DOKUZ EYLÜL UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

INVESTIGATION OF THE POSSIBLE EFFECTS OF AUTONOMOUS VEHICLES ON URBAN USES

by

İrem Merve ULU

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İZMİR

INVESTIGATION OF THE POSSIBLE EFFECTS OF AUTONOMOUS VEHICLES ON URBAN USES

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M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"INVESTIGATION OF THE POSSIBLE EFFECTS OF AUTONOMOUS VEHICLES ON URBAN USES"** completed by **İREM MERVE ULU** under supervision of **ASSOC. PROF. DR. HİLMİ EVREN ERDİN** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for degree of Master of Science.

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INVESTIGATION OF THE POSSIBLE EFFECTS OF AUTONOMOUS VEHICLES ON URBAN USES

ABSTRACT

Developing technology affects the quality of life of the citizens as well as the components and infrastructure of transportation systems. Innovations in the transportation system have affected the form of the city throughout history and are in direct/indirect relationship with many issues such as urban land use, urban life quality, and environmental problems. Today, especially in metropolitan cities, a decrease is observed in the quality of life due to transportation-related problems such as traffic congestion, air/noise pollution, and increase in travel times. Autonomous vehicles (AVs), which are planned to be launched soon, are a solution to transportation-related problems and are expected to revolutionize urban mobility.

While studies have explored AVs' effects on traffic, environment, and safety, their impact on the city itself remains less explored. This study focused on the spatial implications of AVs and made predictions about the future of the city, with the Alsancak/İzmir as the study area, and PTV VISSIM software being used for modeling. Five scenarios were developed to assess different penetration rates, autonomous public transportation (APT) services, alternative to public transportation (PT), special lanes, and potential urban area gains.

Results show that AVs can address transportation issues but aren't a complete solution because their effectiveness depends on operational strategies. APT can alleviate congestion on main roads but AVs shouldn't replace existing services. Special lanes may adversely impact the transportation network while using AVs can ensure creating new city center areas. Proper policies are vital to ensure that AVs improve cities instead of exacerbating problems like urban sprawl, high land values, housing pressure, and increased transportation demand.

Keywords: Autonomous vehicles, transportation, urban planning, urban uses

SÜRÜCÜSÜZ KARAYOLU TAŞITLARININ KENTSEL KULLANIMLARA OLASI ETKİLERİNİN İNCELENMESİ

ÖZ

Gelişen teknoloji, ulaşım sistemlerinin bileşenlerini ve altyapısını olduğu kadar vatandaşların yaşam kalitesini de etkilemektedir. Ulaşım sistemindeki yenilikler, tarih boyunca kent formunu etkilemiştir ve kentsel arazi kullanımı, kentsel yaşam kalitesi, çevre sorunları gibi birçok konu ile doğrudan/dolaylı ilişki içindedir. Günümüzde özellikle büyükşehirlerde trafik sıkışıklığı, hava/gürültü kirliliği gibi ulaşım kaynaklı sorunlar ve seyahat sürelerinin artması nedeniyle yaşam kalitesinde düşüş gözlemlenmektedir. Yakın zamanda piyasaya çıkması planlanan sürücüsüz karayolu taşıtları, ulaşım kaynaklı sorunlara çözüm potansiyeli taşımaktadır ve şehir içi mobilitede devrim yaratması beklemektedir.

Çalışmalar sürücüsüz karayolu taşıtlarının trafik, çevre ve güvenlik üzerindeki etkilerini araştırırken, kent üzerindeki etkileri daha az araştırılmış durumdadır. Alsancak/İzmir çalışma alanı olarak belirlenmiş ve PTV VISSIM yazılımının modelleme için kullanıldığı bu çalışmada AV'lerin mekansal etkilerine odaklanmış ve kentin geleceği hakkında tahminlerde bulunmuştur. Farklı penetrasyon oranlarını, otonom toplu taşıma hizmetlerini, toplu taşımaya alternatif olarak sürücüsüz karayolu taşıtları, sürücüsüz karayolu taşıtları için özel şeritleri ve potansiyel kentsel alan kazanımlarını değerlendirmek için beş senaryo geliştirilmiştir.

Sonuçlar, sürücüsüz karayolu taşıtlarının ulaşım sorunlarına iyileştirmeler sunabileceği ancak tek başına tam bir çözüm olamayacağını, çünkü etkinliklerinin operasyonel stratejilere bağlı olduğunu göstermektedir. Otonom toplu taşıma, ana yollardaki tıkanıklığı azaltabilir, ancak sürücüsüz karayolu taşıtları mevcut toplu taşıma hizmetlerinin yerini almamalıdır. Özel şeritler ulaşım ağını olumsuz etkileyebilirken, sürücüsüz karayolu taşıtlarının yaygınlaşması kent merkezlerinde yeni alanların kazanılmasını sağlayabilir. Sürücüsüz karayolu taşıtlarının kentsel yayılma, yüksek arazi değerleri, yapılaşma baskısı ve artan ulaşım talebi gibi

sorunları şiddetlendirmek yerine uygun politikalar ile mevcut kentsel sorunların iyileştirilmesi için kullanılması hayati öneme sahiptir.

