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THESIS TITLE

Deployment of Connected Autonomous Vehicles (CAVs) for Mass Transit using Car Sharing Services

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ABSTRACT

CAVs can enhance transportation network capacity, minimize congestion, make travel journeys stress-free, and maximize safety. The implementation of CAV technology occurs through a project-by-project deployment scenario rather than a system-wide rollout. CAVs are implemented initially as pilot programs or installations at specific locations. Deployment in this manner allows the evaluation of CAV applications and the gradual availability of investments. Incorporating CAV deployment for mass-transit application is a crucial area of research, where the CAV development represents a high potential for business markets and service users.

This thesis aims to develop modeling and simulation of scenarios for CAVs car-sharing services in Turin city. A service that will provide users with access to CAV vehicles for movement from fixed pick-up, drop-off points and gives options for urban and sub-urban stops and a possibility to share the ride by subscribing to the service by the dedicated vendor. Integrating scenario planning in CAV deployment for mass transit in such cases provides a better understanding of emerging trends and assists in planning possible future conditions. The modeling and simulation of the proposed scenarios were performed on a multi-modal traffic simulation software to analyze CAV performance in real-world scenarios. The simulation models developed with considerations that support the analysis of traffic-flow patterns, where the results are accumulated and assessed using key performance indicators for the planned strategies. Finally, a case study was formulated based on the methods developed, highlighting the main attributes, proposed approach, actors involved, given the underlying integrating levels.

ACKNOWLEDGEMENT

First and foremost, I want to convey my heartfelt appreciation to Professor Hossam Gaber at Ontario Tech University, who served as a teacher, mentor, and lead supervisor during this work. None of this work would have been possible without his unwavering patience, direction, and inspiration. He has undoubtedly contributed to my growth as an individual and as a researcher providing me with an outstanding example of professionalism and intelligence.

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Finally, I would like to dedicate this work to my parents, who have always believed in me, to achieve my goals - all my friends and family for their support through thick and thin.

Muhammad Sami Ullah Khan

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LIST OF ACRONYMS

3D	3 Dimensional
4G/3G	Fourth Generation/Third Generation
ABD	Absolute Braking Distance
ACC	Adaptive Cruise Control
ADAS	Advanced Driver Assistance System
ADS	Automated Driving System
AI	Artificial Intelligence
ATMA	Autonomous Truck Mounted Attenuator
ATMS	Advanced Traffic Management System
AV	Autonomous Vehicle
CAV	Connected and Autonomous Vehicle
CMS	Changeable Message Sign
CS	Car Sharing
CV	Connected Vehicle
FTA	Federal Transport Agency
GNSS	Global Navigation Satellite Systems
GPS	Global Positioning Systems
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Standards Organization
ITS	Intelligent Transport System
KPIs	Key Performance Indicators
LIDAR	Light Detection and Ranging
LTE	Long Term Evolution
MTC	Mobility Transformation Center
OEMs	Original Equipment Manufacturers

P2P	Peer-to-Peer
PennDOT	Pennsylvania Department of Transportation
PHEV	Plug-in Hybrid Electric Vehicle
PT	Passenger Transport
RPMs	Raised Pavement Markers
SAE	Society of Automotive Engineers
TDM	Transportation Demand Management
TLRT	Traffic Light Recognition Technology
USDOT	United States Department of Transportation
V2C	Vehicle-to-Cloud
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Everything
VSL	Vehicle Speed Limits
Wi-Fi	Wireless Fidelity

1 INTRODUCTION

1.1 CAV Background

CAV technology comprises two components: connected vehicle (CV) and automated vehicle (AV). Distinguishing CAV technology into these two names facilitates basic comprehension of the possibilities accessible in these vehicles. In general, connected cars (CVs) are equipped with low-latency communication technologies such as short-range radios, Wi-Fi, or cellular data connections. CV communication systems enable secure, anonymous, timely, and standardized communication with other adjacent communication equipment. The communications with V2V, V2I, and V2X are all possible. CVs, transportation agencies, and third-party agencies then use the data gained from V2V or V2I communications to increase consumer safety and mobility through the operation of onboard and agency-based applications. While CVs use communication, AVs use a range of embedded technologies that assist, supplement, or completely control the functioning of the individual vehicle. At the same time, it travels the roadway without communicating with other vehicles or infrastructure [1].

Given that a high-level overview of the technology presented, the term 'CAV' will refer to the vehicles and deployment of connected vehicle technology as a whole. In contrast, the term 'CV' will refer to the technologies, communications, and applications that enable both connected vehicles and connected and automated vehicles. While CV and AV technologies work independently, they do not always contradict. On the contrary, the idea projects that automobiles will emerge with seamless integration of connected and automated vehicle technology, giving motorists the most value and advantage [2]. Figure 1 provides a graphical depiction of the individual applications of both CVs and AVs and further depicts the merging of the two technologies [3].

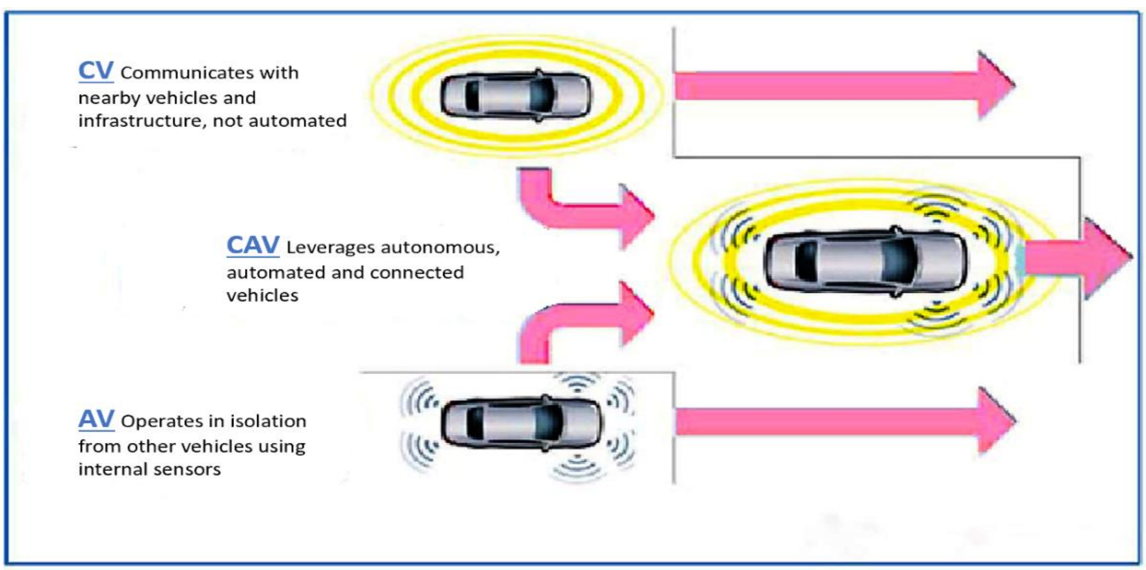

Figure 1 Integration of CV and AV into CAV

1.1.1 CV Technology

CV technology enables the communication between the onboard computer of each vehicle and neighboring vehicles or infrastructure. In simple words, connected vehicles (CV) communicate with one another and also the environment. Our automobile is probably already connected to a greater extent than we realize. Navigation systems currently incorporate functions associated with linked vehicles, such as dynamic route guidance. Through cellular connections (4G LTE/3G), the GPS receives information about congestion ahead on the roads and proposes an alternate route. The National Highway Transportation Safety Administration in the United States of America has previously suggested a rule requiring all new automobiles to include 5.9 GHz-capable equipment to be CV-ready. This technology can eliminate 80 percent of unimpaired crash scenarios, which would result in the annual saving of tens of thousands of lives [1]. The concept of a connected car is to provide relevant information to a driver or a vehicle to assist the driver in making safer or more informed decisions. The use of a "connected car" does not mean that the car makes decisions on the driver's behalf. Rather than that, it provides information to the driver, such as potentially harmful scenarios to avoid.

Without risking individual privacy, transport organizations can obtain vehicle data such as position, speed, and trajectory, allowing for improved traffic flow management. Thus, in addition to communicating with the driver, CVs will communicate with deployment authorities to improve their understanding of current road conditions and generate historical data to aid agencies in better planning and allocating future resources. Transportation authorities can fully engage in the statewide rollout of the connected car system by putting equipment on the roadside that collects and transmits signals to and from these automobiles [2].

1.1.2 AV Technology

Specific vehicles with already equipped autonomous features such as self-parking and collision avoidance are prominent aspects of this technology. However, until a vehicle can autonomously drive itself, it cannot be termed an autonomous vehicle (AV). A fully autonomous car does not operate by a human driver; instead, controlled by a computer. The majority of manufacturers will gradually introduce varying degrees of autonomy until the general public has validated and accepted it extensively.

Compared to connected vehicles, transportation organizations have less control over the deployment of autonomous vehicles and the technologies used in them; this is determined mainly by the private sectors that design them and respond to market demands. However, organizations can take specific immediate steps to aid in the adoption of autonomous vehicles. For instance, several authorities are already enhancing road infrastructures to help autonomous vehicles recognizing the route. Additionally, agencies can encourage and support policies that promote the adoption of antivirus software, like certification and licensing requirements and adhering to distance requirements [4].

Autonomous vehicles do not require connected car technologies to operate because they are capable of self-navigating the transport network. On the other side, CV technologies provide crucial data about the road ahead, allowing for route changes in reaction to new information such as traffic jams or road obstructions [3].

1.1.3 Integrating CVs and AVs

With the incorporation of CV technology, AVs will become safer, quicker, and more effective. Additionally, most autonomous vehicles will require some form of internet connectivity in order to maintain software and data collection. Since autonomous vehicles rely on knowledge of their path; changes to the roadside, new development, or construction would necessitate the sort of accurate information transfer supplied by CV technology. While this is a difficult challenge, deployment organizations must assist both connected and autonomous vehicles by maximizing technology utilization, establishing specified deployment timelines, and addressing regional/geographic demands [1].

1.2 CAV Technology Timeline

Globally, the transportation departments of various advanced countries collaborate to conduct research, standardize, and complete early deployments of CAV technologies before the private sector. Global authorities frequently use CAV systems for V2I applications in areas such as more competent work zones, addressing location-specific safety problems, evaluating, and monitoring pavement conditions, and broadcasting real-time traffic light phase and timing information. While various critical considerations on standardized communication protocols, procedures, and security remain, the industry prediction for CAV deployment remains intact and described in the following general timeframes: near, mid, and long term [3].

1.2.1 Short Term

The short term implementation of CAV deployment covers the following aspects [3]:

- The penetration rate is limited to testbed locations and the early deployment of private vehicles.
- Gradual availability of technologies for new car models or purchases by the general public is implemented.
- CV data/decision applications are still being developed and evaluated for their utility.

1.2.2 Middle Term

The middle term implementation plan of CAV deployment covers the following aspects [3]:

- Gradual penetration increases, allowing for increased data flow from automobiles to the cloud.
- Additional cars and infrastructure.
- Increased application development and realization of public benefits motivate policymakers to increase the rate of deployment.
- Agencies begin to disseminate data more widely, allowing for enhanced decision-making.
- Optimization of processes and analysis of data analytics.
- CAVs begin to appear on public roadways.

1.2.3 Long Term

The Long term implementation plan of CAV deployment covers the following aspects [3]:

- High penetration rates of CAVs on roadways enable CAVs to reach their full potential and capabilities for cooperative automation.
- Older ITS and transportation technology solutions may be phased out.
- Agencies start leveraging sophisticated data streams, predictive travel technologies, and demand forecasting.
- Formalization of management tactics and other systems of decision support to be carried out.

1.3 Autonomy Level in Vehicles

We must be precise in our language when discussing various stages of autonomous vehicle technologies, from driver assistance to totally automated driverless vehicles. SAE International Standard J3016 [1] defines the taxonomy to be utilized when discussing the various levels of autonomy, as described below.

Two divisions within the levels help to define the possibilities of vehicle autonomy:

1. A human driver monitors the driving environment (Level 0-2)

2. The automated driving system monitors the driving environment (Level 3-5)

1.3.1 Human Driver Monitors Driving Environment

This corresponds to three levels, from 0 to 2, and is enumerated below.

LEVEL 0 – ZERO AUTOMATION

The human driver has complete control over all phases of the driving process.

LEVEL 1 – ASSISTANCE TO THE DRIVER

The driver aid system assists the human driver with steering and acceleration/deceleration.

LEVEL 2 – SEMI-AUTOMATIC MANAGEMENT

The driver assistance system is responsible for steering and acceleration/deceleration, while the human driver is responsible for all other functions.

1.3.2 Automated Driving System Monitors Driving Environment

This corresponds to three levels, from 3 to 5, and is enumerated below.

LEVEL 3 – AUTOMATION ON A CONDITIONAL BASIS

The automated driving system is responsible for all aspects of dynamic driving in the expectation that the human driver will respond adequately to an intervention request.

LEVEL 4 – ULTRA-AUTOMATIC

Even if a human driver does not respond adequately to an intervention request, the automated driving system performs all components of the dynamic driving task.

LEVEL 5 – COMPLETE AUTHORIZATION

The automated driving system can perform all aspects of dynamic driving tasks under all road and environmental situations.

1.4 CAV Deployment Challenges

CAV deployment for mass transit has the potential to enhance transportation safety, sustainability, and efficiency. However, these prospects come with challenges, [5] specifically management and deployment related [6]. Some of the major challenges are enlisted below.

1.4.1 Management Related

The potential management related challenges that can occur when CAVs deployed widely are briefly enlisted below:

• Demographic: the geographical and socioeconomic elements that influence the composition of a population.

• Market size: the total number of cars, both autonomous and conventional.

• External environment: road network and physical environment, as well as their CAV readiness.

• Perception/adoption rate: the population's attitude or view of CAVs, predicts future acceptance.

• Regulations: legislation enacted in a particular market to demand the ownership or sale of CAVs, as well as the creation of necessary infrastructure.

• Willingness to pay (WTP): a cost-benefit analysis of whether the population believes the associated benefits of acquiring CAVs outweigh the financial expense.

1.4.2 Deployment Related

The potential deployment related challenges that can occur when CAVs deployed widely are briefly enlisted below:

• Recurrence and control of congestion.

• Safety of pedestrians and cyclists.

• Predictability of travel times.

• Intersections management and operations.

• Emergency Response, Incidents, and Evacuations.

• CAVs effectiveness in a mixed-vehicle setting.

1.5 Problem Statement

CAV Technology can reduce the footprint of vehicular travel, medium, and low-density transit while creating space for safe and inviting infrastructure for walking and cycling. CAVs are implemented initially as pilot programs or installations at specific locations. Incorporating CAV deployment for mass-transit application is a crucial area of research, where the CAV development represents a high potential for business markets and service users.

At the same time, the strategic planning for CAV deployment for a mass transit service should effectively address the destructive potential for heterogeneous traffic, travel time management, and on-street congestion that may result from CAV Technology deployment [6]. It is imminent that the parameters settling these challenges be thoroughly discussed. Integrating scenario planning in CAV deployment for mass transit services provides a better understanding of emerging trends and assists in planning possible future conditions.

This thesis aims to develop modeling and simulation scenarios for CAVs car-sharing services in Turin city, explicitly highlighting the scenario planning for the said deployment. Moreover, the study would then follow a simulation analysis with the help of a multi-modal traffic simulation software developed with considerations that support the analysis of traffic-flow patterns, which helps an effective comparison of the CAV deployment. Finally, a case study formulated based on the work developed highlights main attributes, proposed approach, actors involved, and underlying integrating levels.

1.6 Thesis Objectives

In accordance with the preceding critical considerations and the problem statement identified, the following research objectives are outlined:

1) Analyze, assess, and discuss the existing state of practices for CAV deployment, integration, and implementation.
2) A model scenario planned and designed for CAV deployment of a Car-sharing service for the mass-transit case study.
3) Simulation analysis of the developed scenarios with the help of a multi-modal traffic simulation software.
4) Result analysis using essential performance measures for effective comparison of the proposed CAV deployment case study.

1.7 Thesis Outline

The thesis consists of six chapters. The first chapter includes a brief introduction to the topic and the challenges faced concerning CAV deployment. It also describes the thesis problem statement and objectives. The second chapter is dedicated to the existing literature review related to the topic of discussion. In the third chapter, the process of scenario planning and design is described in detail. The fourth chapter describes the simulation of the planned scenarios, key parameters, and statistical data. Also, the compilation of results and discussion are presented in this chapter. The fifth chapter consists of case study development, its goals, and the approach used. The sequence diagram of the case study is also presented. In the last chapter, the conclusion and recommendations for future work are described. The contributions and limitations during the study are also enlisted. The outline of the thesis is shown in figure 2.

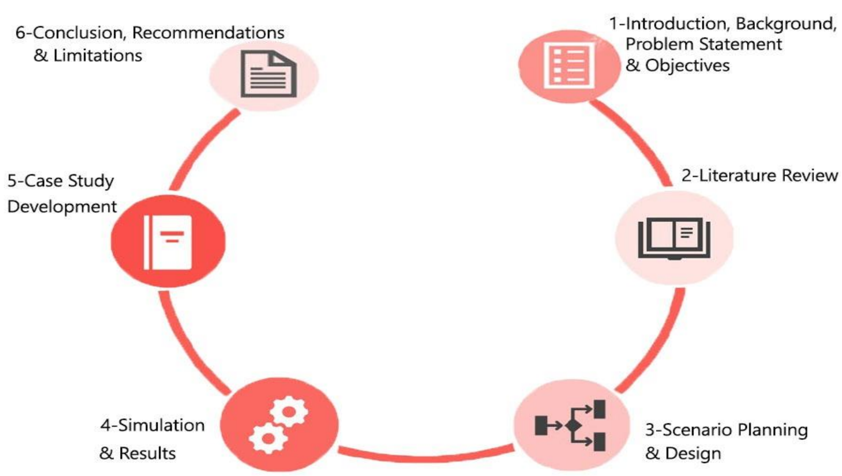

Figure 2 Thesis Outline

2 LITERATURE REVIEW

2.1 Existing Practices for CVs/AVs/CAVs

The existing state of practices helps us assess the criticalities of deployment more concretely. CAV deployment occurs through a project-by-project deployment scenario rather than a system-wide rollout. Typically, CAVs are implemented initially as pilot programs or installations at specific locations. Deployment in this manner allows the evaluation of CAV applications and the gradual availability of investments [7]. Some of the effective practices are described as follows.

2.1.1 Connected Smart Work Zone in Pennsylvania

Pennsylvania Department of Transportation (PennDOT) recently completed a Connected Smart Work Zone project along with the Northeast expansion in Pennsylvania. The Project employed live construction sites to demonstrate intelligent work zone technology to exchange queue, delay, and incident information within the Trip-Talk application. Standard work zone equipment is integrated into the system in many ways, some of which are noted below following a review of the PennDOT case study [8]. The department included Variable Speed Limits (VSL) technology, allowing for dynamic and static displays of speed limits dependent on project requirements. This method increased worker safety by restricting exposure and enabling technology to slow down road users within work zones. PennDOT used permanent ramp meters in its Advance Traffic Management System (ATMs) and completed a pilot deployment in a work zone that demonstrates the ability to implement both static and dynamic ramp metering regardless of the period required[9].

PennDOT has identified the following applications to improve the accuracy, timeliness, and relevance of traffic data [8].

<u>Trip Time Messaging</u> — With recent advancements in third-party probe data for reporting speeds, the department successfully established and provided work zone travel-time information using the same ATMS Travel-Time messaging module.

<u>Queue Warning Systems</u> — This program can be set to leverage PennDOT's ATMS-connected Changeable Message Signs (CMS). By incorporating this logic into a work zone, real-time automated slowdown and queue messages can be transmitted via probe data. Historically, these types of devices might be installed with much effort placed on physical detection location. As a result, a new application was developed to employ both field detectors and probe data to give critical queue messages.

<u>Integrated Corridor Management</u> - PennDOT created a method for evaluating multiple routes and displaying pertinent traveler information. It enables road users to make informed choices when navigating between two parallel corridors that are identical.

2.1.1.1 Case Synopsis

PennDOT's approach to work zone safety and mobility through this more holistic deployment strategy benefits road users, industry partners, designers, and internal employees by providing clarity. Additionally, this strategy aids stakeholders in comprehending the future planning, design, and implementation of these technologies. The ATMS software and its effective management by Traffic Management Centers enable a greater emphasis on automated messaging, providing road users with more accurate, timely, and relevant information to make informed decisions while traveling through PennDOT's Work Zones [8]. The department continues to prepare for compliance with the Work Zone Data Exchange Standard and some of the more advanced CAV applications; this work zone approach prepared PennDOT to provide appropriate information to road users in order for them to make actionable and informed decisions.

Framework Table adapted from the Pennsylvania Department of Transportation's Case Study of the Integrated Smart Work Zone Initiative is presented below [9].

Table 1 Framework for PennDOT Case Study

FRAMEWORK
Indicate the relationship between speed, speeding, and safety
Safe and credible speed limits are modeled in light of the road hierarchy
Governmental agencies and stakeholders collaborating closely for increased road safety
The road design is affiliated with other engineering measures
Assuring that speed limits adhere to modeling and design of awareness measures with a specific purpose
The promotion of viable vehicle technologies is necessary to reduce and manage over speeding

2.1.2 China's CAV Driving Testing Zones

Following Guangzhou's pilot program allowing connected and automated cars (CAVs) to carry passengers at the end of 2018, other Chinese cities have begun enacting new road testing regulations to give self-driving vehicles the green light to conduct passenger-carrying road tests[10].

A new 40-square-kilometer area has been designated for testing self-driving vehicles with passengers, as the Chinese capital city works to expand the technology's applicability. For the tests, the city opened many highways totaling around 325 kilometers in the Beijing Economic-Technological Development Region in the southeast suburb, spanning practically the entire area except for areas including schools, hospitals, and office complexes [11]. Among the passenger-carrying testing standards currently followed in China, Shanghai's standards contain the most comprehensive requirements for conducting passenger-carrying tests, including specific privacy protections for passengers and template application forms. As a result, it is reasonable to predict that other cities currently considering passenger-carrying testing laws will likely model theirs after Shanghai's to facilitate the future commercialization of CAVs [11].

Passenger Carrying Testing in Guangzhou

The program was named "Guidance on Road Testing for Connected and Autonomous Vehicles." It incorporated provisions for self-driving vehicle testing with passengers in its initial policy design.

AA of Pilot Materialization in Shanghai and Changsha

The program, dubbed "Testing Management V2.0," was designed to address management measures for CAV Vehicles Road testing, application, and assessment (AA) of pilot materialization.

The detailed table from the case study of the driving testing zone is summarized below [12].

