideal combination for each leg. This integrated and improved transportation system offers numerous benefits, including eliminating the need for roads and parking, reducing congestion, air pollution, greenhouse gas emissions; support for capital optimization in the transportation sector; and an increase in the region's living standards. There are numerous strategies to achieve an optimal level of urban growth; for example, creating a mix of land uses in which employment opportunities and housing units located close to one another could significantly minimize the need for travel. Additionally, flexible work schedules combined with public transportation incentives can help eliminate unnecessary travel during rush hours and enhance mobility during non-rush hours, leading to more efficient and affordable transportation services [29].

2.5 Social and Environmental Challenges

As our reliance on automobiles grows, coupled with an aging population and the demand for unique and flexible lifestyles, cities face new problems in developing innovative mobility solutions that enable people's rapid and flexible movement. Furthermore, the latest technologies create enormous expectations for innovative mobility capabilities (for example, real-time traffic information for travelers and network management, drivers, and fleet operators). Additionally, such technological advancements enable the assimilation of data for travel planning and computerized ticketing and smart cards to facilitate interoperability among various modes of public transport. Global warming, scarcity of energy sources, and rising energy prices dominate European, national, and local policy agendas, highlight the urgent need for green solutions to mitigate the environmental impact of urban transportation. City traffic accounts for forty percent of CO2 emissions and seventy percent of other road transport emissions in Europe, necessitating developing a strategy for sustainably reducing the emissions by transport services [28]. Congestion and pollution at the municipal level, according to specialists, contribute to disability, premature death, aggravation of respiratory illnesses, and sleep disturbances. Simultaneously, these impacts asserted to be contributors to the climate change impacts associated with global warming. All of these harmful attitudes are a result of urban transport services. As urban population growth has increased in recent years, it has compounded its effects, resulting in the highest demand for freight flows ever required to maintain large urban populations [26].

2.6 Implementation of CAVs in Public Transportation

According to published research [30], the transit industry is growing increasingly interested in the uses and benefits of autonomous transit vehicles. There is considerable interest in automating bus travel on a partial to complete basis, with various demonstrations and test locations planned or already operational. According to expectations, automation will provide a range of benefits, including increased safety, efficiency, and cost savings. Additionally, automation may enable the development of new modes of transit that enhance mobility, flexibility, and convenience. Transit agencies' claimed interest in automation applications varies according to their service patterns and local context; for example, agencies with limited available space indicate a greater interest in automated distant parking. While cost and capability estimates are currently in refinement estate, the initial analysis indicated that specific partial automation applications offer a compelling commercial case for transit agency investment. Through operational savings in the future, the technology investment expenses for these applications would be quickly recouped.

Additionally, the research revealed a relatively modest pace of investment in the development and deployment of automated transportation applications. Implementation in revenue service has been somewhat restricted. Transit agencies are notoriously risk-averse and typically lack the internal resources necessary to explore emerging technology or test innovative service models. Through stakeholder consultation and literature review, identified several key issues and uncertainties surrounding automation. These include the following: – Product availability in the transit market is less advanced than in the light-duty and commercial truck sectors, in part due to the market's small size. In comparison to other CAV-leading countries, transit automation in Europe and Asia is relatively low.

According to research findings, whereas user acceptance of automated systems is well established in specific rail environments, it is relatively unknown in bus transport. Additionally, a fully driverless operation necessitated customer service, fare collection, and other non-driving responsibilities that require additional research [30].

2.6.1 Potential Impact of CAVs on Public Transport

With advancements in driverless technology, CAVs can dramatically reduce crew costs, hence revolutionizing the existing means of transportation. According to the literature, system costs include about 80% of service running expenses in the transport system. Around 50% includes crew costs, 25% bus capital expenses, and 25% additional costs (fuel, repair, maintenance, insurance, and taxes). The authorities identified that in peak-hour service, the primary cost is the driver cost by conducting different surveys. According to conducted cost analysis of the urban bus transit industry in the United States, by utilizing data from transit bus agencies. According to the findings, Labor costs account for over fifty percent of total expenditures [31].

Similar findings from other parts of the world indicate that operational costs are the most significant cost component of public transportation bus operations. Numerous studies have been conducted to determine the economic costs associated with autonomous technology's impact on public transit. According to the literature, integrating several types of autonomous buses (semi- or completely autonomous) on a single fixed line can address these expenses. Bus size can be leverage as a choice variable to minimize the system's general costs; waiting for costs, riding costs, operating costs, and capital costs. The authors conclude that fully autonomous buses can bring significant benefits to all transportation system stakeholders.

They examined the implications of autonomous buses on public transportation networks by using single-line case studies in Germany, utilizing an analytical methodology based on Jansson's square root approach. The researcher determined that automation benefits operators and end-users in a variety of ways [32]. According to a study about the possible benefits of autonomous buses, fixed-line automation benefits transportation agencies and operators more than flexible automation benefits urban passengers.

2.6.2 Impacts on Environment and Fuel Consumption

According to studies, increased driving efficiency can be achieved in CAVs by various processes, including optimized driving behavior, enhancing dynamic eco-routing, reducing the idle times, reducing the cold start, smoothing the route, and harmonizing the speed. In identical scenarios, human drivers make varying real-time decisions, frequently resulting in unsatisfactory outcomes. In CAVs, removing driver variability and optimizing driving decision-making contributes to optimizing the driving cycle. The study's results showed that providing continuous feedback to drivers leads to up to twenty percent fuel savings and reducing emissions without significantly increasing trip time. Additionally, vehicle connectivity provides the most efficient route selection. Trip refinement and speed harmonization are additional tactics that aim to minimize repetitive braking-acceleration cycles by adaptive speed adaptation, smooth beginnings, fewer speed changes, and the removal of stops. CAVs facilitate and magnify these practices greatly; when cars are automated to precisely match prescribed speed profiles, they can save up to 50percent more gasoline than when driven manually. At the fleet level, coordinated communications between vehicles can help reduce energy consumption even further, with experiments reporting fuel savings and carbon reductions. According to the literature, fuel consumption can be reduced when a CAV follows a lead vehicle with the specific objective of minimizing accelerations and decelerations. By incorporating a single CAV into traffic, stop-and-go patterns are reduced, resulting in up to a forty-percent reduction in total traffic fuel use.

According to a study, utilizing CAVs technology can significantly boost efficiency. With an energy-efficient CAV architecture, significant fuel savings and emissions reductions are conceivable. Fuel savings at the vehicle level range between five to twenty-five percent and occasionally up to 40percent. Environmental benefits associated with CAVs originate from fleet optimization, for instance, improved traffic behavior, more utilization efficiency, and availability of shared mobility services at the transportation system level.

2.6.3 Public Perception about CAVs

According to the literature, connected and autonomous bus transportation can lower rates due to eliminating driver costs, included a question concerning the appeal of such a benefit in the survey. The overwhelming majority of respondents (44 percent rated themselves as "extremely attractive," 26% as "moderately attractive," and 4% as "somewhat attractive") replied positively. The most appealing benefit of autonomous buses would be lower bus prices due to eliminating driver costs. At the same time, passenger security would be a primary concern, particularly during nighttime trips. In the study about people perception, around two-thirds of respondents preferred CAV bus service, if they must choose with while driver on board, whereas about a third preferred non-CAVs. Sixty percent of autonomous bus customers indicated that they would use autonomous buses with onboard employees, while forty percent indicated that they would use autonomous buses without onboard crew. In practice, autonomous buses are likely to offer lower fares than human-driven buses due to the absence of driver costs, but in that study, users were presented with the same fare rate. However, the extent of decrement rate is dependent on whether to utilize the onboard staff or not; as per regulations, currently, human presence is mandatory in the vehicles [33].

2.7 Dense Events

Dense events play a vital role in the economic building of metropolitan cities; these are of high importance for policymaking discussions of the cities. These events play a critical role in the development of the economy of the host nations [34]. The new urban issue is concerned with the concept and practice of enterprise planning. According to the Harvard University, cities experience similar business issues. Globalization of the economy and communication systems results in territorial competition [35]. Despite its decentralized nature, this new economy demands centralization with infrastructure for economic and political control, which has driven competition among cities globally to win the economic race. Cities that lack the resources necessary to compete with industrialized cities and their administration have a tremendous potential to benefit economically by developing their cities as a global commercial domain. Organizing dense events in the city is one of the best opportunities. Barcelona serves as a good model for other cities. Barcelona hosted the Olympic Games in 1992. This incident altered the city's history in terms of tourism and economic development. The city's organizational style is widely regarded as one of the best examples of leveraging a significant event for city development and urban marketing the city's image to the world. This festival brings thousands of tourists to Barcelona each year, which would not have happened otherwise. The staging of a significant event can aid in attracting investment and stimulating growth in a large metropolis. However, there are some flaws there that result in long-term challenges for society following the incident. It is very dependent on how municipal management uses public monies to host the event and how these monies may prove helpful in the long term. Poor management may result in public outrage as a result of the long-term consequences. Another potential cause of friction is the relationship between the two primary actors responsible for organizing a dense event, such as a mega event, who have entirely different needs: the international event organizers and the local government [36]. They will outline the urban transformation process required to ensure the success of the event and the benefit of citizens. This partnership is often controversial because whereas the event proprietor focuses mainly on short-term demands, local governments must also meet individuals who want these benefits' long-term aspirations. Transportation and urban mobility concerns are inextricably linked, and necessary expenditures in this sector must meet public demand and expectations for target events [37].

2.7.1 Planning and Management of Transportation for the Dense Events

Hosting a dense event, (considering a Mega event), can assist begin the process of urban change, but it comes with a slew of obligations. Inappropriate investments might have unforeseen repercussions. Underutilized infrastructures engender contempt for the state at the expense of the populace. Transportation is crucial in this setting; the structure for accepting passengers by various means of travel, using air service, land transport, and urban services is of prime importance for the successful hosting of the events. It requires a detailed plan of the transport system, which operates as a displacement dissipator or inducer [38].

Nevertheless, transportation planning is dominated by decision-makers interests; these players share two critical characteristics: they have a vision for the city and the ability to accomplish it. Two actors exhibit the characteristics mentioned above: event organizers and state leaders. Their interests occasionally diverge, with one concerned with the event's success and the other with the city's legacy. It is critical to involve all stakeholders in strategic planning in order to minimize divergence [39].

According to the literature, transportation planning is complex. It encompasses various technical, social, and environmental issues that are usually inconsistent and susceptible to interpretation, diverting political plans away from the genuine transportation demands. According to the writers, the approach is to build a Strategic Plan qualitatively and then monitor and track it for years.
The study emphasizes the elements that affect mobility service planning for mega-events; these elements should be considered throughout the strategic planning process to achieve a beneficial outcome, as follows:

- The spatial and territorial planning
- The Government's Policy
- Economic vitality
- Utilization of technology
- Social and behavioral trends.
- Stages of transportation planning

Three steps can be used to evaluate the transportation service planning for the dense event, as follows:
-Assessment of service planning before the start of the event: It entails classifying the event's nature, fully characterizing the event's dimensions, defining the research area, identifying stakeholders and their duties, and conducting demand research.
-Assessment of service planning during the event: This requires transportation system operations, including the transportation service, the training system, traffic control signage, and event access.
-Affect evaluation post-event: After the event, the level of interaction between the different actors and the mega-ramifications events must be evaluated [39].
According to the objectives of IOCs, the planned service must ensure safety, dependability, a social gathering that is pleasing and inviting that must ensure. The service must ensure any essential movement during the event. Service should be adaptable, minimizing the risk of interruptions, environment-friendly, and contribute to the host city and region's mobility legacy.

Additionally, the IOC establishes a scale of service priorities for the event participants, organizers, and visitors [39], as follows:

- Transportation of Athletes via special bus
- Officials in the media and the press, as well as individual employees, must be provided the service at stops
- First-class sponsors, as well as individual accredited vehicles
- Personnel and volunteers, as well as public transportation
- Transportation for the General public

2.7.2 Accessibility

Adequate access is another critical component; the IOC requires that the games have secure and reliable access pathways. Additionally, it is recommended that a boundary be established around the game's site to demarcate the city's territory area from the central event place.

In the city's where events are hosted, equipment distribution requires a high-performance mode of transit to ensure efficient displacement, as a concentrated location might cause congestion and conflicts with people. The IOC's criteria on time travel, on the other hand, promote the cluster format or a more specialized organization. A proven solution is a new and efficient control, command, and communication system capable of rapidly responding to potential traffic fluctuations.

The major challenge in planning is predicting additional capacity to match the peak demands. That results in the underutilization of the proposed capacity throughout the year, rendering it uneconomic. Thus, the critical nature of long-term planning integrates transportation, urban development, and social behavior in the city. Metro lines, transport routes, and airport development are all being planned. Consider the population's demands and the city's development and structures that can be decommissioned following the games.

2.7.3 Post Event Analysis

Cities achieved a variety of outcomes; the success of this measure served as a guide for the recommendations of the International Olympic Committee (IOC).
Some of the primary positive outcomes are enlisted below:

- New public transportation initiatives are being developed in conjunction with a long-term vision
- These provide the guidelines for implementing new technology and establishing management centers equipped with advanced knowledge about new routes and lines, automated passenger transportation, and surveillance cameras
- Fleet and urban center enhancements and beautification
- Establishment of Olympic parks and Clusters
- These events are adherent to a long-term urban vision project, as well as a factor affecting mobility
- The events provided opportunities for Transport planning and operational coordination

3 SCENARIO MODELLING AND DESIGN

This chapter includes scenario modeling and design, with detailed objectives and methodology of the scenario modeling approach. The modeled scenarios are based on the peak demand for the planned CAV service to manage the transportation during the dense event. To model, the detailed service assessment of mobility demand is carried out, which is presented in the chapter. Before modeling the scenarios, there is a need to define obvious objectives; the first section below highlights the objectives of planned scenarios.

3.1 Objectives of Scenario Modelling

The following objectives are defined for the scenario modeling:

- To analyze the behavior of system while accommodating maximum demand load during peak hours
- Safety analysis of the system, and to identify optimum number of vehicles can be installed in the system
- To analyze the cost effectiveness of the system
- Optimum fleet size calculation to meet the demand

3.2 Flow Diagram

The methodology approach is represented in the Figure 2 below, from scenario modeling to the analysis of modeled scenarios. The significant steps involved in the modeling of scenarios and critical components of the modeled scenarios are highlighted. The flow diagram also depicts the calculated fleet size of each scenario. Figure 2 is on the next page.

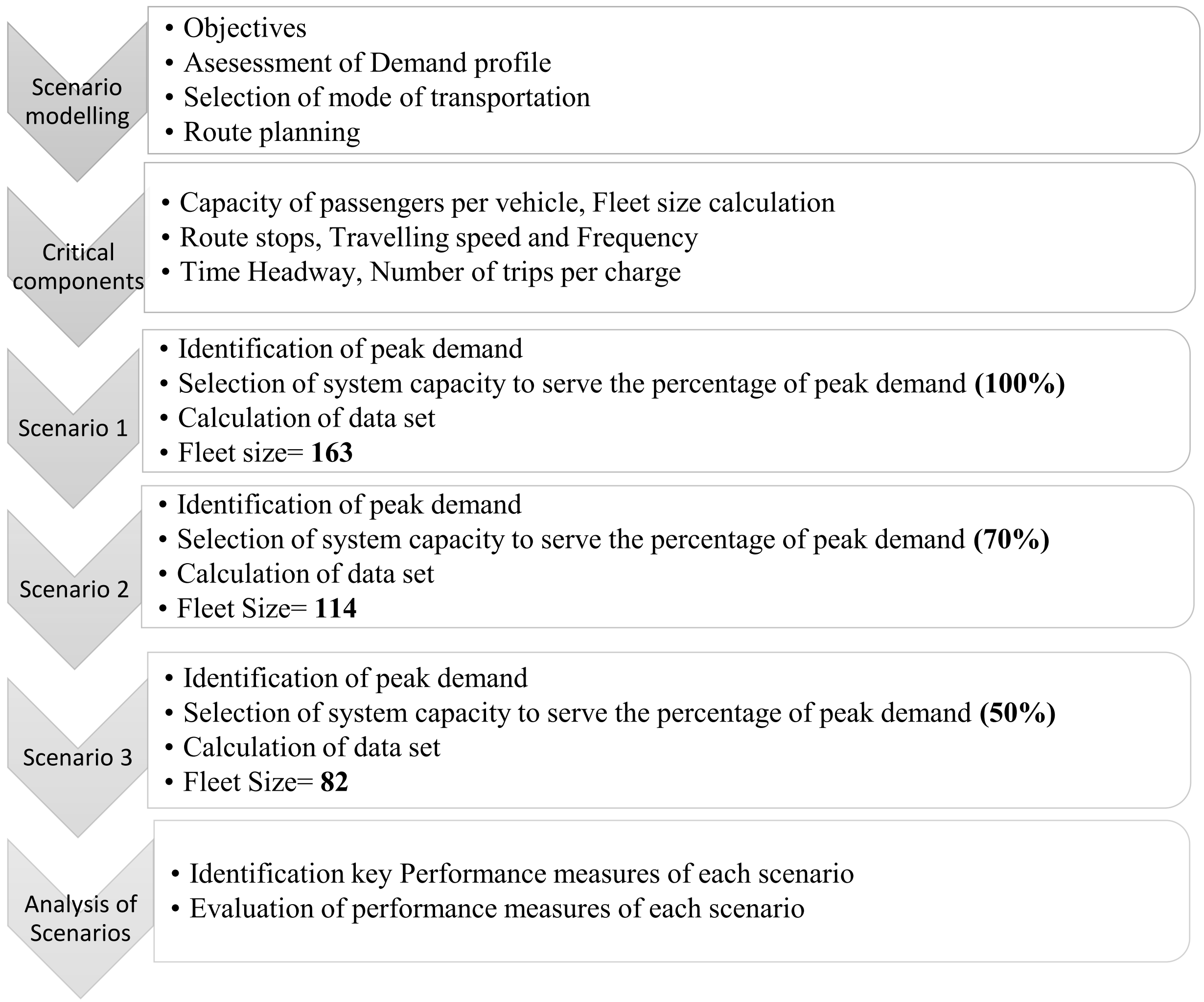

Figure 2 Scenario Modeling Flow Diagram

3.3 Mobility Demand Assessment

In the below Table 3 are enlisted eighteen city districts; The represented land area is in km^2. The city's total area is 38 km^2; however, the occupied area is 19 km^2, and the rest is an open green area. Moreover, population capacity and expected residential population capacity is mentioned. Marina is the most populated district of all districts, and then there is the district stadium, which the audience would populate. Fox Hills is the third most populated district in the city. The city's total capacity is 450 000, and the figure counts to about five hundred thousand as including stadium capacity. There are about 200,000 people expected to live in the city. The expected count for the spectators is Eighty thousand. Population capacity and the expected residential population are also highlighted below in Figure 3 [40]. The given data shows that the highest demand load is on the stadium district, while people are going to and coming back from the stadium to watch the games.