Anahtar kelimeler: Sürücüsüz karayolu taşıtları, ulaşım, kent planlama, kentsel kullanımlar

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ABBREVIATIONS

AV : Autonomous vehicles
APT : Autonomous public transport
PT : Public transport
CBD : Central business district
GPS : Global Positioning System
ADAS : Advanced Driver Assistance Systems
SAE : Society of Automotive Engineers
ST&B : Steering, throttle, and braking
LIDAR : Light Detection and Ranging
RADAR : Radio Detection and Ranging
Sonar : Ultrasonic sensors
CAV : Connected autonomous vehicles
SAV : Shared autonomous vehicles

CHAPTER ONE
INTRODUCTION

The transportation system in urban areas is an integral part of modern life and is becoming more complex with the rapidly increasing population and number of vehicles. Dependence on conventional transportation vehicles causes problems such as traffic congestion, air pollution, and energy consumption. The search for solutions to these challenges has brought up the potential opportunities that AVs can offer in the field of urban transportation. AVs can drive safely and efficiently without human intervention thanks to their self-driving capabilities. With its detection, decision-making, and control algorithms, AVs are expected to have different driving characteristics than human drivers and therefore have different characteristics of traffic. It is also expected that AVs will change their travel demands and choices. Within the scope of this thesis, the reflections of the changes that AVs can make in the transportation system are discussed.

1.1 The Importance of the Study

Transportation and land use have a bidirectional relationship that significantly impacts urban form. Historically, highways, railways, and other transportation networks have opened new areas for development and increased access to resources. However, automobile-oriented transportation systems have led to low-density city forms and negative effects on the environment and public health. Land use patterns significantly affect transportation demand, and compact mixed-use development models can mitigate negative impacts. There is a growing demand for integrated and sustainable planning to enhance accessibility and mobility. By implementing such planning strategies, more equitable, vibrant, and livable communities can be established.

Although social resistance is shown at first to the innovations emerging all over the world with the development of technology, it is soon accepted and turned into a necessity with the effect of being a consumer society. In this process, it is important for the future of cities to be able to predict the changes that may occur when some projects that will directly affect our urban transportation network, habits and cities, such as AVs, are implemented. The prediction of this change, which may affect especially urban mobility and land use decisions, is essential in terms of preventing the problems that may occur after the introduction of AVs in cities, which are planned according to our current habits and lifestyle.

AVs can perform their own driving functions without the need for any driver control. It can carry passengers between selected points, and while doing this, it can determine the route selection, speed control, turn/overtaking maneuvers, lane changes, and following the vehicle in front of it with lower headways. These vehicles can sense their surroundings with the sensors they have, make instant route optimization thanks to their network connections, follow other vehicles with shorter headways and react in a shorter time than human drivers.

After AVs are released, it is expected to lead to changes in many areas such as individual vehicle ownership, PT use, parking lot use, traffic safety, environmental pollution, and street use. There are many studies in literature examining the possible effects of AVs, especially on traffic and the environment. However, there is a very limited number of studies examining the effects of the changes created by AVs on the city. Examining this issue is of great importance for future site choices, road and pedestrian road designs, and determination of transportation and planning policies.

1.2 Aim and Methodology

Studies have suggested that AVs can provide more comfortable, safer and more sustainable travel, but this may reduce the use of PT, increase the capacity of the transportation network, and gain space in city centers with less lanes and parking lots. If the assumptions about the impact of AVs are realized, it will affect not only the transportation system but also urban uses.

This study hypothesizes that the influence of AVs on urban transportation systems can yield both positive and negative effects on the transformation of city center areas and urban quality of life. These effects are contingent upon the use specific operational strategies. The research question guiding this study is: What are the potential spatial implications of integrating AVs into city centers? Additionally, how do various strategies, including different AV penetration rates, the introduction of autonomous public transportation services, alternatives to existing public transportation options, and the implementation of dedicated AV lanes, contribute to the transformation of city center areas, the enhancement of urban quality of life, and the evolution of transportation infrastructure?

This thesis aims to make an important contribution to improving the transportation systems of urban areas and exploring the potential of AV technology in the planning of urban uses. The results can guide efforts to design sustainable, efficient and pedestrian-oriented transport systems in urban areas.

In the methodology, Alsancak/İzmir was chosen as the study area for examining the effects of AVs in high-density urban areas. This area has a central business district (CBD) with heavy traffic, mixed-use developments, and multiple transportation modes. It also has hospitals, schools, tourism areas, museums, hotels, commercial units, restaurants, sports fields, and hosts many activities at Izmir Fair (Kültürpark). Then the transportation system in this area was modeled in PTV VISSIM software and the model was run with different scenarios. It has been examined how much space can be gained in the urban area with the use of different AVs market penetration rates, autonomous public transportation (APT), the preference of passengers to use AVs instead of PT, the separation of special lanes for AVs, and lastly, and lastly, having redesignable urban areas in the city center with the use of AVs. Then it was evaluated from the perspective of urban planning.

1.3 Scope of the Study

The second part of the study presents an analysis of the relationship between urban land use, transportation systems, and a concise overview of the history of automobiles.