Table 2 China's CAV Testing Zone Criteria

REQUIREMENTS	**DETAILS**
PRE-ESSENTIAL REQUIREMENTS	-Testing organizations must complete a certain number of tests over specified distances without causing traffic accidents or losing control. -The testing company must have secured road testing permits in Shanghai for at least three vehicles. -Each vehicle must have been evaluated over an average distance of 1,000 kilometers. -Results of tests demonstrating that the automobiles have not been involved in any traffic accidents or infractions of traffic laws. -The automobiles must have been evaluated and passed mandatory testing at least 30 times at the designated enclosed locations.
TEST ROADS	- Trial Testing was restricted to designated and dedicated routes.
NUMBER OF CARS	- Automobiles Testing businesses can seek permission to test up to 30 cars in Guangzhou and Changsha, or up to 50 cars in Shanghai, on their initial application. All cities permit testing businesses to increase the number of testing vehicles if their vehicles function without causing traffic accidents or losing control for six months. To qualify for this increase in Shanghai, the applicant must complete testing for each car over an average distance of no less than 5,000 kilometers.
DRIVER	- It was vital to have a person in the automobile at all times, ready to take charge if necessary.
INSURANCE AND ASSOCIATED COSTS	- It was mandated that all program companies provide necessary and essential insurance to all parties involved at no cost. The testing phase is non-commercial, and corporations are not permitted to benefit from it.

2.1.2.1 Case Synopsis

Table 2 above demonstrates that the rules in these three cities are remarkably similar. Guangzhou and Changsha place stricter rules on testing organizations, requiring them to adhere to particular distance thresholds while testing their vehicles. In contrast, Shanghai requires each vehicle to be tested over a set distance and pass functional tests. Additionally, Shanghai invites testing businesses to apply for more passenger-carrying CAVs to be tested in its initial application. Guangzhou has opened around 50 kilometers of roads to date for CAV testing by testing businesses in test roads. Since 16 September 2019, Shanghai has permitted CAV testing on 55 kilometers of highways. On the other side, Changsha plans to test CAVs on 100 kilometers of intelligent highways and 135 city streets. Although it is unknown whether these routes can be used for passenger-carrying experiments, it is believed that additional routes will become available in the future. These specific details were mentioned in the literature reviewed [12].

2.1.3 Peugeot's Initiative for Self-Driving Vehicles

Peugeot's concept automobile was created to cater to the owner's needs. A concept car is an actual automobile that has been modified to demonstrate a future or upcoming technology. The prototype car features four distinct driving modes: two for active driving and two for self-driving, as depicted in figure 3 [10]. The figure is formulated from the data provided on the dashboard of this self-driving initiative from Peugeot [13].

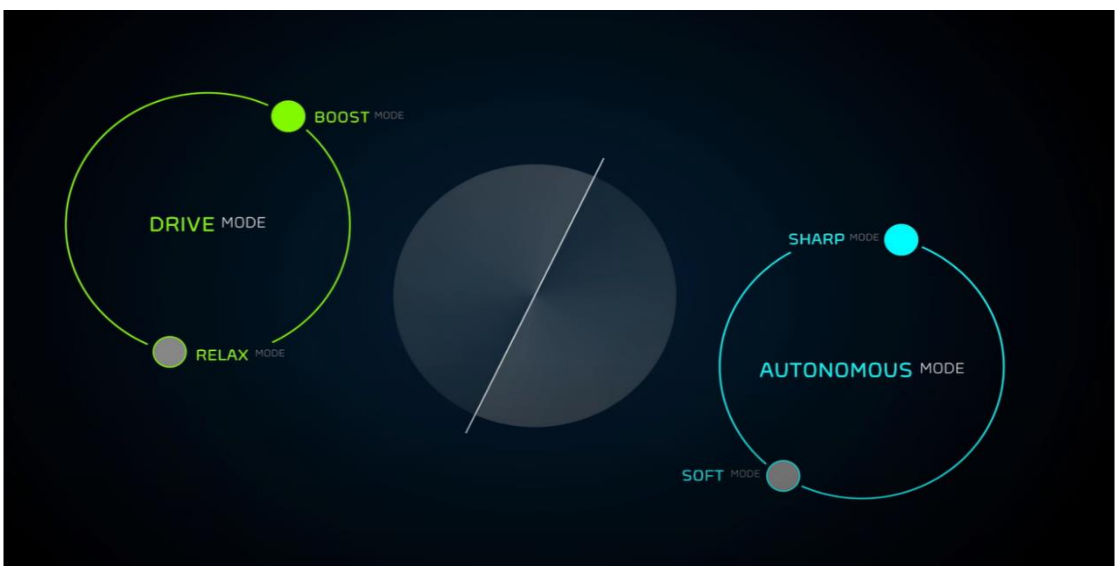

Figure 3 Driving modes of PEUGEOT Self-driving Car

Drive Boost is the active-driving mode for a completely dynamic drive, while Drive Relax assists the driver with modern driving aid technologies. Additionally, Autonomous Sharp is a design for daily commuting. It optimizes journey times through precise, efficient road management, while

Autonomous Soft is designed for comfort and lets passengers watch a film, read, or rest during longer rides. In Drive mode, the holographic cluster displays vehicle information such as speed, the split of energy between the two energies used in the power chain, and battery level. The computerized rear-view mirror warns the driver when a vehicle enters the blind spot [13].

These characteristics include more information in Autonomous mode, which becomes increasingly important as time becomes the only concept that truly matters. Each passenger has access to the time, mileage traveled thus far, and remaining journey time. By switching between driving modes, the onboard atmosphere changes. Apart from the information displayed, the seat arrangements, illumination, and audio options can also be modified [14].

2.1.3.1 Case Synopsis

The vehicle is pre-configured with various functions, including driving mode, seat and interface settings, ambient lighting, and a stereo system. However, the driver retains complete control and can drive manually or allow the car to drive itself in autonomous mode. Additionally, Peugeot's car includes a built-in Internet-of-Things platform from Samsung that connects the vehicle to the user's cloud. It creates a user profile using deep learning technology, connects to the user's devices daily, and gathers the user data. The vehicle incorporates data from the user's smartphone or home automation system [10]. Peugeot feels that the automobile is a valuable source of information because it is with us throughout the day and is familiar with our regular routes, favorite destinations, and driving style. The goal of this initiative was to gather this data and use it to draw out an instinctive response [14].

2.1.4 Audi’s TLRT Approach

The technology of Traffic Light Recognition is a type of connectivity that falls under the category of V2I. This informs vehicles about the signal time phases as they approach a signalized intersection. The technology informs the driver of the required speed to pass through the intersection on a green light, or they may have to reduce their speed to get safely at the intersection before the light turns red. When a driver is stopped at a red signal, a countdown is also displayed. The device helps drivers save money and time by lowering their fuel usage and pollutants [14]. Drivers have a greater sense of control with the Traffic Light Information function. They drive more efficiently and with greater confidence since they know 250 meters ahead of time to make it through on green [5].

The traffic light phase assistant indicates that a connection has been established between the vehicle and the traffic light. The arrow symbol indicates which line has been detected, and the display of recommended speed to get a green light without having to stop is illustrated. The display in the onboard computer assistant indicates the remaining red time. It helps to inform the driver about how much waiting time at a red light (rest) until the next green phase. These assistant features proved pivotal in travel time management and recognition and is shown in Figures 4 and 5 [14].

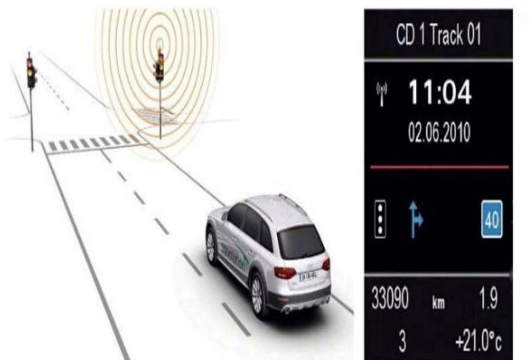

Figure 5 AUDI's Traffic light phase assistant

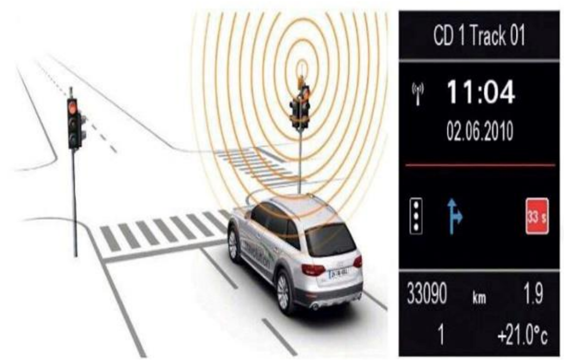

Figure 4 AUDI's Onboard display assistant

2.1.4.1 Case Synopsis

This technology requires very intricate collaboration with local authorities and is presently used in Berlin at 1,000 signalized intersections. Additionally, it is being tested in the cities of Las Vegas and Verona. Urban traffic will benefit in the long run. When cars transmit anonymized data to the city, traffic signals may operate with greater flexibility. Every driver is familiar with the following scenario: late at night, waiting at a red light - with no other automobile in sight far and wide. Then, networked traffic signals would respond to demand [14].

2.1.5 City Mobil2 Program

The City Mobil2 program is an EU-funded initiative to test CAV systems across Europe. The program's primary purpose is to determine whether autonomous vehicles can supplement public transportation networks by bridging the first & last-mile interconnections [15] [16].

The CityMobil2 work plan was divided into two sections [15].

<u>Phase I</u>

During the study phase, 12 cities examined Automated Road Transport Systems (ARTS) integration into their communities and submitted bids to host a demonstration. Simultaneously, the research team developed technical specifications for the ARTS fleets utilized in the Project's demonstrations. The consortium's five ARTS manufacturing partners prepared bids following these standards. Two fleets of six and ten passenger vehicles opted.

<u>Phase II</u>

During the demonstration phase, two procurement fleets were deployed in seven selected cities for varying durations of time to provide real-world transportation services.

2.1.5.1 Case Synopsis

CityMobil2 described where these automated systems should operate and how roadways should be adapted to be as safe as a rail but as adaptable as vehicles. This also introduced two new concepts: the AV, which is a conventional road vehicle equipped with an increasing number of ADA Systems (ADAS) and which, one day, will permit the driver to be distracted, or even be absent; and the Cyber-Car which is a vehicle that is part of an ARTS and does not require a driver and can drive itself [15].

2.1.6 ATMA Demonstration

Royal Truck and the South West Regional Institute (SWRI) showcased the Autonomous Truck Mounted Attenuator. The ATMA vehicle incorporated a safety element known as an attenuator, which attaches to the rear of a truck and absorbs impact in the case of a vehicle collision. Along with remote driving, the truck employs "leader-follower" technology, enabling it to follow other vehicles by copying their speed and turns [17].

The ATMA is guided by a leader vehicle that broadcasts high-precision position, speed, and heading data. The ATMA uses steering, throttle, and braking actuators to mirror the leader's motions. The ATMA's front-mounted radar detects obstacles. ATMAs are designed to deflect vehicles and are frequently struck, increasing the danger of their drivers being involved in a crash [18]. ATMAs utilize self-driving technology to eliminate the need for a driver in the vehicle, removing them from danger while yet efficiently protecting roadside personnel. Installation of communications and GPS antennae, a control module, and emergency stop controls are required on the leader cars [18].

Important Metrics [18]

Constant Gap - The distance between the leading and following vehicles must be field-adjustable.

Traffic Signals - If the leading car enters an intersection during a yellow/all-red interval, would the following car continue through the intersection, even on red, or will it stop.

Turn Signal Activation - Is the turn signal of the following vehicle activated concurrently with the lead car's turn signal.

Around Corners Radar – How does the system react when confronted with a tight corner? The following vehicle should be able to identify the leading car as an obstruction and stop.

GPS-Disabled Environments — The system must operate in areas where GPS signals are unavailable, such as under overpasses or tunnels.

Maintenance - What are the required maintenance procedures? The system should have ongoing software maintenance in addition to routine hardware maintenance.

2.1.6.1 Case Synopsis

Mostly slow-moving operations (7mph to 15mph) were demonstrated in the study. The paint truck is especially well-suited for testing purposes due to the inclusion of a "doghouse" in the rear, which provides an additional layer of human monitoring. In the future, this technology may be customized to do tasks such as sweeping, mowing, weed spraying, traffic management, and the installation of Raised Pavement Markers (RPMs). Although the following vehicle systems are pre-installed on new vehicles, they can also be retrofitted into existing TMAs [17].

2.1.7 Google Chauffeur Privé

According to Google Cloud website data; Google, from the last decade, has openly trialing its AV technologies with the use of its Cloud Software, and over 10 million kilometers [19] have been traveled by various AVs and CVs powered by Chauffeur Privé software.

The AVs monitor their surroundings with various lasers and sensors, relying on data from pre-programmed routes for understanding road facilities such as traffic signals and crossings.

Chauffeur Privé leverages Google Compute Engine, Google Cloud SQL, and other Google Cloud Platform capabilities to run a robust and multi-cloud system and execute requests in real-time, ensuring that its drivers remain on the road [19].

2.1.7.1 Case Synopsis

The Chauffeur software was crucial, particularly in implementing and deploying AVs on public highways. The apparent outcomes, as mentioned on the cloud google website [19] are as follows:

• Google Compute Engine powers its monitoring stack for real-time processing.

• Facilitates monitoring and management with Google Groups access.

• Integrates into a redundant, multi-cloud environment, assisting in the maintenance of high availability.

2.1.8 M City, Michigan, USA

M City, located on the University of Michigan's campus, is a 32-acre trial ground for linked cars, including V2V and V2I technology [20]. The M City is intended for the research and development of CAV vehicles at an early level. The megaproject's objective was to evaluate new technologies in a controlled, safe environment, critical before deploying connected and automated vehicles on public streets, highways, and freeways. The full-scale outdoor laboratory replicates the wide variety of challenges encountered by automobiles in urban and suburban settings. The traffic laboratory is located adjacent to the building for traffic networking, monitoring, signal operation management, and augmented reality testing [20].

2.1.8.1 Case Synopsis

As stated in the State of Michigan's M City portfolio, "the facility provides a controlled and realistic environment for testing the performance and safety of connected and autonomous cars and technology." Their portfolio reveals the following characteristics [20]:

• The facility's state-of-the-art equipment comprises a control network that collects data regarding traffic behavior via wireless, fiber optics, and Ethernet connections, as well as an exact kinematic positioning system operating in real-time.

• Patent-pending augmented testing technology enables real-time interaction between physical test vehicles and virtually connected cars within the facility.

• An open-source API is used to manage testing conditions across the facility.

• Software can be used to manage infrastructure.

• The facility is equipped with vehicle-to-everything (V2X) communication and a 5G connection.

2.2 Car Sharing

Carsharing is a car-rental service that serves as an alternative to private vehicle ownership. Carsharing places a premium on accessibility and convenience. Vehicles are conveniently positioned near households, are rented on an hourly basis, and need no effort to check-in and out. Carsharing is a viable alternative to owning a personal vehicle that traveled less than ten thousand kilometers each year [21].

Car sharing is constantly evolving as a result of technological advancements in the information and communications technology sector. This has increased the service's flexibility and simplicity (location, booking, payment, and vehicle opening are now generally done via mobile phone). As a result of changing consumer preferences, increased consumer acceptance of shared vehicles as an alternative to owning one. Carsharing offers lower fixed expenses than private vehicle ownership but more significant variable costs. This pricing structure makes occasional vehicle use accessible to low-income households as well [22]. Additionally, it provides drivers with an incentive to reduce their reliance on their vehicles and maximize their usage of alternative modes of transportation. Car sharing often reduces average vehicle use by half for drivers who use it, making it a practical approach for managing transportation demand [23].

2.2.1 Car Sharing Models

Car sharing is a fairly broad word, and it is vital to differentiate it in terms of distinct business models. This include free-floating, stationary, and peer-to-peer car sharing. Certain companies provide both free-floating and stationary models, giving their customers the best of both worlds. In general, these models (free-floating, stationary, and hybrid) can be used for Business to Consumers or Business to Business transactions. Additionally, another trend can be detected in the automobile sharing business [24]. However, it is not the subject of this Point of View: O2O platforms consolidate offerings by bridging the online and offline worlds, increasing consumer ease and comparability. Each strategy is distinct in product offering, pricing, pick-up and return, collaboration, and ownership structure [25].

While business models differ, car-sharing companies can ensure positive prospects for success by addressing common success characteristics, such as solid availability and network coverage, transparent and flexible pricing, and a diverse fleet to accommodate many use cases. Additionally, both providers and investors must be aware of the particular success criteria associated with each company model [26].

2.2.1.1 Free-Floating Car-Sharing Model

The fact that most free-floating suppliers have been in business for less than five years demonstrates how new this strategy is; yet this sector is booming. Customers can pick up and return the vehicle anywhere within a particular area, demonstrating the model's primary advantage: flexibility. Free-floating automobiles are primarily utilized in urban areas for short one-way trips as an alternative to taxis [24]. German providers have a high turnover rate of 125 users per vehicle, enabling them to operate profitably despite low use. Compared to fixed car sharing, free-floating car-sharing has higher charges that are frequently based on time only and become much more expensive during traffic jams in urban locations [22].

Given that most free-floating companies operate in urban areas, the majority offer small to medium-sized cars, which also makes parking reasonably straightforward for consumers. Flexible parking rules obligate suppliers to work with local governments to avoid parking restrictions.

The service provider can utilize this medium to promote their vehicles and gain direct insight into their customers by following a set of factors [25]:

• Location: dense population to attract a significant number of customers per car.

• Pricing: time-based (usually per minute), not distance-based.

• Convenience: a steady supply of (small) cars that meet urban needs.

2.2.1.2 Stationary Car-Sharing Model

Stationary car sharing has a more extended history (>20 years). While free-floating vehicle sharing emphasizes flexible one-way excursions, stationary vehicle sharing has fixed stations and (in most cases) only provides circular trips with the same start and end places. As a result, the use case is more suited to extended travels and is expected to supply rental automobiles or (second) car ownership. What stationery providers lack in flexibility, they compensate for fleet diversity in terms of brands and types, catering to all needs. Providers of stationary car sharing are concentrated in small to medium-sized cities and rural areas. Due to longer drives and well-planned automobile utilization, utilization is higher, while turnover is lower than free-floating (45 users/vehicles, Germany) [24].

Stationary providers are frequently organized locally and do not operate on a large/global scale. Rather than OEMs or automobile rental companies, many stationery suppliers are backed by public funds or private investors. Success is frequently associated with regional peculiarities founded on in-depth knowledge of the local market and a grasp of client wants. They frequently rely extensively on collaboration with other providers to grow their network and, for example, to offer free-floating services [22].

To be effective, stationary car-sharing service providers must take the following aspects into account [25]:

• Geographical distribution: small and medium-sized cities, rural locations.

• Availability: an extensive network of stations, including those located at significant hubs.

• Pricing: distance-based or hourly pricing.

• Fleet: diversification for a multitude of objectives.

2.2.1.3 Peer-to-Peer Car-Sharing Model

Initially a small business, peer-to-peer car-sharing is gaining traction. While providers make automobiles available for free-floating and stationary car sharing, P2P car sharing connects users to automobiles owned by private persons. Players provide a platform for transaction processing, insurance, and the installation of telematics devices in the car to provide simple access. Because the automobile must be returned to the pick-up area, it can only be used for round trips. Due to the decentralized nature of the fleet, consumers have a more excellent choice of brands and models. Pricing is based on a daily fee, and it is a viable alternative to stationary vehicle sharing or rented cars. The P2P market is relatively dynamic, with new participants entering often and financial investors engaging in investing activities [24]. While both free-floating and stationary car sharing have global participants, most peer-to-peer firms operate in a single nation.

To be effective, service providers must take the following aspects into account [25]:

• Technology: cutting-edge platform and telematics for maximum ease of use.

• Availability: an extensive and diverse network enables users to provide the most significant match worldwide.

• Insurance: a sound insurance policy for auto owners alleviates lending issues.

• Community: the lender and the driver create trust.

Comparative Table for Car-Sharing Models

In the following table, a comparison analysis is presented for the three different car-sharing models discussed, based on the key aspects that differ them.

Table 3 Comparative analysis of Car-Sharing Models

KEY ASPECTS	**CAR SHARING MODELS**		
	FREE-FLOATING	**STATIONARY**	**PEER-TO-PEER**
MODEL BASIS	Customers can pick up and return the vehicle anywhere within a particular area	Stationary vehicle sharing has fixed stations and only provides circular trips with the same start and end places	P2P car sharing connects users to automobiles owned by different private persons or groups
FLEET DISTRIBUTION	Urban-areas targeted and Flexible fleet	For extended travels and Diverse fleet in terms of brands and types	City wide target audience and decentralized nature of fleet
PRICING	Time based (usually per minute)	Distance based (sometimes hourly based)	Daily fee based (fixed pricing)
LOCATION	Dense population to attract a significant customers per car	Small and medium-sized cities, rural locations	Most peer-to-peer firms operate in a single nation
PRIMARY FEATURE	Only used for short one-way trips	Provides circular trips with fixed start and end places	Because the automobile must be returned to the pick-up area, it can only be used for round trips

Table 3 provides a summary and comparison analysis of the three different Car-sharing models discussed, based on the key aspects of pricing, location, fleet distribution and on their primary feature.

2.2.2 Italy's Car-Sharing Practices

The CS market in Italy began almost two decades ago and has significantly evolved since then; spontaneous efforts to a centralized system available in many of the country's larger cities and several medium-sized ones [27].

Since 2013, Italy's overall number of shared vehicles has expanded dramatically, reaching approximately 8250 in 2019, depicted in figure 6 [25][28].

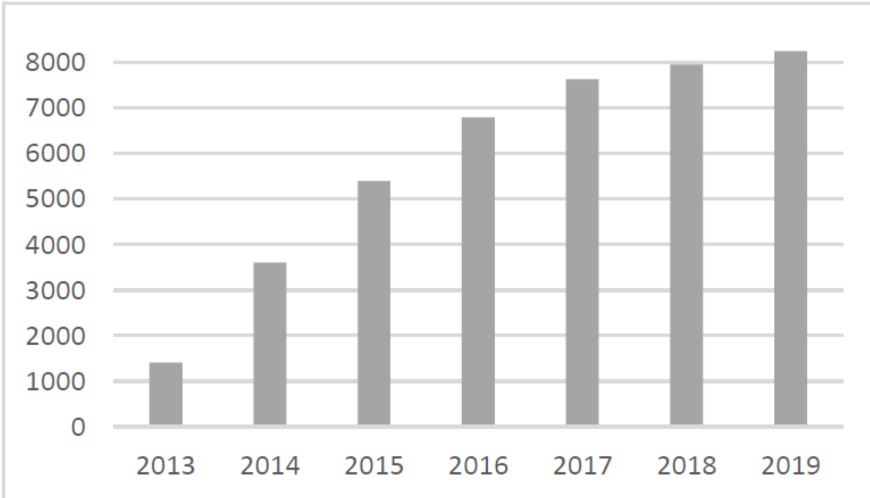

Figure 6 Overall number of shared vehicles in Italy

The total distance accumulated by CS services, which averaged 7.4 kilometers per rental, climbed by 9.9 percent, nearly three times the rate of rental growth, enhancing CS services' financial sustainability [28].