Table 3 Population Distribution of Lusail City

NO.	DISTRICTS	AREA (km^2)	POPULATION CAPACITY	EXPECTED RESIDENTIAL POPULATION
1	Golf district	3.66	29,000	22,000
2	Waterfronts West and Northern Residential	1.78	7,100	5,400
3	Al Kharayej Towers	0.29	11,000	10,500
4	Stadium district	1	80000	N/A
5	Waterfront Residential	0.53	19,000	17,000
6	Energy City 1	0.72	25,000	Nil
7	Waterfront Commercial	0.54	29,700	9,600
8	Fox Hills (Jabal Thuaileb)	1.68	50,000	38,600
9	Al Erkyah	0.26	12,000	10,600
10	Energy City 2	0.46	20,700	18,000
11	Entertainment City	0.98	32,400	8,400
12	Entertainment Island	0.23	4,200	N/A
13	Medical and Education	1.64	N/A	N/A
14	Qatar Petroleum District	0.45	N/A	N/A
15	Marina	1.88	103,900	31,000
16	Qetaifan Islands	2.56	37,500	22,000
17	Boulevard Commercial	0.52	20,900	5,500
18	Lusail Towers	0.16	19,300	Nil
Total			**507,950**	**198,600**

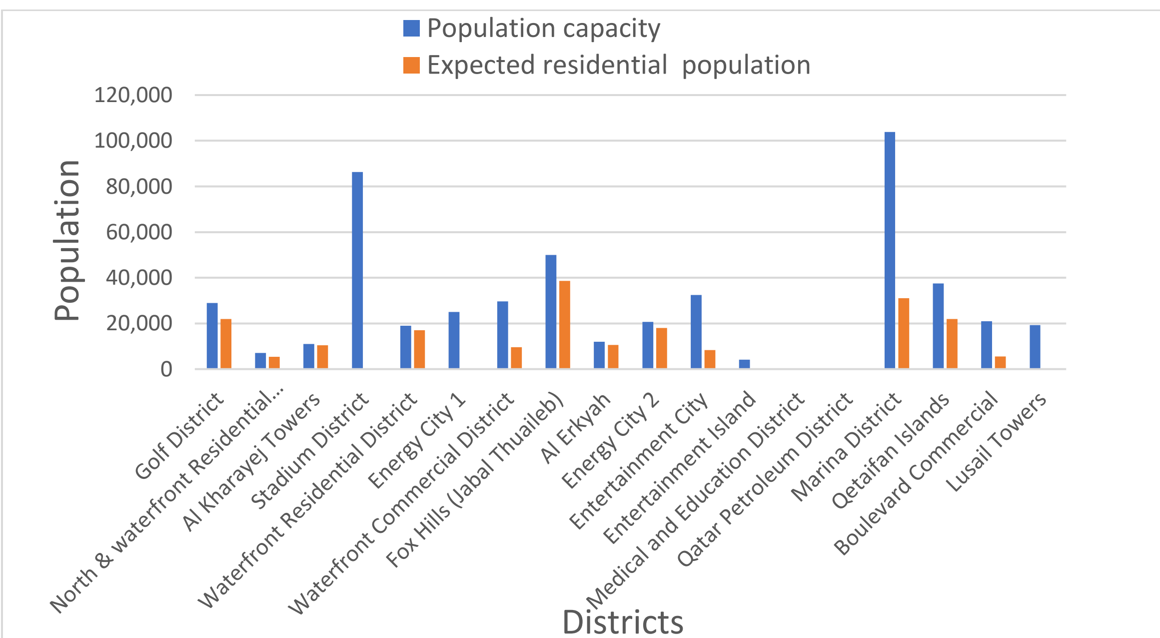

Figure 3 Population Distribution of Lusail City

3.4 Route Planning and Design

The planned route facilitates the maximum number of people traveling from different locations to the stadium. The selected route passes through the center of the city and can provide service to all the users living in the city. Bing map tool of PTV VISSIM software is used to model the route, which is represented below. The route comprises of two lines, **Red Line** and the **Green Line**, and each line has a **12 km** route length.

Red Line:

The Red Line starts from the stadium district and stretches to the Marina district by connecting all the districts on the south of the stadium district. The total route length of the red line is 12 km. It includes 20 stations, ten stations per direction. Figure 4 represents the Red Line.

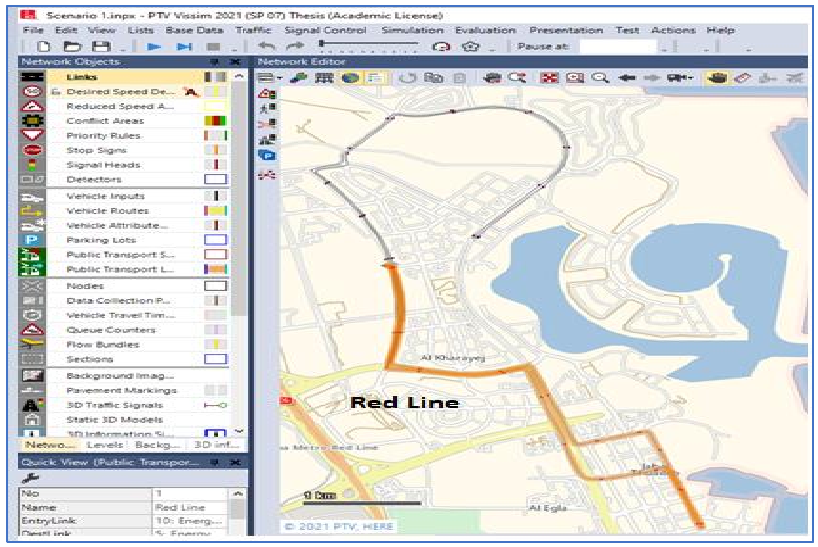

Figure 4 Planned Route Line

Green Line:

The Green Line starts from the stadium district and stretches to the Fox Hills district by connecting the districts on the north of the stadium district. The total route length of the Green Line is equal to the Red Line, which is 12 km. It also includes 20 stations, ten stations per direction. Figure 5 represents the Green Line.

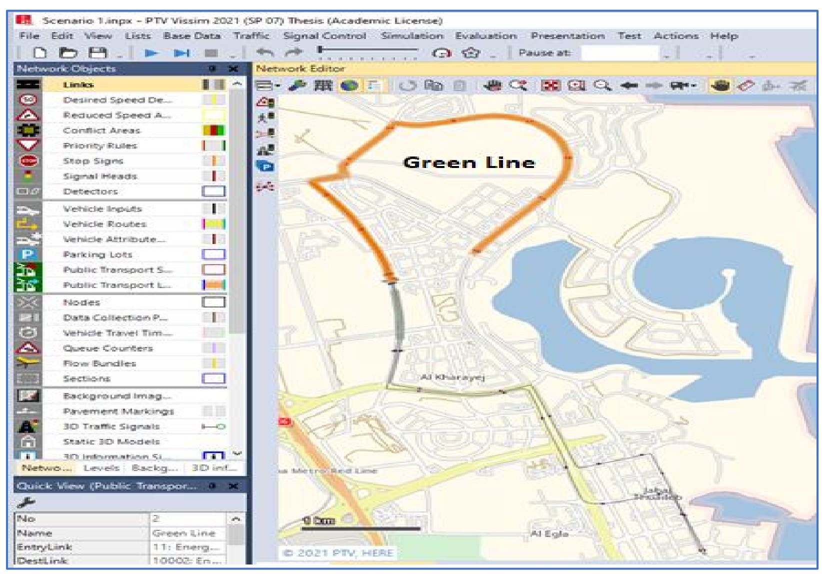

Figure 5 Planned Route Line

3.4.1 Route Description

Table 4 depicts the description of the modeled route in PTV VISSIM. The route links are the essential elements to plot the complete road network; these links are connected by using connecters that provide smooth curves to the route. The width of the link is 3.5 m wide as per norms. There are eighteen links used to complete the planned network comprised of two lanes depicted below.

Table 4 Designed Route Description

LINKS (RED LINE)	CONNECTING DISTRICTS
1	Marina
2	Marina
3	Entertainment City
4	Energy City-2
5	Energy City, Commercial Boulevard, Stadium District
6	Golf District
7	North Residential Villa
8	North Residential, Waterfront Residential, Seef Lusail, Lusail Tower Fox Hills North & South
9	Marina District
10	Marina District
LINKS (GREEN LINE)	
11	Energy City, Commercial Boulevard, Stadium District
12	Golf District
13	North Residential Villa
14	North Residential, Waterfront Residential, Seef Lusail, Lusail Tower, Fox Hills
15	North Residential, Waterfront Residential, Seef Lusail, Lusail Tower, Fox Hills
16	North Residential Villa
17	Golf District
18	Energy City, Commercial Boulevard, Stadium District

3.4.2 Dedicated Lanes

As the goal of planned service is to provide fast service to the user without any unnecessary delays. A dedicated route is assigned to the system to avoid unnecessary stops, as stops are selected to facilitate maximum users. Dedicated lanes also help avoid time lapses in the system by avoiding conventional vehicle interference in the CAV network. It helps to ensure the system's safety by avoiding the risk of collisions.

3.5 Mode of Transportation

The selected mode of transportation service is connected and autonomous buses, which will operate on the network model like Bus rapid transit. According to size, the available options of buses are enlisted below, categorized into three groups. Typically, 12-meter buses or articulated 18-meter buses are employed. Bi-articulated buses are prohibitively expensive, typically double the price of an articulated bus, and their principal application is in corridors with high demand and little road space.

The chosen size is 12 meters in length and is an autonomous bus. The fleet size reduces by using articulated buses. This also results in fewer fleet requirements. But the system will operate with reduced frequency, and users will have to wait longer. Similarly, by reducing the size of the vehicle, a more extensive fleet is required. However, because frequency improves and passengers do not have to wait as long, there is a need to trade-off available possibilities. Some standard bus sizes are represented in Table 5 [41].

Table 5 Standard Bus Sizes

BUS TYPE	BUS LENGTH (METERS)	BUS CAPACITY (OCCUPANCY)
Standard Bus	12	90
Articulated Bus	18	150
Bi-Articulated Bus	25	220

3.6 Critical Components of Scenario Building

It is pivotal to identify and present the components of the scenarios that play a crucial role in the scenarios' successful modeling. The critical components of scenario building are enlisted below with their importance, and formulas are provided to calculate the values.

3.6.1 Passengers Capacity per Vehicle

Appropriate vehicle sizing entails weighing the operational cost savings associated with larger vehicles against the social cost associated with passenger added waiting time. There are scalability benefits associated with larger vehicles; the cost per customer served typically decreases with size. On the other side, larger vehicles imply a lower frequency, and a lower frequency translates into more waiting time at stops.

The capacity of each vehicle can be expressed in terms of its size. The capacity of each vehicle can also be determined using the relation [41].

$$Vsize = MaxLoad \div Freq * LoadFactor$$

Where:

- V-size: Vehicle capacity
- Max load: Peak load
- Freq: Frequency
- Load factor: taken as 0.85

3.6.2 Route Stop Planning

The Standards provide two points for a system with an average stopping distance between stations of between 0.3 and 0.8 kilometers (or 0.2 and 0.5 miles), with 450 being a typical appropriate stopping distance between stations. If a rapid service is required and there are numerous stations, a stopping distance of 600 meters can be selected.

3.6.3 Travelling Speed

Due to the reduced wait at stations, high speeds can be obtained. According to accepted norms, average speeds should be greater than 20 kilometers per hour in places with frequent intersections, 25 kilometers per hour in regions with minimal mixed traffic, and greater than 40 kilometers per hour for limited-stop services.

3.6.4 Frequency

The service frequency refers to the number of vehicles per hour, which is generally high during peak hours, and it can be calculated by using formula given below [41].

$$Freq = MaxLoad \div Vsize * LoadFactor$$

3.6.5 Headway

The term "time headway" refers to the amount of time between two vehicles operating on the same route. It is crucial for the vehicle's safety during high demand and to reduce excessive passenger wait times at stops. It can be estimated by using the relation.

$$hdwy = 1 \div Freq$$

3.6.6 Number of Trips per Vehicle

The number of trips made per vehicle during peak demand hours is a crucial component. It is critical to understand this because cars must be accessible at all times during the operation to convey all people during peak hours.

3.7 Modelled Scenarios

Three scenarios are modeled to assess the system's ability to satisfy demand during peak hours and assess the system's performance measures. The scenarios are planned based on peak demand percentage. The chosen values are 100% for the first scenario, 70% for the second scenario, and 50% for the third scenario. Scenarios are modeled on these three percentage values to meet the maximum possible demand while observing the system's limitations.

Table 6 summarizes the data set calculated for each scenario. Table highlights the percentage peak demand, the number of passengers, vehicle capacity, fleet size, service frequency, Time headways, and the load factor applied for each scenario. Table also depicts the key performance indicators of each scenario. The further detail of the modeled scenarios is described in the following sections.

Table 6 Key Parameters and Key Performance Indicators of Modeled Scenarios

KEY PARAMETERS	**SCENARIO 1**	**SCENARIO 2**	**SCENARIO 3**
Percentage peak demand transported by CAV (%)	100	70	50
Number of passengers	40000	28000	20000
Vehicle capacity	85	85	85
Fleet size	163	114	82
Number of Stops	20	20	20
Traveling speed (kph)	25	25	25
Frequency per hours	148	104	74
Time headway (s)	29	35	49
Number of trips per vehicle	4	4	4
Load factor	0.85	0.85	0.85
KEY PERFORMANCE INDICATORS			
Vehicle kilometer traveled (km)	1780.57	1250.76	890.14
System capacity (passengers)	40000	28000	20000
Station saturation (Network queues)	0	0	0
System average speed (kph)	20.75	20.82	20.75
Emissions	0	0	0
Vehicles travel time (s)	308904.20	216252.22	154473.20
Vehicle delays (s)	25389.15	16975.57	12398.00
Error probability	0	0	0

3.7.1 Scenario 1

First scenario based on the following considerations.

i. Maximum load on the route is at the stadium district, a large number of people will be there at peak hours before and after the matches, it is assumed that the out of maximum capacity 80000, as this city is very close to other cities which are also hosting the event besides, residents of the country will also travel from other cities to attend the event, so considering half of the spectators from other cities who will use intercity transport
ii. Taking 100% of the peak demand, our CAV service must accommodate 40000 passengers during peak demand
iii. The time required to accommodate the peak demand is two and a half hours

DATA SET:

Based on above considerations the scenario is planned and critical components calculated by using formulas. Calculated data set is shown in Table 7. Selected values based on accommodation of demand in two and half hour. Optimum vehicle speed and number of stops are assigned.

Table 7 Data Set Scenario 1

KEY PARAMETER	CALCULATED VALUES (Per hour)	SELECTED VALUES (Peak demand)
Percentage peak demand transported by CAV (%)	100	100
Number of passengers	40000	40000
Vehicle capacity	85	85
Fleet size	406	163
Stops	20	20
Traveling speed (kph)	25	25
Frequency	370	148
Time headway (s)	9.8	29
Number of trips per vehicle	4	4
Load factor	0.85	0.85

3.7.2 Scenario 2

Below enlisted are the considerations for the second scenario.

i. Considering that 30% of the users during peak demand traveling by their cars and our service must accommodate 70 % of the peak demand
ii. Taking 70% of the peak demand. Our CAV service must accommodate 28000 passengers during peak demand
iii. Time required to accommodate the peak demand capacity is two and a half hours

DATA SET

Based on the above considerations, the scenario is planned, and critical components calculated by using formulas. The route selected, the number of stops, and the vehicle's speed maintained the same as in the first scenario. The data set is depicted in Table 8.

Table 8 Data Set Scenario 2

KEY PARAMETER	CALCULATED VALUES (Per hour)	SELECTED VALUES (Peak demand)
Percentage peak demand transported by CAV (%)	70	70
Number of passengers	28000	28000
Vehicle capacity	85	85
Fleet size	285	114
Number of Stops	20	20
Traveling speed (kph)	25	25
Frequency per hours	259	104
Time headway (s)	14	35
Number of trips per vehicle	4	4
Load factor	0.85	0.85

3.7.3 Scenario 3

Below enlisted are the considerations for the third scenario.

i. Considering that our service is deployed parallel to another service, so our service must share the 50 % of peak demand load, and the rest will be shared by already existing service
ii. Taking 50% of the peak demand. Our CAV service must accommodate 20000 passengers during peak demand
iii. The time required to accommodate the peak demand is two and a half hours

DATA SET

Based on the above considerations, the scenario is planned, and critical components are calculated using formulas. Selected values based on demand accommodation in two and half hours as mentioned in previous scenarios. The route selected, the number of stops and the vehicle's speed maintained the same as in previous scenarios. The data set is presented in Table 9.

Table 9 Data Set of Scenario 3

KEY PARAMETER	CALCULATED VALUES (Per hour)	SELECTED VALUES (Peak demand)
Percentage peak demand transported by CAV (%)	50	50
Number of passengers	20000	20000
Vehicle capacity	85	85
Fleet size	204	82
Number of Stops	20	20
Traveling speed (kph)	25	25
Frequency per hours	185	74
Time headway (s)	20	49
Number of trips per vehicle	4	4
Load factor	0.85	0.85

3.8 Key Performance Measures

It is pivotal to identify the critical performance measures of the system to assess the designed system. At the same time, selecting the KPI's for assessing system performance, it necessary that the selected KPI's should be achievable and accurate good enough to predict the system response in predefined conditions. Therefore, a good KPI can be defined as a performance metric valuable and achievable in the target context achieving the main objectives of the designed system. Below enlisted are the performance measures selected for the system assessment.

3.8.1 Vehicle Kilometer Traveled

It is an essential parameter to analyze the system working, provides the traffic flow in the network. Calculated by multiplying the system's route length with the total number of vehicles in the network. It ensures the availability of the vehicle in the network during demand hours to meet the transport demand.

3.8.2 System Capacity

The capacity of the transit system is expressed in terms of people or transit vehicles. The term "passenger capacity" refers to the maximum number of seated and standing passengers (capacity in passengers per hour per direction) that a system can accommodate safely and pleasantly. Transit vehicle capacity is defined as the maximum number of transit vehicles (in vehicles per hour per direction) that a designed system can transport past a site. In practice, this means meeting the required passenger demand while maintaining a variety of service characteristics (e.g., operating speed, comfort, and reliability). As a result, systems must have a sufficient capacity.

3.8.3 Station Saturation

Many factors play a critical role in achieving the desired speed of the system, but none of them is pivotal as the stop saturation. A not well-designed system leads to congestion in the network, which results in the system's failure. For a smooth system's working, it is essential to plan the boarding and alighting areas efficiently. After the design, it is essential to assess the queues at stations. A well-functioned service should avoid excessive station saturation through proper planning.

3.8.4 System Reliability

The term "variability of trip times" is commonly used in the literature. Various authors have supported this term who consider that "the variability of trip time performance is proposed as the best indicator of reliability." Nonetheless, this subject lends itself to a multitude of approaches. In some publications, the term "reliability" refers to schedule delays and timeline adherence. In any case, reliability is defined primarily by "our capacity to ensure consistent travel times and service availability."

It is critical to recognize how critical this metric is, as passengers are more inclined to use a service if they believe it is trustworthy. User trust entails providing a service of exceptional quality and performance in the case of the CAV transport system.

3.8.5 Travel Time Saving

Travel time savings: It is undoubtedly the most critical component for transport service users when boarding a public transportation service, especially while going from home to work or vice versa. This travel time can be classified as follows:

- The operating time, or the amount of time spent by bus services between stations.
- The dwell time, or the amount of time spent in vehicles at bus stops as passengers embark or alight
- The wait time, or the time spent at the beginning of the trip by clients waiting to board a bus

The transportation system should be constructed so that passengers' journey times are minimized, hence improving the attraction of the service.

3.8.6 Safety

Safety refers to the hazards free transport service, such as free from accidents, injuries, and collision avoidance through intelligent systems. It is essential to assess the system's safety, and it should ensure the safety of passengers. Safety of the systems also plays a critical role in the gain of public interest.

3.8.7 System Average Speed

One of the majors' goals of the designed service is to provide fast service. Speed is another essential aspect of the system's effectiveness. High uniform speeds compensate for the additional time required to walk and catch the bus at the stop.

3.8.8 Environmental Aspects

Environmental effect is another critical consideration for deployed services, as conventional deployed systems are already causing significant environmental damage. It essential for successful service deployment; it should be emission-free.

3.8.9 Time Headway

In CAVs, the timing is dependent on the ACC or CACC settings, which can always maintain the set values. Therefore, it is predicted that the time headway can be kept uniform by the deployed system, which is challenging to maintain in conventional transport services. Small headways also lead to high system capacity and efficiency.

4 SIMULATION AND RESULTS

This chapter includes the simulation of modeled scenarios, results obtained from performed simulations, and discussions about the obtained results. It is of prime importance to analyze the performance of the designed system virtually before deploying it to real-world scenarios. Fortunately, in the modern era, we are blessed with several software tools to simulate real-world conditions. Therefore, bearing the importance of simulation, PTV VISSIM software is used to simulate the designed CAV service, and the results obtained are presented in this chapter. Before going to simulation, it was necessary to define the inputs for each simulation model, which are enlisted below.