Moving on to chapter three, an in-depth examination is conducted on AVs, including their definition, operational principles, classification, historical context, social acceptance, ownership models, shared usage, barriers to implementation, and their impacts. The effects of AVs are scrutinized across various domains, namely transportation, urbanization, environment, security, and infrastructure.

In chapter four, the study defines the study area boundaries and employs the widely utilized PTV VISSIM software, which is commonly employed in traffic engineering, to model the area. The model undergoes calibration, validation, and testing with diverse scenarios to assess the impact of integrating AVs into the urban transportation system.

The fifth chapter delves into the spatial implications of potential effects arising from the adoption of AVs in urban transportation.

In the final chapter, this study provides strategic recommendations to optimize the operational aspects of AVs within urban transportation, maximize the efficiency of road infrastructure utilization, and facilitate the most suitable urban planning approaches in response to the dynamic nature of the evolving transportation system. Furthermore, the chapter outlines potential areas for further research and investigation in subsequent studies.

CHAPTER TWO
RELATIONSHIP BETWEEN TRANSPORTATION AND LAND USE

The relationship between transportation and land use is a critical aspect that shapes the urban form. Historically, the development of highways, railways, and other transportation networks has influenced the city form, opened new areas for development, created opportunities for housing and trade, and increased access to natural resources. In the past, important cities were established on significant roads such as the Silk Road and the Spice Road. Similarly, maritime trade and transportation development led to the emergence of port cities in the XVth century. Later, high-capacity PT systems provided by the rail system resulted in linear and radial city forms. In contrast, the automobile's flexibility in the XXth century eliminated the need for new development areas to be in proximity to urban centers, creating a scattered and low-density city form over long distances (Adıgüzel et al, 2015). Moreover, while the construction of highways can lead to the destruction of natural habitats and fragmentation of communities, high volumes of traffic restrict access to certain areas. In addition, the automobile-oriented transportation system causes increase in congestion and pollution and worsens the negative effects.

The relationship between transportation and land use is bidirectional, where land use patterns significantly affect transportation demand. For instance, low-density development models increase automobile travel demand, leading to traffic congestion, air pollution, and other adverse effects. Conversely, compact mixed-use development models promote walking, cycling, and PT, reducing the need for automobiles and mitigating negative impacts on the environment and public health. Land use patterns can also affect the efficiency of transport infrastructure, and providing efficient PT can be challenging and expensive if most of the population resides far from their work areas. Similarly, if residential and commercial spaces are not well integrated, it can be challenging to offer effective transportation options that serve the needs of all users.

The connection between transportation and land use has evolved in parallel with the growth of cities and rural areas. In recent years, there has been a growing demand for integrated and sustainable planning of transportation and land use. Following the significant impact of transportation on city functions and human mobility in the XXth century, particularly with the proliferation of motor vehicles, innovative technologies have been identified to revolutionize our approach to urban planning and design (Duarte & Ratti, 2018). Contemporary urban planners have introduced new concepts such as the 20-minute city, sustainable urban mobility plan and smart mobility, incorporating a more integrated and sustainable planning approach to enhance accessibility and mobility (Calafiore et al., 2022; Toan, 2022).

The transportation network that shapes land use patterns and the land use patterns that influence transportation system demand are deeply interconnected. Although this relationship has historically had negative impacts on the environment, public health, and social equity, new planning approaches have emerged to create more sustainable and integrated transportation and land use systems. By implementing such planning strategies, more equitable, vibrant, and livable communities can be established for all.

2.1 History of Automobiles

The automobile, one of the most pivotal inventions of modern times, has profoundly impacted the ways in which individuals live and work today. The history of the automobile has been shaped by intricate and multifaceted interactions between technological, economic, social, and environmental factors. Karl Benz's 1885 introduction of the first gasoline vehicle was soon followed by Henry Ford's 1908 mass production of the affordable Model T (Womack et al., 1990). In the mid-20th century, massive highway construction projects were initiated worldwide. Notably, Hitler constructed high-speed highways in 1939, while Mussolini expanded Italy's motorway network. Subsequently, extensive networks such as England and America's interstate highway system were developed (May, 1972; Rae, 1984; Sperling & Gorgon, 2009; Womack et al., 1990).

This period saw the emergence of alternative fuels to gasoline-based engines. In the 1970s, General Motors converted passenger car engines to diesel operation, subsequently leading companies such as Mercedes-Benz, Volkswagen, and Peugeot to market diesel vehicles. The fuel crisis in 1973-74 further bolstered interest in electric vehicles, leading to the launch of electric vehicles by companies such as CitiCar and ComutaCar. In 1997, Toyota introduced a hybrid model featuring a small petrol engine and an electric motor. Tesla's fully electric cars achieved significant success in 2003 (Purdy & Foster, 2023). Since the introduction of automobiles, various trends have emerged in terms of both design and fuel consumption, while new safety and comfort features have also been added. The 1920s and 1930s witnessed the rapid technological developments of electric starter motors, hydraulic brakes, and automatic transmissions, while seat belts and airbags were developed in the 1940s and 1950s (Rae, 1984; Womack et al., 1990). Recently, The Global Positioning System (GPS) navigation, rearview cameras, and autonomous driving have become increasingly common following these technological advancements (Sperling & Gordon, 2009).