<u>SHARENOW</u>

Sharenow operates in Milan, Rome, Turin, and Florence, with a fleet of 2815 vehicles. Sharenow is a German corporation that offers car-sharing services in major cities throughout Europe and North America. It is a joint venture between Daimler AG and BMW, which joined their separate car-sharing businesses in 2018. It operates a fleet of over 14,000 vehicles in 18 European cities[28].

<u>ENJOY</u>

Using the 2550-strong fleet of vehicles in Milan, Rome, Turin, Florence, Bologna, and Catania, ENJOY is an Italian firm formed by ENI that rents solely Fiat 500 automobiles. Enjoy began operations in Milan in 2013, expanded to Rome and Florence in 2014, and has grown to become Italy's second-largest car-sharing firm [28].

<u>SHARE’NGO</u>

Share'ngo operates in Milan, Rome, Florence, and Modena, with a fleet of 1164 vehicles. Share'ngo is a joint venture between Italy and China that launched the world's first fully electric, free-floating car-sharing service in Milan in 2015 [28].

<u>BLUE TORINO</u>

Blue Torino, a CS operator, based in Turin, began offering a station-based service in 2015 with a fleet of 500 FCA-manufactured electric vehicles and 430 charging stations [28].

2.2.2.1 Synopsis

While the Italian car-sharing market is experiencing remarkable growth in terms of members, rentals, and kilometers traveled; the various business cases demonstrate how the expansion is dangerous and challenging, even more so when the market to be served composed of less densely populated locations. Indeed, while CS services are currently concentrated in large cities, they would be far more advantageous in rural areas with limited, if not non-existent, public transit [29].

2.2.3 Benefits of Car-Sharing

Carsharing can benefit a broad spectrum of consumers, including many relatively wealthy households looking to save the expense of a second or third vehicle. Significant benefits as indicated in the research paper are described below [30].

Enhanced Mobility

Carsharing enables individuals who cannot afford a private car to utilize a vehicle on an as-needed basis. These benefits can be enormous, given how often nondrivers' mobility is restricted. Giving someone who does not currently have access to a car the capacity to drive once or twice a week, for example, is likely to result in relatively high-value excursions. Currently, such trips are avoided or completed inefficiently via alternative modalities.

Economic Growth

Carsharing can boost economic productivity by providing access to a car for job seekers who cannot afford a personal vehicle. Additionally, car-sharing can serve specific market segments. This is especially true for vehicles that are only used on an as-needed basis if there is no nearby conventional vehicle rental provider.

Equity

It is unjust and inequitable that nondrivers have less mobility and a competitive disadvantage when competing for jobs and education with drivers. Thus, car-sharing can contribute to fairness by increasing the mobility options available to disadvantaged persons.

Value of an Option

Even those who do not utilize car-sharing may benefit by having it available in the event of an emergency or a change in their circumstances. This is referred to as the option value [30]. As a result, people who already own their automobiles may value the availability of car-sharing choices in their neighborhoods, just as many drivers enjoy the availability of public transportation.

Savings for the User

Vehicle ownership is a significant household budget item that can significantly strain moderate- and low-income households. Additionally, some homes can save money on residential parking. While car sharers sacrifice some benefits in order to reduce driving, they must be better off in the long run if their incremental savings exceed their incremental expenses; otherwise, they would not make such adjustments [31].

Vehicle Selection

Generally, a less expensive, more resource-efficient vehicle would fulfill the need of users. Numerous car-sharing organizations offer various vehicle types, allowing users to select the vehicle that best suits their needs on any given journey. This benefits consumers and may positively affect the environment by limiting the usage of big cars in situations where smaller cars are sufficient [31].

Demand Management in Transportation

Carsharing contributes to transportation demand management (TDM) by reducing per capita vehicle travel. Carsharing enables more flexible infill construction and creates more livable communities by lowering vehicle traffic and parking requirements [30].

2.3 Implementation of CAV

2.3.1 Necessary Requirements

Local governments, network operators, and private businesses must prepare for emerging trends in CAV deployment. The essential requirements that must be in place for the successful implementation of CAVs are described below [32].

Information Technology Infrastructure

Numerous benefits that CAVs will bring will be improved by interconnectivity between the vehicles and surrounding facilities. Within metropolitan areas, wi-fi communication systems will enable vehicles to communicate in real-time with traffic management systems, exchanging information such as signal phasing and timing, as well as real-time traffic conditions. CAVs will optimize their speed and routing based on this knowledge, reducing journey times and overall congestion. Transportation agencies and municipal governments are essential in achieving this goal by establishing the necessary digital infrastructure network [32].

Data Collection and Utilization

CAVs will generate enormous amounts of data about how and when people move throughout cities and transportation systems; the value of this data is substantial. CAVs enable the collection and analysis of this vital data to improve transportation systems and gain a better understanding of how people interact with their cities [32].

Data brokerage plays a critical role; relevant datasets and the ability to make sense of them are pivotal to agencies deploying CAVs. How data is stored, how useless material is separated from essential data are linked to fixed geographical places [3].

Infrastructure

Local governments should explore how to prepare their infrastructure — from traffic signals and lampposts to highways and bridges – for CAVs. Is current infrastructure capable of supporting the wireless communication required by connected car technologies – notably those involving traffic signals? This is especially critical as infrastructure is replaced or upgraded as a result of maintenance and improvement. Instead of replacing like-for-like, organizations should investigate how to modernize their infrastructure in advance of CAV adoption. Additionally, transportation officials should evaluate the impact of CAVs on new modes of transport. For example, the congestion benefits gained by CAVs may eliminate the need for new road construction or parking lots in some places [32].

Information Security

Companies have to make specific cyber environments secure before accepting CAV technology and cars' safety and security. External and internal dangers to data and information must be guarded. The unrestricted flow of data throughout a firm is critical for global organizations. To ensure that a company's network is continuously secure, real-time monitoring of threats, mitigations, and vulnerabilities is essential [4].

Direction

From an operational approach, transportation authorities must examine their involvement in CAV development, asking them to look at the commercial aspects and their operations' technological and strategic sides. Many companies have dedicated a transportation technology advisor with the directive to analyze and prepare for the arrival of self-driving vehicles [33].

Collaborations

Transportation agencies should consider positioning themselves to capitalize on the early possibilities of CAV technology. One possibility is to collaborate with companies that are developing CAVs and other automotive manufacturers to offer testing and development possibilities. Already, many towns have developed a reputation for their relationships with CAV developers, which provides them with competitive benefits [33].

2.3.2 Key Performance Indicators (KPIs)

The most critical and essential key performance indicators (KPIs) used by road and transportation administration worldwide are given below [34]:

1) Reliability of travel time

2) The volume of traffic

3) Traffic Safety

4) The safety of vulnerable road users

5) The possibility of eco-growth

6) Carbon dioxide emissions from motor traffic

7) A well-connected and accessible road network

8) Optimization of freight

9) Increased usage of active modes of transportation

2.3.2.1 Impact of Cavs on Key Performance Indicators

The deployment of CAVs affect the critical performance measures in many ways [34]. To better understand their potential impacts, the assessment of these impacts is necessary. It is important to consider whether the impact factors are beneficial or not, when the eventual deployment takes place [33][35].

<u>Reliability of Travel Times – Beneficial</u>

With the increased implementation of CAVs, it is envisaged that travel time reliability would improve as occurrences causing delay (such as collisions) reduce. Congestion-related impacts will be mitigated since CAVs may travel closer together, boosting roadway capacity without jeopardizing safety.

<u>The volume of Traffic - Unknown</u>

CAVs' impact on traffic volumes is unknown. According to a widely held belief, CAVs will significantly reduce vehicles on the road. However, they may result in an overall increase in road traffic, as CAVs provide equal access to those who currently cannot drive.

<u>Road Safety - Positive Effects</u>

CAV technology has the ability to drastically reduce the number of crashes by minimizing the possibilities for human error. Where incidents occur, the damage is predicted to decrease as CAVs take evasive action more quickly than a human driver.

<u>Safety of Vulnerable Road users - Positive Impact</u>

As is the case with other aspects of road safety, CAVs will enhance the safety of the most vulnerable road users.

<u>Potential for Eco-Growth – Positive Impact</u>

By lowering congestion and increasing the reliability of travel times, the driving network contributes to an area's economic growth potential by enabling efficient and dependable transport.

<u>Emissions from Automobile Traffic – Positive</u>

Carbon emissions per vehicle are predicted to decrease as CAVs are implemented, and the technology increases driving efficiency (by eliminating stop/start driving situations, for example).

Accessibility and Linkage - Positive Impact

CAVs will enable equal access to the road network. This will broaden people's mobility options and travel perspectives, having a direct impact on enhancing economic, social, and personal well-being.

Optimization of Freight – Beneficial

CAVs will play a role in optimizing and expediting logistical movements, from networked platooning to automated and predictable last-mile delivery. This improves scheduling and meets shorter delivery times.

Increased use of Active Means of Transport – Unknown

The effect of CAVs on persons who travel actively is uncertain. Individuals who currently rely on active travel modes because of their inability to drive or inaccessibility, lessening their reliance on active travel modes. On the other hand, the increased road safety provided by CAVs may result in increased cycling and walking.

2.4 Factors affecting the Deployment of CAVs

The effects of CAVs on society and how cities and organizations can adapt must be extensively examined, as well as several of the significant challenges raised, including the following [36]:

1) The potential influence of CAVs on business models
2) The human factor in the deployment of CAV technology
3) Considerations for cybersecurity
4) Prerequisites for communication
5) Testing, both virtual and actual

2.4.1 Business Models

The CAV market creates new possibilities and challenges for diverse industries, upending established business models and introducing new ones. We live in an ever-changing world. People's expectations are continually rising and altering as new technology, sustainability, and urbanization contribute to this growth and evolution. Many individuals are reconsidering their connection with automobiles, favoring access over ownership — particularly among urban youth. The supply side has challenges and opportunities due to changing consumer behaviors and their interaction with transportation and the various solutions available, such as CAV. While the future is unknown, one thing is sure: current solutions will not meet future needs [36].

2.4.2 Individuals and their habits

While technology is crucial to the advancement of CAV, it is people's attitudes regarding this new product and the services it may deliver that will determine its adoption and rollout. We must comprehend the emotional reactions that the deployment of CAVs would bring out. Additionally, it is critical that we fully address the attitudes and behavioral differences that may occur between generations and how CAVs might give a solution that delivers value and meaning to everyone, from the elderly to Millennials. CAVs can create new economic opportunities for individuals who do not drive or cannot afford to drive, as well as to involve the next generation, which does not view automobile ownership as a need. They can help make journeys less stressful [33].

2.4.3 Information Security

Public acceptance of CAV technology and the cars' safety and security are contingent on secure cyber systems. Data and information must be safeguarded against external and internal threats. A cyber framework model will assist in accomplishing this. It focuses on the overall system while also recognizing each sector's cyber-related strengths and weaknesses. It enables effective measurement of safety and vulnerability by drilling down into deployed systems, assets, and architectures [4].

2.4.4 Communication and Interlinkage

Wireless connections that are fast, secure, and dependable are necessary to leverage the benefits of linked automobiles. Numerous vehicle communication standards have been suggested throughout the years, with IEEE 802.11p being the most widely adopted [37]. CAVs will benefit from wireless connectivity because it will enable instantaneously and secure communication between cars. Despite considerable advancements in computer vision, humans are still significantly better at perceiving visual information than machines. The only method of delivering signaling information to machines that is 100 percent dependable is by resilient, safe, and adequately configured wireless systems. Wireless communication infrastructure is naturally low-cost and flexible [36].

2.4.5 Testing in Physical and Virtual Environment

CAV testing, certification, and validation are critical components of CAV acceptance and usability. Safety, handover methods, and cybersecurity will all need to be extensively evaluated and understood from the manufacturer, regulator, and user standpoint. Businesses must guarantee that people, or end-users, connect with CAVs in the usual manner and comprehend the benefits and usability of available solutions. Testing and the facilities required to undertake these necessary steps are viewed as potential opportunities for job growth and intellectual property generation [4].

3 SCENARIO PLANNING AND DESIGN

3.1 Purpose

Scenario planning enables the conceptualization of alternative possibilities and the assessment of the implications of a variety of significant uncertainties. The appropriate actions for deploying CAV in existing infrastructures to support automated and connected vehicles were determined through modeling and other research exercises [38]. The primary objective was to create a series of scenarios that would serve as a guide for envisioning the future. This, in turn, aimed to assist in a better understanding of how the future might look and position ourselves to deal with potential future challenges. The scenario planning for Connected and Automated Vehicles (CAV) demonstrates the importance of incorporating CAV into vast development plans. Scenario planning provides a framework for responding to a dynamic and uncertain environment. It demonstrates the value of concurrently planning multiple infrastructure projects, such as transportation on distinguishable lanes and land-use regions [39]. Additionally, this section emphasized the importance of considering how users would like to use the service and how variable options are valued from their perspective and taking into account other performance measures [40].

3.2 Statistical Data

Statistical data is fundamental in any scenario planning process. It provides the opportunity to analyze and calculate the demand requirements as in our case [41].

3.2.1 Annual number of Passengers at Torino-Caselle Airport

The annual number of passengers traveling through the Turin-Caselle airport from the year 2010 to the year 2019 in millions is represented below [41]. The bar graph is derived from the report of Airport Traffic APT given by Traffic data Italia. This data helps us in creating a profile for mobility demand for our scenarios and other necessary calculations [42].

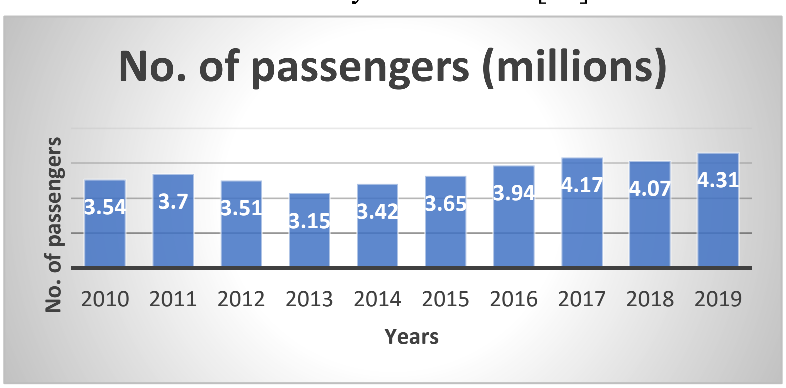

Figure 7 Annual number of passengers at Turin Airport

3.2.2 Passenger Segregation

Passengers arriving and departing from Turin airport are tabulated below. The table is derived from the same report as above [42]. The percentage increase in passengers per year is also mentioned, which shows a positive increment. This data helps us approximate the daily passengers traveling from Turin airport, which creates a daily demand profile [41].

Table 4 Passenger segregation of Turin Airport

Airport	**No. of passengers (n.)**		**% increase 2017-2019**
Turin Caselle	**Arrivals**	**Departures**	
	907,105	903,044	8.90%

3.2.3 Car-Sharing usage in Turin City by Time slot

The bar graph derived from the National Sharing mobility report indicates the Car Sharing usage in the city of Turin by time slots. This indicates the peak demand hours in a day for the service, which is vital in scenario planning considerations. Since no such deployment of CAV service is present in Turin city, this helps with the necessary assumptions regarding the usage rate and the number of passengers to be accommodated [42].

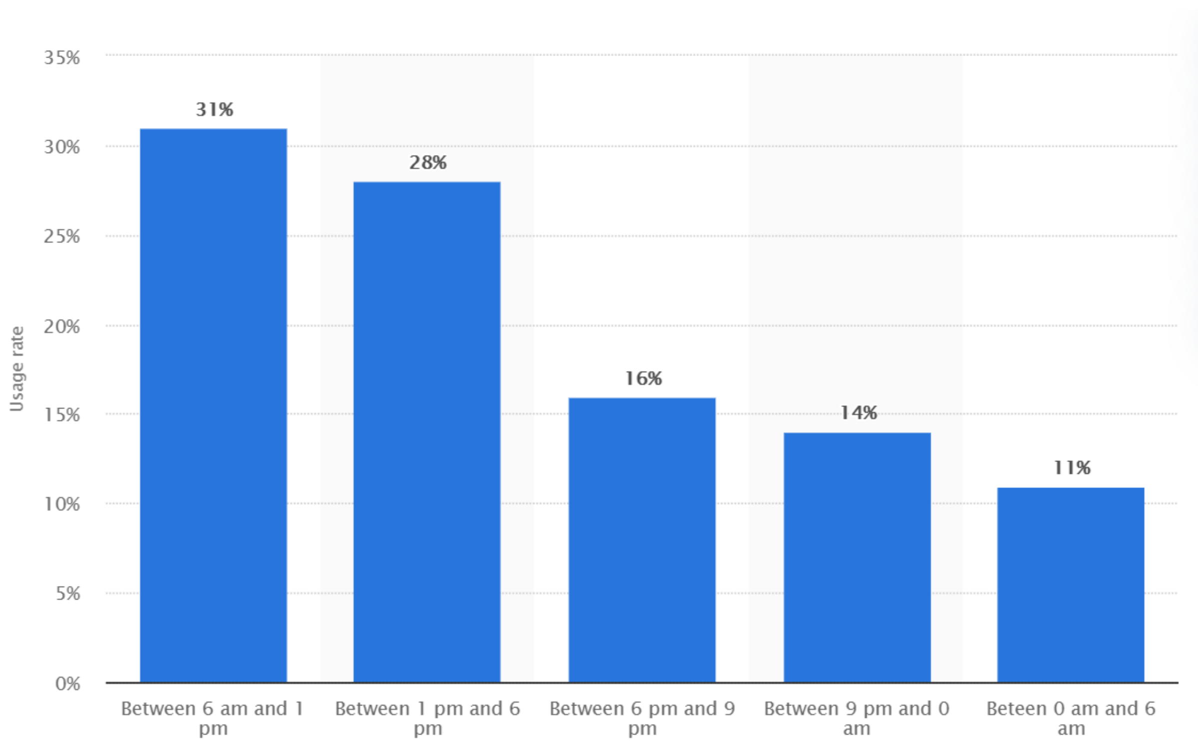

Figure 8 Car sharing usage in Turin by time slot

3.2.4 Public Opinion survey on Car Sharing in Turin City in 2018

The below bar graph depicts the result of a public survey done in the city of Turin to analyze the public opinions and their habits regarding the usage of Car-sharing services. Public acceptance is a vital step in any deployment, so it is necessary to represent the opinions based on the service's features and why the need for use is a necessity [42].

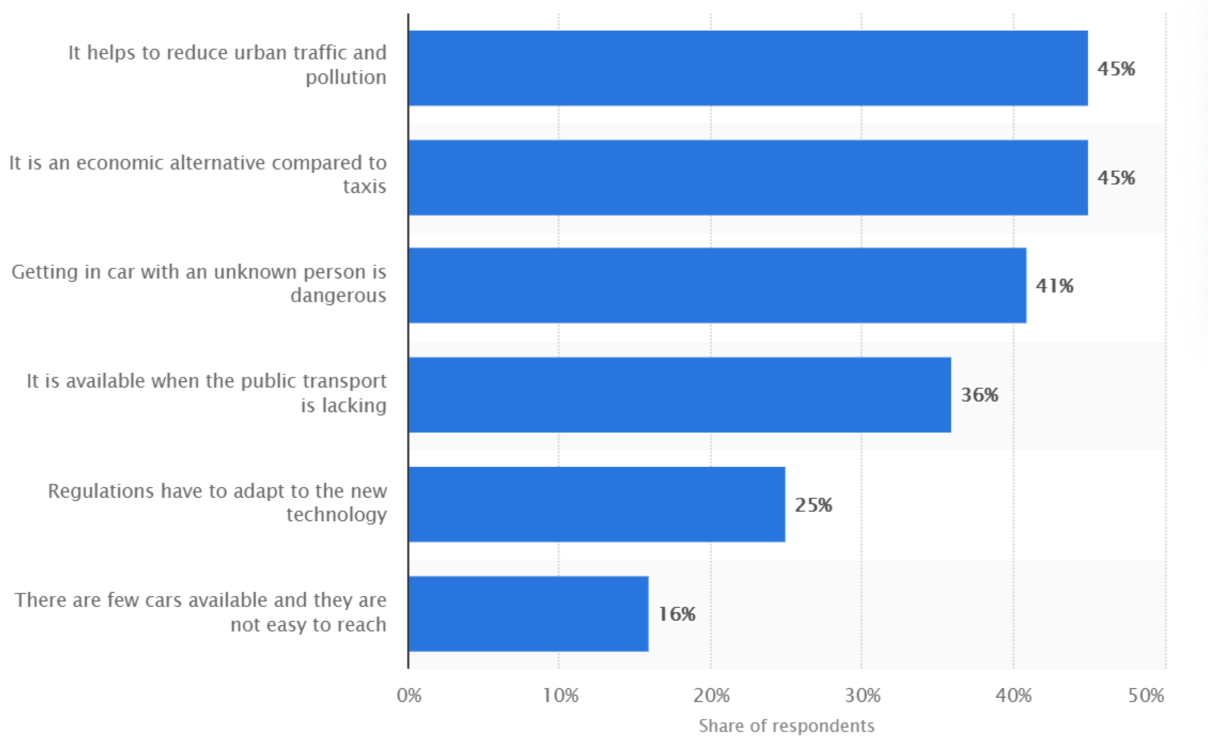

Figure 9 Public opinion survey data on Car Sharing

3.3 Map Routing and Design

The planned map route was designed on PTV Vissim software after the considerations of critical parameters of design.

3.3.1 Key Parameters for Design

Vehicle Inputs

Vehicle Inputs set the volume of vehicles input in the specific link/lane. Unique configurations like which vehicle permitted into specific links can also be added.

Vehicle route selection

Vehicle route selection enables whether partial, static routes are designed for some specific vehicles. Parking lots category can also be added for Pick up & drop off points.

Conflict areas recognition

Conflict areas are added to imitate the actual time behavior of CAVs. Such as when to prioritize which lane vehicles and on two or more lanes are emerging into one. Whether CAV Lane vehicles need to stop and prioritize or carry on with their movement irrespective of the traffic in exceptional cases.

Priority rules designed

Priority rules are added to reciprocate the traffic flow. Whether lane changing or turning onto another path is allowed or not in some conditions is verified.

Signal Head and Stop heads

Signal heads and Stop traffic signs in the route are added upon necessity and account for CAV behavior implementation. Vehicles would stop at traffic lights and stop signs, and the same behavior would ensure the following vehicles.

Signal control configuration

Proper Signal heads are integrated into the path with real-time configuration. Green, amber, and Red lights for set periods are added on intersections to check for actual traffic flows and queue behaviors. Time slots are managed according to the expected flow behaviors on each highway and where necessary.

Obstacle Detection

Detectors are added in the vehicle route and on the links added. They account for the detection of any obstacles in the vehicle path and case of accident emergencies.

Pedestrian Attributes

Pedestrian routes and attribute decisions are added to reciprocate a real-time environment. CAVs validation would check whether they follow the actual time patterns in such cases.

3.3.2 Description

Five links were designed, and four intermediate connectors were used to join them.

The table on the next page, represents the description of the links and connectors used.