4.1 Scenario Inputs

The simulation is run only for one complete round trip of the vehicles, all the scenarios scaled down to factor 1:4, and results and data set are prepared for simulation. The simulation inputs for each scenario also depicted in B-4, B-5, and B-6 of Appendix B. The route length and number of stops remain the same in all three scenarios. Following data sets prepared for each of the scenarios.

4.1.1 Data Set for Scenario 1

The data set for 100% peak demand is depicted in the Table 10; the simulation run time is set to 5000 seconds, the total trip duration including stops is set to 2400 seconds, and the vehicle input is set to 74 vehicles per line.

Table 10 Simulation Inputs Scenario 1

ROUTE	ROUTE LENGTH (km)	STOPS	PASSENGERS INPUT	VEHICLE INPUT	TRAVEL TIME (s)	SIM. TIME (s)
Red Line	12	20	5000	74	2400	5000
Green Line	12	20	5000	74	2400	5000
Total	24	40	10000	148	2400	5000

4.1.2 Data Set for Scenario 2

The data set for 70% peak demand is represented in the Table 11; the passenger input is 3500, the vehicle input is 52. The simulation and journey times are 5000 and 2400 seconds respectively as in scenario 1.

Table 11 Simulation Inputs Scenario 2

ROUTE	ROUTE LENGTH (km)	STOPS	PASSENGERS INPUT	VEHICLE INPUT	TRAVEL TIME (s)	SIM. TIME (s)

Red Line	12	20	3500	52	2400	5000
Green Line	12	20	3500	52	2400	5000
Total	24	40	7000	104	2400	5000

4.1.3 Data Set for Scenario 3

The data set for 50% peak demand is represented in the Table 12; the passenger input is 2500, the vehicle input is 37, and the simulation and trip times are 5000 and 2400 seconds respectively.

Table 12 Simulation Inputs Scenario 3

ROUTE	ROUTE LENGTH (km)	STOPS	PASSENGERS INPUT	VEHICLE INPUT	TRAVEL TIME (s)	SIM. TIME (s)
Red Line	12	20	2500	37	2400	5000
Green Line	12	20	2500	37	2400	5000
Total	24	40	5000	74	2400	5000

4.2 CAV Behavior Implementation (PTV VISSIM)

Set the parameters for the connected and autonomous vehicles in PTV VISSIM to perform the simulations. There are three types of autonomy behavior implementations that are possible. In all these behaviors, cooperativeness and communication are pre-condition.

4.2.1 Description

The classifications of the AV behaviors in VISSIM are as follows:

AV CAUTIOUS:

In this type of behavior, the implementation of brick wall stop distance is possible. Significant gaps are easily implemented; that is, the distance between vehicles is more considerable.

AV NORMAL:

In this, the autonomous vehicle behaves like the human driver with excellent safety. The vehicle can operate at minimum headways.

AV AGGRESSIVE:

In this type of behavior, autonomous vehicles can operate faster and maintain the safety distance accordingly.

4.2.2 Selection of AV Behavior

For simulations, AV Normal is the selected driving behavior. The reason for this selection is because it is closer to real-world scenarios. The advance merging and cooperative lane changing are set ON by default. According to the requirements, the safety distance reduction factor is smaller, and the minimum headway can be defined by the user.

4.3 CAV Parameter Setting

The desired speed is the limit set at 25 for the vehicles in the network. Lower bound and upper bound values are kept uniform to maintain the same speed for the whole system. The occupancy is set at 73 passengers per vehicle after applying the load factor in each scenario. It can variate depending on the requirements. The occupancy distribution is also configured as the capacity and the maximum permitted number of passengers per vehicle; if the capacity is reached, no more passengers would be allowed to board. As shown in the A-6 and A-7 of Appendix A.

In the Autonomous driving mode, absolute braking distance can be enforced. By enforcing absolute braking distance, vehicles can stop safely anytime without crash even if the leading vehicle stops instantly and prioritizes vehicles in conflict areas, as shown in A-4 of Appendix A. By adjusting the vehicle following feature, look ahead and look back distances were selected, ranging from minimum to maximum. Also, the number of interacting objects and vehicles is defined. The recommended values are selected for each parameter of the car-following model, depicted in A-2 of Appendix A.

In the car following model selection setting, Wiedemann 99 was selected over Wiedemann 74 because of the availability of multiple modal parameters, that is shown in A-1 of Appendix A. The driving error probability was set to zero, and the probability of temporary lack of attention during the following is set, that is represented in A-5 of Appendix A. Distraction probability is also defined for maximum CAV implementation and safety. According to vehicle classes defined in the simulation, the link behaviors are selected at AV Normal to provide the connected and autonomous environment to the vehicles, depicted in A-3 of Appendix A.

4.4 Simulation

Simulations were performed for each of the three planned scenarios to analyze the system performance. Five simulations were performed for each scenario to achieve the consistent system's performance, as per recommendations by VISSIM's Manual. For each run, a random seed increment is applied to account for the stochastic variations of the vehicle arrivals in the network to predict the real-world behavior of the designed network. Simulation parameters are depicted in B-1 of Appendix B.

As shown in Figure 6, two separate lines represented as Green and Red are designed in the network. This configuration of two separate lines represents the two sections of the city that will be managed during the event.

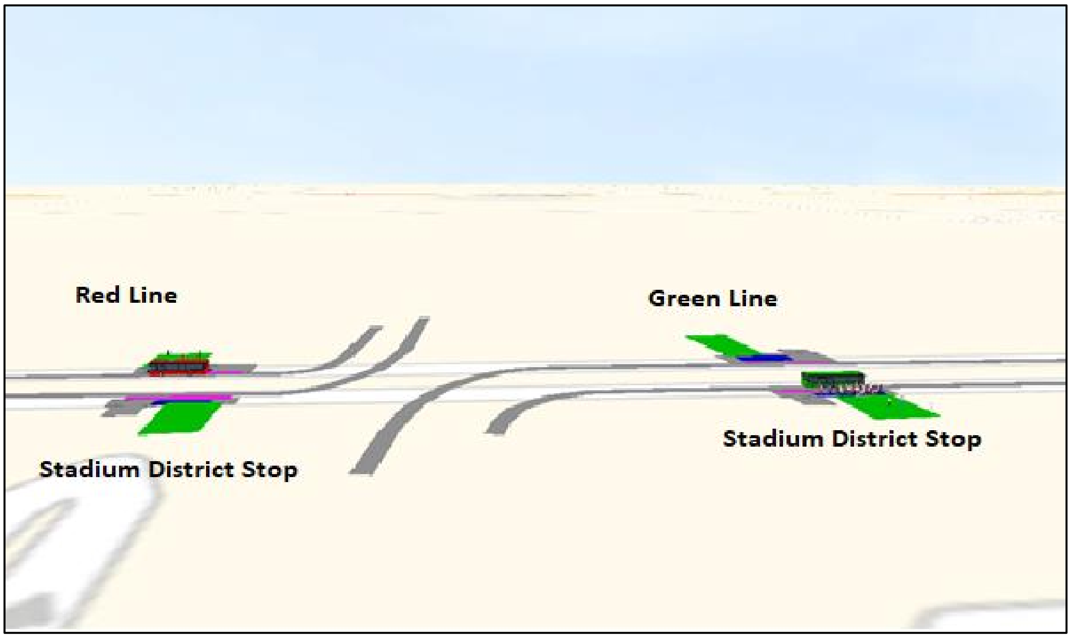

Figure 6 CAV Service Lines

STOPS DESIGN:

Figure 7 represents the designed stop and configuration of the boarding and alighting of the passengers. For each line (Red and Green) similar stop configuration has been set and simulated. Thus, the Figure's green area represents the passenger input, the blue area is the waiting area for the passengers, and the pink area is to alight and board the bus. Stops list is also depicted in B-2 and B-3 of Appendix B.

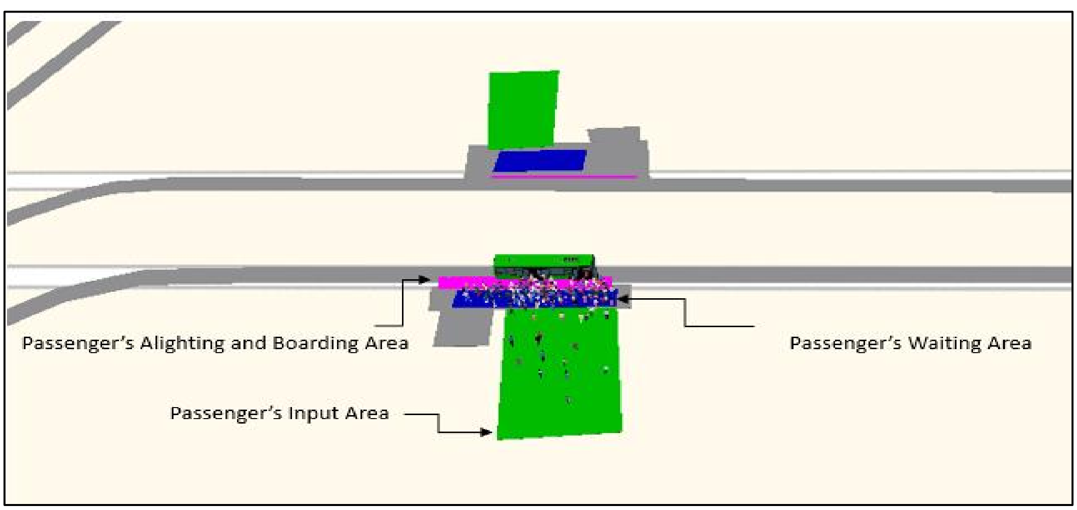

Figure 7 CAV Service Stop

4.5 Simulation Results

The simulation results were compiled for designed scenarios separately to analyze the network performances. The result discussion represents the overall performance evaluation of the vehicles in the network, their travel time, and the total delays in the system. Total kilometers traveled by the vehicles in the network are also presented; queue counters configured in the system generate the queue results. The results also demonstrate the total vehicles that reached their destination or that are active in the network by the end of the simulation.

4.5.1 Scenario 1

1- Delays

The results of the five simulations run are depicted in Table 13. For each simulation run average stopped delay per vehicle without PT stops and average delay time for all vehicles in seconds is compiled against each configured line (Green Line and Red Line). The total number of vehicles active and arrived at the destination also calculated. Delay results are also depicted graphically in Figure 8.

Table 13 Scenario 1 Delay Results

SIM. RUN	SERVICE LINES	VEHICLE DELAYS (s)	VEHICLES (ALL)
1	Green Line	171.66	74
1	Red Line	170.74	74
2	Green Line	169.86	74
2	Red Line	170.54	74
3	Green Line	170.68	74
3	Red Line	171.18	74
4	Green Line	170.14	74
4	Red Line	172.28	74
5	Green Line	170.78	74
5	Red Line	171.15	74

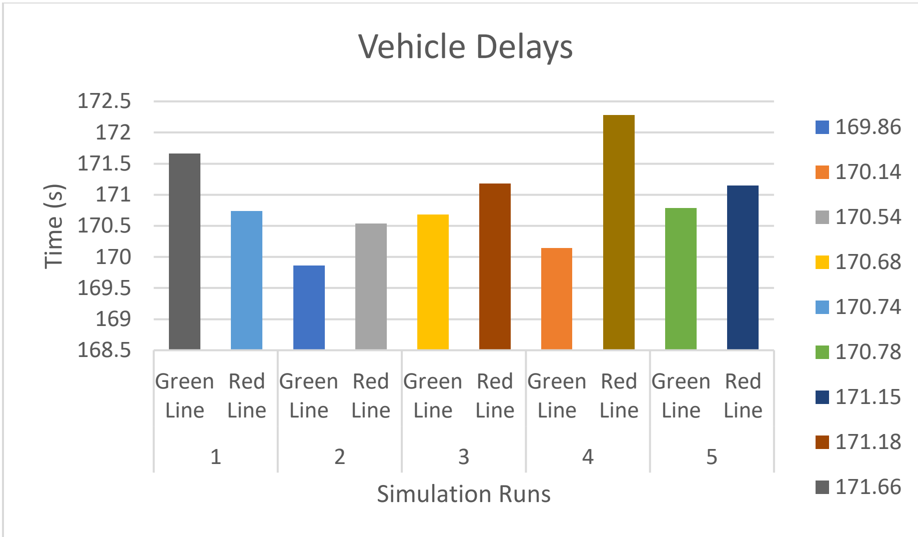

Figure 8 Scenario 1 Delay Results

Average Delays:

Table 14 below represents the average, maximum, minimum, and standard deviation of the delay results. Results are graphically depicted in Figure 9.

Table 14 Scenario 1 Average Delay Results

SIM. RUN	SERVICE LINES	VEHICLE DELAYS (s)	VEHICLES (ALL)
AVG	Green Line	170.62	74
AVG	Red Line	171.18	74
STDDEV	Green Line	0.69	0
STDDEV	Red Line	0.67	0
MIN	Green Line	169.86	74
MIN	Red Line	170.54	74
MAX	Green Line	171.66	74
MAX	Red Line	172.28	74

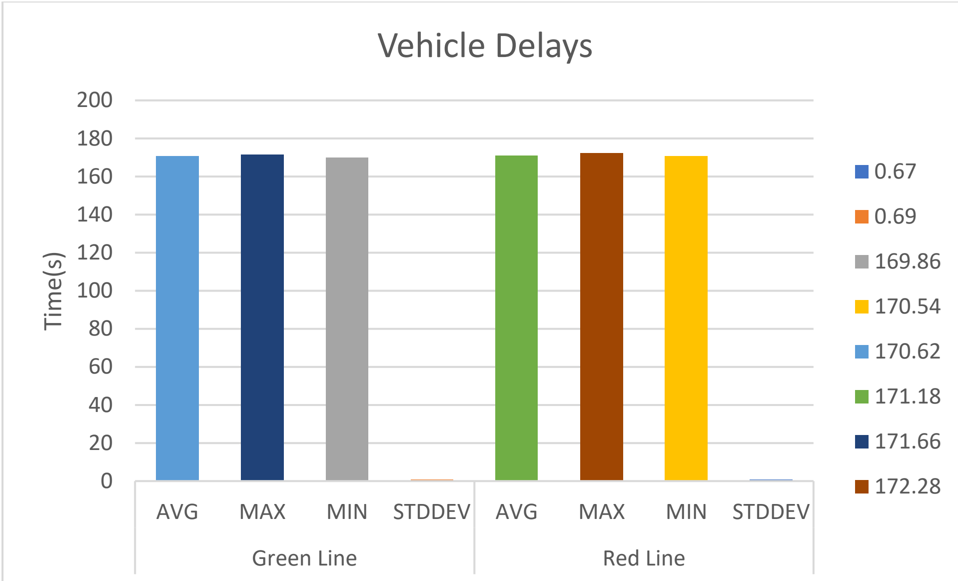

Figure 9 Scenario 1 Average Delay Results

2- Travel Time and Distance Traveled

Table 15 depicts the results for five simulations. Vehicle travel time in seconds and distance traveled in meters are compiled for each vehicle in the network of configured lines.

Table 15 Scenario 1 Travel Time and Distance Traveled

SIM. RUN	SERVICE LINES	VEHICLES	TRAVEL TIME (s)	DISTANCE TRAVEL (m)
1	Green Line	74	2081.84	12000
1	Red Line	74	2082.92	12000
2	Green Line	74	2081.46	12000
2	Red Line	74	2082.63	12000
3	Green Line	74	2081.73	12000
3	Red Line	74	2082.64	12000
4	Green Line	74	2080.86	12000
4	Red Line	74	2083.66	12000
5	Green Line	74	2080.96	12000
5	Red Line	74	2082.55	12000

Average Travel time and Distance Traveled:

Table 16 represents the average, minimum, maximum, and standard deviation of the computed results. Results are also graphically depicted in Figure 10 and Figure 11.

Table 16 Scenario 1 Average Travel Time and Distance Traveled

SIM. RUN	SERVICE LINES	VEHICLES	TRAVEL TIME (s)	DISTANCE TRAVEL (m)
AVG	Green Line	74	2081.37	12000
AVG	Red Line	74	2082.88	12000
STDDEV	Green Line	0	0.44	0
STDDEV	Red Line	0	0.46	0
MIN	Green Line	74	2080.86	12000
MIN	Red Line	74	2082.55	12000
MAX	Green Line	74	2081.84	12000
MAX	Red Line	74	2083.66	12000

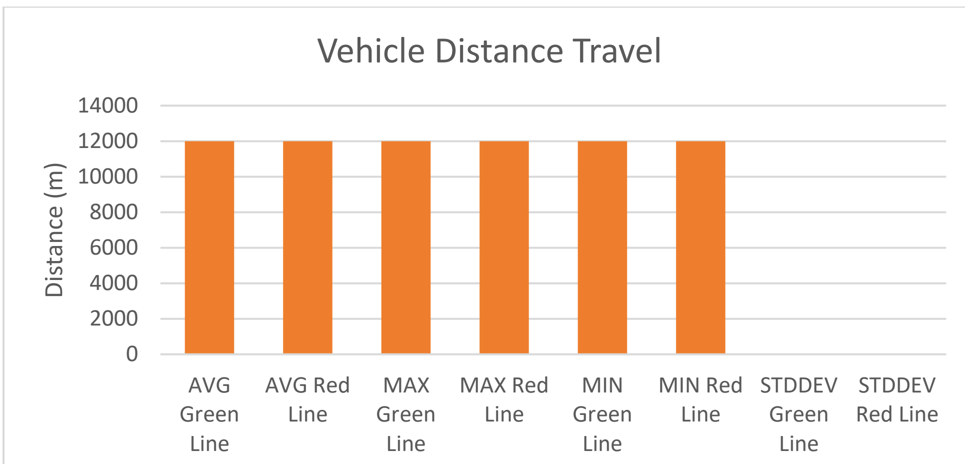

Figure 10 Scenario 1 Average Distance Traveled Results

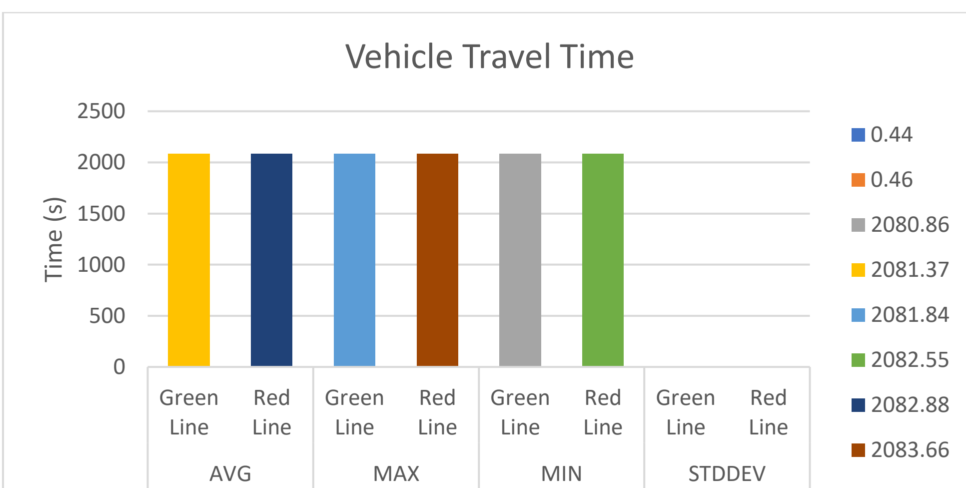

Figure 11 Scenario 1 Average Travel Time Results

3- Queue Results

Table 17 illustrates the results of queue counters placed at a particular position to evaluate queues due to congestion in the network. The first column depicts the placed queue counters, and in the last two columns, queue length and queue stops are represented, respectively. Queue results are also depicted in Figure 12 below.