When the history of automobiles in Turkey is examined, many automobiles were produced between the years 1930-1960 with the investments of foreign countries and the automobile factories established with Turkish investments. In 1961, the first domestic automobile Devrim was produced, but it could not go into mass production. In the years 1960-1980, domestic and mass production Anadol, followed by foreign partners such as Tofaş and Oyak, were produced. In the recent past, TOGG was produced as an electric car (Bloomberght, 2022).

Numerous research studies have examined the consequences of the widespread use of automobiles in the transportation system. Appleyard (1981) contends that the domination of automobiles in cities leads to an increase in noise and air pollution, as well as the erosion of community and social interaction. Consequently, it is advocated for a street design that prioritizes pedestrians and cyclists, with automobiles playing a supporting role.

In contrast, Gakenheimer (1999) maintains that reliance on automobiles results in excessive dependence on fossil fuels and that cities should develop more sustainable transportation systems that reduce greenhouse gas emissions and mitigate climate change. Kenworthy & Laube's (1999) study of urban transport and land use patterns internationally suggests that cities that prioritize public and non-motorized transportation exhibit lower levels of automobile dependency and greater sustainability.

Newman & Kenworthy (1999) argue for a transportation approach that prioritizes PT, cycling, and walking while encouraging car-sharing and other innovative mobility solutions to decrease automobile reliance. Shaheen & Cohen's (2009) research on car-sharing highlights its potential to reduce car ownership and usage, alleviate congestion, and reduce air pollution. Moreover, car-sharing could enhance transport access for low-income and underserved communities.

In the studies, it is seen that the changes in automobile production characteristics, ownership and use have many effects on the transportation system and city form. However, how this effect will be and whether it will be to the benefit or detriment of the citizens varies depending on the practices and operating styles. For this reason, policies and strategies that are pedestrian-oriented, more sustainable and that support urban mobility can be followed rather than a motor vehicle-oriented transportation system to increase the quality of life of the citizens.

CHAPTER THREE
AUTONOMOUS VEHICLES

AVs are vehicles that can travel from one point to another without driver assistance. Another definition is vehicles that sense their environment and can move without human input (Ondruš et al., 2020). AVs are based on the Greek words autos (self) and nomos (govern). In addition, AVs are also called driverless car, self-driving cars, robotic cars and self-driving cars.

3.1 Advanced Driver Assistance System

Advanced Driver Assistance Systems (ADAS) refer to sophisticated electronic systems that form a part of intelligent transportation systems (Wang et al., 2020). These systems aid drivers in performing driving-related tasks and parking maneuvers by providing real-time assistance. Their primary objective is to alert drivers to potential threats/dangers and improve the comfort and safety of all road users (Rana & Hossein, 2021). In recent times, ADAS technologies and features have become increasingly prevalent in human-operated vehicles, and their integration is now a common feature (Table 3.1) (Lengyel et al., 2020; Mitchell, 2019).

Table 3.1 Common ADAS features and functions (American Automobile Association, 2019; Rana and Hossein, 2021; Mitchell, 2019)

ADAS Features	**Functions**
Adaptive cruise control (ACC)	Accelerates or stops the vehicle along with many other functions
Back-up cameras/sensors	Assists in parking and observes the backside
Adaptive headlights	Adjusts the headlight to draw attention in corners and turns
Lane departure warning	Warns when the driver leaves the lane
Lane centering assist	Keeps the vehicles in the center of the lane
Lane-keeping system	Confines the vehicles in the lane width

Table 3.1 Continued

ADAS Features	Functions
Automatic parking	Parks the cars automatically without any assistance
Blind spot monitoring	Alerts the drivers about objects in the blind spot
Emergency braking	Applies brakes to avoid the collision
Pedestrian detection	Differentiates between pedestrians and objects
Drowsy drivers detect	Prevents drivers from falling asleep and crashing
Night vision	Provides clear vision at night and in bad weather conditions

3.2 Classification of Autonomous Vehicles

Automated driving technology has the potential to mitigate human errors, reduce accidents, increase traffic efficiency, minimize driver liability, provide a more comfortable ride, and enhance mobility for everyone. Consequently, it can significantly transform urban transportation and improve the overall quality of life.

The continuous advancements in technology have led to a notable increase in the integration of automation within automobiles, constantly improving through the incorporation of new features. In 2014, the Society of Automotive Engineers (SAE) introduced a classification system that categorizes vehicles based on their level of automation, ranging from no automation to full automation. This classification primarily focuses on the required degree of driver intervention and attention, rather than solely on the inherent capabilities of the vehicle itself. As a result, the standard classification and technical report, revised in 2016, established standardized terminology and concepts for vehicles equipped with automated systems (Table 3.2).

Table 3.2 SAE's levels of driving automation (SAE, 2016)

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
Human driver **monitors the driving environment**						
0	No Automation	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
Automated driving system **("system") monitors the driving environment**						
3	Conditional Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	High Automation	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	Full Automation	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

The automotive industry is currently categorized into six levels of automation, each indicating the extent to which a vehicle can handle tasks previously done solely by human drivers. According to SAE (2016), at Level 0, most cars and trucks require the driver to manually perform all functions, including steering, throttle, and braking (ST&B), as well as monitoring the surrounding environment and navigating the vehicle. However, some basic warning systems, such as blind-spot and collision warnings, may be present.