Table 5 Description of Links and Connectors of Route design

Links	**Description**
1	Designed to depict the Freeway from Torino airport parking
2	Designed to depict the Autostrada Torino-Caselle
3	Designed to depict the Extra-Urban Principale
4	Designed to depict the Extra-Urban Secondary
5	Designed to depict the Extra-Urban Secondary
Connectors	
101	Connecting Link 1&2, Freeway to Autostrada
102	Connecting Link 2&3, Autostrada to EU-P
103	Connecting Link 3&4, Intersection representation
104	Connecting 4&5, Intersection representation

3.3.3 Model Design

A map was developed on PTV Vissim software, using links. A dedicated lane developed reciprocating accurate maps and roads used, as shown in figure 10. Start and endpoint are placed according to the Airport parking and at city center drop-off zones. Different links were adapted to reflect natural road environments. Each link will be progressively used as either Freeway, Urban Highway, or Extra-urban motorway. This is to project different speed limits during simulation that can be controlled on the software. Intermediate connections are used to connect the different links.

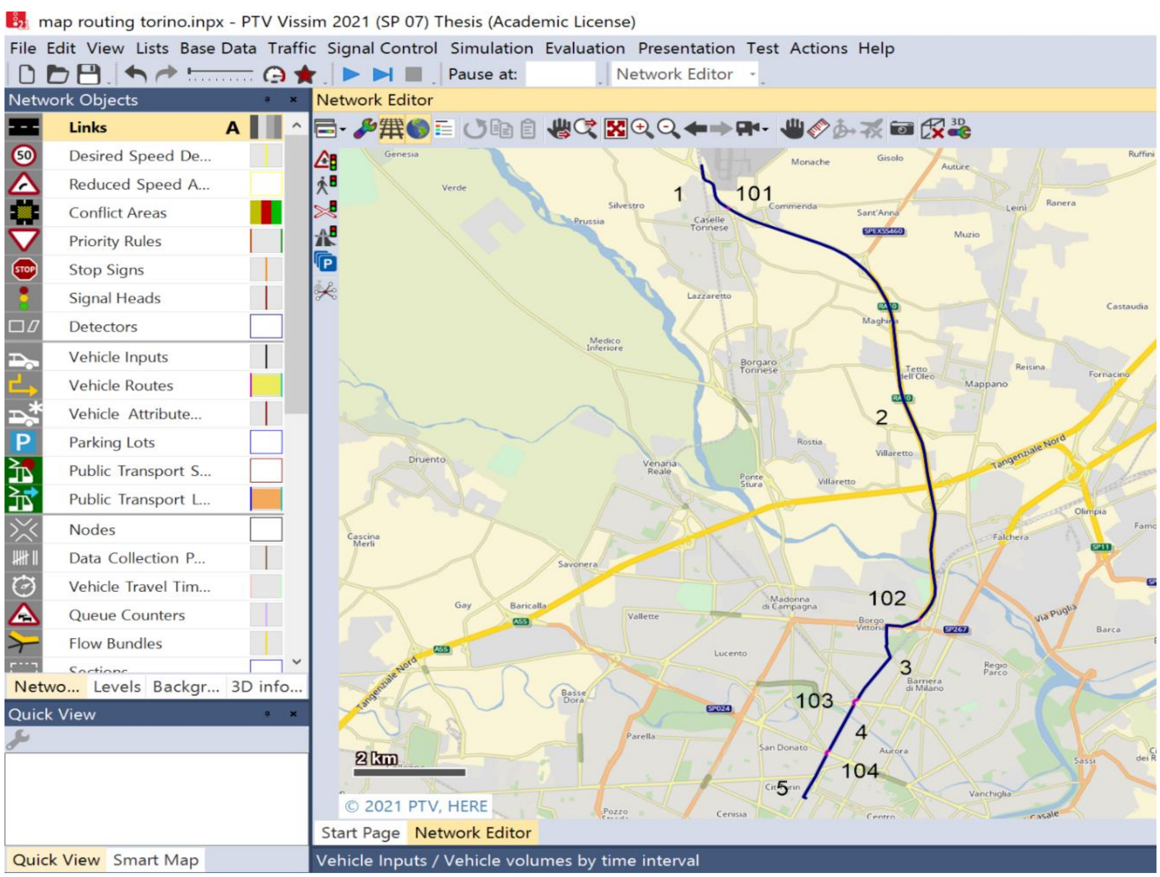

Figure 10 Route design for CAV service

3.3.4 Intersection Design

An Intersection was designed with PTV Vissim to simulate the intersection along the route selected for the case study. Actual road structures were employed for the design to implicate real scenarios of traffic simulation and management.

In figure 11, the intersection design is shown. The red lane marked is the CAV dedicated lane from the airport to the city center through movement. The links designed are named in the simulation as the existing road network present in the google binge map for clarification.

Thus, the simulation will be performed keeping in view the signal head configurations, stop signs wherever needed, and priority rules designated. The simulation after implication of the protocols would provide the proper management implementation, and desired results would be compiled.

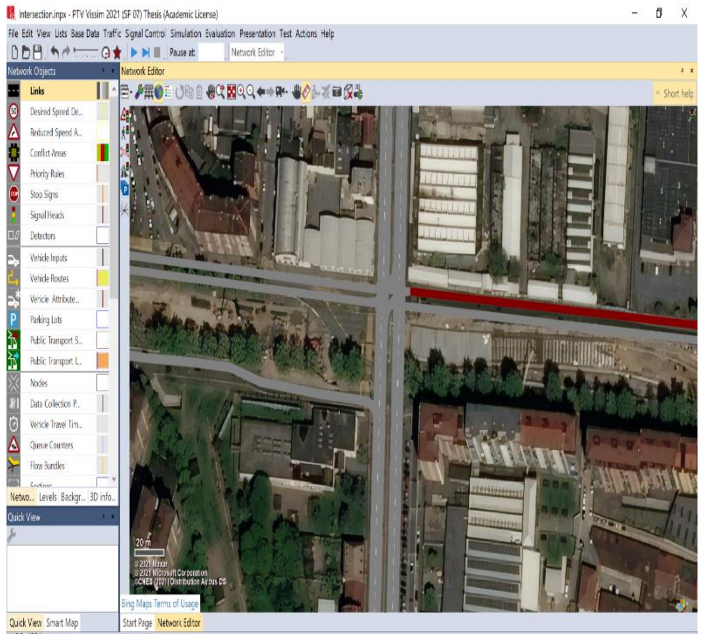

Figure 11 CAV Lane and Intersection Design

Design

Links and interconnections between them design the intersection. The possibility of through movement as well as turning is present, as shown in the figure below. The arrows of the link show the direction of the road network present. The design of this intersection shows us the three primary critical areas that need to be managed as per road and traffic management protocols. It implies a signal head configuration, and also, a stop and priority sign needs to be implemented. Figure 12 illustrates the design modeled on PTV Vissim.

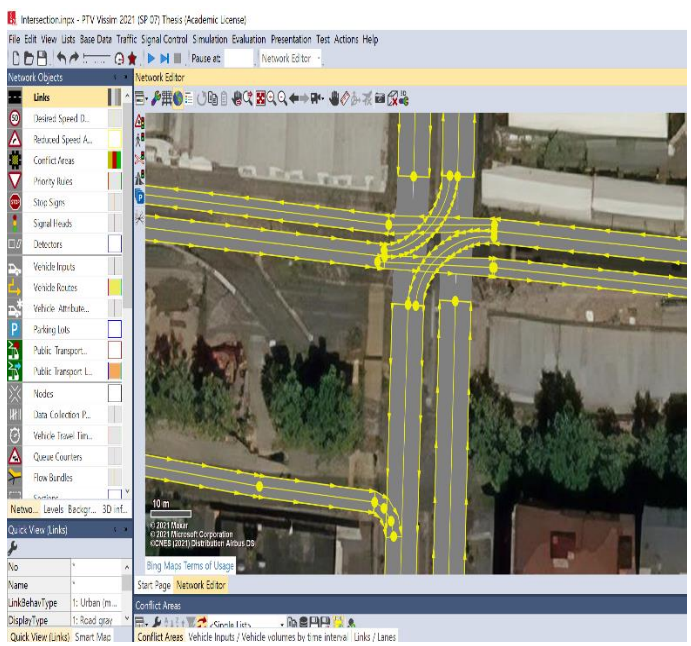

Figure 12 Interconnections and Link design

3.3.4.1 Critical Areas

The three most critical areas of the intersection design are represented in the figure below. These are represented as 101, 102, 103 purely for representation purposes. It is evident from the design that Area 101 & 102 would need a signal head configuration with signal time management. In contrast, area 103 would only need a stop sign and a priority rule description and sign implying the priority.

Table 6 Critical Areas description

AREA	LINK	DESCRIPTION
101	Left turn from East-West	Vehicles wanting the left turn from Corso Grosetta towards Via Aldi would approach this trajectory
102	CAV Left turn	CAV that will be turning from Corso Grosetta towards Via Aldi through City center would approach this trajectory
103	Link road merging	Vehicles on the Link road merging into Via Aldi would approach this trajectory

<u>Area 103 Design</u>

This specific area is designed by adding a Stop sign, indicated as an orange link mark on the Westbound Road, in the figure below. Now, as traffic rules are implied, priority rules were designated and as shown in the figure. The green sign shows that the vehicles on that road would prioritize the vehicles from the merging road, marked red. The vehicles would wait at the stop sign and only merge on the main highway when it is clear, prioritizing highway vehicles.

<u>Area 101 & 102 Design</u>

These areas are the most critical areas of the intersection design. A signal network configuration is designed, and also priority rules are deployed marked in the figure. The Corso Grosetta signals, both east and Westbound, would turn red when the Via Aldi through movement would turn green. Then, for the Left turns, priority rules are designed that, first of all, would give priority to the CAV dedicated lanes. Then the 2nd left turn of regular vehicles from Corso Grosetta towards Via Aldi Northbound, as shown in figure 13.

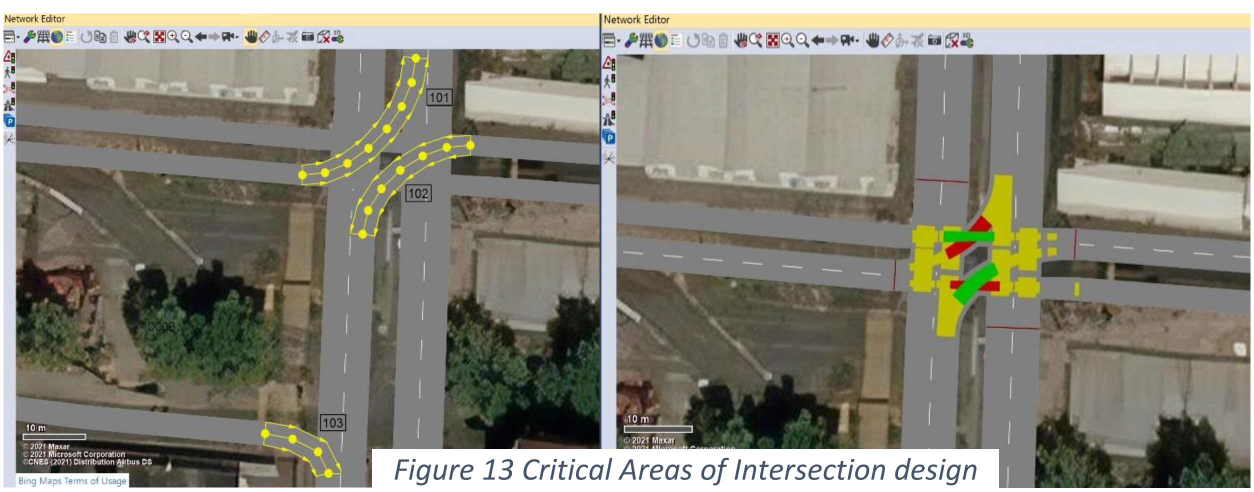

Figure 13 Critical Areas of Intersection design

3.4 Planned Scenarios

3.4.1 Base Scenario

Two separate lanes are designed for the base scenario for CAV mass transit purposes, i.e. Car Sharing in our case. One dedicated lane will be used for traveling from Turin Airport to Turin City center. At the same time, the other will be dedicated for the transit from the City center towards Airport, as shown in figure 14. Only CAVs would be allowed to travel on the dedicated lanes in the scenarios planned, and the performance indicators are valued and presented in the simulation and results chapter. The scenarios were modeled on the following consideration, supported by the statistical data provided in the literature [43]:

- Yearly passengers at Turin Airport are approximately provided in the data as 950,000. These are segregated as passengers at arrival and departures.
- This depicts the daily passengers traveling to and from Airport, more or less at 2600.
- From the statistical data and the mobility demand of Car-Sharing users in Turin City, passengers inbound and outbound from Airport are approximated at 30% of the daily demand. i.e., 780 passengers
- Peak hours of travel for Car Sharing service usage is depicted in the statistical data as 6 hours (7 am – 1 pm)
- Also, the daily demand of the service users during peak hours is about 31% of daily passengers. i.e., approximated at 240 passengers.
- Load factor is considered one because maximum utilization is possible and thus assumed.
- From the literature, 10% of the actual Fleet size calculated must be considered and added as the reserved fleet in the Total Fleet size.
- The following formula is used for the Fleet size calculation, [43] as supported in the literature.

  FLEET SIZE = $(Max.Load * Cycle\ Time) \div (Vehicle\ Capacity * Load\ Factor * Peak\ \ hours)$

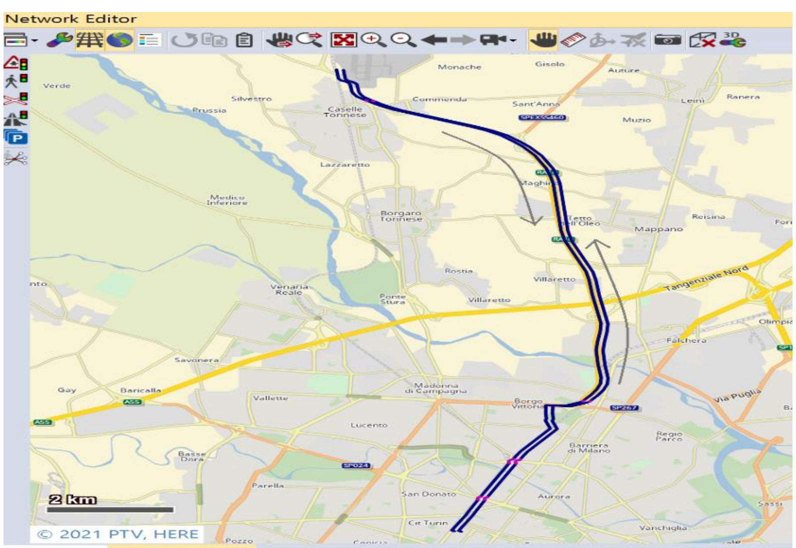

Figure 14 Base scenario route design

3.4.2 Scenario A - Fixed Pick-Up & Drop-Off Points

A fixed pick-up and drop-off point are allocated and set in this scenario, as shown in figure 15. The scenario planned would imply that only two starting/ending points of the journey would be present: the Airport Parking and the parking lot dedicated at the City center for CAVs parking and charging. The car-sharing service in this scenario would provide the opportunity to make travel direct from one point to another without any in-between stops, see B-1 of Appendix B.

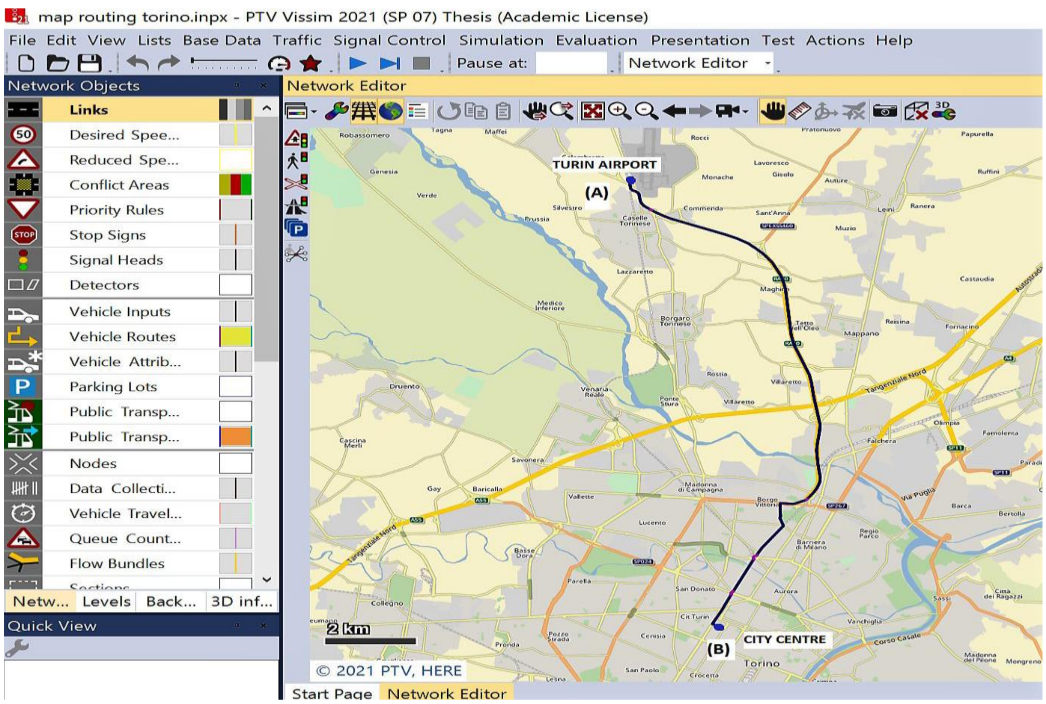

Figure 15 Scenario-A Design (Fixed Pick-up & Drop-off)

<u>DATA SET</u>

Based on the considerations in our base scenario, the following data set is tabulated that represents the parameters and their corresponding calculated values for scenario A.

Table 7 Data set for Scenario-A

PARAMETERS	CALCULATED VALUES FOR PEAK DEMAND
Peak demand hours	6
Number of passengers	240
Vehicle capacity	1
Fleet size	19
Stops	2
Traveling speed (kph)	40
Route Length (km)	16
Frequency	17
Time headway (secs)	212
Trip or journey time (mins)	25

3.4.3 Scenario B - Passenger Occupancy Share/Intermediate Stops

In this scenario, intermediate stops are planned to provide the user, traveling from Airport, to pick the drop-off location at dedicated stops located at the outskirts and inside Turin city, as shown in figure 16. This also provides the opportunity to share rides/journeys among a group of passengers or different users, increasing passenger occupancy in a single ride. The stops dedicated are selected by population segregation so that the urban and sub-urban users both use the service effectively and efficiently, see B-3 of Appendix B.

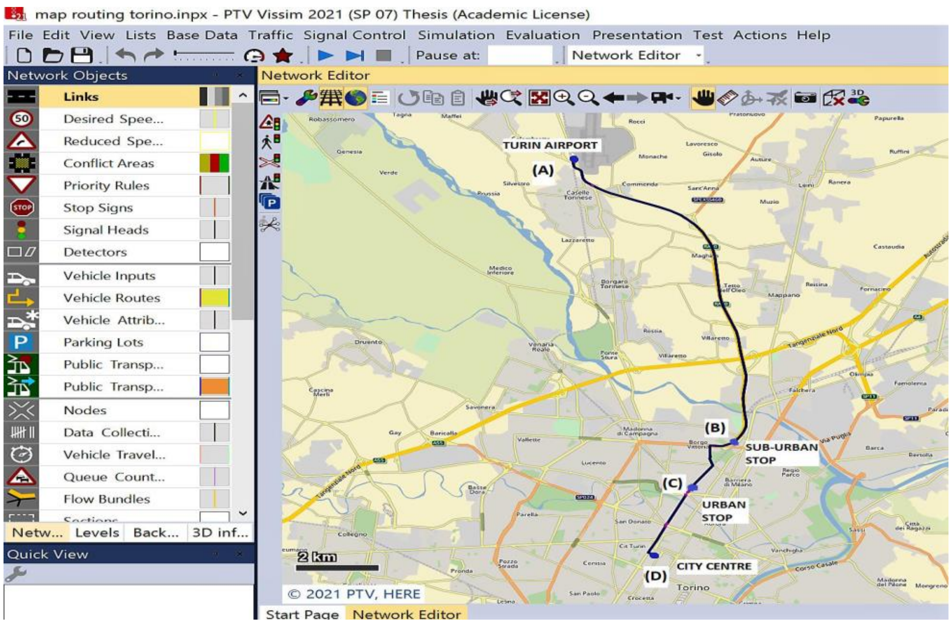

Figure 16 Scenario-B Design (Intermediate Stops)

<u>DATA SET</u>

Based on the considerations in our base scenario, the following data set is tabulated that represents the parameters and their corresponding calculated values for scenario B.

Table 8 Data set for Scenario-B

PARAMETERS	**CALCULATED VALUES FOR PEAK DEMAND**
Peak demand hours	6
Number of passengers	240
Vehicle capacity	2
Fleet size	10
Stops	4
Traveling speed (kph)	40
Route Length (km)	16
Frequency	9
Time headway (secs)	400
Trip or journey time (mins)	25

4 SIMULATION AND RESULTS

4.1 Input Parameters for Simulation

4.1.1 For Planned Scenarios

The simulation time is set at 3200 seconds because of the recommended settings of PTV Vissim to adjust the simulation time greater than double the trip evaluation time. The route length is measured from the scaling tool in the PTV Vissim software, and the vehicle inputs for the CAV lane are calculated for the planned scenarios. This is also depicted in B-2 and B-4 of Appendix B. The input parameters considered and calculated for the scenarios are summarized in the table below.

Table 9 Input parameters for Scenarios

Scenarios	Route length (km)	No. Of stops	Passenger input	Vehicle input	Occupancy	Trip time (secs)	Sim. Time (secs)
A	16	2	240	17	1	1500	3200
B	16	4	240	9	2	1500	3200

4.1.2 For Intersection

The simulation time is set at 3200 seconds because of the recommended settings of PTV Vissim to adjust the simulation time greater than double the trip evaluation time. The route length measured from the scaling tool in the PTV Vissim software is enlisted below in the table. Vehicle inputs for the CAV lane are calculated for the planned scenarios and, therefore, set the same for the Intersection simulation to attain coherence between the scenarios and the intersection design. The input parameters considered for the simulation of the designed Intersection, through calculation from the statistical data explained in the previous section, are summarized in the table below. This is also depicted in B-5 of Appendix B.

Table 10 Input parameters for Intersection

LINKS	ROUTE LENGTH (m)	VEHICLE INPUT	SIM. TIME (sec.)
Grosetta EB	520	500	3200
CAV Lane	420	17	3200
Gro. Section	236	100	3200
Via Aldi NB	290	1000	3200
Via Aldi SB	290	1000	3200

4.2 CAV Implementation on Vissim software

4.2.1 Description

In PTV Vissim, three AV behaviors are possible. In all these behaviors, cooperativeness, connectivity, and communication are pre-condition.

1) 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 comparatively larger. Driving behavior is set at cautious.