Table 17 Scenario 1 Queue Results

SIM. RUN	QUEUE COUNTER	QUEUE LENGTH	QUEUE STOPS
1	GL 1	0	0
1	GL 2	0	0
1	GL 3	0	0
1	GL 4	0	0
1	GL 5	0	0
1	RL 1	0	0
1	RL 2	0	0
1	RL 3	0	0
1	RL 4	0	0
1	RL 5	0	0
1	RL Last Stop	4.03	74
1	GL Last Stop	3.41	74

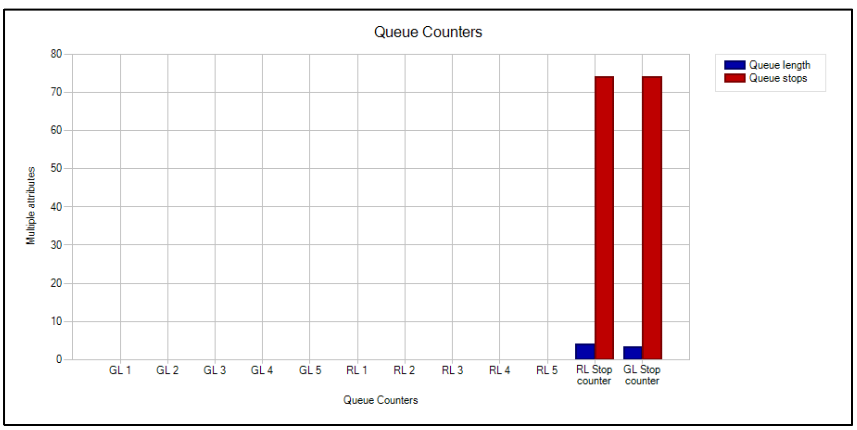

Figure 12 Scenario 1 Queue Results

4- Network Performance Evaluation Results

Table 18 shows the results of the overall network performance of five simulations run. The average delay value, the average number of stops per vehicle, average speed of the vehicle is presented. Total distance, travel time, and total delay of all the vehicles in the network or reached the destination are depicted. The last column represents the total vehicles reached at destination.

Table 18 Scenario 1 Network Performance Evaluation

SIM. RUN	DELAY AVG (s)	SPEED AVG (kph)	DISTANCE TOTAL (km)	TRAVEL TIME TOTAL (s)	DELAY TOTAL (s)	VEHICLE ARRIVED (ALL)
1	171.85	20.75	1780.57	308942.00	25433.35	148
2	170.85	20.75	1780.57	308891.80	25285.64	148
3	171.58	20.75	1780.57	308913.30	25393.62	148
4	171.86	20.75	1780.57	308924.20	25434.72	148
5	171.61	20.75	1780.57	308849.80	25398.44	148

Average Performance Results:

Table 19 represents the average, minimum, maximum, and standard deviation of the computed results. Figure 13 below represents the average speed of the vehicles.

Table 19 Average Network Performance Results

SIM RUN	DELAY AVG (s)	SPEED AVG (kph)	DISTANCE TOTAL (km)	TRAVEL TIME TOTAL (s)	DELAY TOTAL (s)	VEHICLE ARRIVED (ALL)
AVG	171.55	20.75	1780.57	308904.20	25389.15	148
STDDEV	0.41	0.00	0.00	35.44	60.93	0
MIN	170.85	20.75	1780.57	308849.80	25285.64	148
MAX	171.86	20.75	1780.57	308942.00	25434.72	148

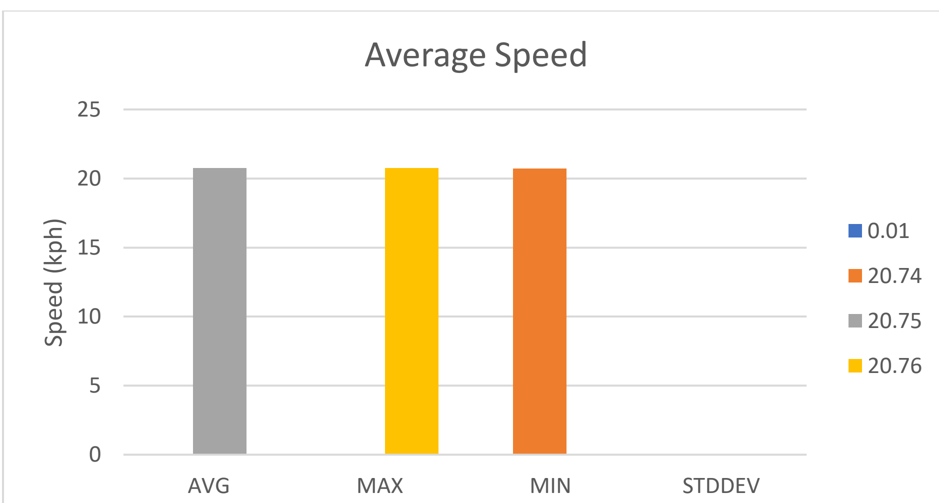

Figure 13 Scenario 1 Network Average Speed Results

4.5.2 Scenario 2

1- Delays

In Table 20, the results of the five simulations run are depicted. For each simulation run average stopped delay per vehicle without PT stops and average delay time for all vehicles in seconds is compiled against each configured line (Green line and Redline). The total number of vehicles arrived at the destination are calculated. The results are also depicted in Figure 14.

Table 20 Scenario 2 Delay Results

SIM. RUN	SERVICE LINES	VEHICLE DELAYS (s)	VEHICLES (ALL)
1	Green Line	167.34	52
1	Red Line	159.41	52
2	Green Line	166.25	52
2	Red Line	157.00	52
3	Green Line	167.28	52
3	Red Line	158.01	52
4	Green Line	168.97	52
4	Red Line	157.28	52
5	Green Line	167.66	52
5	Red Line	157.65	52

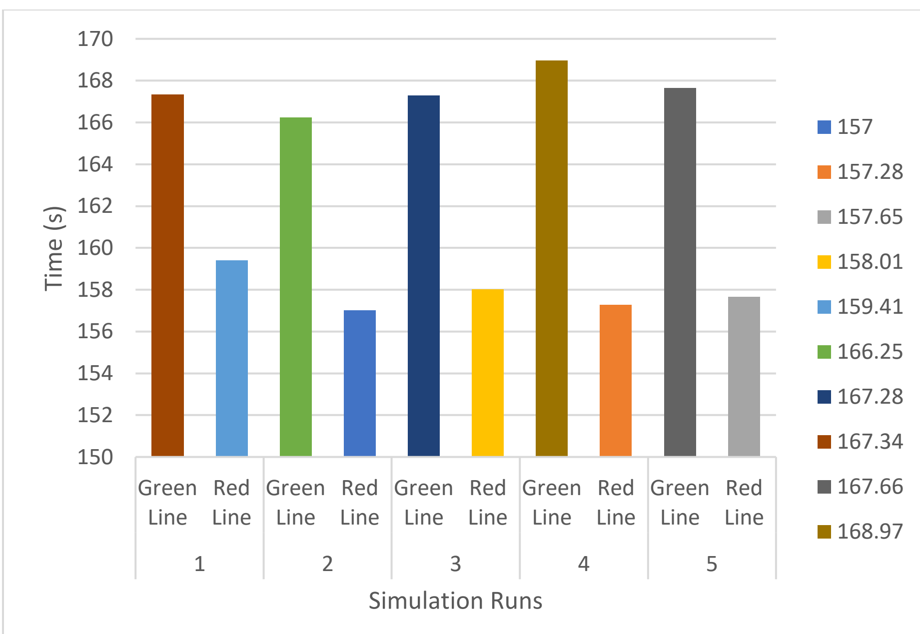

Figure 14 Scenario 2 Delay Results

Average Delays:

Table 21 illustrates the average, maximum, minimum, and standard deviation of the delay results. Results are graphically depicted in Figure 15.

Table 21 Scenario 1 Average Delay Results

SIM. RUN	SERVICE LINES	VEHICLE DELAYS (s)	VEHICLES (ALL)
AVG	Green Line	167.50	52
AVG	Red Line	157.87	52
STDDEV	Green Line	0.98	0
STDDEV	Red Line	0.94	0
MIN	Green Line	166.25	52
MIN	Red Line	157.00	52
MAX	Green Line	168.97	52
MAX	Red Line	159.41	52

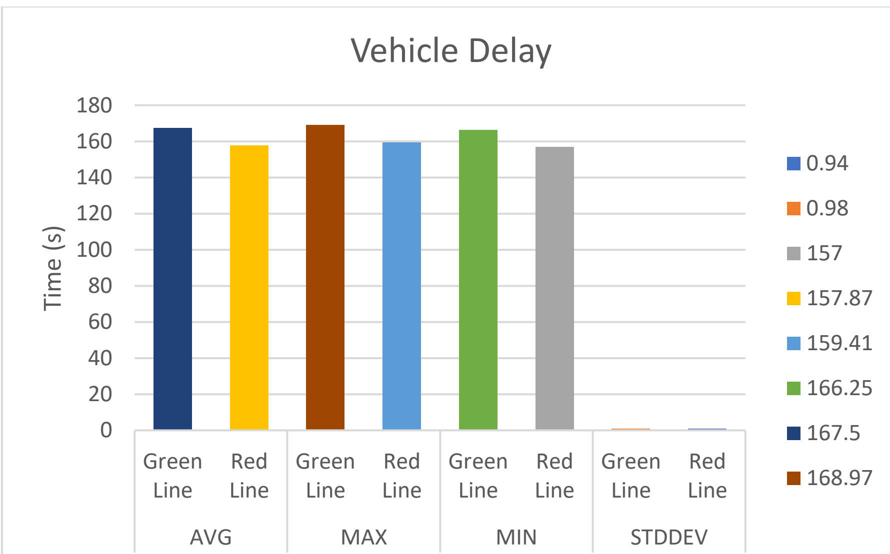

Figure 15 Scenario 2 Average Delay Results

2- Travel Time and Distance Traveled

Table 22 depicts the results for five simulations. Vehicle travel time in seconds and distance traveled in meters are compiled for each vehicle in the network of configured lines. Figure 16 illustrates the distance traveled.

Table 22 Scenario 2 Travel Time and Distance Traveled

SIM. RUN	SERVICE LINES	VEHICLES	TRAVEL TIME (s)	DISTANCE TRAVEL (m)
1	Red Line	52	2083.69	12000
1	Green Line	52	2067.83	12000
2	Red Line	52	2082.55	12000
2	Ged Line	52	2066.54	12000
3	Red Line	52	2082.81	12000
3	Green Line	52	2066.59	12000
4	Red Line	52	2084.76	12000
4	Green Line	52	2066.71	12000
5	Red Line	52	2083.07	12000
5	Green Line	52	2065.47	12000

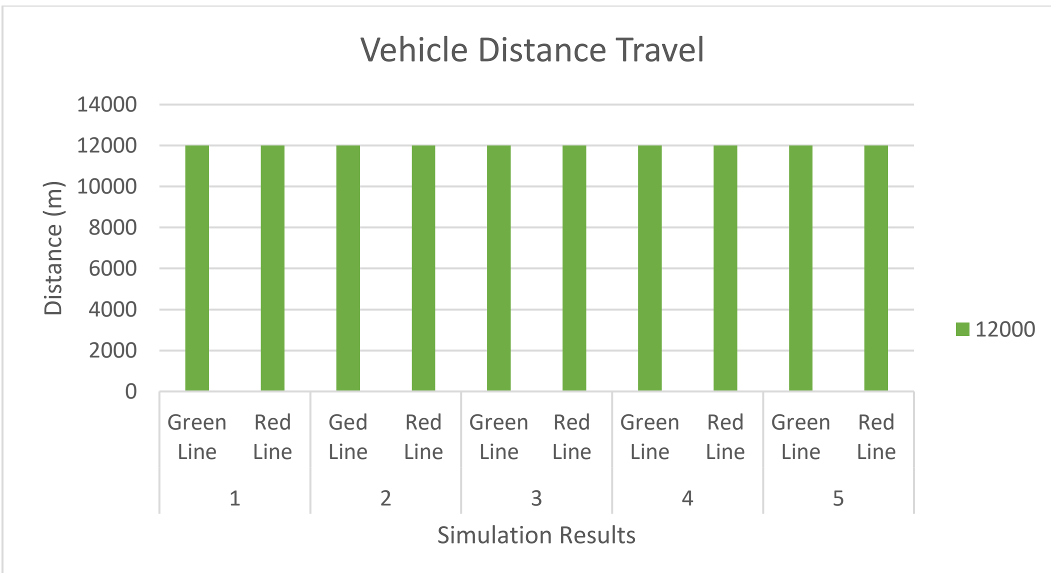

Figure 16 Scenario 2 Average Distance Traveled Results

Average Travel time and Distance Traveled:

Table 23 represents the average, minimum, maximum, and standard deviation of the computed results. Figure 17 illustrates the average vehicle travel time.

Table 23 Scenario 2 Average Travel Time and Distance Traveled

SIM. RUN	SERVICE LINES	VEHICLES	TRAVEL TIME (s)	DISTANCE TRAVEL (m)
AVG	Red Line	52	2083.38	12000
AVG	Green Line	52	2066.63	12000
STDDEV	Red Line	0	0.88	0
STDDEV	Green Line	0	0.84	0
MIN	Red Line	52	2082.55	12000

MIN	Green Line	52	2065.47	12000
MAX	Red Line	52	2084.76	12000
MAX	Green Line	52	2067.83	12000

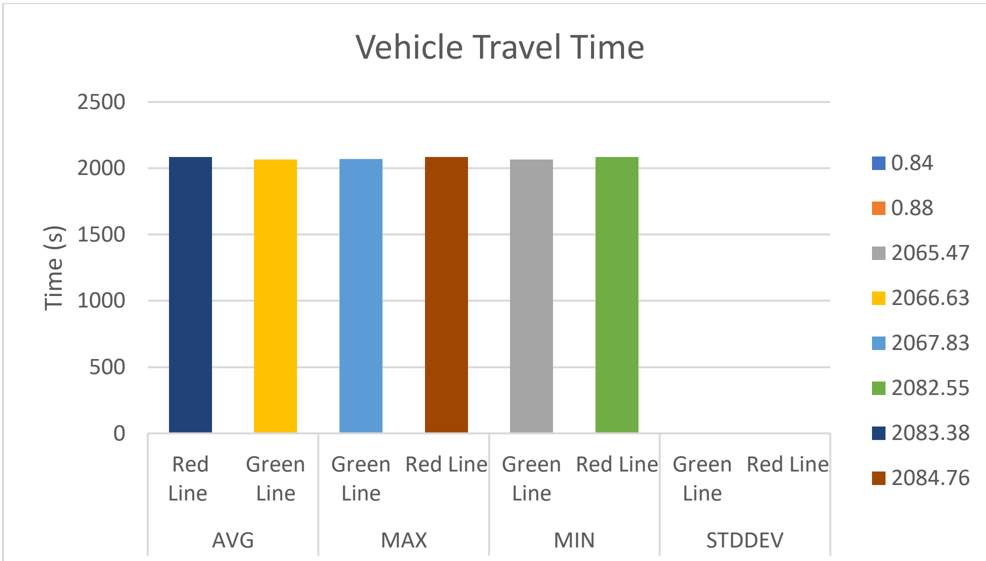

Figure 17 Scenario 2 Average Travel Time Results

3- Queue Results

Table 24 depicts the results of queue counters placed at a particular position to evaluate queues due to congestion in the network. The first column depicts the placed queue counters, and in the last two columns, queue length and queue stops are represented, respectively. Figure 18 illustrates the results graphically.

Table 24 Scenario 2 queue Results

SIM. RUN	QUEUE COUNTER	QUEUE LENGTH	QUEUE STOPS
1	GL 1	0	0
1	GL 2	0	0
1	GL 3	0	0
1	GL 4	0	0
1	GL 5	0	0
1	GL LAST STOP	1.77	52
1	RL 1	0	0
1	RL 2	0	0
1	RL 3	0	0
1	RL 4	0	0
1	RL 5	0	0
1	RL LAST STOP	1.95	52

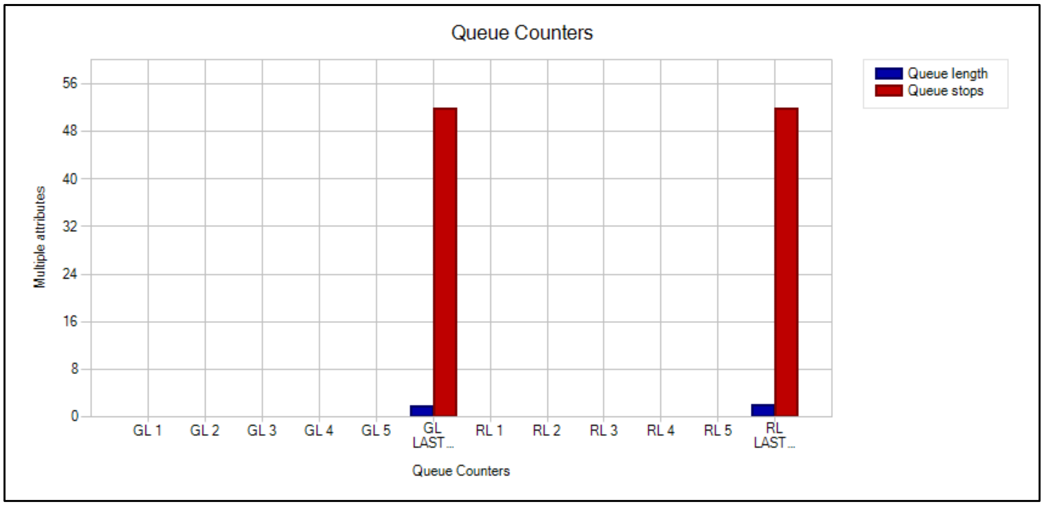

Figure 18 Scenario 2 Queue Results

4- Network Performance Evaluation

Table 25 shows the results of the overall network performance of five simulations run. The average delay value, the average number of stops per vehicle, average speed of the vehicle is presented. Total distance, travel time, and total delay of all the vehicles in the network or reached the destination are depicted. The last column represents the total vehicles reached at destination.

Table 25 Scenario 2 Network Performance Evaluation Results

SIM. RUN	DELAY AVG (s)	SPEED AVG (kph)	DISTANCE TOTAL (km)	TRAVEL TIME TOTAL (s)	DELAY TOTAL (s)	VEHICLE ARRIVED (ALL)
1	163.92	20.81	1250.76	216331.10	17047.37	104
2	162.17	20.83	1250.77	216205.10	16865.41	104
3	163.19	20.82	1250.76	216220.30	16971.55	104
4	163.66	20.81	1250.76	216328.20	17020.92	104
5	163.2	20.83	1250.76	216176.40	16972.62	104

Average Performance Results:

Table 26 represents the average, minimum, maximum, and standard deviation of the computed results. Average speed is also depicted in Figure 19.

Table 26 Average Network Performance Results

SIM RUN	DELAY AVG (s)	SPEED AVG (kph)	DISTANCE TOTAL (km)	TRAVEL TIME TOTAL (s)	DELAY TOTAL (s)	VEHICLE ARRIVED (ALL)
AVG	163.23	20.82	1250.76	216252.22	16975.57	104
STDDEV	0.67	0.01	0	72.43	69.59	0
MIN	162.17	20.81	1250.76	216176.40	16865.41	104
MAX	163.92	20.83	1250.77	216331.10	17047.37	104

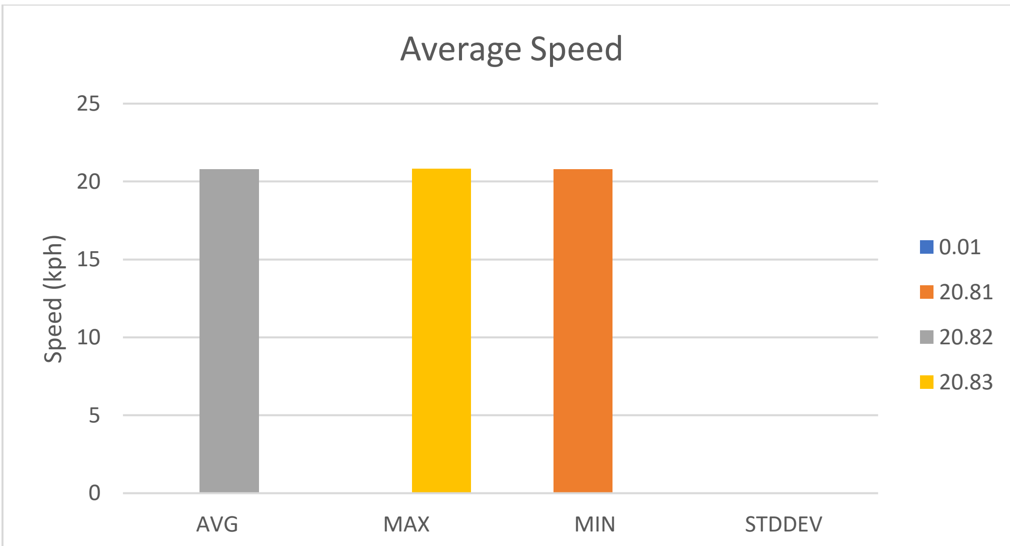

Figure 19 Scenario 2 Network Average Speed Results

4.5.3 Scenario 3

1- Delays

In Table 27 results of the five simulations run are depicted. For each simulation run average stopped delay per vehicle without PT stops and average delay time for all vehicles in seconds is compiled against each configured line (Green line and Redline). The total number of vehicles arrived at the destination are calculated. Results are also depicted in Figure 20.