At Level 1 autonomy, the vehicle offers some driver assistance features. However, the driver must always remain attentive and in control of the vehicle. While the vehicle can manage speed and steering in certain situations, the driver is responsible for all other aspects of driving.

Level 2 represents partial assistance, wherein the vehicle is capable of handling ST&B but requires the driver to take over immediately if it detects objects or events that it is not equipped to handle. At these levels, the driver is responsible for monitoring the surrounding environment, traffic, weather, and road conditions.

Level 3, or conditional assistance, represents a significant leap in automation. In certain environments, such as freeways, the vehicle can monitor its surroundings and perform all ST&B functions, but the driver must be ready to intervene if necessary.

At Level 4, high automation is achieved, with the vehicle capable of handling ST&B and monitoring its surroundings in a wider range of environments. However, it may not be equipped to handle severe weather conditions, and the driver must manually initiate automatic driving only when it is safe to do so. After that, the driver is not required to intervene.

Finally, Level 5 represents full automation, where the driver need only input the destination and initiate the vehicle, after which the vehicle can handle all other tasks, making independent decisions and driving to any legal destination. The above levels serve as general guidelines for assessing the technological sophistication of a vehicle, with the most significant difference arising at Level 3, where the automated driving system gains the ability to monitor the driving environment.

3.3 History of Autonomous Vehicles

The development of AVs has been a long and arduous journey. Long before powered road vehicles even existed as we think of them today, Leonardo da Vinci conceptualized, designed, and possibly even made the first AV in 1478 (Fuller, 2008).

With roots dating back to the 1920s, the idea of self-driving cars has fascinated and intrigued engineers, scientists, and the public alike. The emergence of artificial intelligence and machine learning in recent years has propelled AVs to the forefront of innovation and has paved the way for a revolution in transportation.

3.3.1 Early Days of Autonomous Vehicles

The development of experimental AVs dates to the early 20th century, with the first known prototype having been created by Houdina Radio Control in 1925. This early model utilized a small electric motor, which could be maneuvered through radio signals. Following this, Achen Motor introduced an updated version of this model, which was marketed as the Phantom Auto in 1932 (The Free-Lance Star, 1932).

Later, in 1939, a collaboration between General Motors, the Radio Corporation of America (RCA), and others resulted in the introduction of radio-controlled electric cars at the New York World's Fair. These vehicles were able to be driven with electromagnetic fields generated by circuits embedded in the road (Wolf, 1974, p: 28).

In the 1950s, further advancements were made in the field of AVs, with car models featuring specialized radio receivers and audio/visual warning devices capable of simulating automatic steering, acceleration, and braking control (Bartz, 2009; Hicks, 2017; Wetmore, 2003).

In the 1960s, a driverless Citroen DS was successfully tested in the United Kingdom, utilizing magnetic cables that were embedded in the road (Reynolds, 2001; Waugh, 2013). During the period spanning from 1960 to 1990, many universities and organizations developed models that increased automation in automobiles, or integrated new systems into road infrastructure (Biss et al, 1976; Reynolds, 2001; Schmidhuber, 2011; Stretch, 1961; Waugh, 2013).

In the 1980s, the advent of fully AVs marked a significant technological milestone. Carnegie Mellon University's Navlab and ALV projects, initiated in 1984, along with Mercedes-Benz and Munich Bundeswehr University's EUREKA Prometheus Project, which commenced in 1987, were among the first projects to produce self-contained, truly AVs (Kalašová et al., 2018).

3.3.2 Recently

In recent years, AVs have emerged as a reality in urban settings. DARPA, the Defense Advanced Research Projects Agency, established an organization in 2003 to promote competition among AVs operating in varying conditions within urban areas, which continues to this day (Buehler et al., 2009). Consequently, AVs have transitioned from a science fiction concept to a research topic. In the year 2010, Google joined the pursuit of AVs and began developing its own. Subsequently, Vislab's BRAiVE made its debut in 2013 as an AV that could operate in public spaces. Tesla Motors introduced its semi-autonomous driving assistant, Autopilot, in all its cars after 2014 (Ondruš et al, 2020). Then, Tesla Motors introduced Model S, featuring autonomous steering, brake and speed limit adjustment, and lane control based on image recognition (Lowensohn, 2014). Subsequently, in 2016, a driverless taxi service was experimentally launched in Singapore by a company called nuTonomy (Watts, 2016), and in 2018, the first robotaxis were introduced under the name Waymo One (Fingas, 2018). At present, several automotive organizations such as BMW, Nissan, and Toyota are actively engaged in the development of AVs (Russel, 2015).

On the other hand, research and development studies for the development of AVs continue in Turkey. In addition to the OKANOM project introduced by Okan University in 2011, many studies were conducted by Istanbul Technical University and Middle East Technical University to develop AVs and AVs infrastructure for AVs (NTV, 2019; Okan University, 2019).

3.4 Working Principles of Autonomous Vehicles

3.4.1 Perception

For AVs to navigate safely in traffic, it is imperative that they possess the ability to perceive their surroundings in a manner like a human driver. To achieve this, a multitude of sensors are placed on vehicles to detect any obstacles that may obstruct the vehicle's path, thus preventing collisions between vehicles (Figure 3.1).