2) AV Normal

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

3) AV Aggressive

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

For our run of simulations, we selected the **AV Normal** driving behavior, see A-6 of Appendix A. 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. The safety distance reduction factor is small, and the minimum headway can be defined by the user according to the requirements.

4.2.2 CAV Parameters Selection

1) Autonomous Driving Mode

In the selection of this mode, two distinctive features according to our simulation model were implemented, i.e. absolute braking distance and platooning. By enforcing Absolute braking distance vehicle is made capable of safely stopping anytime, even if the vehicle in front of it stops suddenly. Also, it is used for prioritizing vehicles in conflict areas. Platooning was not required, therefore, not implemented. This is depicted in A-4 of Appendix A.

2) Vehicle Following

In this mode, look ahead and look back distances are selected, ranging from minimum to maximum. Also, the number of interacting objects and vehicles is defined. The recommended values are selected for each, see A-5 of Appendix A.

3) Car Following Model Selection

The car following Model Wiedemann 99 was selected over Wiedemann 74 because of the availability of multiple modal parameters, see A-1 of Appendix A.

4) Signal Control Behavior

In this, behavior at the amber signal is specified, and the reactions after green and red lights are also specified. Continuous check at amber signal is selected for CAV control. Also, the optimum reduced safety distance close to a stop line is selected, see A-3 of Appendix A.

5) Driving errors Probability

The probability of temporary lack of attention during the following is set, and distraction probability is also defined for maximum CAV implementation and safety. The parameters are set at zero to reciprocate the real-time CAV behavior, see A-2 of Appendix A.

6) Link behavior Selection

The link behaviors are selected at AV Normal according to vehicle classes defined in the simulation. In this, the choice of vehicle class and its corresponding driving behavior is selected.

7) Occupancy

The occupancy is set as per requirement for the planned scenarios, see A-7 of Appendix A. It can variate depending on the vehicle model that defines the look, length, width, and height of the vehicle. The occupancy distribution is also configured as well as the capacity. Capacity is the maximum permitted number of passengers per vehicle; if the capacity is reached, no more passengers would be allowed to board.

4.3 Simulation

The simulation was carried out separately for planned scenarios as well as for the intersection design. A set of 5 simulations were performed to analyze the network performance, based on the recommendation given in one of the software manuals. A random seed and a random seed increment were applied for each simulation run to account for the stochastic variations of vehicle arrivals and performances in the network systems. This is done to maintain correspondence with the real-world traffic behavior in the designed network.

The simulations were performed by setting the input parameters. Firstly, signal groups were created for signal heads on both roads through movement in the intersection design. As shown in figure 17, a signal program was created that links the two signal groups designed. It ensures the interconnectivity of both signals. An offset of 0 seconds was set, and cycle time for the signals is set at 60 seconds. The timing sequence of this specific signal was physically validated.

Table 11 Signal group sequence and timings

SIGNAL GROUP	SEQUENCE	TIMINGS (seconds)
SG Grosetta	Green – Amber – Delay – Red	25 – 3 – 2 – 30
SG Via Aldi	Red – Green – Amber – Delay	30 – 25 – 3 – 2

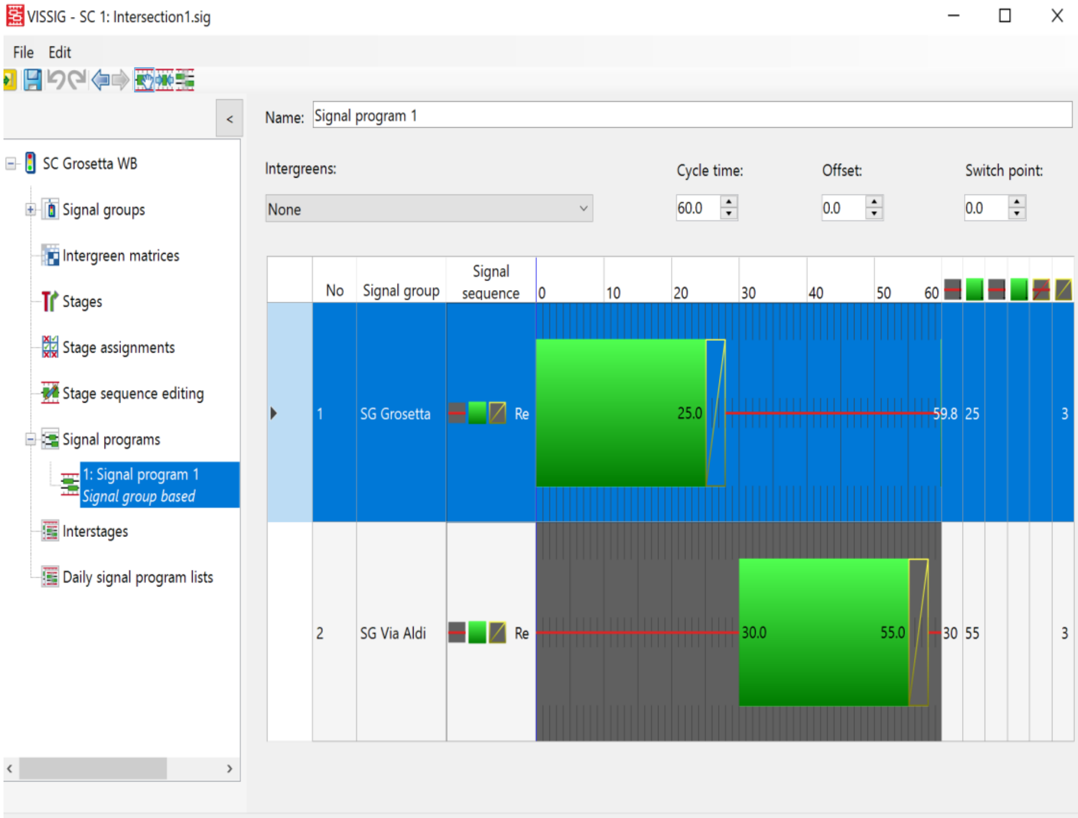

Figure 17 Signal program and Signal group configuration

Figure 18, shown below, of the simulation in 3D, depicts the vehicles in the designed intersection network. This shows that the vehicles are correctly following the intersection protocols and the signal head configuration.

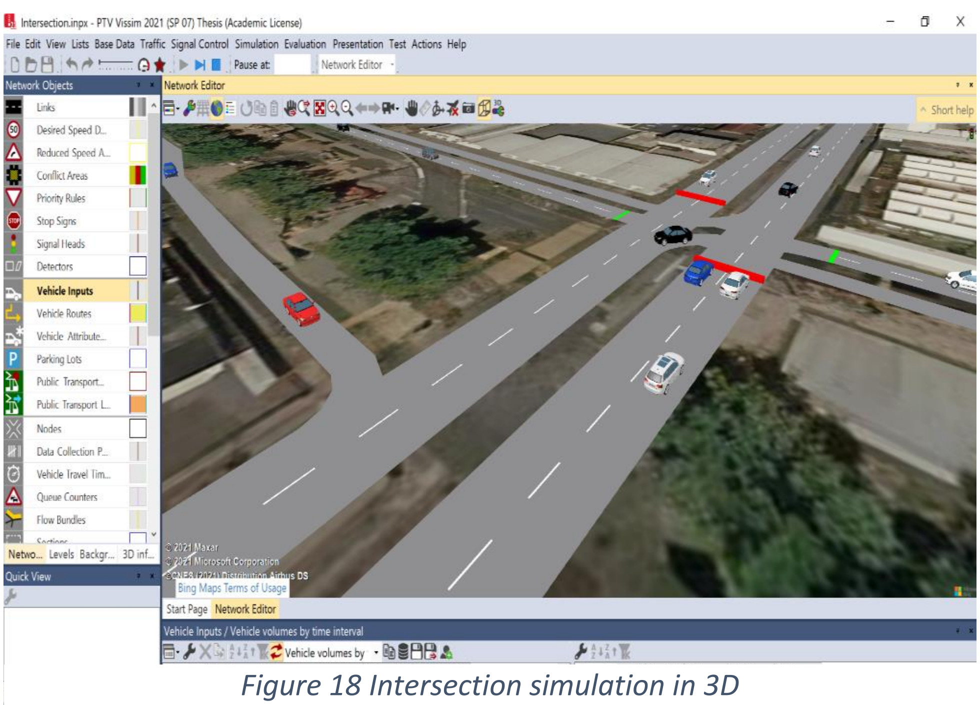

Figure 18 Intersection simulation in 3D

Figure 19, shown below, of the simulation in 3D, represents the stop design and the configuration settings for the passengers boarding and alighting at the stops. The green area generates the passenger input; the blue one is the waiting area, and the pink is the boarding platform. All stops planned in the scenarios are configured with the same parameters and design with the intricate changes of activity and non-activity of the stops implemented.

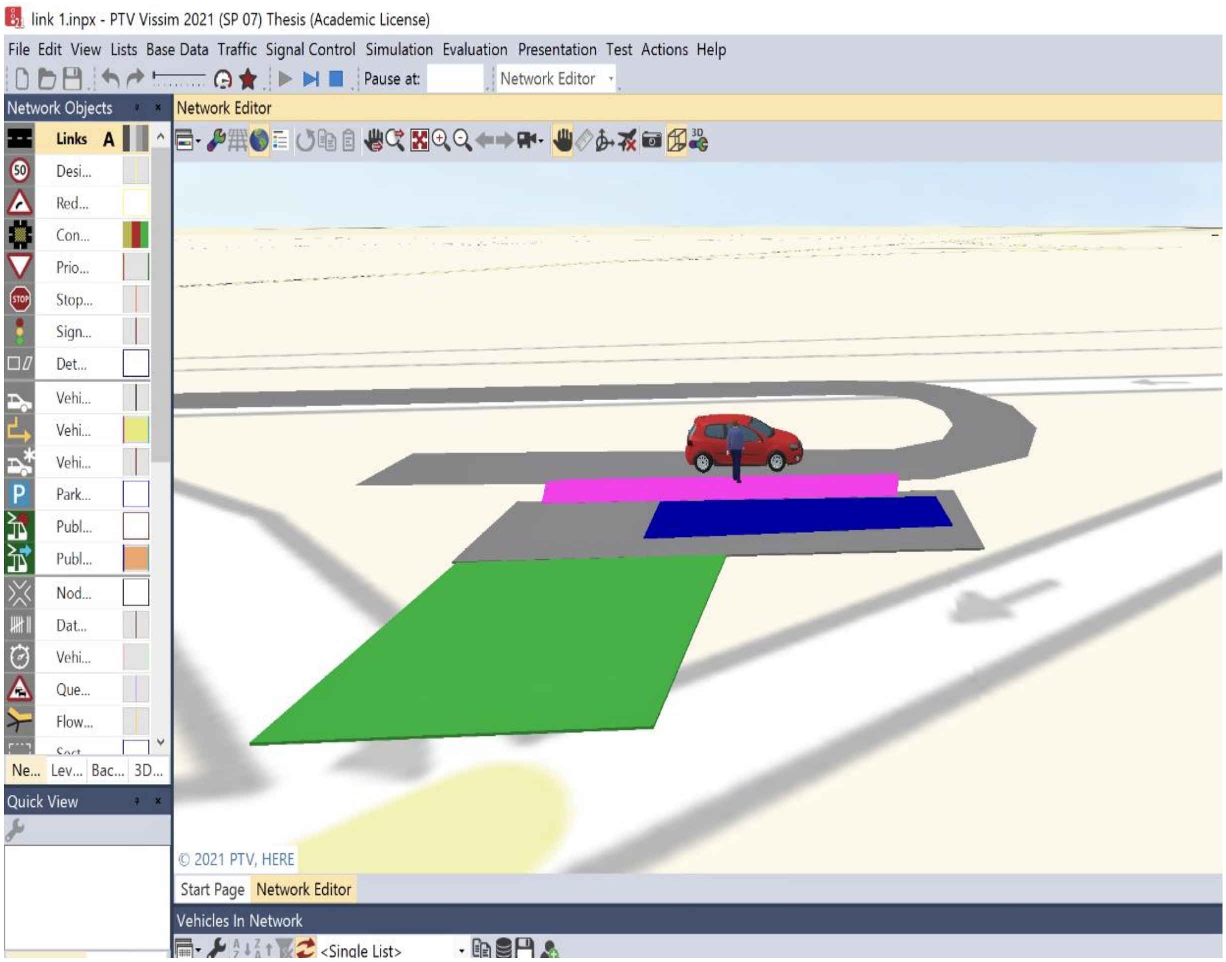

Figure 19 Passenger stop design in 3D

4.4 Results

The simulation results were compiled for each scenario separately and for the intersection design to efficiently analyze the system performances. The result discussion shows the overall vehicle network performance evaluation, the delays, and the vehicle travel times in the network. Also, Queue results were generated from the counters configured in the network links. The result also demonstrates the total vehicles that have reached their destination or are still active by the end of the simulation. Total kilometers traveled by the vehicle in the network are also presented.

4.4.1 Scenario A Results

1) Delays

The delay measurement evaluation for the five different simulation runs with corresponding time intervals has been presented in the table below. The stop delay is the average stop delay per vehicle in seconds at Passenger Traffic Stop, and the vehicle delay is the average delay time of all vehicles. The number of vehicles input in this scenario was 17, and the simulation result shows the exact number of vehicles in the network. The persons' delay is the average delay of all the passengers in seconds without the passenger service time offset at the stops.

Table 12 Scenario-A Delays results

DELAY MEASUREMENT EVALUATION

SIM RUN	TIMELINE	STOP DELAY(ALL)	VEH. DELAY(ALL)	VHS(ALL)	PERS. DELAY(ALL)
1	0-3200	0	11.3	17	0
2	0-3200	0	11.2	17	0
3	0-3200	0	11.31	17	0
4	0-3200	0	11.3	17	0
5	0-3200	0	11.32	17	0
AVG	0-3200	0	11.29	17	0
STUDENT	0-3200	0	0.05	0	0
MIN	0-3200	0	11.2	17	0
MAX	0-3200	0	11.32	17	0

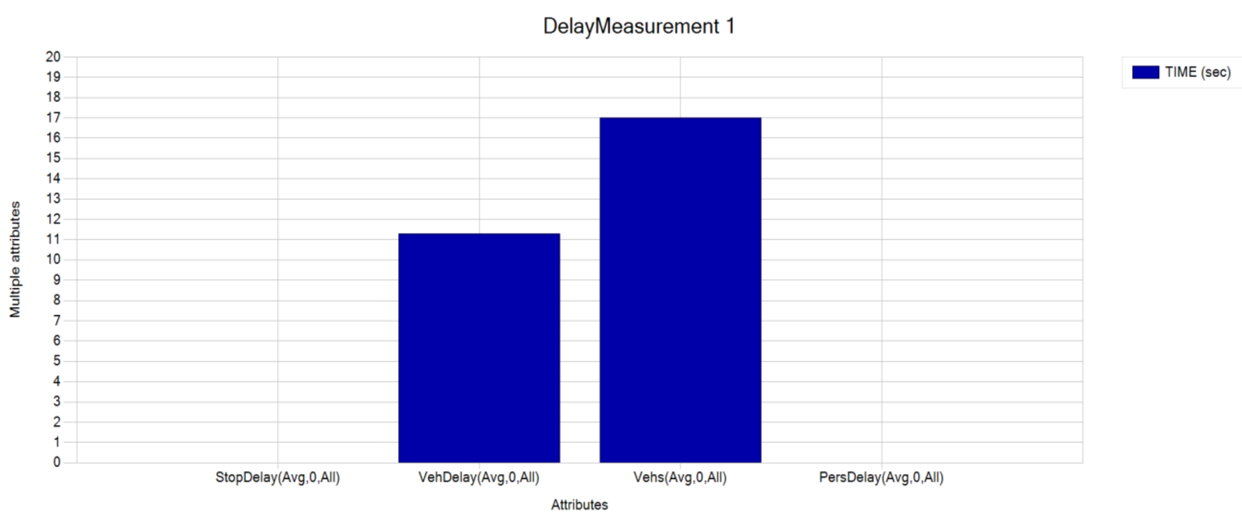

Figure 20 Scenario-A Delay results

2) Vehicle Travel Time

The vehicle travel time measurement evaluation for the five different simulation runs with corresponding time intervals has been presented in the table below. The number of vehicles recorded in each simulation run and their corresponding average travel time in the network is presented. The total distance traveled by each vehicle against each simulation run has also been compiled. The bar graph presented shows the average values of the parameters defined.

Table 13 Scenario-A Travel Time results

VEHICLE TRAVEL TIME MEASUREMENT EVALUATION

SIM RUN	TIMELINE	VHS(ALL)	TRAV. TM (sec.)	DIST. TRAV (m)
1	0-3200	17	1481.13	16040.16
2	0-3200	17	1481.47	16040.16
3	0-3200	17	1480.99	16040.16
4	0-3200	17	1481.03	16040.16
5	0-3200	17	1482.01	16040.16
AVG	0-3200	17	1481.33	16040.16
STUDENT	0-3200	0	0.43	0
MIN	0-3200	17	1480.99	16040.16
MAX	0-3200	17	1482.01	16040.16

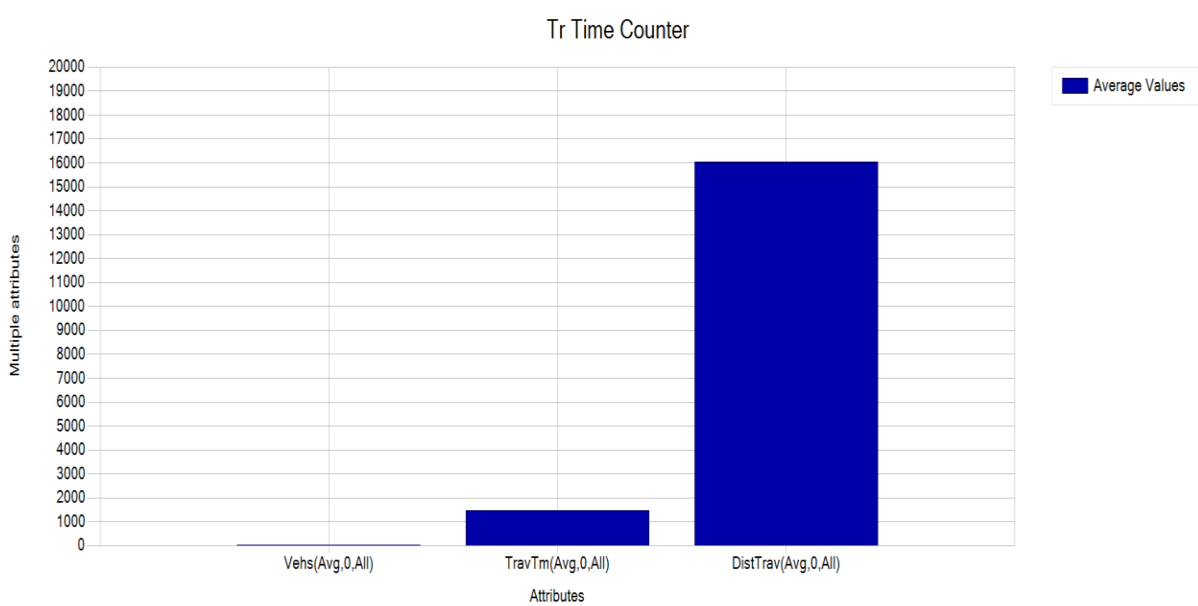

Figure 21 Scenario-A Travel Time results

3) Queue Counters

Six different Queue counters were placed in the network at different positions in each link to check for the queue evaluation of the overall system. One of the queue counters was placed at the end stop to count for the vehicles entering and stopping at the last stop after completing the journey. The queue length represented in the table is the average length in each step, measured upstream by the queue counter. The queue stop is where one directly upstream vehicle falls below the Begin attribute defined for the queue condition.

Table 14 Scenario-A Queue results

QUEUE COUNTER EVALUATION

TIME INT	QUEUE COUNTER	LINK	POSITION (m)	QUE. LEN (m)	QUE. STOPS
0-3200	1: First Counter	1	1000	0	0
0-3200	2: Second Counter	2	3000	0	0
0-3200	3: Third Counter	3	1000	0	0
0-3200	4: Fourth Counter	4	500	0	0
0-3200	5: Fifth Counter	5	500	0	0
0-3200	6: Counter at Stop	5	1040	0.57	17

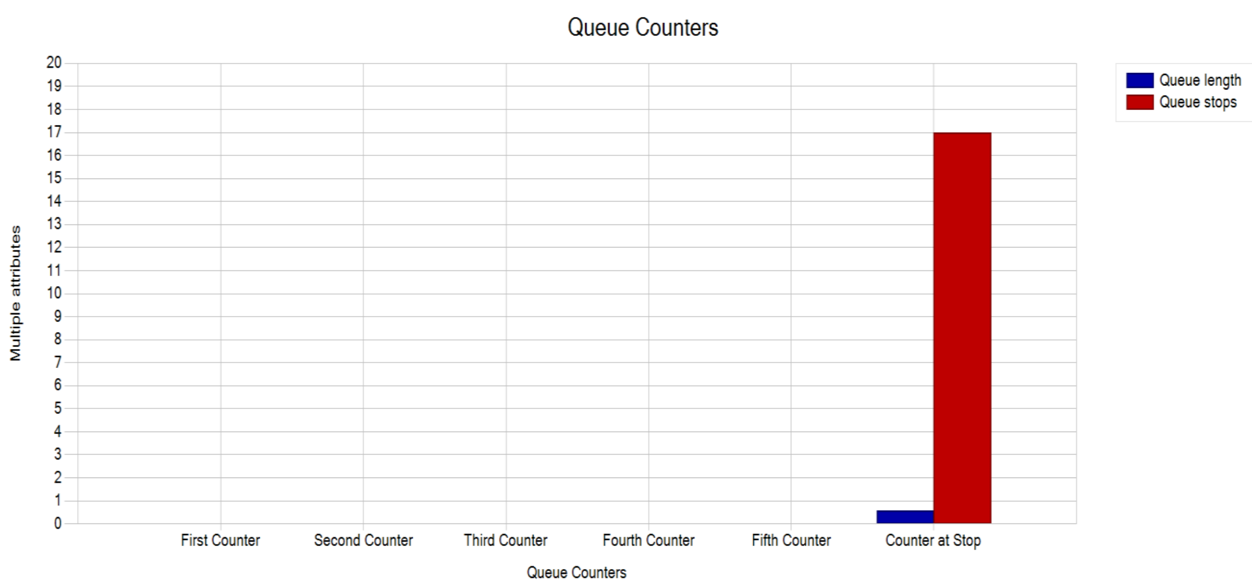

Figure 22 Scenario-A Queue results

4) Network Performance Evaluation

The vehicle network performance evaluation for the five different simulation runs with corresponding time intervals of 0-3200 seconds has been presented in the table below. The table shows the average delay per vehicle and the average number of stops per vehicle. The speed was set at 40kph of the CAV vehicle in the simulation parameter but accounting for the stops and starts, the average vehicle speed is reduced, as shown in the table. The total travel time of the vehicles traveling in the network and the vehicles that have completed the journey at the end of the simulation is tabulated with their total distance traveled. Finally, the network performance evaluation table also represents the total vehicles that have arrived at their destinations and, if any, active vehicles in the network.