Table 27 Scenario 3 Delay Results

SIM. RUN	SERVICE LINES	VEHICLE DELAYS (s)	VEHICLES (ALL)
1	Green Line	167.66	37
1	Red Line	167.62	37
2	Green Line	166.42	37
2	Red Line	164.26	37
3	Green Line	167.45	37
3	Red Line	165.90	37
4	Green Line	169.21	37
4	Red Line	165.48	37
5	Green Line	167.56	37
5	Red Line	166.03	37

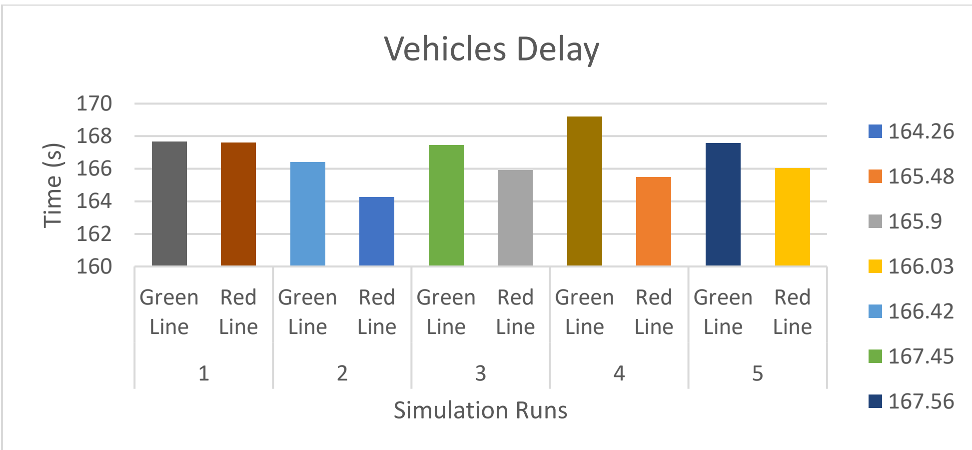

Figure 20 Scenario 3 Delay Results

Average Delays:

Table 28 depicts the average, maximum, minimum, and standard deviation of the delay results. Results are graphically illustrated in Figure 21.

Table 28 Scenario 3 Average Delay Results

SIM. RUN	SERVICE LINES	VEHICLE DELAYS (s)	VEHICLES (ALL)
AVG	Green Line	167.66	37
AVG	Red Line	165.86	37
STDDEV	Green Line	1.00	0
STDDEV	Red Line	1.21	0
MIN	Green Line	166.42	37
MIN	Red Line	164.26	37
MAX	Green Line	169.21	37
MAX	Red Line	167.62	37

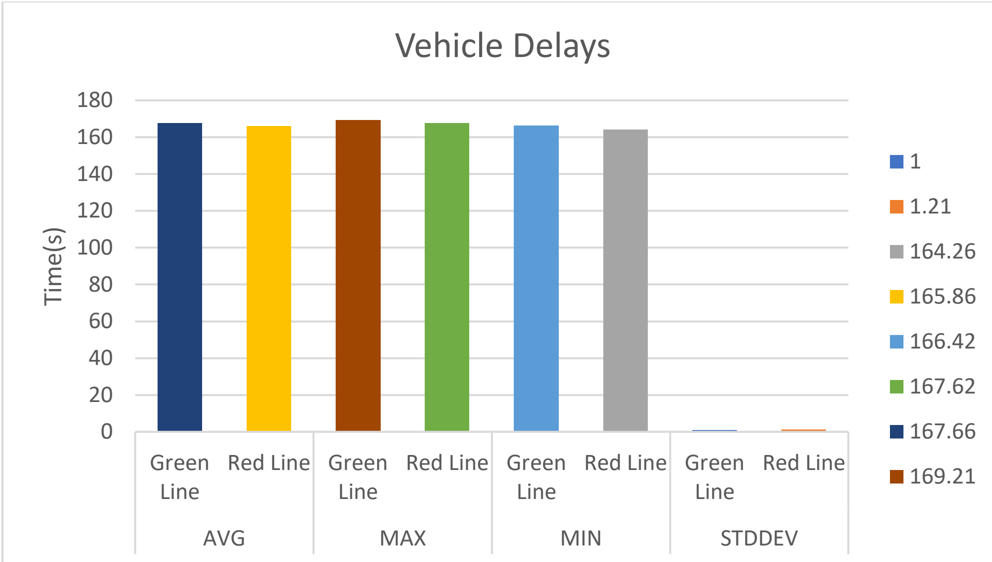

Figure 21 Scenario 3 Average Delay Results

2. Travel Time and Distance Traveled

Table 29 depicts the results for five simulations. Vehicle travel time in seconds and distance traveled in meters are compiled for each vehicle in the network of configured lines. The bar graph represents the average traveled time and distance traveled by each vehicle. Vehicle distance traveled also depicted in Figure 22.

Table 29 Scenario 3 Travel Time and Distance Traveled

SIM. RUN	SERVICE LINES	VEHICLES	TRAVEL TIME (s)	DISTANCE TRAVEL (m)
1	Red Line	37	2083.07	12000
1	Green Line	37	2082.07	12000
2	Red Line	37	2083.69	12000
2	Ged Line	37	2079.55	12000
3	Red Line	37	2083.10	12000
3	Green Line	37	2080.92	12000
4	Red Line	37	2084.32	12000
4	Green Line	37	2080.75	12000
5	Red Line	37	2082.13	12000
5	Green Line	37	2080.45	12000

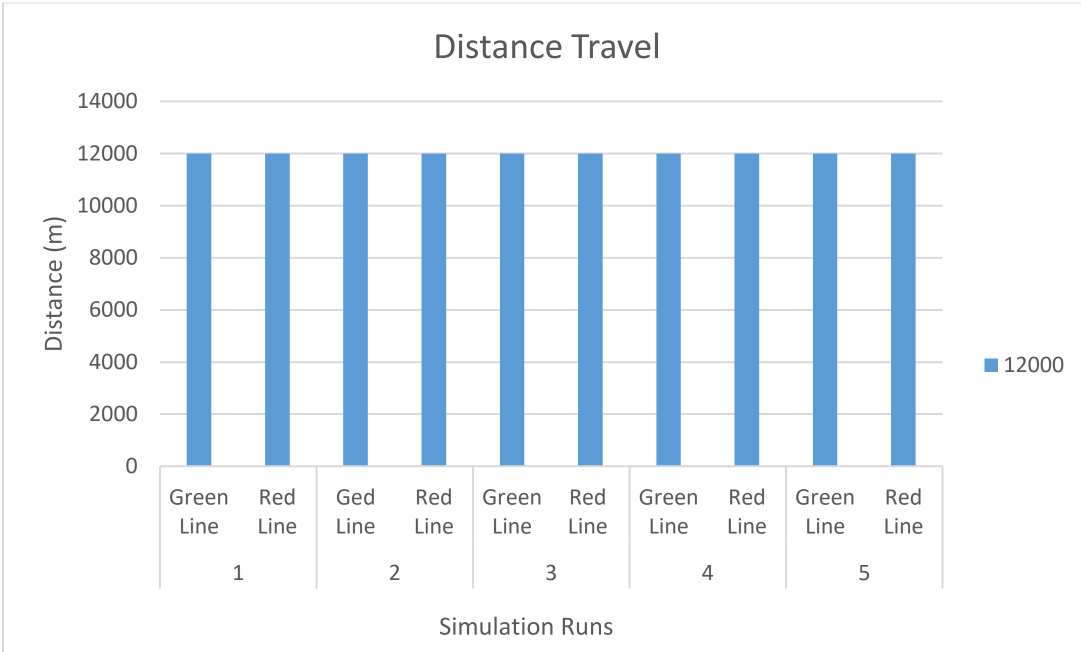

Figure 22 Scenario 3 Average Distance Traveled Results

Average travel time and Distance Traveled:

Table 30 represents the average, minimum, maximum, and standard deviation of the computed results. Figure 22 illustrates the travel time.

Table 30 Scenario 3 Average Travel Time and Distance Traveled

SIM. RUN	SERVICE LINES	VEHICLES	TRAVEL TIME (s)	DISTANCE TRAVEL (m)
AVG	Green Line	37	2083.26	12000
AVG	Red Line	37	2080.75	12000
STDDEV	Green Line	0	0.81	0
STDDEV	Red Line	0	0.91	0
MIN	Green Line	37	2082.13	12000
MIN	Red Line	37	2079.55	12000
MAX	Green Line	37	2084.32	12000
MAX	Red Line	37	2082.07	12000

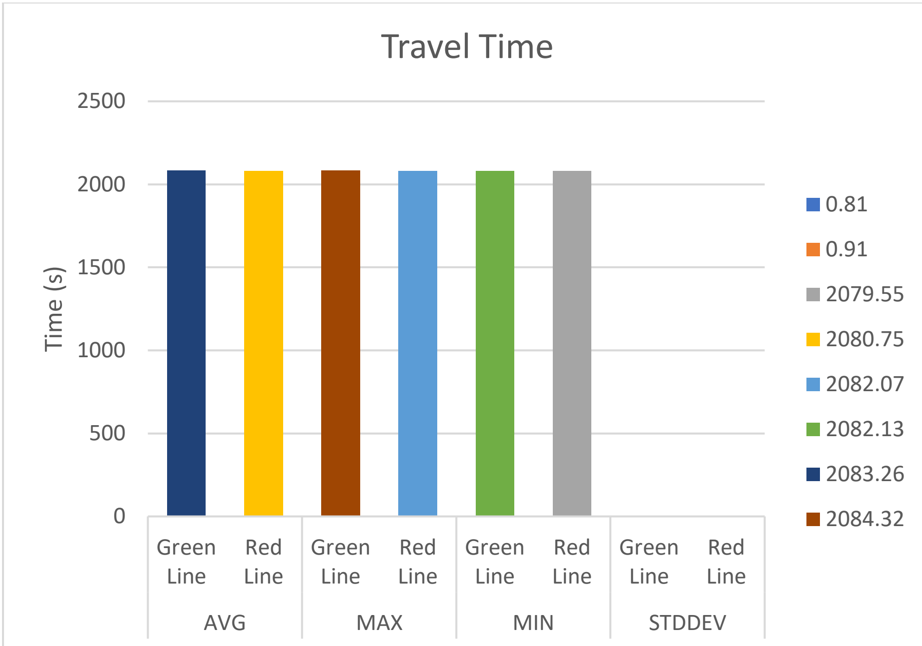

Figure 23 Scenario 3 Average Travel Time Results

3- Queue Results

Table 31 depicts the results of queue counters placed at a particular position to evaluate queues due to congestion in the network. The first column depicts the placed queue counters, and in the last two columns, queue length and queue stops are represented, respectively. Queue results also illustrated in Figure 24.

Table 31 Scenario 3 Queue Delay Results

SIM. RUN	QUEUE COUNTER	QUEUE LENGTH	QUEUE STOPS
1	GL 1	0	0
1	GL 2	0	0
1	GL 3	0	0
1	GL 4	0	0
1	GL 5	0	0
1	GL LAST STOP	1.60	37
1	RL 1	0	0
1	RL 2	0	0
1	RL 3	0	0
1	RL 4	0	0
1	RL 5	0	0
1	RL LAST STOP	1.31	37

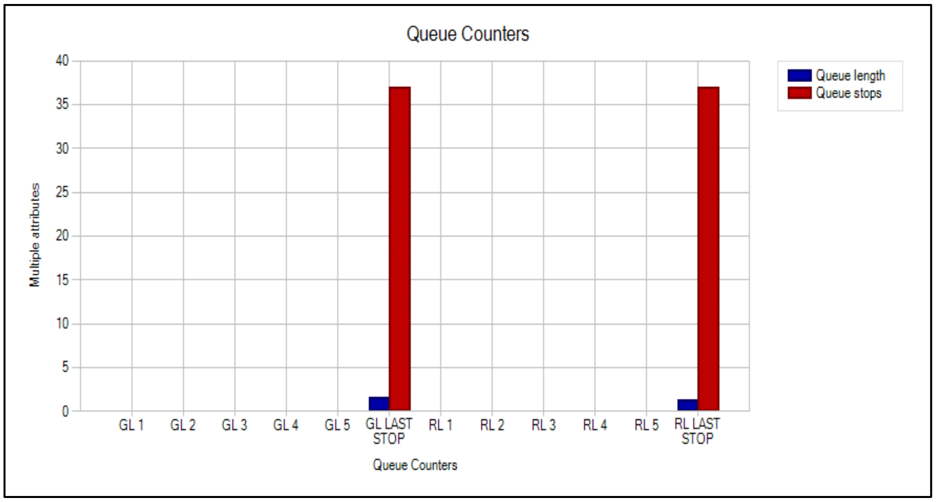

Figure 24 Scenario 3 Queue Results

4- Network Performance Evaluation

Table 32 shows the results of the overall network performance of five simulations run. The average delay value, the average number of stops per vehicle, and the average speed of the vehicle are presented. Total distance, travel time, and total delay of all the vehicles in the network or reached the destination are depicted. The last two columns represent the total vehicles in the network reached at destination.

Table 32 Scenario 3 Network Performance Evaluation Results

SIM. RUN	DELAY AVG (secs)	SPEED AVG (kph)	DISTANCE TOT. (km)	TRAV. TIME TOT. (secs)	DELAY TOT. (secs)	VEH. ARRIVED (ALL)
1	168.42	20.74	890.14	154473.20	12462.86	74
2	166.12	20.75	890.14	154403.90	12292.95	74
3	167.46	20.75	890.14	154432.10	12392.09	74
4	168.13	20.75	890.14	154470.90	12441.46	74
5	167.58	20.76	890.14	154379.20	12400.62	74

Average Performance Results:

Table 33 represents the average, minimum, maximum, and standard deviation of the computed results. Vehicle average speed is represented in Figure 25.

Table 33 Average Network Performance Results

SIM RUN	DELAY AVG (s)	SPEED AVG (kph)	DISTANCE TOTAL (km)	TRAVEL TIME TOTAL (s)	DELAY TOTAL (s)	VEHICLE ARRIVED (ALL)
AVG	167.54	20.75	890.14	154431.86	12398.00	74
STDDEV	0.89	0.01	0	41.19	65.52	0
MIN	166.12	20.74	890.14	154379.20	12292.95	74
MAX	168.42	20.76	890.14	154473.20	12462.86	74

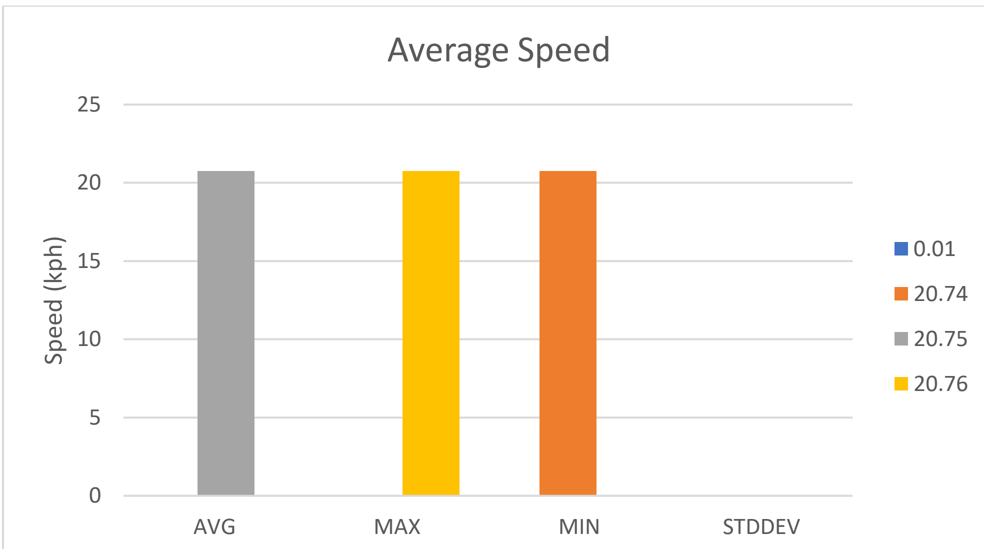

Figure 25 Scenario 3 Network Average Speed Results

4.6 Discussion

The simulation of planned scenarios is performed to evaluate the system performance; the results are compiled for each planned scenario and represented. The calculated results validate the theoretical calculation of distance traveled by the vehicle in the network. The overall performance of the modeled scenarios is depicted in Table 34.

Table 34 Overall Performance of the Modeled Scenarios

SCENARIOS	AVG. SPEED (kph)	TOTAL DISTANCE TRAVEL (km)	AVG. TRAVEL TIME (s)	TOTAL DELAYS (s)	VEHICLES	TOTAL PASSENGERS
1	20.75	1780.57	308904.20	25389.15	148	10000
2	20.82	1250.76	216252.22	16975.57	104	7500
3	20.75	890.14	154431.86	12398.00	74	5000

Due to necessary stops in the network, it can be observed that the average speed of the vehicles drops in each scenario. The average speed drops 17% in a scenario first and third, whereas 16.7% in the third scenario, the maximum achieved an average speed of the system is 20.82 (kph).This drop-in speed results in vehicle delays in the network; from the results, it could be found that the vehicle delay is high in the first scenario compared to the second and third scenarios.

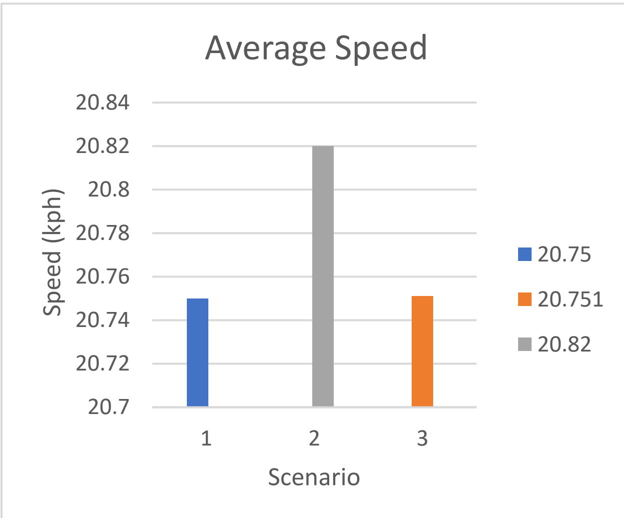

Figure 27 Average Speed Results

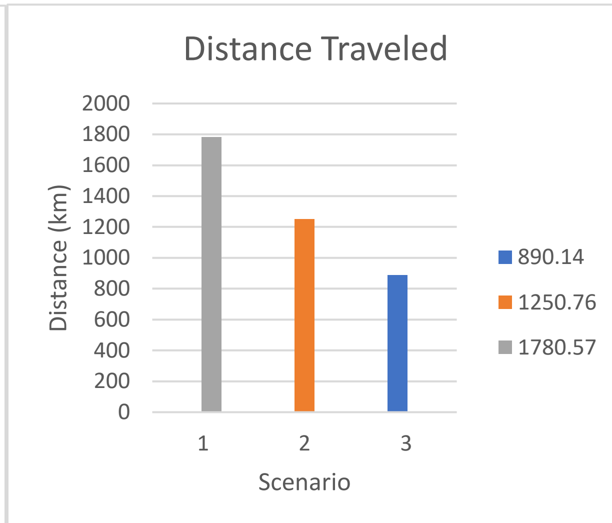

Figure 26 Distance Traveled Results

The total distance traveled, and the travel time significantly varies in all three scenarios designed to meet the considered peak demand. Figure 28 and Figure 29 illustrates the Travel time and vehicle delay results of all three scenarios.