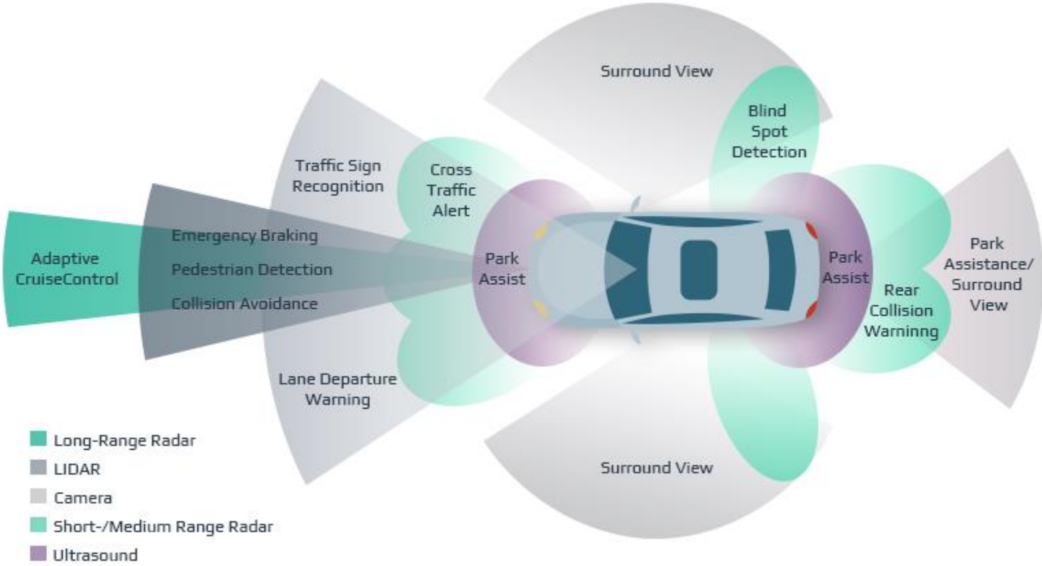


Figure 3.1 Autonomous vehicles perception (Odukha, 2018)

LIDAR (Light Detection and Ranging) is considered one of the most important sensor for AVs. It comprises a LIDAR emitter, mirror, and receiver and is usually mounted on the roof of the vehicle. This 360-degree rotating sensor provides remote sensing by emitting a light beam and analyzing the reflected light to measure the distance (Chang et al., 2019, Yun et al., 2019). The returned beam creates a high-precision 3D map of the environment. The short wavelength of light enables the LIDAR to reflect all kinds of surfaces and objects, making it highly effective in detecting obstacles (Ondruš et al, 2020).

RADAR (Radio Detection and Ranging) calculates the speed of the vehicle in front by sending an electromagnetic signal and measuring the frequency of the returning signal (Šarkan et al., 2017). Unlike LIDAR, it cannot identify the shape of the scanned area, as it has a larger wavelength and uses lower signal energy. The data obtained from RADAR, which detects the environment around the vehicle, is combined with LIDAR data by the central system computer, thus aiding the driving task in many areas such as approaching vehicles, their speed, other obstacles, self-parking, blind spot detection, lane change assistance, and adaptive cruise control (Gerstmair et al., 2019).

Ultrasonic sensors (Sonar) are also employed, mounted on various sides of the vehicle, to detect objects near the vehicle and to determine the position of other vehicles during parking (Ondruš, et al, 2020). They provide assistance for parking, collision warning, and lane departure.

Video cameras placed in front of the vehicle create real-time 3D images of the road, aiding in the detection of traffic lights, signs, unexpected occurrences such as pedestrians and animals, and recognition of specific movements that other sensors may not detect (Yun et al., 2019).

GPS (The Global Positioning System) is a satellite-based system that provides information about the current position of the vehicle, enabling a map of the area to be uploaded to the central computer via GPS (Ondruš et al., 2020).

Inertial Measurement Unit (IMU) uses a combination of accelerometers, gyroscopes, and magnetometers to provide outputs that are combined with GPS data. The IMU is an electronic device that measures the vehicle's speed, direction, gravitational forces, etc. (Yun et al., 2019).

All the sensor data obtained is processed by the central processing unit (CPU), which is loaded into the central computer that makes decisions based on the data obtained from the sensors (Ondruš et al., 2020). The central computer is a powerful processing unit that manages electromagnetic units such as the steering wheel, gas pedals, and brakes. It is also connected to the internet and GPS.

3.4.2 Motion Planning

The task of dynamically devising a path for an AV entails a high degree of complexity. The motion planning process encompasses the integration of hardware components, algorithmic systems, and communication architectures, which jointly regulate path variables, namely steering (direction) and speed, and thereby ensure the avoidance of any untoward incidents. The AV is therefore mandated to generate paths that can be followed by modulating these parameters. Once an array of alternative routes is procured, the vehicle must discern and select the most optimal pathway, which is predicated on diverse factors such as temporal constraints, economic considerations, traffic conditions, and various other limiting factors (Rajasekhar & Jaswal, 2015).