Table 15 Scenario-A Network Performance Evaluation

VEHICLE NETWORK PERFORMANCE MEASUREMENT EVALUATION

SIMRAN	DELAY AVG(ALL)	STOPS AVG(ALL)	SPEED AVG(ALL)	DIST. TOT(ALL)	TRAV. TM. TOT(ALL)	DELAY. TOT(ALL)	VEH. ACT(ALL)	VEH. ARR(ALL)
1	13.15	0	38.94	272.83	25223.6	223.56	0	17
2	13.06	0	38.93	272.83	25229.6	222.02	0	17
3	13.15	0	38.94	272.83	25221.3	223.59	0	17
4	13.1	0	38.94	272.83	25221.5	222.71	0	17
5	13.18	0	38.92	272.83	25239	224.13	0	17
AVG	13.13	0	38.93	272.83	25227	223.2	0	17
STUDENT	0.05	0	0.01	0	7.5	0.83	0	0
MIN	13.06	0	38.92	272.83	25221.3	222.02	0	17
MAX	13.18	0	38.94	272.83	25239	224.13	0	17

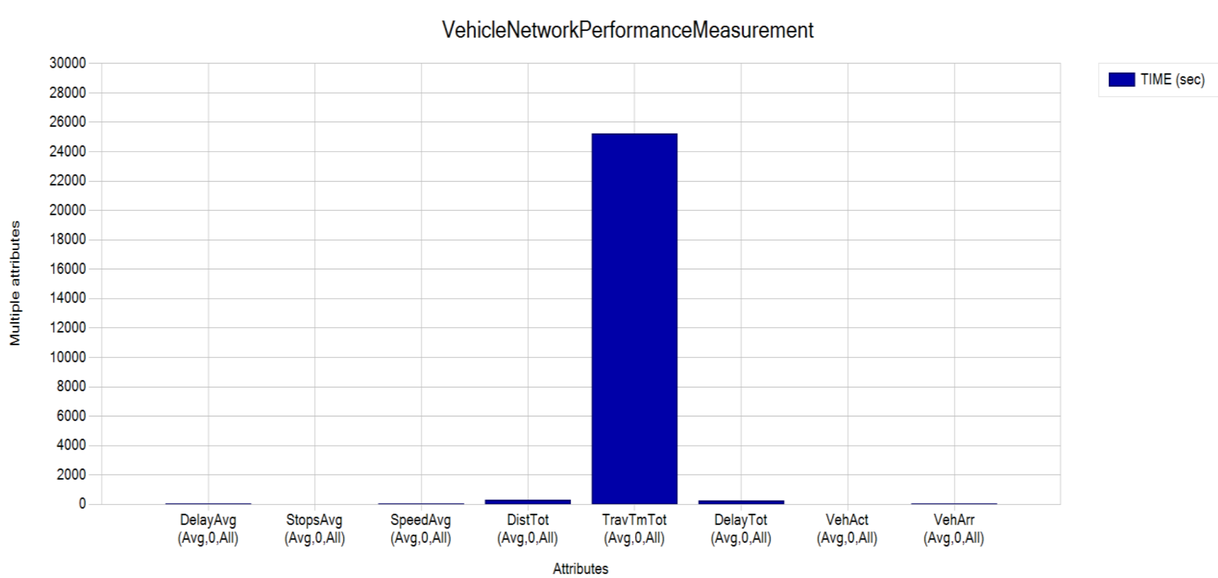

Figure 23 Scenario-A Network Performance Evaluation

4.4.2 Scenario B Results

1) Delays

The delay measurement evaluation for the five different simulation runs with corresponding time intervals has been presented in the table below. The stop delay is the average stop delay per vehicle in seconds at Passenger Traffic Stop, and the vehicle delay is the average delay time of all vehicles. The number of vehicles input in this scenario was 9, and the simulation result shows the exact number of vehicles in the network. The persons' delay is the average delay of all the passengers in seconds without the passenger service time offset at the stops.

Table 16 Scenario-B Delay results

DELAY MEASUREMENT EVALUATION

SIM RUN	TIMELINE	STOP DELAY(ALL)	VEH. DELAY(ALL)	VHS(ALL)	PERS. DELAY(ALL)
1	0-3200	0	23.37	9	0
2	0-3200	0	23.16	9	0
3	0-3200	0	23.22	9	0
4	0-3200	0	23.28	9	0
5	0-3200	0	23.4	9	0
AVG	0-3200	0	23.29	9	0
STD DEV	0-3200	0	0.1	0	0
MIN	0-3200	0	23.16	9	0
MAX	0-3200	0	23.4	9	0

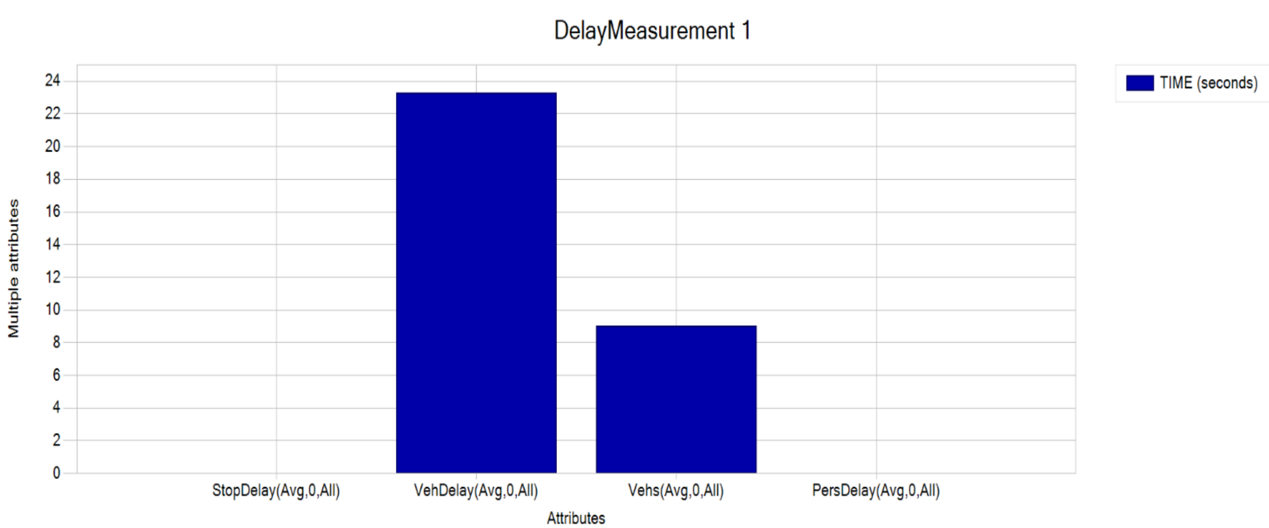

Figure 24 Scenario-B Delay results

2) Vehicle Travel Time

The vehicle travel time measurement evaluation for the five different simulation runs with corresponding time intervals has been presented in the table below. The number of vehicles recorded in each simulation run and their corresponding average travel time in the network is presented. The total distance traveled by each vehicle against each simulation run has also been compiled. The bar graph presented shows the average values of the parameters defined.

Table 17 Scenario-B Travel time results

VEHICLE TRAVEL TIME MEASUREMENT EVALUATION

SIM RUN	TIMELINE	VHS(ALL)	TRAV. TM (sec.)	DIST. TRAV (m)
1	0-3200	9	1600.99	16040.16
2	0-3200	9	1600.98	16040.16
3	0-3200	9	1600.59	16040.16
4	0-3200	9	1600.81	16040.16
5	0-3200	9	1601.35	16040.16
AVG	0-3200	9	1600.94	16040.16
STD DEV	0-3200	0	0.28	0
MIN	0-3200	9	1600.59	16040.16
MAX	0-3200	9	1601.35	16040.16

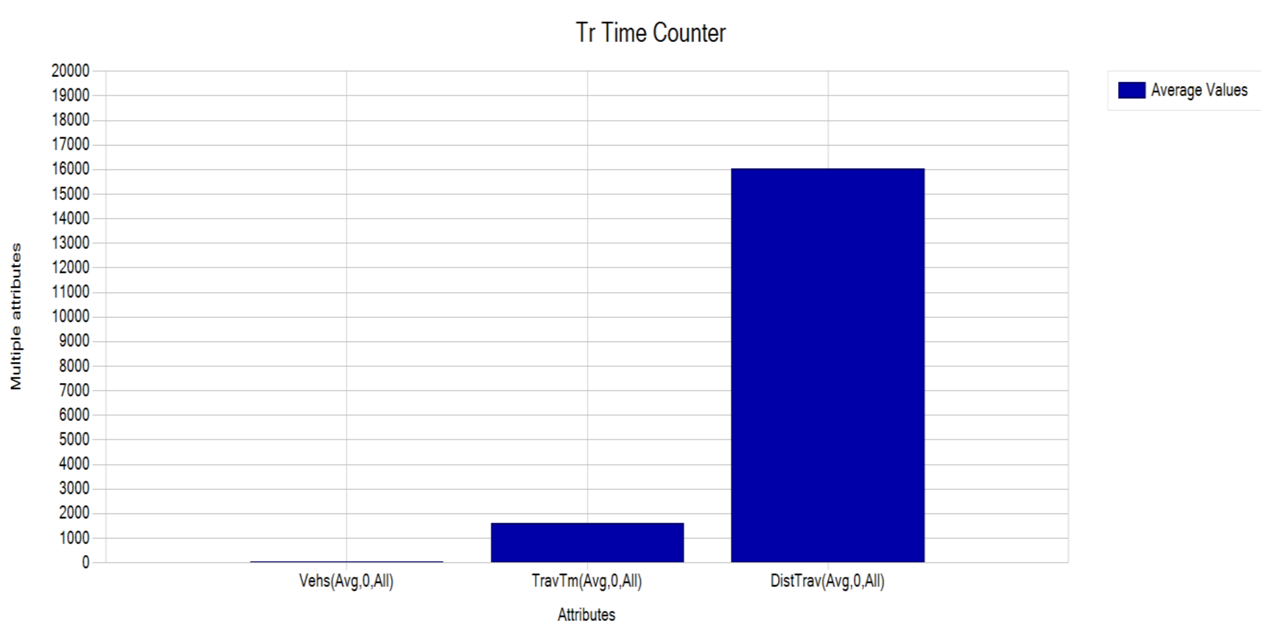

Figure 25 Scenario-B Travel time results

3) Queue Counters

Six different Queue counters were placed in the network at different positions in each link to check for the queue evaluation of the overall system. One of the queue counters was placed at the end stop to count for the vehicles entering and stopping at the last stop after completing the journey. The queue length represented in the table is the average length in each step, measured upstream by the queue counter. The queue stop is where one vehicle that directly upstream falls below the Begin attribute defined for the queue condition.

Table 18 Scenario-B Queue results

QUEUE COUNTER EVALUATION

TIME INT	QUEUE COUNTER	LINK	POSITION (m)	QUE. LEN (m)	QUE. STOPS
0-3200	1: First Counter	1	1000	0	0
0-3200	2: Second Counter	2	3000	0	0
0-3200	3: Third Counter	3	1000	0	0
0-3200	4: Fourth Counter	4	500	0	0
0-3200	5: Fifth Counter	5	500	0	0
0-3200	6: Counter at Stop	5	1040	0.223409	9

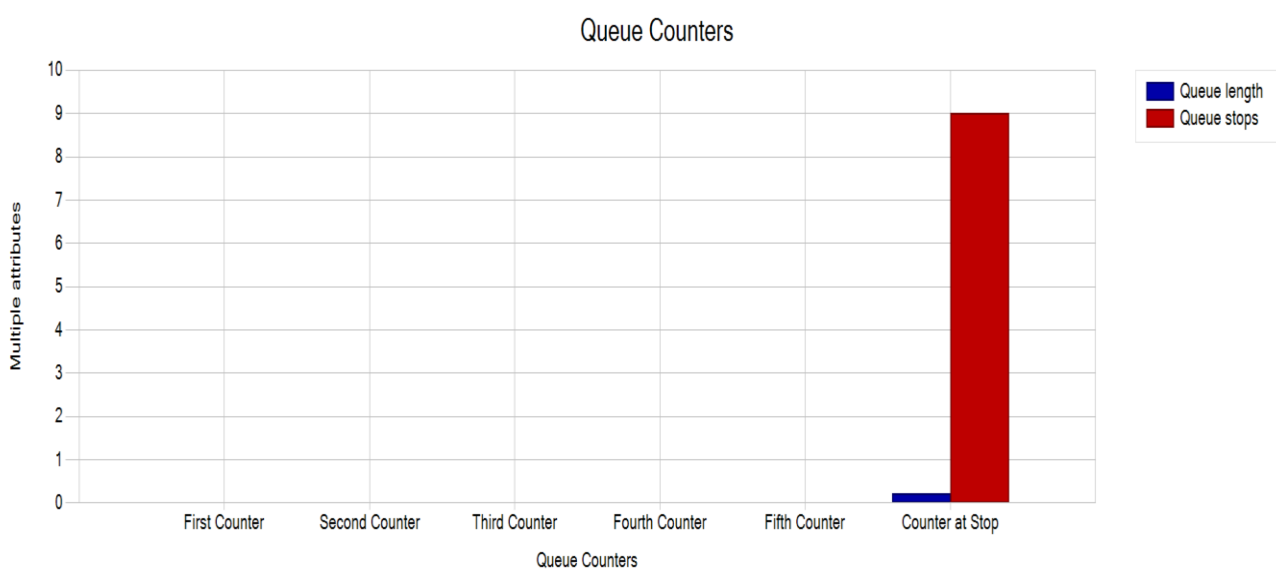

Figure 26 Scenario-B Queue results

4) Network Performance Evaluation

The vehicle network performance evaluation for the five different simulation runs with corresponding time intervals of 0-3200 seconds has been presented in the table below. The table shows the average delay per vehicle and the average number of stops per vehicle. The speed was set at 40kph of the CAV vehicle in the simulation parameter but accounting for the stops and starts, the average vehicle speed is reduced, as shown in the table. The total travel time of all the vehicles traveling within the network or that have completed the journey at the end of the simulation is tabulated with their total distance traveled. Finally, the network performance evaluation table also represents the total vehicles that have arrived at their destinations and, if any, active vehicles in the network.

Table 19 Scenario-B Network Performance Evaluation

VEHICLE NETWORK PERFORMANCE MEASUREMENT EVALUATION

SIMRAN	DELAY AVG(ALL)	STOPS AVG(ALL)	SPEED AVG(ALL)	DIST. TOT(ALL)	TRAV. TM. TOT(ALL)	DELAY. TOT(ALL)	VEH. ACT(ALL)	VEH. ARR(ALL)
1	25.18	0	36.03	144.44	14432.2	226.6	0	9
2	25.05	0	36.03	144.44	14432.6	225.41	0	9
3	25.07	0	36.04	144.44	14428.9	225.65	0	9
4	25.08	0	36.03	144.44	14430.6	225.76	0	9
5	25.3	0	36.02	144.44	14436.2	227.7	0	9
AVG	25.14	0	36.03	144.44	14432.1	226.22	0	9
STUDENT	0.1	0	0.01	0	2.72	0.94	0	0
MIN	25.05	0	36.02	144.44	14428.9	225.41	0	9
MAX	25.3	0	36.04	144.44	14436.2	227.7	0	9

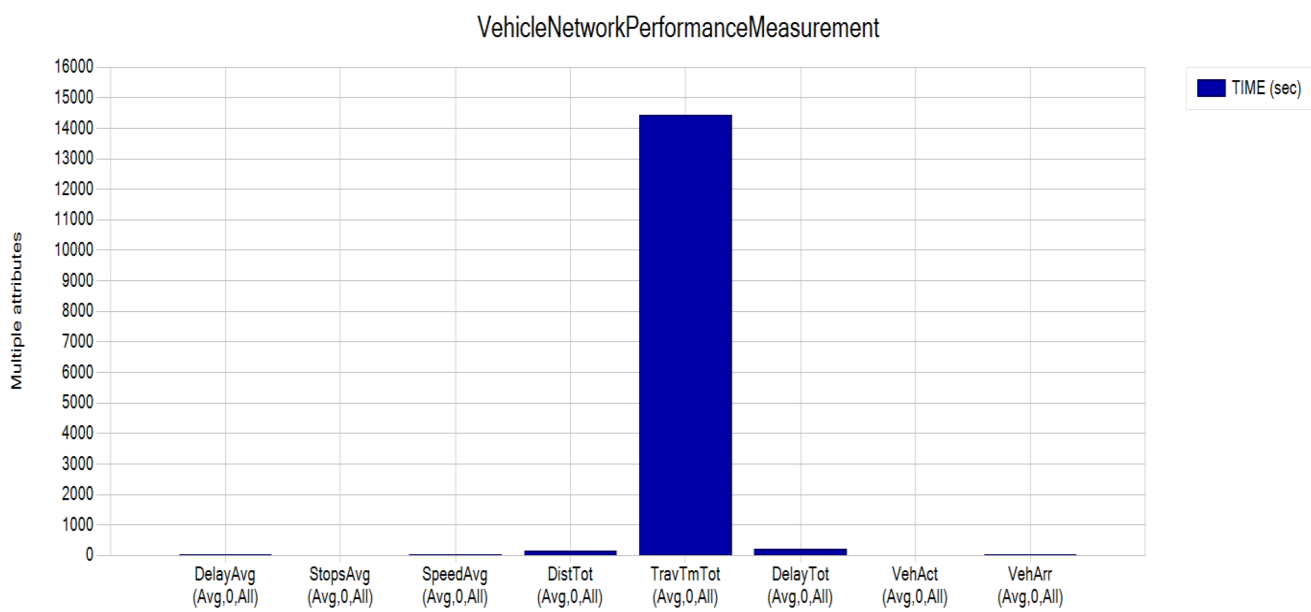

Figure 27 Scenario-B Network Performance Evaluation

4.4.3 Intersection Results

The Intersection's simulation primary focus was to check whether the CAV Lane had any queue formation. The scenario was aimed at the possibility that CAV vehicles in their dedicated lanes would have priority in the conflict areas and the Intersection. For this, queue counters were placed in the network at each link and in the CAV lane segments. Also, stop delays and vehicle delays are verified in the CAV lane.

Queue Counter Evaluation

The bar graph is showing no queue formation in the CAV lane.

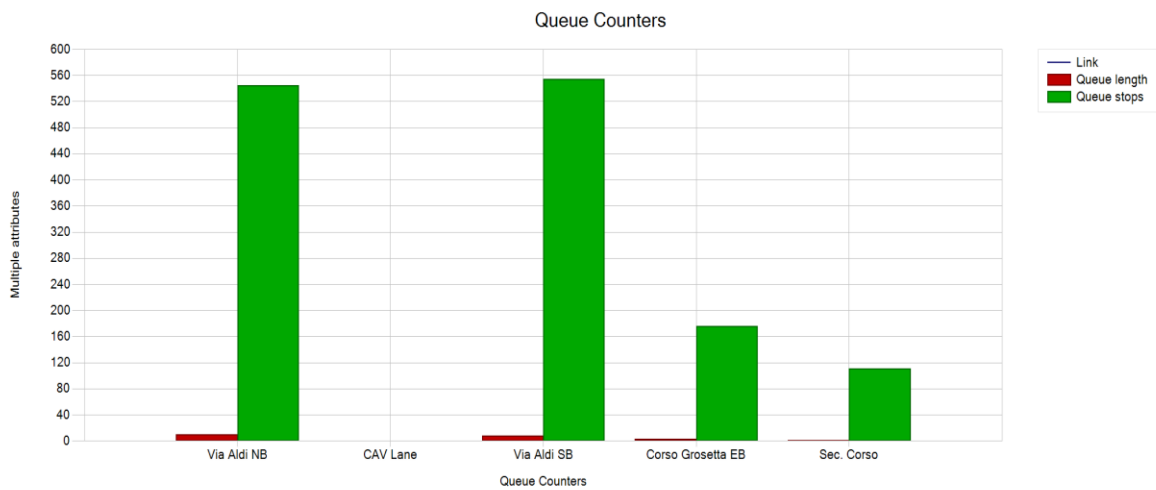

Figure 28 Intersection queue evaluation

Delays Evaluation

The bar graph depicts no stop and vehicle delays in the CAV lane at the Intersection.

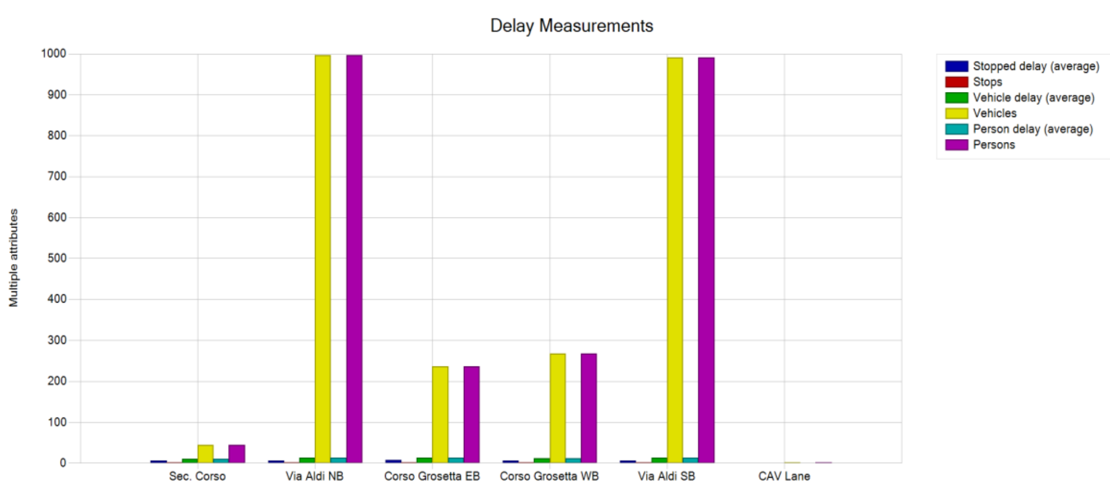

Figure 29 Intersection delays evaluation

4.4.4 Discussion

The simulation of the planned scenarios based on different data sets presented the results that have been compiled and are assessed hereafter. Firstly, the total distance traveled by all the vehicles in the network calculated while planning the scenarios is validated by the simulation results. The trip or journey time indicated by the simulation results is also the same, excluding the network delays and the stops that are active during the journey. In both scenarios, the active stops affect the travel time, vehicle delays, and the average speed of the vehicles in the network, as indicated in the results. The average speed set at 40 kph at the beginning of the simulation decreases by 10% in the scenario with all the stops active. Whereas, in the scenario with half of the stops active, the average speed is dropped by 5%. The number of vehicles or the fleet size in scenario A is almost double than that of scenario B; however, the vehicle delays in scenario A are significantly less than that in scenario B. This is because the average speed attained during the simulation in both scenarios is different. The results of both the scenarios simulation show no queue formation in the dedicated CAV lane. Also, the active vehicles and vehicles arrived that are indicated in the simulation result of each scenario confirms that each vehicle completes the journey in the allocated time slot, set in the scenario modeling.