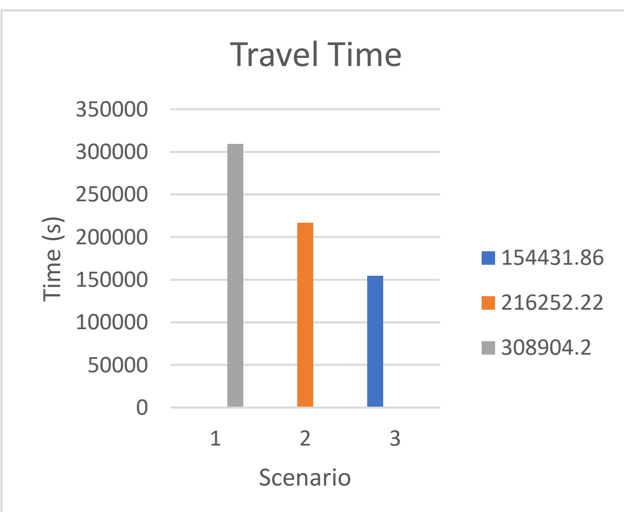

Figure 29 Travel Time Results

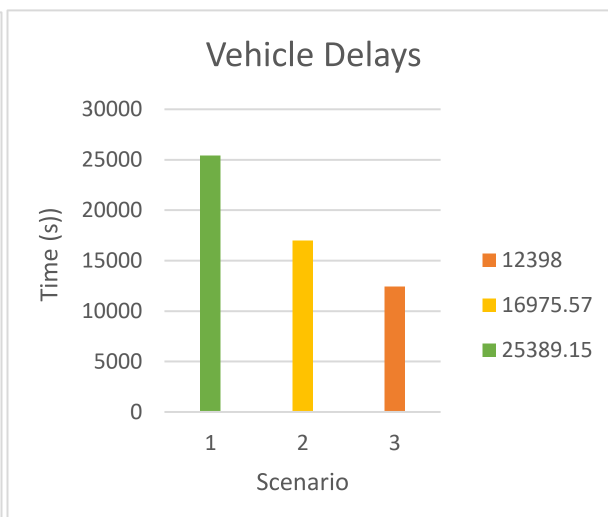

Figure 28 Vehicle Delay Results

5 CASE STUDY DEVELOPMENT

This chapter is dedicated to a case study development to assess the benefits of the designed model. The central idea of this case study is to develop a business case for CAV deployment, keeping in mind the two main stakeholders, the city management and the CAV deployment company. What they have in term of,

- Benefits for City management in CAV deployment
- Reusability of the model for CAV deployment company

5.1 Key Aspects

The key aspects and the concept are of the case study is highlighted in Table 35 below.

Table 35 Case Study's Key Aspects

KEY ASPECTS	CONCEPT
Concerning City management	**Benefits for city management to adopt this transport model**
Cost	• Cost analysis and cost effectiveness of the model
Time	• Analysis of project completion time compared to other transportation modes
Safety	• General safety parameters comparison
Health	• Contribution of the model in health sector
Environment measures	• Analysis of the positive impacts of model on environment aspects
Concerning CAV deployment Company	**Benefits for deployment company**
Reusability of the model	• To highlight the potential benefits of the model for deployment companies going from one region to another
Proactive Planning	• Guideline for proactive planning to ensure the project's success.
Full-scale Deployment opportunity	• Potential project as full-scale deployment opportunity
Model Flexibility	• Assessment of model flexibility

5.2 Benefits

The benefits of the designed model are segregated concerning management of the city where CAV model is going to be deployed and the deployment company, that are described as follow.

5.2.1 Concerning City Management

For the city management, the key benefits of the planned service model are enlisted below.

1- Cost Effectiveness

The development of a public transportation network for dense events in a city is not a common occurrence. That is why, before the start of construction, each component and feature must be planned to assure its continued effectiveness for extended times following the incident. For these reasons, the perspective of maintenance and retraining is critical for both existing and new mass transport networks. It's worth noting that by making a few minor tweaks to existing infrastructure and installing the CAV-required environment, efficient, high-quality service can be ensured, providing a handy solution for local administrations.

We can take CAV service as a highly sophisticated system that emulates light rail systems with reduced costs and construction times. For example, the construction costs for a single kilometer of the rapid transit system as per literature are only fifty-two percent of the costs of a light rail system and eight percent of those of massive rail system construction. The designed CAV service utilizes the existing road infrastructure, which results in further reduction of cost.

The cost per passenger kilometer is calculated annually, based on available data in the literature and compared to the conventional service. The purchase price of CAV vehicles varies significantly in the literature, as well as from industry listing. This is mainly attributed to the variation of Battery Electric Buses purchase price to the procurement process, leading to significantly varied discount rates associated with each procurement and the cost of autonomous technology. For the calculation took the vehicle cost $650000 including the battery pack. The energy cost is taken as per current cost in the selected city. Vehicle cost data is represented in Table 36.

Table 36 Vehicle Cost Data

BUS CAPITAL AND INFRASTRUCTURE COSTS (USD)	**UNIT**	**ANNUAL**
Electric Bus unit cost	650000	650000
BUS operating assumptions and cost (USD)		
Maintenance cost/km	0.21	15391
Electricity cost/kWh	0.04	3614
Energy consumption kWh/km	1.3	-
Overnight charging unit cost	50000	50000
En-route Dc fast charger unit cost	110000	-

Total	-	719005

The total available day of operation for buses is 329, as 10% of the working days are utilized to maintain the vehicles. The total kilometer traveled by each vehicle is 206 kilometers, if service availability is 10 hours per day, at an average speed of 22.6 kilometers taken from simulation results. Calculated cost is illustrated in Table 37.

Table 37 Calculated Cost

MODELLED SERVICE	ANNUAL VKT	ANNUAL PKT	ANNUAL COST	COST US$/ PER PASSENGER-KILOMETER
CAV	67774	4947502	719005	0.15

Inherent heterogeneity in the cost of road infrastructure and scarcity of data in the literature, these expenses are not included in the calculations. Currently, the cost per passenger is very high, but as technology advances, these acquisition costs will decrease, making the CAV service even more affordable.

2- Fast Completion Time

According to the report, a rapid transit system takes approximately two years to complete. In contrast, LRT and metro service require five and ten years, respectively, resulting in project delays and increased investment over time. As CAV service uses pre-existing road infrastructure, there is no need to invest more time or resources in the project, and it takes the least completion time compared to conventional transportation systems.

3- Health Improvements

The designed CAV service model can facilitate health measures in a variety of ways. CAVs have the potential to increased vehicle and occupant safety with advanced divining systems and connectivity. Must reduce the number and severity of accidents by reducing the human error aspect that leads to accidents. Because of the resulting concerns about accidents caused by distracted driving and the growing number of elderly drivers, the autonomy of the vehicles promises a significant move towards the safety of occupants. CAVs can enhance human health by assessing occupant's health parameters by passive health monitoring systems. This will lead to the detection of acute conditions (e.g., early warning of an impending heart attack or asthma attack while in the vehicle) and long-term problems by providing regular, probably daily, updates on vital health parameters. The response can also be quicker; in the event of an emergency, the passenger monitoring device can warn the caller for emergency service. Accurate location information coming from the vehicle's GPS would make it simpler and quicker for the nearest respondents to locate the position. CAV service would connect with the nearest hospital and have a faster response in an emergency during the event.

The planned CAV service model can also play a critical role in health emergencies. For example, the world is currently experiencing the Covid-19 crisis, and additional measures are being taken globally. Particular directions are being given to transportation agencies regarding social distancing to ensure passenger safety and prevent disease spread. In such health emergencies, CAV services can effectively maintain passenger safety through intelligent technology; the system is aware of all relevant instructions and may communicate with officials about any passenger misconduct. The percentages of vehicles boarding, and alighting can be specified, as well as the pedestrian routing. Additionally, vehicle passenger monitoring at stations is made simple by the intelligent technologies inherent in CAV infrastructure.

4- Safety Improvements

The severity and frequency of accidents and injuries sustained by transportation system passengers and personnel serve as indicators of safety. Nonetheless, collisions involving buses are a severe safety concern, owing to their size, operational features, and passenger capacity. A transit agency's level of safety is measured through performance indicators such as accident rates (per service hour or service mile) and public perception of safety. Often, passenger surveys or information gleaned from customer comments are used to gauge the public's opinion of safety.
In general, modeled CAV service provides a high level of safety and security due to high service frequencies that reduce perceived vulnerability at stations. Individual rights of way (run on dedicated lanes) eliminate hazards and conflict with other vehicles, low floors that eliminate tripping hazards, electronic fare collection that eliminates passenger vulnerability during cash transactions, and advanced technology.

5- Environmental Impact

The designed CAV service will play a critical role in mitigating air pollution caused by transportation sources. The variables that contribute to these improvements are primarily the employment of zero-emission electric vehicles and the fact that this service will decrease personally used automobiles, which also contribute significantly to reduce emissions during dense events.

6- Smart City Vision

The designed CAV service complies with the vision of the smart city, as connected and autonomous vehicles are the fundamental pillar of the smart city. CAVs, with the feature of connectivity and intelligent behavior, play a vital role in the prosperity of Smart cities; CAVs enabled Smart cities to achieve social, economic, and sustainability goals. Moreover, Smart cities collect data to manage traffic flow, making mobility safer and environment friendly this goal cannot come true without the intelligent transport network. Therefore, the CAVs are becoming an integral part of Smart city development.

5.2.2 Concerning Deployment Company

Deployment of CAV is under consideration throughout the world, the pilot deployment programs initiated by the government and private firms working successfully. Deploying CAV service for the dense event would be a landmark in the largescale deployment of CAVs. This CAV service will provide the limelight to the deploying companies. It would be a strong business case for the deployment companies, always rely on investment for the CAV deployments. Some of the key benefits of the designed model are enlisted below.

1- Proactive Planning

The modeled CAV service for the dense event offers a service like the metro with minimum implementation cost. Fast completion with the citywide reach, as these vehicles can enter and leave the designed corridor. This service ensures the hundred percent guarantee of these benefits due to its flexible nature. The main hurdle in any of the services is developing the infrastructure; the modeled service utilizes the existing infrastructure with enabled connectivity, making it more efficient and cost-saving. In the early stages of the project, the deployment company must assess the benefits related to the project and ensure their delivery after implementing the service. Just as the well-planned delivers benefits, the poorly designed lead to failure of the project and deployment company. This model provides the guideline for proactive planning to ensure the project's success.

2- Opportunity of Full-scale CAV Deployment

The proposed CAV will support dense event. In addition, the deployment companies can translate the service to long-term service to a long term, which merged to the city transportation service after the completion of event. The presented model can easily be translated into the city service for the long run by assessing the mobility demand. This would become a long-term business for the deployment companies.

3- An Opportunity of Colossal Marketing

The presented model is the first of its kind for large-scale deployment of CAVs. Due to the flexible deployment nature, using guidelines provided in the designed CAV service model can be deployed in any region. The deployment of the CAV service in the dense event will provide huge potential for bringing public awareness towards the use of CAV service as visitors to attend these events. CAV service will provide higher level of safety and security for CAV users, which promotes the shift towards CAVs. Successful service completion would be a colossal marketing gain for the deployment company.

4- Model Flexibility

The designed CAV model presents multiple scenarios, enabling the deployment companies to choose the type of service they can provide. For example, to meet the full-scale demand or the service parallel to the existing service to share the load with excellent efficiency. The presented service planning and modelling of each case can be used as a guideline for the deployment company.

6 CONCLUSION AND DISCUSSION

This chapter is dedicated to the Conclusion, Recommendations, Future work, and Limitations of the conducted research.

6.1 Conclusion

The research goal proposed in the first chapter, identified the importance of studying CAV deployment in dense events such as FIFA 2022, Lusail Qatar. To achieve the stated goals, methodology is developed to plan and manage the implementation of CAVs for the selected event. The results achieved after planning and simulation of the CAV service for the event showed promising results and potential benefits of the deployed CAV service. The analysis of the planned scenarios modeled based on demand data depicted that this service could convincingly handle the peak demand during the event. The modeled service effectively addresses the criteria for heterogeneous traffic, emissions from more driving, and on-street congestion that may result in the case of a dense event. The study assessed that this service complies with the efforts being carried out worldwide to make transportation safer and pollution-free. CAV service is able to handle any emergency requirements as equipped with intelligent technology. From the system performance analysis, this CAV service is more efficient, reliable, accessible, and accounts for minimum delays due to the uniformity of the service. The developed case study provided many benefits concerning city management regarding cost-effectiveness, safety, health, and environmental measures. And deployment companies in term of proactive planning, opportunity of full-scale deployment, colossal marketing, and flexible service planning. The designed model and presented results showed flexibility to manage the implementation of CAV in dense events in other regions where it uses the existing roads with dedicated lanes. The planned service can be deployed to meet the entire demand or can be utilized in parallel to the existing service depending on the available resources and target demand.

6.2 Recommendations

The thesis study showed that the modeled CAV service has tremendous potential benefits. There is a need to practically implement the service to manage the transportation during the dense event. Concerning the feasibility of the proposed service, it perfectly aligns with the smart city vision, as Lusail city is recently developed and equipped with connectivity and smart technology, which is an integral part of the CAV service. As mentioned in chapter five, deploying CAVs for dense events has benefits for the city management and the deploying companies. This project is an excellent opportunity for the CAV deploying company to complete this milestone, take the lead and become a tycoon in the field, as this is the first project of its kind to deploy full-scale CAV service.

6.3 Future Work

This CAV service is modeled based on peak demand requirements; from the past practices of dense event transportation planning, it is concluded that the proposed service must comply with the long-term mobility planning of the city. Transportation planning for the dense event should be considered a catalyst for city development. And must plan it to merge into urban transport after the event.

Using Articulated buses in the network with the availability of articulated autonomous buses will result in less fleet size with high passenger capacity. Public awareness would be proved essential for the successful deployment of CAV service. Allocation of more resources can be beneficial for CAV bus service implementation in mixed traffic flow. CAV bus services would be more beneficial by advancing technology and expertise in the deployment field.

6.4 Limitations

The thesis study faced some limitations, as mentioned below:

-The planned CAV service is based on the best-known available mobility data from resources; actual mobility demand may vary depending on the future conditions.
- For the simulation, the student license of the software is used, the maximum pedestrian input range is 10000, with certain limits to perform the simulations. To achieve more refined results complete service pack of the software is needed.
- Due to covid-19 restriction, all the communications carried out virtually, distant communication intervened the great opportunity of learning under the supervision of referenced professors.
- Formula-based passengers routing and station design required a high level of software command beyond the research scope.

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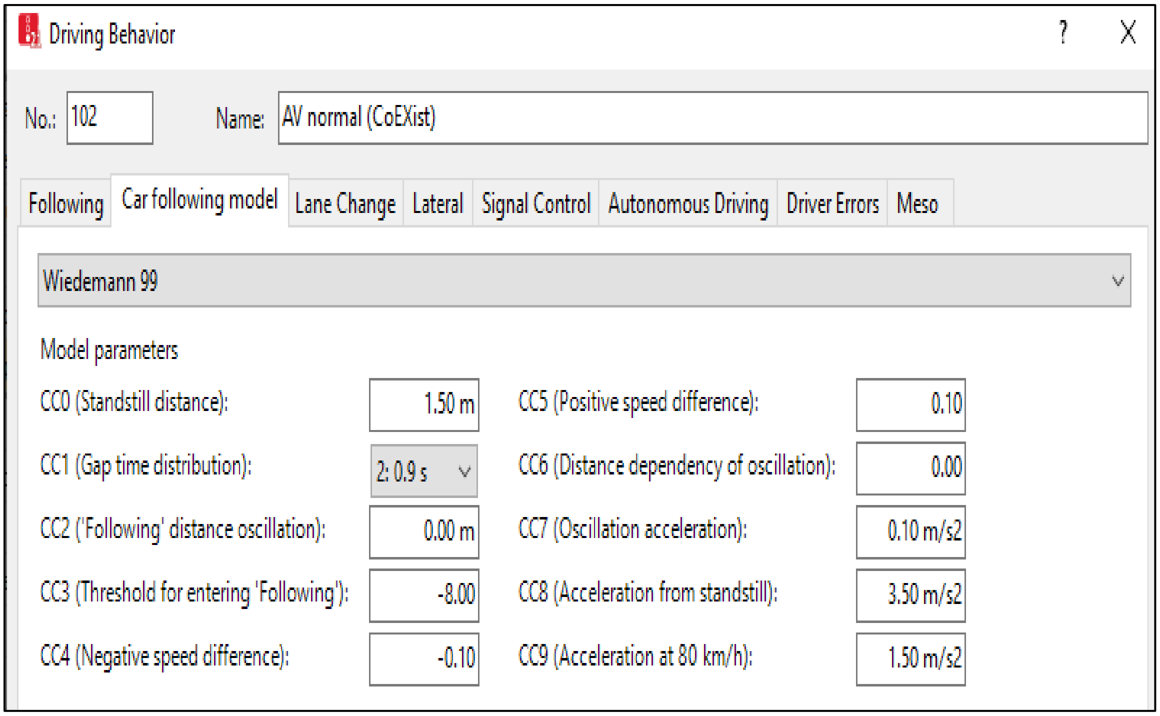
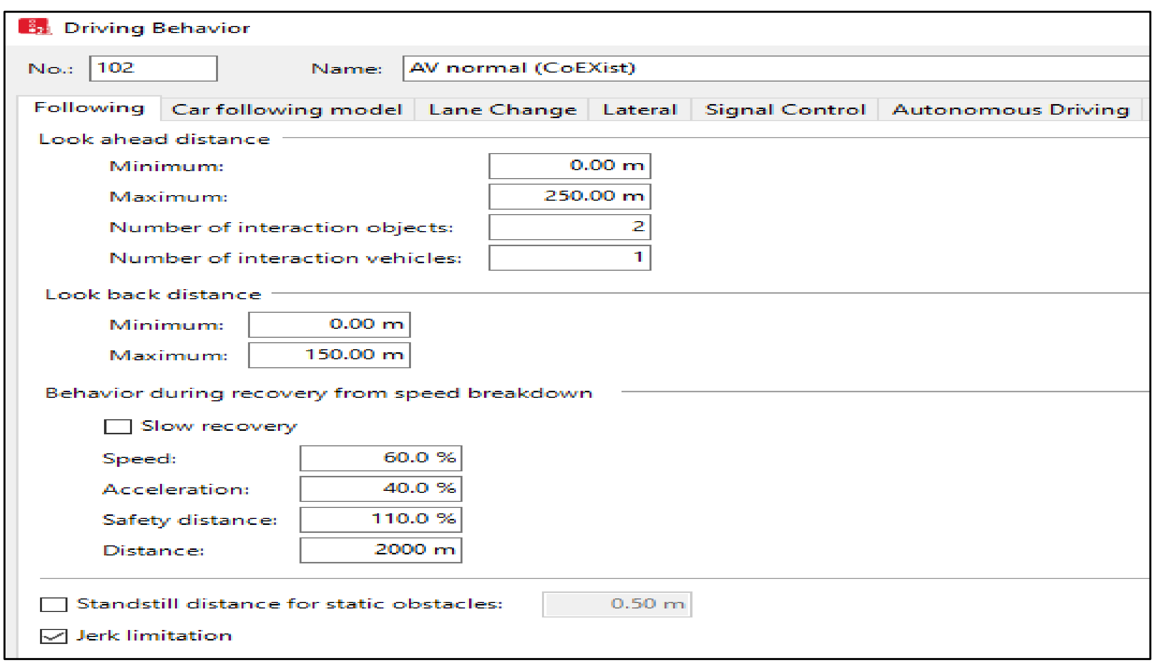
APPENDIX A