3.4.3 Navigation

AVs use their sensors to determine their own position as well as detecting their surroundings. By receiving signals from orbiting satellites, AVs' GPS systems enable them to precisely determine their position on the road (Rajasekhar & Jaswal, 2015). In conjunction with internal navigation systems consisting of gyroscopes and accelerometers, the GPS system continuously calculates the vehicle's position, direction, and speed. As a result, the vehicle's location can be determined without reliance on an external reference (Rajasekhar & Jaswal, 2015).

3.4.4 Behavior

Upon sensing its surroundings and executing motion planning, an AV undertakes decision-making and action implementation based on a set of parameters. Such a vehicle is met with several challenges such as analyzing lanes and performing overtaking maneuvers (Rajasekhar & Jaswal, 2015). In AVs, multiple lane analysis techniques have been implemented, including different lane patterns such as solid or dashed lines, as well as varied lane models such as 2D or 3D, straight or curved, and various techniques such as Hough transform or Template matching (Rajasekhar & Jaswal, 2015). However, testing the capabilities of AVs on poor roads is a challenging task, as current testing has been confined to well-planned and constructed roads. Moreover, overtaking maneuvers, known for being the leading cause of accidents worldwide, can be a cause for concern in AVs. This is because for an AVs to overtake, it must detect the vehicle in front using sensors, estimate the distance and speed, and then decide to overtake. If a vehicle approaches from the opposite lane during an overtaking maneuver, the AV abandons the attempt and moves the vehicle to a safer distance.

3.4.5 Communication

AVs possess the ability to navigate through traffic and make decisions without human intervention, yet they require communication to interact with other vehicles, pedestrians, and infrastructure. AVs with communication capability are called connected AVs (CAVs). Communication types of AVs are given below.

Vehicle-to-Vehicle (V2V) Communication is a type of communication that enables AVs to interact with each other. It allows cars to share information such as location, speed, and direction, which are critical for their safe operation (Darbha & Choi; 2012; Swaroop & Yoon, 1999). V2V communication is vital, as it enables a vehicle to alert other cars in its vicinity to avoid potential accidents or obstacles on the road.

Vehicle-to-Infrastructure (V2I) Communication involves AVs communicating with traffic signals, road signs, and other roadside infrastructure. V2I communication is paramount for safe navigation through traffic. For instance, traffic signals can relay information about upcoming intersections, enabling AVs to adjust their speed accordingly and safely (Bento et al., 2019).

Vehicle-to-Pedestrian (V2P) Communication enables AVs to communicate with pedestrians, which is crucial for ensuring their safety, particularly in busy urban areas (Hussein et al., 2016). For instance, audio and visual signals can alert pedestrians that an AV is approaching or slowing down.

Vehicle-to-Network (V2N) Communication involves AVs communicating with cloud-based services and other internet-connected vehicles. V2N communication provides real-time traffic information, weather updates, and other critical data that can affect the performance of AVs.

Vehicle-to-Everything (V2X) Communication is an overarching term that encompasses all types of communication between AVs, infrastructure, pedestrians, and other connected devices. V2X communication is essential for creating a comprehensive network that enables AVs to operate safely and efficiently.

In conclusion, AVs depend on a diverse range of communication types to interact with their surroundings. These communication modalities are fundamental to ensuring the safety and efficiency of AVs. As AVe technology continues to evolve, it can be expected to see even more cutting-edge communication solutions that will make our roads safer and more efficient than ever before.

3.5 Social Acceptance, Ownership, and Shared Use of Autonomous Vehicles

Social acceptability refers to the collective judgment or opinion of a project, plan, or policy, which determines its outcome on a local, regional, or national level (Quebec, 2023). In the context of AVs, the impact on the transport system and the city will depend largely on their social acceptability and market penetration. This acceptability is influenced by the behavior and preferences of passengers, including their perception of ease of use, which is shaped by factors such as attitude, social norms, trust, perceived usefulness, perceived risk, and compatibility. Moreover, safety considerations are affected not only by behavioral factors but also by factors unrelated to behavior, such as the performance/price ratio, mobility, value of travel time, and environmental impact of the technology (Jing et al., 2020). It is important to note that the acceptability of AVs is related to the background and experience of individuals, which may vary between countries and even between regions within the same country (Silva et al., 2019). Research indicates that the social acceptability of AVs is increasing in developing economies where traffic congestion is prevalent and private vehicle ownership is high (Moavenzadeh & Lang, 2018). However, it is worth noting that the acceptability of AVs may change over time, influenced by factors such as their time to market, government policies, availability, and individual preferences (Silva et al., 2019).

The acceptability of AVs has been extensively studied, revealing that demographic characteristics are significant factors influencing AV acceptability levels. For instance, while AV usage offers considerable benefits for the elderly population who are unable to drive, they tend to exhibit lower levels of acceptability compared to other age groups (Haboucha et al., 2017; Koul & Eydgahi, 2020; Liu et al., 2019). This phenomenon has been attributed to technophobia among the elderly population. Conversely, studies have suggested that the younger generation's interest in technology may make them more likely to embrace AVs as early adopters (Haboucha et al., 2017). Moreover, gender has also been found to play a role in determining AV acceptability (Cartenì, 2020). In addition, research indicates that highly educated and high-income young individuals are more willing to pay for AVs (Liu et al., 2019).