5 CASE STUDY DEVELOPMENT

5.1 Goals

The following set of goals are outlined for the case study development:

- Identify crucial needs and necessary assumptions that must be in place to deploy CAV service.
- Define the approach and action plans to execute the service effectively.
- Develop an operation strategy by defining the attributes and their integrating levels for the successful application of the service.
- Develop a sequence time diagram highlighting all the critical actors involved in the case study and their subsequent interactions.
- Discuss the significant benefits of the planned CAV deployment that helps with the general comparison of the service with a non-CAV environment.

5.2 Assumptions

The following assumptions are considered for the development of the case study, which helps in the effectiveness of the study provided for the modeled CAV Car sharing service [39]:

- The car-sharing service is to be used from Turin airport to the city center and dedicated lanes developed for CAVs.
- Pick-up and Drop-off points are per CAV compliance, and accessibility to users is guaranteed.
- All CAV vehicles are correctly interconnected, and the necessary infrastructure is assumed to be in place with the EU regulations.
- The level of automation in vehicles and inter-connectivity is per the SAE International standards.
- The cybersecurity laws are protected, and users are provided with all the relevant information they deem necessary.
- The Car-sharing service users are adequately familiar with concepts of Profile/Account management, metering, and accounting.

5.3 Approach

The most critical point in developing a case study for a car-sharing service is the identification of properly constructed attributes of the service and their integrating levels. After an extensive literature review, the following attributes and coordinating levels were drafted [22]. The attributes, their brief explanation, and concerning levels are presented in a tabulated form below. After developing the essential attributes and the accurate simulation analysis and discussion of results for the planned scenarios in the previous section, an effective comparison with the help of this case study is possible. Lastly, the benefits of choosing CAVs Car-sharing service and a sequence diagram involving all the actors in the car-sharing service are presented.

Table 20 Case-study Attributes and levels

ATTRIBUTES	EXPLANATION/APPROACH	LEVELS
Reservation	Booking/reservation of the Car-sharing service. It can be made either by calling a reservation center or via the internet, like mobile applications.	• via phone call • online website/mobile applications, etc.
Vehicle Location	Two different approaches can be distinguished. First, stationary carsharing, in which users pick up a car at one of several stations. Second, in free-floating carsharing, cars are spatially dispersed. Here, the user can locate the vehicle with his smartphone.	• vehicles are located at fixed stations • vehicles are spatially dispersed - location via app
Vehicle Access	Differentiating between access via key and keyless access. In a key scenario, vehicle keys are normally stored in lockboxes. Keyless access encompasses locking and unlocking vehicles directly via smartcard.	• key has to be picked up at a station and needs to be returned there • access the vehicle with smartphone/membership card
Metering and accounting	In manual systems, users are usually encouraged to keep a trip logbook by writing down the time and mileage at the beginning and end of a trip. On-board data-acquisition hardware allows automated accounting by recording, storing and processing of relevant data	• fixed hourly and mileage rate according to paper and trip logbook • automated usage-based accounting (time and mileage)
Online account	A personalized online account with information about trips and cost overview	• no online account available • online account with information about trips and cost overview
Interoperability	Various services combining for greater user interface and ease	• customer account exclusively for a carsharing provider in one city • customer account allows using various carsharing offers in various cities
Incentive scheme	A monetary incentive scheme based on vehicle sensor data can be used to motivate consumers adopt a more sustainable approach	• no incentive scheme available • cautious driving is rewarded with cash premiums

5.4 Sequence Diagram

The primary purpose of this sequence diagram is to show the actors' interactions arranged in the time sequence of the modeled case study. It depicts the actors involved in the scenario and the sequence of actions that occurred or exchanged between the actors that are needed to carry out the functionality of the scenario [44]. Some functionality may vary accordingly, but the general purpose of the case study remains equivalent to the timing diagram shown.

Critical Actors

The following actors are pivotal to the case study developed and are depicted as such.

1) Service User

The service user is the non-CAV actor for which the service has been designed. He will be taking actions such as reservation or booking of the ride and stops selection, and if any, change of stops.

2) Obstacles/Pedestrians

The actors are being used to depict any obstacles that may arise during the journey or along the path of the CAV. These are represented with the red color symbol to show their high priority.

3) Signals/Stops

The signal heads and stop signs acting along the path of CAV may alter the vehicle travel time and queue behavior of the traffic. These are also represented with yellow to show subsequent high priority management.

4) Car-sharing CAV

The CAV actor transports the service user from the pick-up point to the drop-off point.

5) CAV Data Center

The CAV data center is communicating continuously with CAV and the service user for the primary functions of the journey. It links all the critical actors and maintains connectivity.

Legends

Service User Obstacles/Pedestrians Signals/Stops sign Car sharing-CAV

Directing step from one actor to another

Depicting Interconnectivity among CAV & Data Center

Indicating steps; description table follows

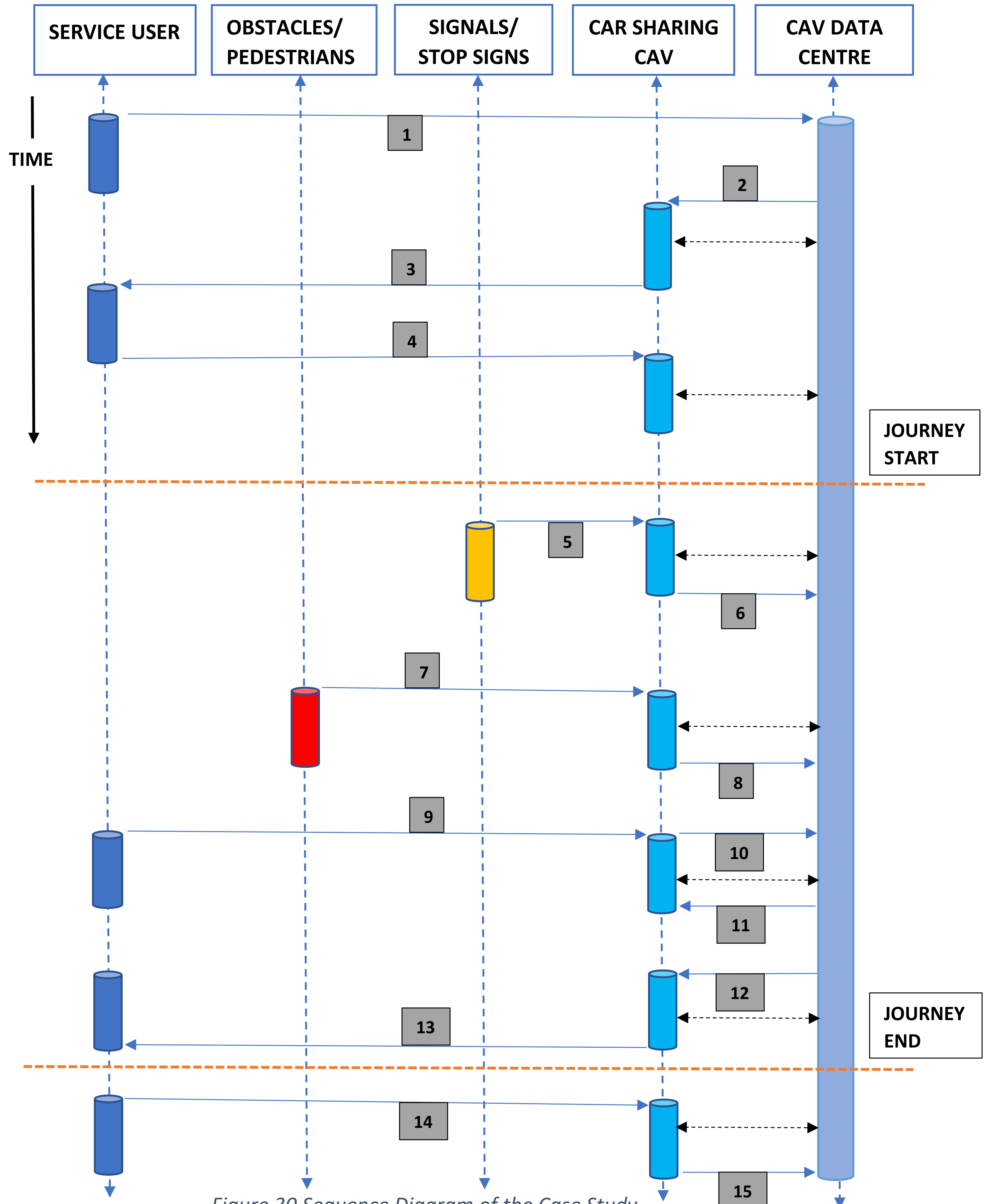

Figure 30 Sequence Diagram of the Case Study

Description of Steps

The steps according to the time sequence mentioned in the diagram are described in the table below.

Table 21 Sequence diagram steps description

STEPS	DESCRIPTION
1	Reservation/booking by the service user
2	Datacenter signaling CAV
3	Vehicle (CAV) approaching service user
4	User accessing the vehicle (CAV)
5	Detection of Signal or Stop sign, if any, by CAV
6	Vehicle Stationery, CAV notifying Data Centre for vehicles interconnectivity
7	Auto-detection of any obstacles or pedestrians
8	Vehicle Stationery, CAV notifying Data Centre for vehicles interconnectivity
9	Re-routing or changing of Stops by service user during journey
10	CAV connecting to Datacenter, possible route detection and selection
11	Datacenter re-routing CAV towards the destination
12	Metering/Accounting of journey by Datacenter to CAV to end-user
13	Payment/End ride by the service user
14	Service user vacating CAV
15	CAV movement towards parking/charging station

5.5 Benefits

The following significant benefits result in choosing CAVs over non-CAV for the modeled service. These parameters prove pivotal in performance evaluation and analysis of the said deployment of CAVs [45].

1) SAFETY

The majority of accidents are caused by driver mistakes. The capacity of CAVs to complete repetitive activities without becoming weary places them ahead of human drivers in certain activities. By significantly minimizing the possibility of driver error, CAV can substantially limit the number of crashes.

2) SHORTER TRIP TIME

The dedicated lanes modeled in the base scenario would eventually lead to shorter travel times, thus minimizing the journey time of the car-sharing service.

2) DECREASED CONGESTION

CAV Vehicles could drive closer together due to connected and automated technologies, increasing roadway capacity without compromising safety, as these vehicles can maintain considerably shorter trailing distances between them than human drivers while also remaining safe. Also, to satisfy mobility demand, CAVs will be a critical next step toward expansion plans.

3) ENHANCEMENT OF EMISSIONS

Fully electric and automated vehicles would eventually result in improved Carbon emissions, and traffic signal data may result in more optimum speeds and efficient fuel consumption, both of which are examples of strategies to minimize emissions.

4) EQUITY

A self-driving car is accessible to anybody. Disabled, younger, someone even without a driver's license, and older individuals would all benefit from enhanced mobility. Naturally, this might significantly raise demand and potentially attract new customers.

5) IMPROVED ROAD DESIGN

Improved safety may eliminate the need for crash barriers, and roadway signage may be replaced by in-vehicle information, simplifying and beautifying our roadways. Additionally, lane widths could be lowered while increasing traffic throughput, resulting in less land requirement for parking lots and other spaces.

6) RESOURCEFULNESS

Humans frequently have additional responsibilities such as employment, children, and school. When drivers are not behind the wheel, their time utilization will be prioritized differently and efficiently.

6 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

CAV deployment for mass transit has the potential to enhance transportation safety, sustainability, and efficiency. However, these prospects come with challenges, specifically management and deployment-related, discussed in this document. This thesis study was conducted to develop a planning model and created scenarios for deploying CAVs for a Car sharing service in the city of Turin. With the help of a case study description, the modeled service provided the approach to access CAVs vehicle for movement from fixed, intermediate stops for the service users. Additionally, the case study discussed critical factors that must be followed to complete the implementation of CAVs on public roads, especially in Car-sharing services.

Further, this study identified the necessary demand profile concerning the route selected, i.e., Turin Airport to City Centre, and modeled base scenarios on the statistical data covered in the literature. The simulation results of the scenarios helped with the analysis of travel times, vehicle delays, and the distance covered by the CAVs in each scenario. The results approve the approach to offering shared mobility services, and the simulation analysis validated the critical selections of design by explicitly highlighting no queue formation in the CAV lanes. The system performance evaluation indicated that peak demand could be accommodated in both scenarios planned if the fleet size is doubled in the scenario of less occupancy. The network model is deemed highly flexible, transferable, and potentially applicable to other territorial areas; because even if mobility demand is increased, the network performance evaluation showed that it could facilitate the demand by increasing the fleet size and other variables.

6.2 Recommendations

Traditionally, long-range planning has assumed that present knowledge of future conditions is reasonably dependable; however, that is not always the case while working with external factors. The need to test multiple designs, strategies and gather accurate data for the assessment of CAVs deployment and its connected infrastructure is highly recommended for future work. The passenger stops and vehicle inputs synchronization is a critical area and requires dedicated work to enhance the system effectiveness. The simulation to reciprocate the actual composition of a car-sharing service requires specific software programming and model segregation techniques, this was beyond the scope of this thesis study and must be catered as a recommended priority in any future work based on this study.

Although, the Italian Car-Sharing market is seeing unprecedented growth in terms of membership, services, and kilometers traveled. The need for progressed coordination, awareness, and public acceptance is ever so needed to deploy CAVs for these services successfully. Technological advancements may be critical in resolving these challenges, as unattended access increases user safety and mitigates access concerns caused by inadequate coordination among users.

6.3 Contribution

The thesis study provided in-depth, flexible scenarios modeled for CAV implementation for a car-sharing service in Turin city. The study's primary contribution is to provide a base for any future implementation of CAV in a smart city for the successful application of mass transit. This study used statistical data provided in various literature and on public domains to incorporate real-world demands and to conceptualize the capacity a car-sharing service can accommodate in a metropolitan city. This study concluded with a case study providing the attributes and the integrating levels that depict the modeled deployment's integral approach. Finally, a sequence diagram is presented that contributes to the representation of all the actors involved in the said deployment and describes the sequence of actions that occurred or exchanged between the actors, needed to carry out the functionality of the modeled case.

6.4 Limitations

This thesis study, however, is subjected to some limitations that are enlisted below:

- The unavailability of refined statistical data on CAV deployment in Turin city limited the study to assumptions of some parameters related to scenario planning.
- The software used the Thesis Academic license that had some limited features during the simulation and results phase.
- The used software did not incorporate the integration of CAVs with the other regular vehicles in the same lane.
- The car-sharing user stop design and vehicle inputs synchronization was limited during the simulation work.

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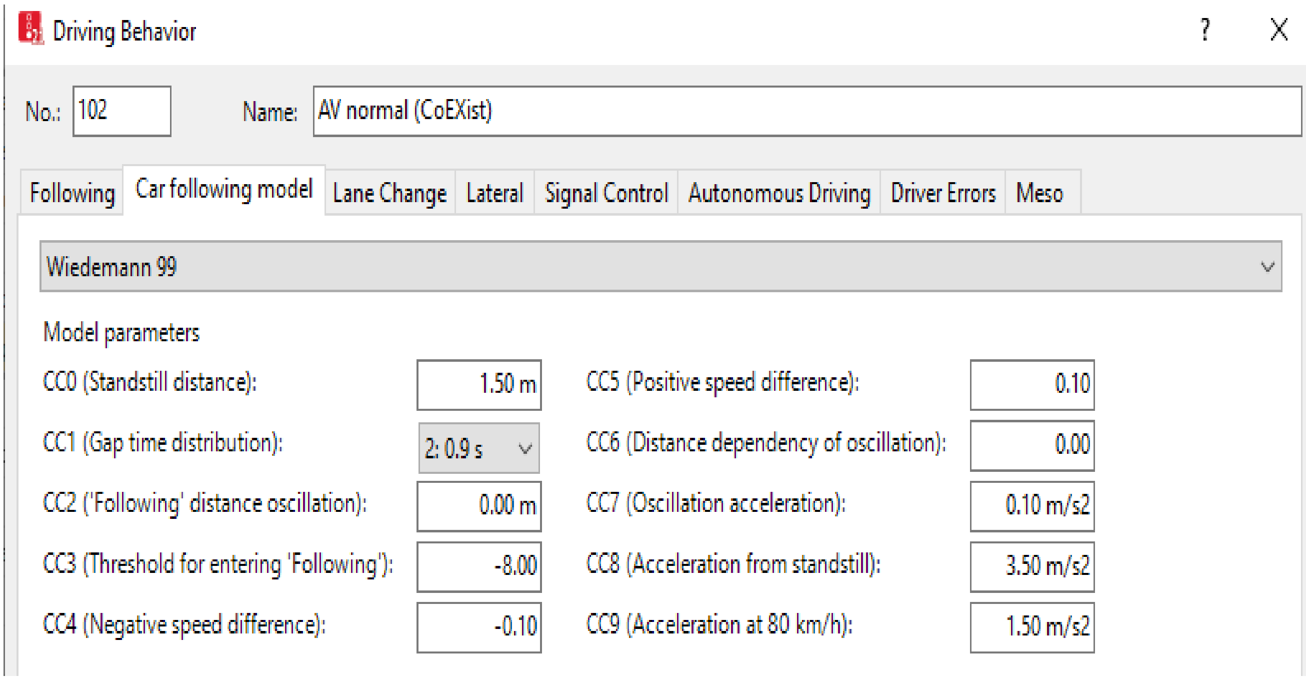
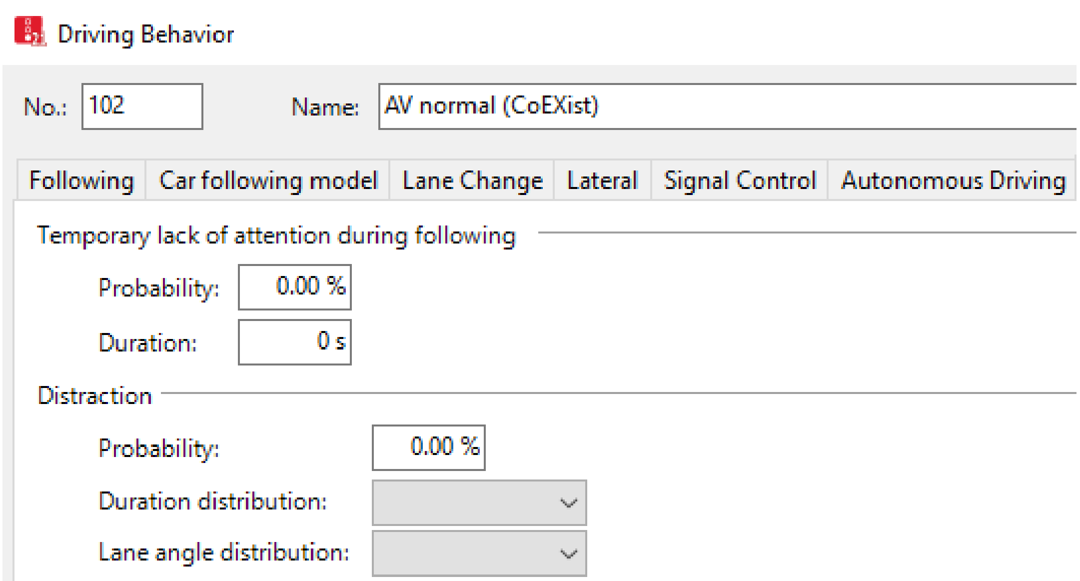
APPENDIX A