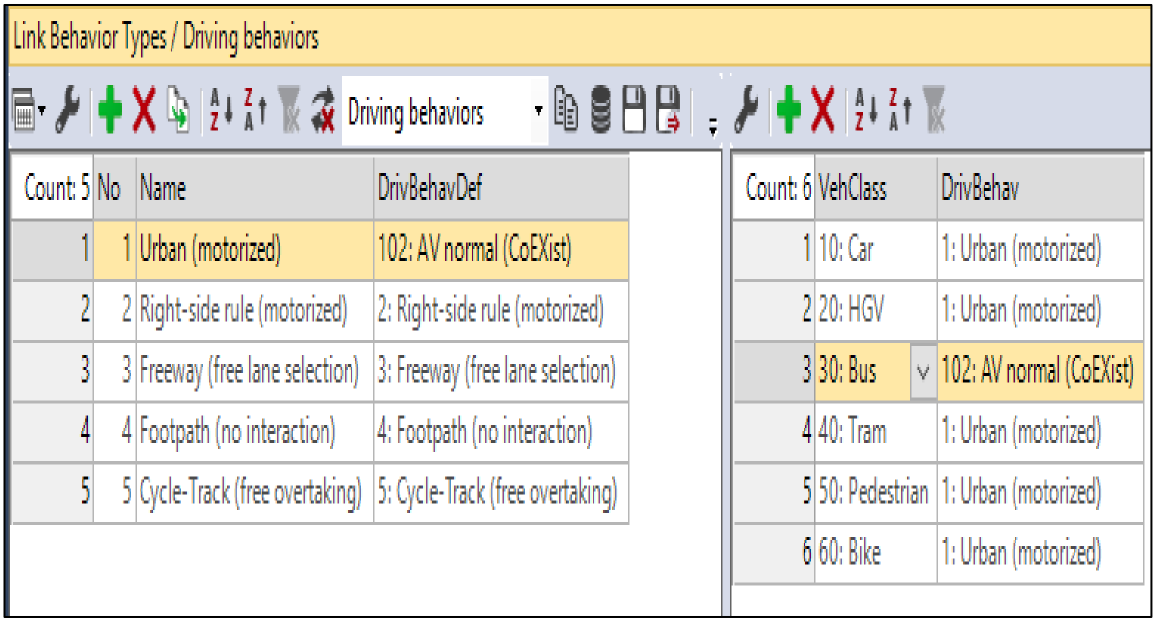
CAV Implementation on PTV VISSIM



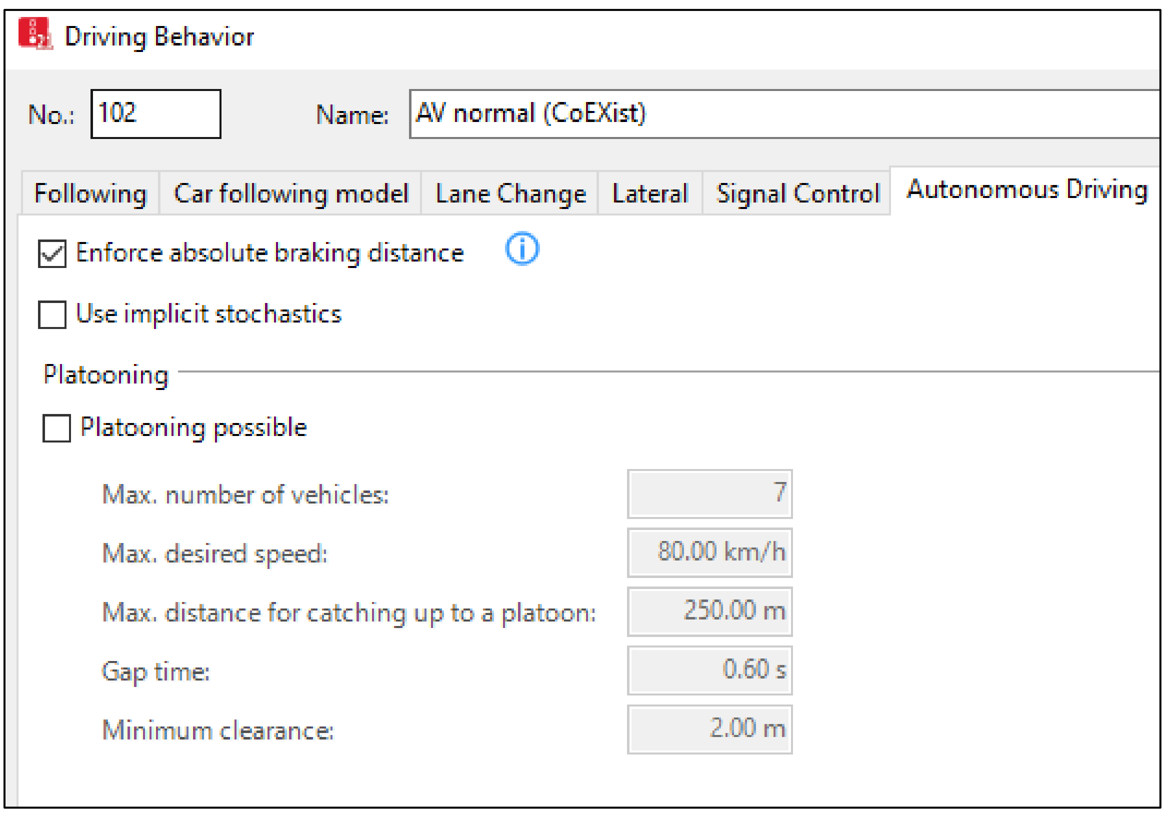
A-1 Wiedemann 99 Car Following Model



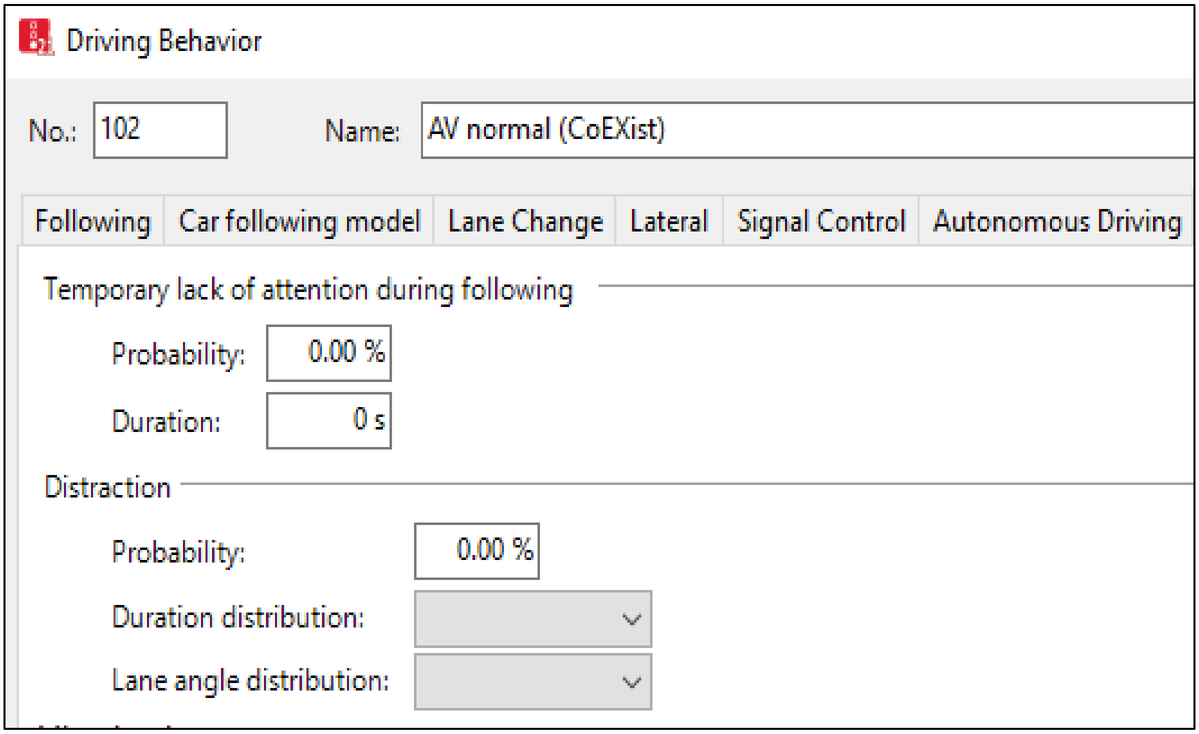
A-2 Vehicle Following Behavior



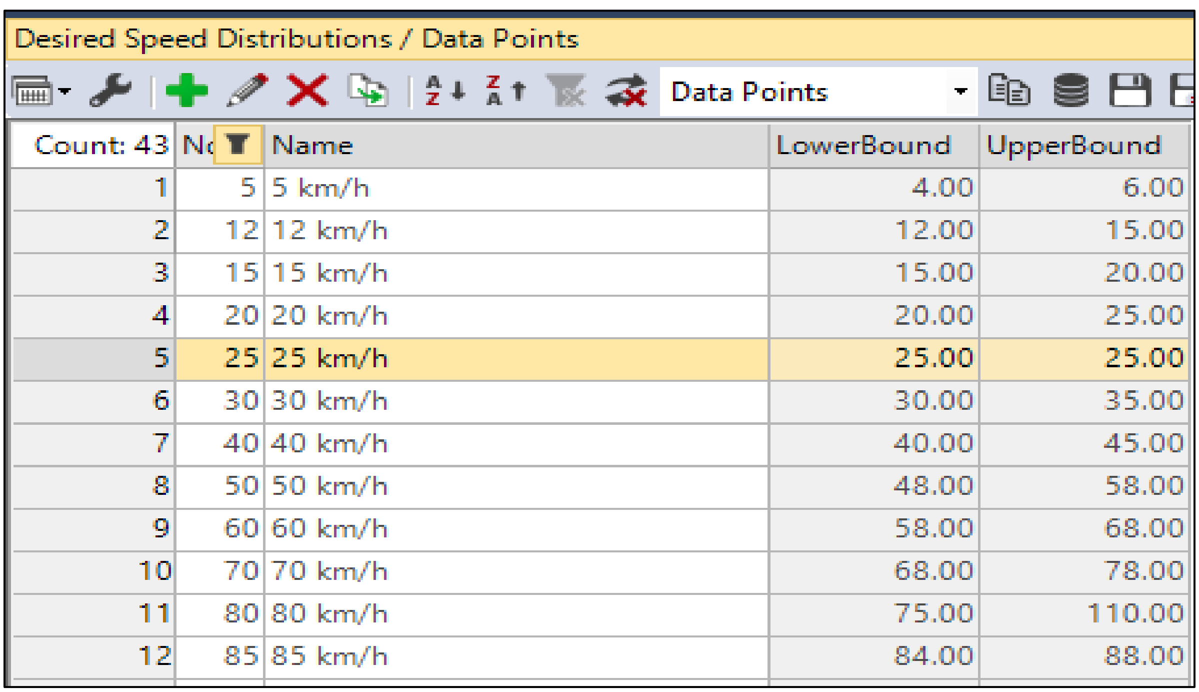
A-3 AV Normal Link Behavior



A-4 Absolute Braking Distance (ABD)

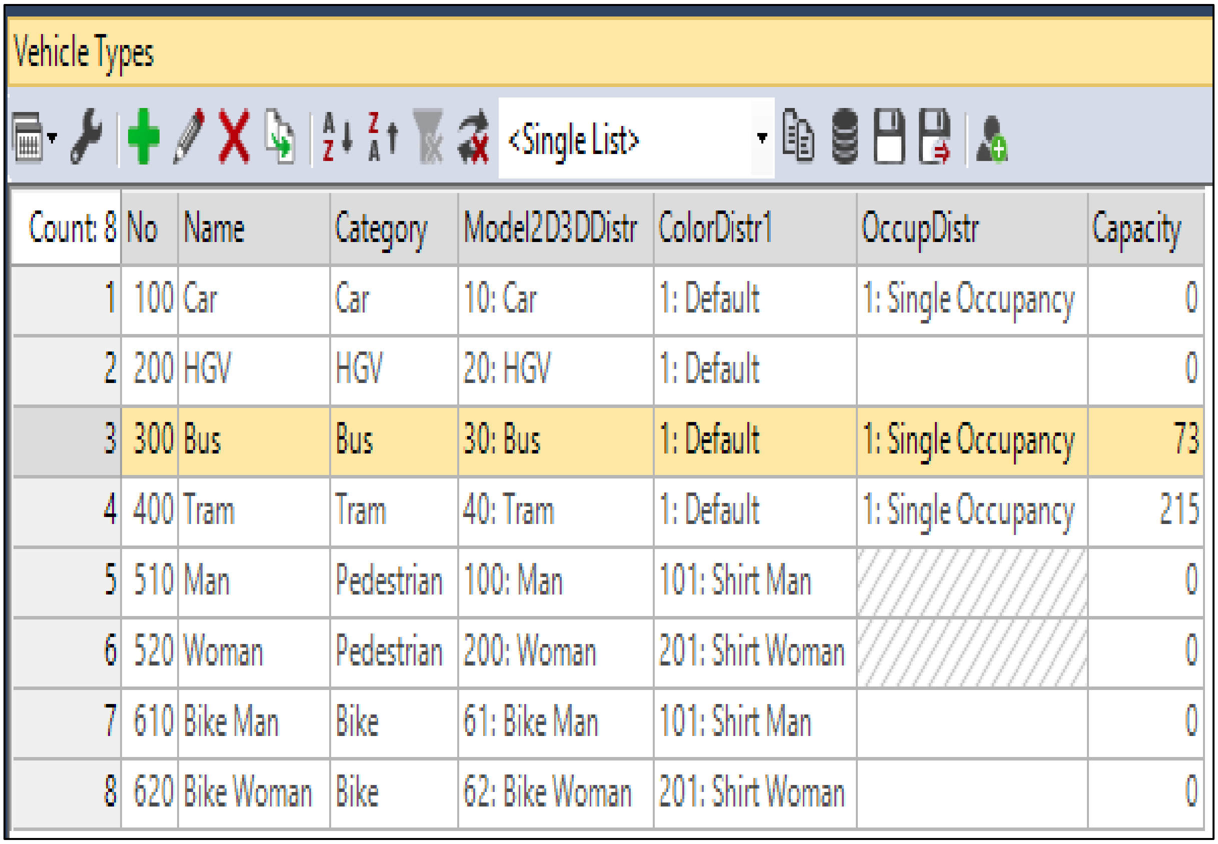


A-5 Error Probability Settings



Count: 43	No	Name	LowerBound	UpperBound
1	5	5 km/h	4.00	6.00
2	12	12 km/h	12.00	15.00
3	15	15 km/h	15.00	20.00
4	20	20 km/h	20.00	25.00
5	25	25 km/h	25.00	25.00
6	30	30 km/h	30.00	35.00
7	40	40 km/h	40.00	45.00
8	50	50 km/h	48.00	58.00
9	60	60 km/h	58.00	68.00
10	70	70 km/h	68.00	78.00
11	80	80 km/h	75.00	110.00
12	85	85 km/h	84.00	88.00

A-6 Desired Speed Distribution


Vehicle Types

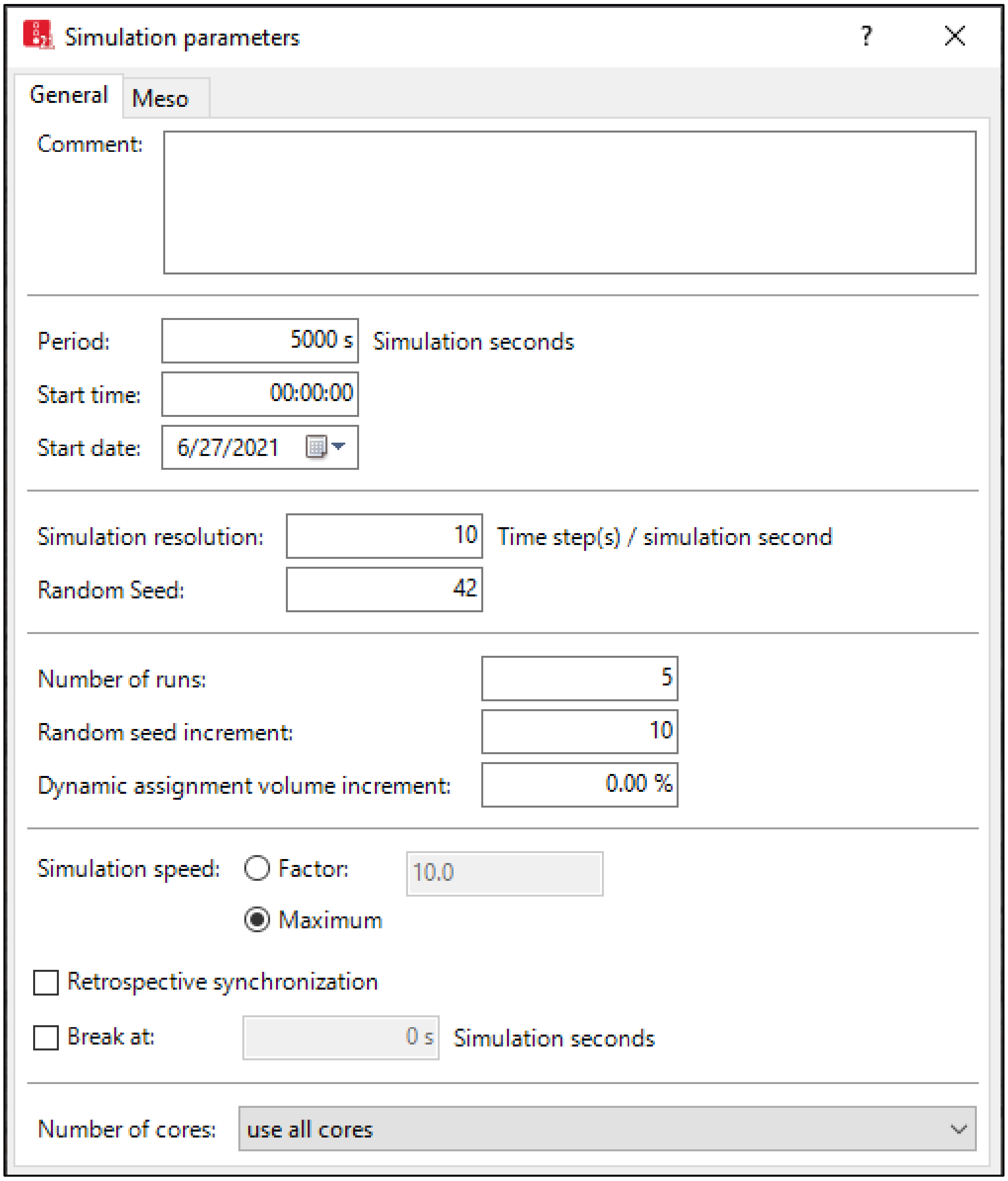
<Single List>

Count: 8	No	Name	Category	Model2D3DDistr	ColorDistr1	OccupDistr	Capacity
1	100	Car	Car	10: Car	1: Default	1: Single Occupancy	0
2	200	HGV	HGV	20: HGV	1: Default		0
3	300	Bus	Bus	30: Bus	1: Default	1: Single Occupancy	73
4	400	Tram	Tram	40: Tram	1: Default	1: Single Occupancy	215
5	510	Man	Pedestrian	100: Man	101: Shirt Man		0
6	520	Woman	Pedestrian	200: Woman	201: Shirt Woman		0
7	610	Bike Man	Bike	61: Bike Man	101: Shirt Man		0
8	620	Bike Woman	Bike	62: Bike Woman	201: Shirt Woman		0

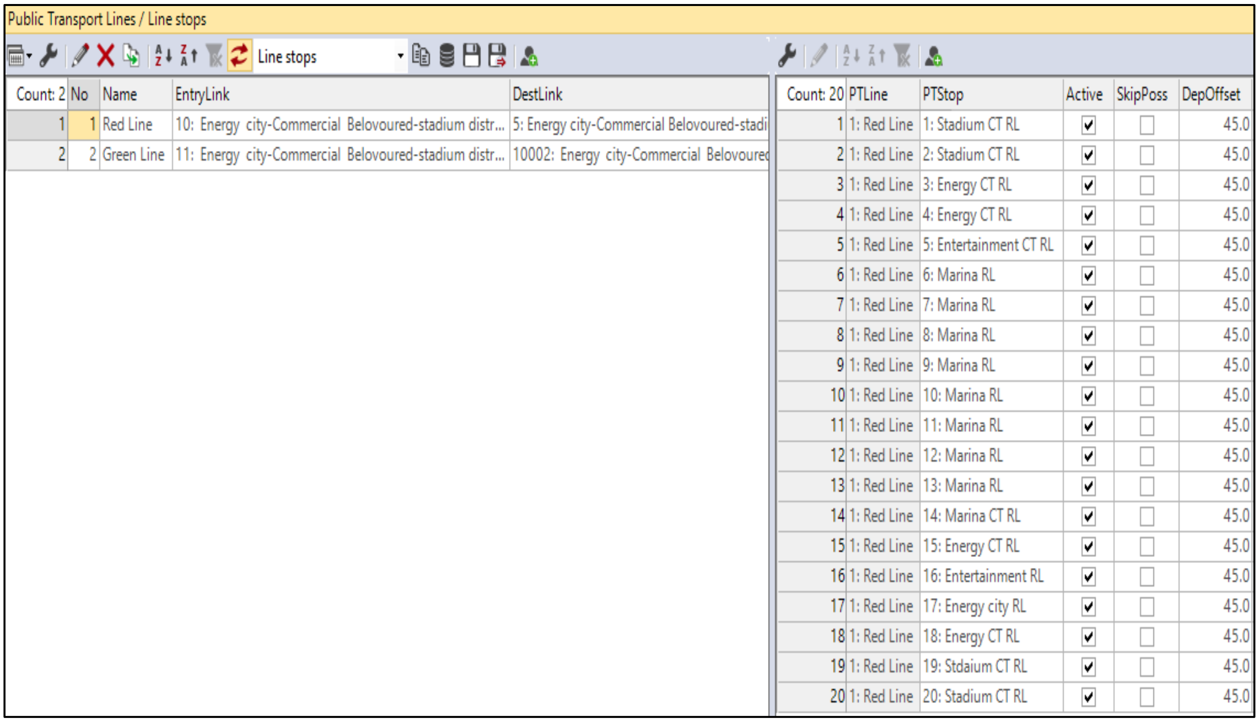
A-7 Vehicle Occupancy Settings

APPENDIX B

Simulation Input Parameters



B-1 Simulation parameters



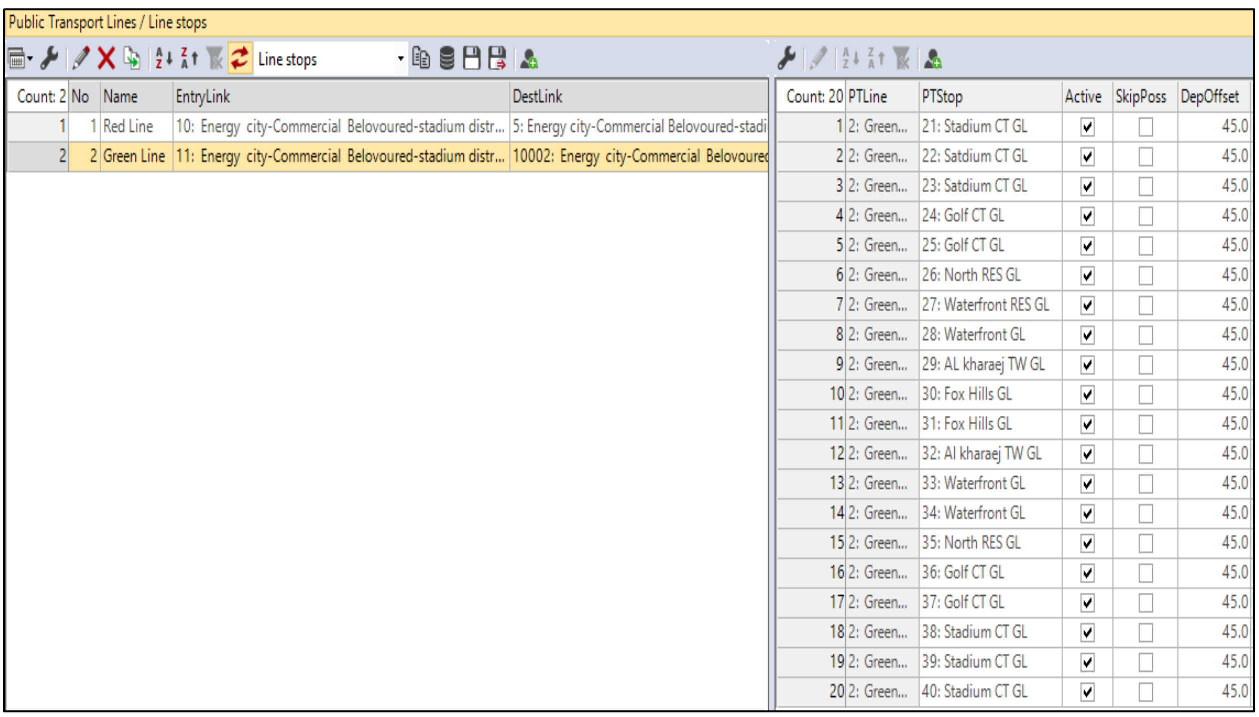
Public Transport Lines / Line stops

Line stops

Count: 2	No	Name	EntryLink	DestLink
1	1	Red Line	10: Energy city-Commercial Belovoured-stadium distr...	5: Energy city-Commercial Belovoured-stadi
2	2	Green Line	11: Energy city-Commercial Belovoured-stadium distr...	10002: Energy city-Commercial Belovoured

Count: 20	PTLine	PTStop	Active	SkipPoss	DepOffset
1	1: Red Line	1: Stadium CT RL	☑	☐	45.0
2	1: Red Line	2: Stadium CT RL	☑	☐	45.0
3	1: Red Line	3: Energy CT RL	☑	☐	45.0
4	1: Red Line	4: Energy CT RL	☑	☐	45.0
5	1: Red Line	5: Entertainment CT RL	☑	☐	45.0
6	1: Red Line	6: Marina RL	☑	☐	45.0
7	1: Red Line	7: Marina RL	☑	☐	45.0
8	1: Red Line	8: Marina RL	☑	☐	45.0
9	1: Red Line	9: Marina RL	☑	☐	45.0
10	1: Red Line	10: Marina RL	☑	☐	45.0
11	1: Red Line	11: Marina RL	☑	☐	45.0
12	1: Red Line	12: Marina RL	☑	☐	45.0
13	1: Red Line	13: Marina RL	☑	☐	45.0
14	1: Red Line	14: Marina CT RL	☑	☐	45.0
15	1: Red Line	15: Energy CT RL	☑	☐	45.0
16	1: Red Line	16: Entertainment RL	☑	☐	45.0
17	1: Red Line	17: Energy city RL	☑	☐	45.0
18	1: Red Line	18: Energy CT RL	☑	☐	45.0
19	1: Red Line	19: Stdaium CT RL	☑	☐	45.0
20	1: Red Line	20: Stadium CT RL	☑	☐	45.0

B-2 Designed Route Red Line



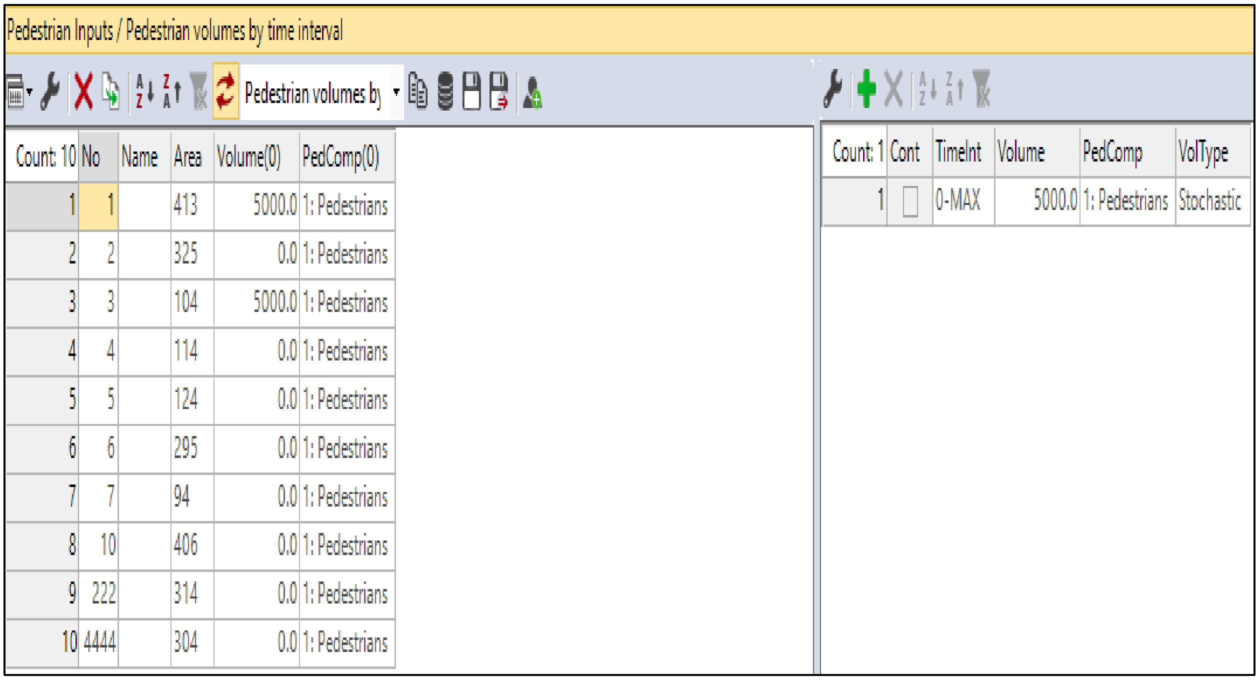
Public Transport Lines / Line stops

Line stops

Count: 2	No	Name	EntryLink	DestLink
1	1	Red Line	10: Energy city-Commercial Belovoured-stadium distr...	5: Energy city-Commercial Belovoured-stadi
2	2	Green Line	11: Energy city-Commercial Belovoured-stadium distr...	10002: Energy city-Commercial Belovoured

Count: 20	PTLine	PTStop	Active	SkipPoss	DepOffset
1	2: Green...	21: Stadium CT GL	☑	☐	45.0
2	2: Green...	22: Satdium CT GL	☑	☐	45.0
3	2: Green...	23: Satdium CT GL	☑	☐	45.0
4	2: Green...	24: Golf CT GL	☑	☐	45.0
5	2: Green...	25: Golf CT GL	☑	☐	45.0
6	2: Green...	26: North RES GL	☑	☐	45.0
7	2: Green...	27: Waterfront RES GL	☑	☐	45.0
8	2: Green...	28: Waterfront GL	☑	☐	45.0
9	2: Green...	29: AL kharaej TW GL	☑	☐	45.0
10	2: Green...	30: Fox Hills GL	☑	☐	45.0
11	2: Green...	31: Fox Hills GL	☑	☐	45.0
12	2: Green...	32: Al kharaej TW GL	☑	☐	45.0
13	2: Green...	33: Waterfront GL	☑	☐	45.0
14	2: Green...	34: Waterfront GL	☑	☐	45.0
15	2: Green...	35: North RES GL	☑	☐	45.0
16	2: Green...	36: Golf CT GL	☑	☐	45.0
17	2: Green...	37: Golf CT GL	☑	☐	45.0
18	2: Green...	38: Stadium CT GL	☑	☐	45.0
19	2: Green...	39: Stadium CT GL	☑	☐	45.0
20	2: Green...	40: Stadium CT GL	☑	☐	45.0

B-3 Designed Route Green Line



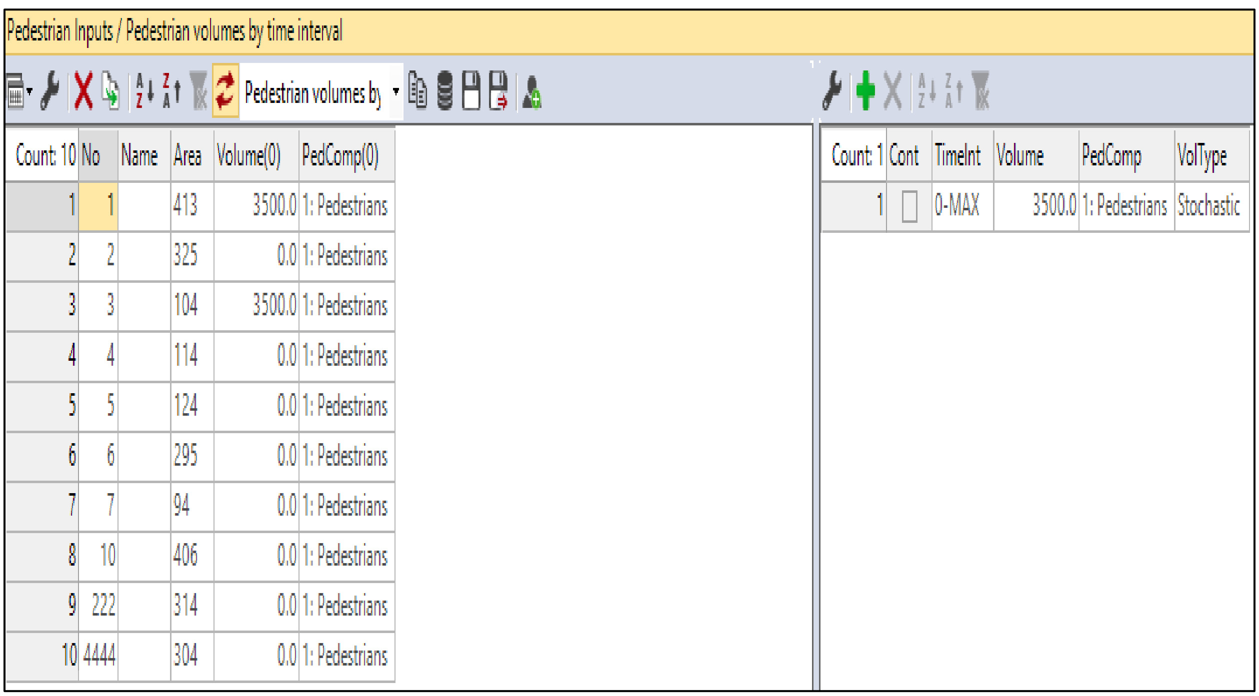
Pedestrian Inputs / Pedestrian volumes by time interval

Pedestrian volumes by

Count: 10	No	Name	Area	Volume(0)	PedComp(0)
1	1		413	5000.0	1: Pedestrians
2	2		325	0.0	1: Pedestrians
3	3		104	5000.0	1: Pedestrians
4	4		114	0.0	1: Pedestrians
5	5		124	0.0	1: Pedestrians
6	6		295	0.0	1: Pedestrians
7	7		94	0.0	1: Pedestrians
8	10		406	0.0	1: Pedestrians
9	222		314	0.0	1: Pedestrians
10	4444		304	0.0	1: Pedestrians

Count: 1	Cont	TimeInt	Volume	PedComp	VolType
1		0-MAX	5000.0	1: Pedestrians	Stochastic

B-4 Pedestrian Input Scenario 1



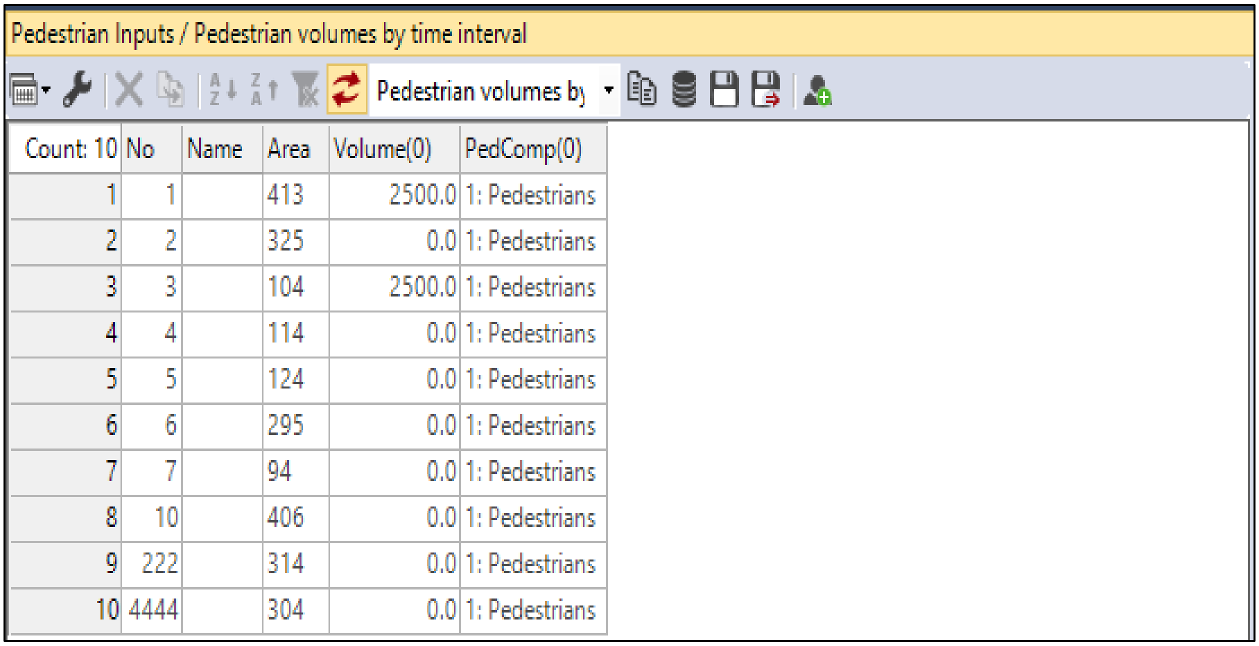
Pedestrian Inputs / Pedestrian volumes by time interval

Pedestrian volumes by

Count: 10	No	Name	Area	Volume(0)	PedComp(0)
1	1		413	3500.0	1: Pedestrians
2	2		325	0.0	1: Pedestrians
3	3		104	3500.0	1: Pedestrians
4	4		114	0.0	1: Pedestrians
5	5		124	0.0	1: Pedestrians
6	6		295	0.0	1: Pedestrians
7	7		94	0.0	1: Pedestrians
8	10		406	0.0	1: Pedestrians
9	222		314	0.0	1: Pedestrians
10	4444		304	0.0	1: Pedestrians

Count: 1	Cont	TimeInt	Volume	PedComp	VolType
1		0-MAX	3500.0	1: Pedestrians	Stochastic

B-5 Pedestrian Input Scenario 2



Count: 10	No	Name	Area	Volume(0)	PedComp(0)
1	1		413	2500.0	1: Pedestrians
2	2		325	0.0	1: Pedestrians
3	3		104	2500.0	1: Pedestrians
4	4		114	0.0	1: Pedestrians
5	5		124	0.0	1: Pedestrians
6	6		295	0.0	1: Pedestrians
7	7		94	0.0	1: Pedestrians
8	10		406	0.0	1: Pedestrians
9	222		314	0.0	1: Pedestrians
10	4444		304	0.0	1: Pedestrians

B-6 Pedestrian Input Scenario 3