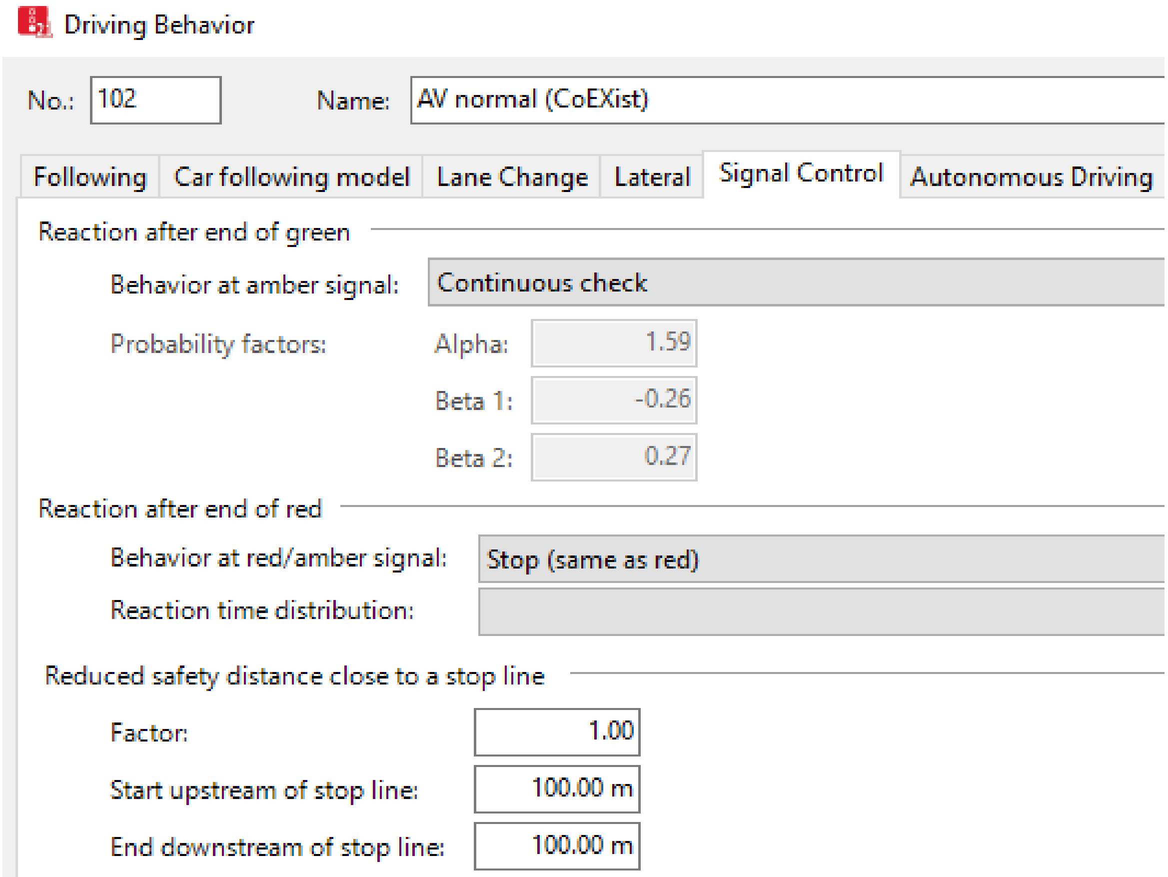
CAV Parameters on PTV Vissim



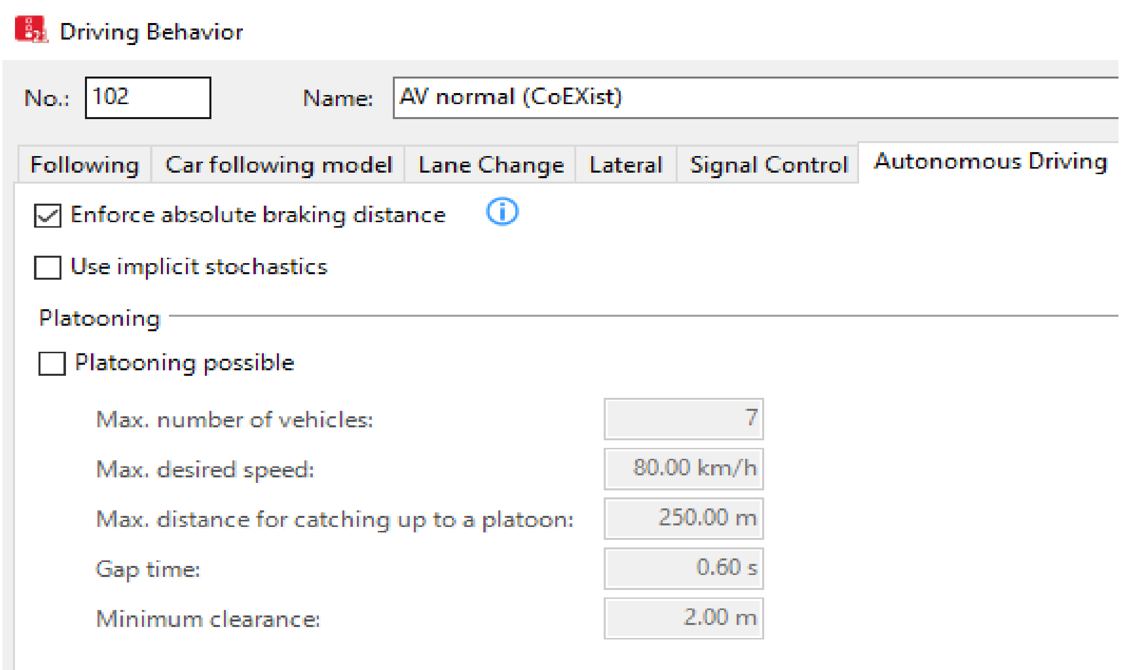
A-1 Car Following Model Wiedemann 99



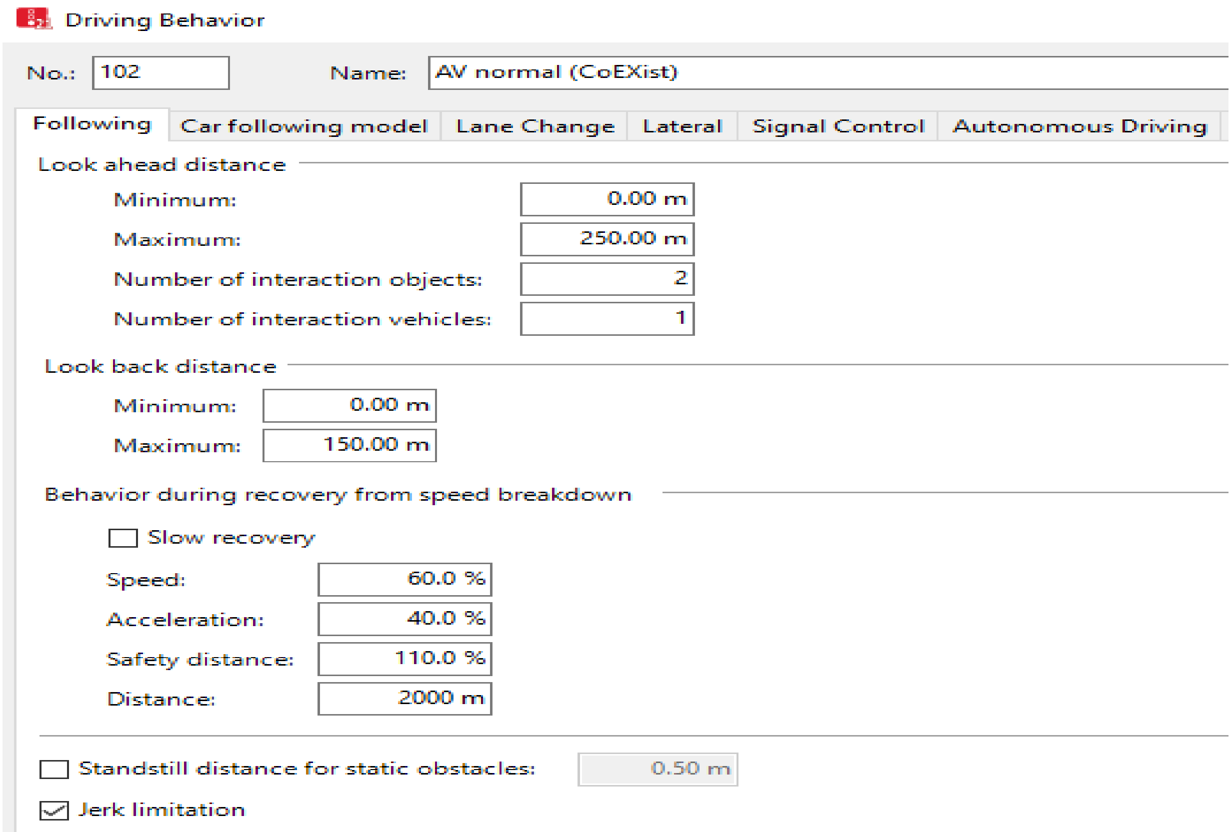
A-2 Driving Errors Probability



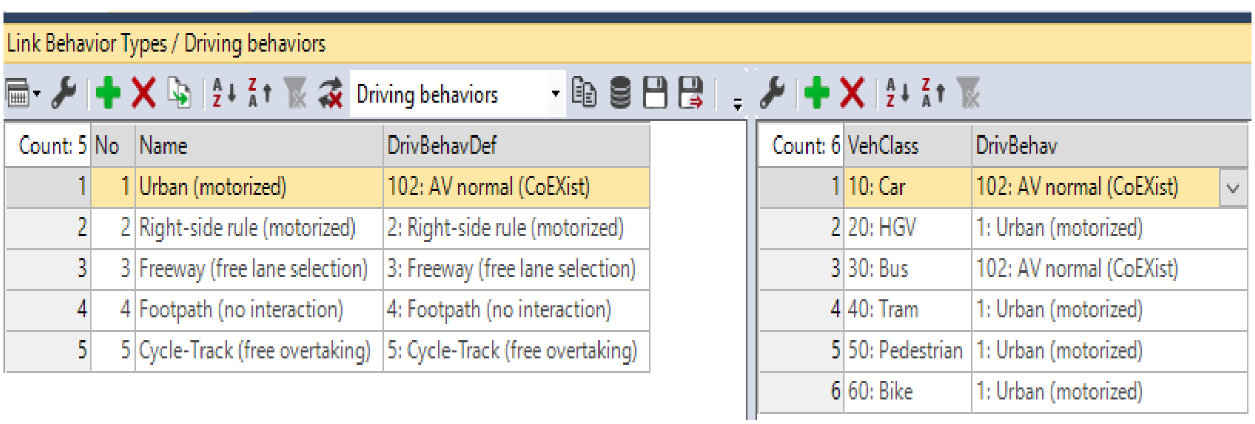
A-3 Signal Control Behavior



A-4 Autonomous Driving Mode



A-5 Vehicle Following Mode



Count: 5	No	Name	DrivBehavDef
1	1	Urban (motorized)	102: AV normal (CoEXist)
2	2	Right-side rule (motorized)	2: Right-side rule (motorized)
3	3	Freeway (free lane selection)	3: Freeway (free lane selection)
4	4	Footpath (no interaction)	4: Footpath (no interaction)
5	5	Cycle-Track (free overtaking)	5: Cycle-Track (free overtaking)

Count: 6	VehClass	DrivBehav
1	10: Car	102: AV normal (CoEXist)
2	20: HGV	1: Urban (motorized)
3	30: Bus	102: AV normal (CoEXist)
4	40: Tram	1: Urban (motorized)
5	50: Pedestrian	1: Urban (motorized)
6	60: Bike	1: Urban (motorized)

A-6 Link and Driving Behavior

Vehicle Types

Count: 8	No	Name	Category	Model2D3DDistr	ColorDistr1	OccupDistr	Capacity
1	100	Car	Car	10: Car	1: Default	1: Single Occupancy	2
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

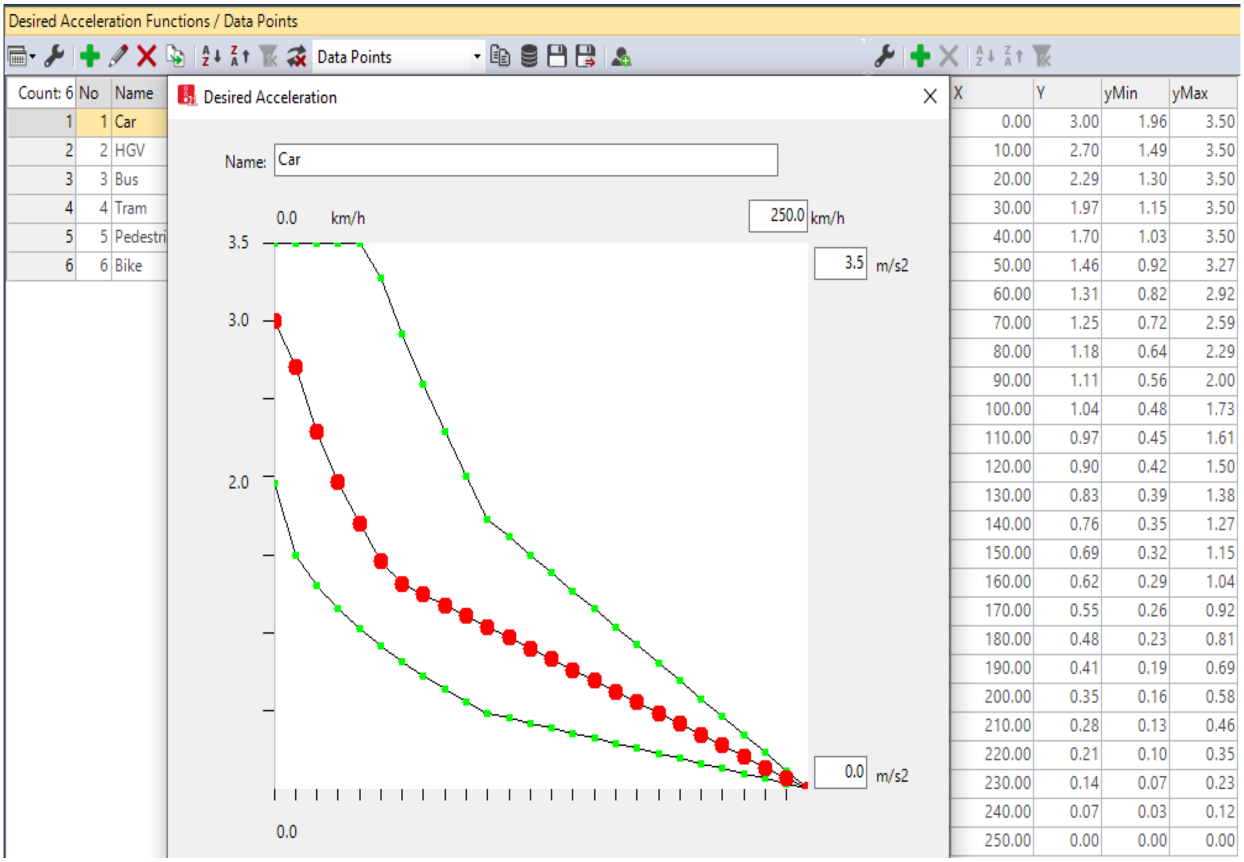
A-7 Vehicle Type and Occupancy

Network Editor

Desired Speed Distributions / Data Points

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	30.00
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
13	90	90 km/h	85.00	120.00
14	100	100 km/h	88.00	130.00
15	120	120 km/h	85.00	155.00
16	130	130 km/h	80.00	170.00
17	140	140 km/h	80.00	205.00

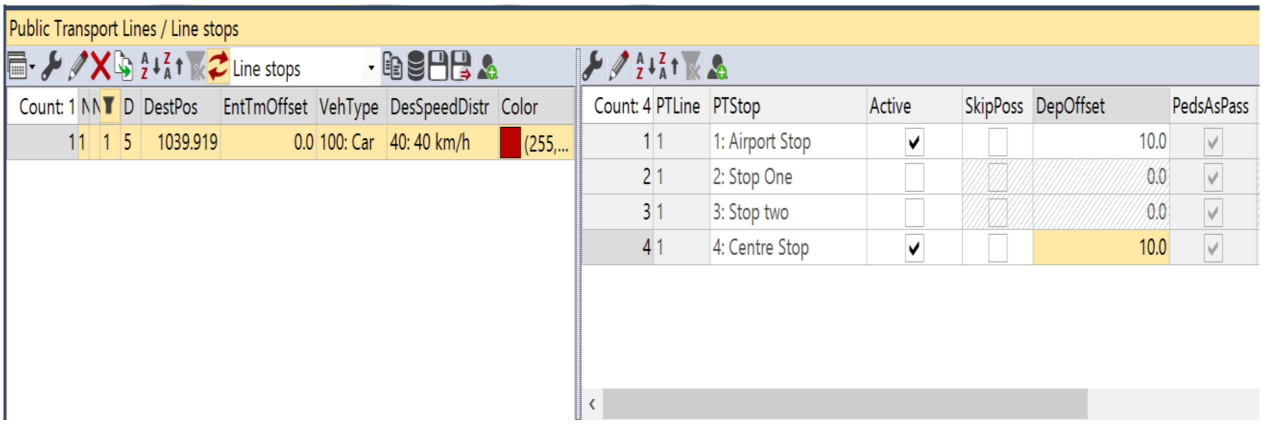
A-8 Desired Vehicle Speed



A-9 Desired Acceleration

APPENDIX B

Design Parameters on PTV Vissim

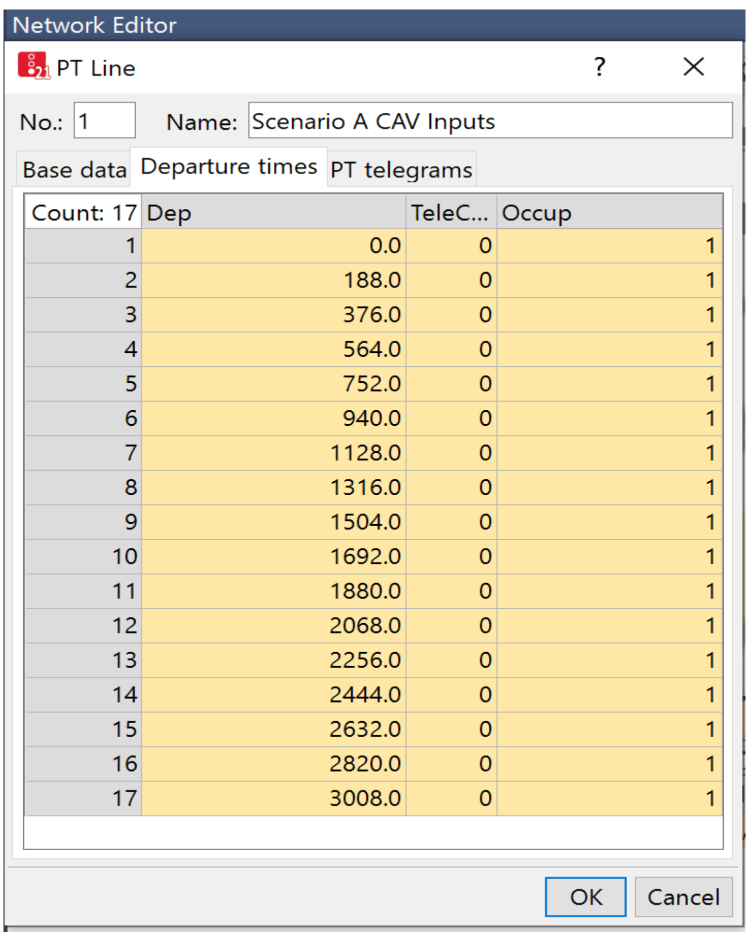


Public Transport Lines / Line stops

Count: 1	No	N	D	DestPos	EntTmOffset	VehType	DesSpeedDistr	Color
1	1	1	5	1039.919	0.0	100: Car	40: 40 km/h	(255,...

Count: 4	PTLine	PTStop	Active	SkipPoss	DepOffset	PedsAsPass
1	1	1: Airport Stop	✓		10.0	✓
2	1	2: Stop One			0.0	✓
3	1	3: Stop two			0.0	✓
4	1	4: Centre Stop	✓		10.0	✓

B-1 Scenario A Design Inputs



Network Editor

PT Line

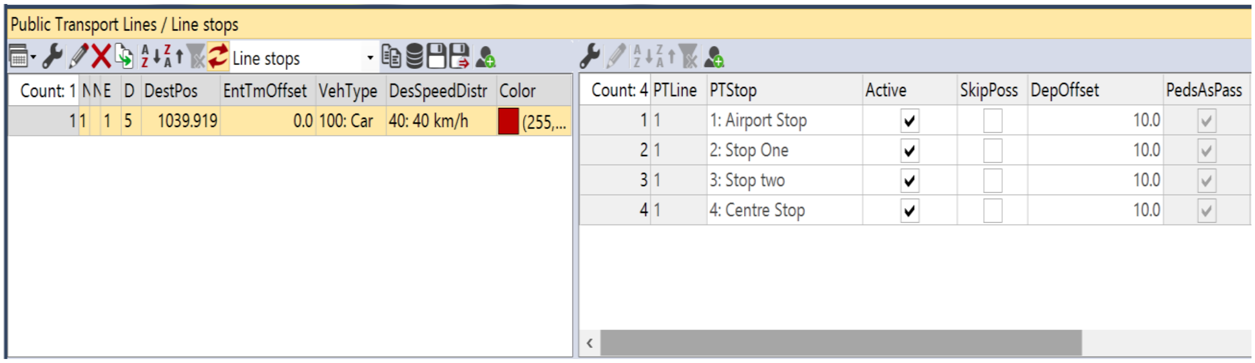
No.: 1 Name: Scenario A CAV Inputs

Base data | Departure times | PT telegrams

Count: 17	Dep	TeleC...	Occup
1	0.0	0	1
2	188.0	0	1
3	376.0	0	1
4	564.0	0	1
5	752.0	0	1
6	940.0	0	1
7	1128.0	0	1
8	1316.0	0	1
9	1504.0	0	1
10	1692.0	0	1
11	1880.0	0	1
12	2068.0	0	1
13	2256.0	0	1
14	2444.0	0	1
15	2632.0	0	1
16	2820.0	0	1
17	3008.0	0	1

OK Cancel

B-2 Scenario A CAV Inputs

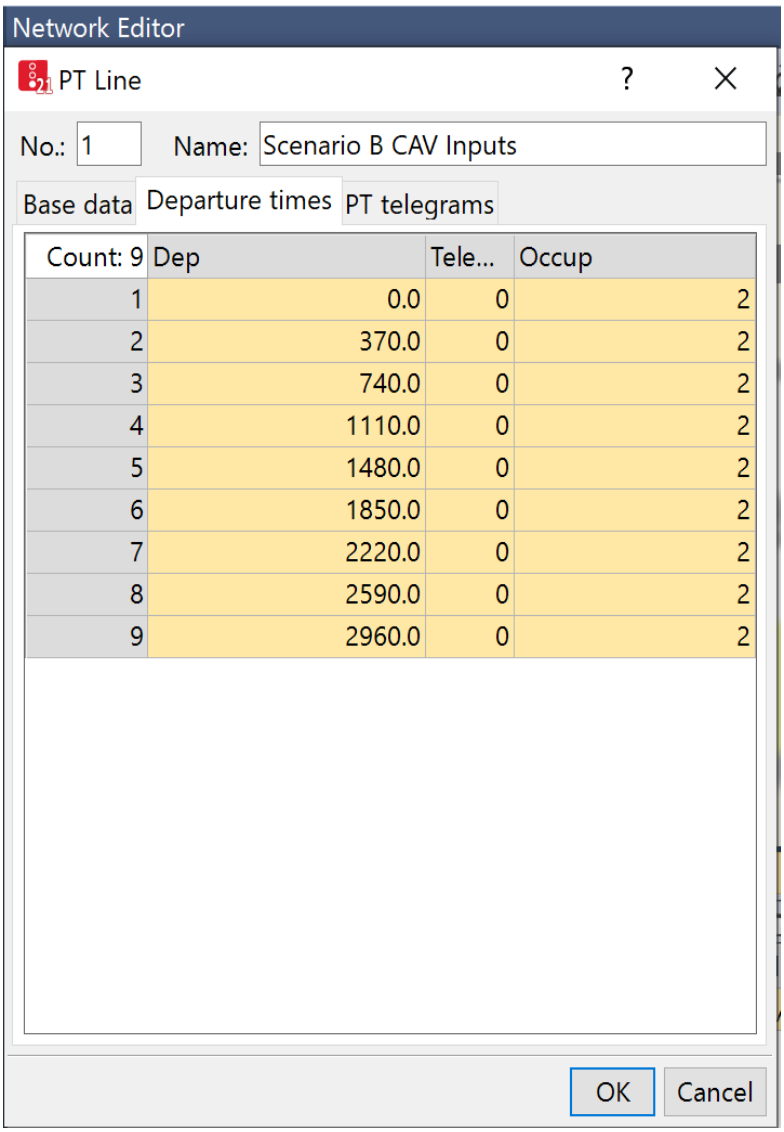


Public Transport Lines / Line stops

Count: 1	N	NE	D	DestPos	EntTmOffset	VehType	DesSpeedDistr	Color
1	1	1	5	1039.919	0.0	100: Car	40: 40 km/h	(255,...

Count: 4	PTLine	PTStop	Active	SkipPoss	DepOffset	PedsAsPass
1	1	1: Airport Stop	✓		10.0	✓
2	1	2: Stop One	✓		10.0	✓
3	1	3: Stop two	✓		10.0	✓
4	1	4: Centre Stop	✓		10.0	✓

B-3 Scenario B Design Inputs



Network Editor

PT Line

No.: 1 Name: Scenario B CAV Inputs

Base data | Departure times | PT telegrams

Count: 9	Dep	Tele...	Occup
1	0.0	0	2
2	370.0	0	2
3	740.0	0	2
4	1110.0	0	2
5	1480.0	0	2
6	1850.0	0	2
7	2220.0	0	2
8	2590.0	0	2
9	2960.0	0	2

OK Cancel

B-4 Scenario B CAV Inputs

Vehicle Inputs / Vehicle volumes by time interval

Count: 5	No	Name	Link	Volume(0)	VehComp(0)
1	1		9: Corso Grozetta Sec EB	100.0	1: Default
2	2		5: CAV Lane	17.0	1: Default
3	3		7: Corso Grosetto EB	500.0	1: Default
4	500		2: Via Aldi NB	1000.0	1: Default
5	501		4: Via Aldi SB	1000.0	1: Default

B-5 Intersection Vehicle Inputs