The emergence of economic models based on resource sharing and collaborative consumption towards the end of the 20th century has fostered the proliferation of sharing economy businesses that leverage online social networks and mobile technologies. Sharing practices have since been extended to various domains, including but not limited to accommodation, transportation, equipment, and food sharing. In parallel with the advent of AVs, another transportation innovation that has gained momentum is car/ride sharing. Ratti % Biderman's (2017) study posits that the widespread adoption of ridesharing has resulted in a reduction in the number of vehicles on roads, with each shared vehicle replacing up to 9-13 cars. The literature has seen a surge in studies concerning the ownership and shareability of AVs once they become commercially available. Silva et al. (2019) identified three groups of shared AVs, namely, private use (a vehicle privately shared among family members), single-person shared use (a vehicle from a car-sharing system used by a single individual), and shared use with multiple occupancy (a vehicle from a car-sharing system used by multiple individuals during the same trip). While definitions of shared AVs may differ across literature, they primarily pertain to the second and third categories described.

Several studies have investigated the acceptability of ride-sharing and shared autonomous vehicles (SAVs) among different segments of the population. In low-density areas where individuals own multiple vehicles, there appears to be a greater reluctance to adopt car-sharing practices compared to city-center residents, university graduates, and frequent car users (Dias et al., 2017; Prieto et al., 2017). Similarly, people who never use PT and frequently rely on individual vehicles express lower levels of interest in SAVs, while those with environmental concerns tend to have a higher preference for these vehicles (Haboucha et al., 2017). Providing personalized services, such as customizable lighting, temperature, and music, has been suggested to enhance the psychological ownership of SAVs, thereby increasing their acceptability (Lee et al., 2019). Furthermore, studies have shown that young passengers, existing car-sharing system users, and individuals who prefer traveling by car are more likely to prefer SAVs with multiple occupants, whereas those who frequently drive alone are more inclined towards single-seater SAVs (Krueger et al., 2016). However, despite the potential benefits of SAVs, some individuals remain reluctant to adopt this technology. In a survey conducted in the USA and Israel, 25% of respondents indicated that they would refuse to use SAVs even if they were free. Additionally, 44% of respondents preferred traditional cars, 32% preferred individual AVs, and only 24% expressed a willingness to use SAVs (Haboucha et al., 2017). Similarly, a study conducted in Italy found that individuals were hesitant to pay for new technology and would rather pay more or travel by other means than use SAVs (Cartenì, 2020).

In conclusion, the acceptability of AVs and SAVs is a complex issue influenced by various factors, including demographic characteristics, personal preferences, attitudes, and behaviors.

The literature suggests that the younger generation and highly educated individuals with higher income tend to be more willing to pay for AVs. While some studies have shown that SAVs can potentially reduce the number of vehicles on roads, their adoption in low-density areas and among frequent car users remains a challenge. Providing personalized services and customizable features may enhance the acceptability of SAVs, but a significant proportion of individuals remain hesitant to adopt this technology. Therefore, it is crucial to continue researching the factors influencing the acceptability of AVs and SAVs to develop effective policies and strategies that encourage their adoption and ensure their success in the future.

3.6 Autonomous Vehicles Impacts

3.6.1 Transportation

Transportation, especially urban transportation, exhibits an extensive scope. Urban transportation encompasses various modes of transportation, be it private, communal, personal, or public, that operate within the city, along with the underlying infrastructure, superstructure, and organizational elements, including coordination, management, and governance, that facilitate these activities (Şenbil, 2012). The advent of AVs is expected to have significant and far-reaching impacts on numerous facets of transportation, including traffic flow, road capacity, travel demand, travel time, pedestrian-vehicle safety, vehicle ownership, parking requirements, and PT.

3.6.1.1 Traffic Flow and Demand

AVs are poised to bring about a significant transformation in the field of transportation. With their advanced sensors, communication capabilities, and artificial intelligence, these vehicles have the potential to revolutionize passenger and driver behavior as well as optimize road networks, resulting in improved traffic flow. In fact, experts believe that AVs could even solve one of the most pressing issues faced by cities today - traffic congestion.

AVs have been found to have a significant impact on traffic flow, which can be influenced by a range of factors such as headways, gap acceptance values, acceleration values, and driver behavior (Fagnant & Kockelman, 2015). The potential benefits of using AVs include improved quality of transportation services, with fewer accidents caused by human error and more comfortable and efficient travel due to smoother braking and finer speed regulation (International Transport Forum, 2018). Moreover, AVs can contribute to more stable traffic flow, speed profiles, and less frequent accidents (Fagnant & Kockelman, 2015). The increased accessibility provided by AVs is expected to lead to a higher demand for travel (SDB Automotive, 2016). Since AVs are more sensitive, they require less road distance and lane width, which can increase infrastructure capacity (Metz, 2018). It is anticipated that AVs will have a more significant impact on shared capacity than conventional cars (Gavanas, 2019). These findings point to the potential of AVs to revolutionize the transportation industry and improve the overall efficiency and safety of travel.

The implementation of AVs in the market has been found to have a significant impact on traffic congestion, according to research studies. A 10% market penetration of AVs could lead to a 15% reduction in traffic, while a 90% market penetration could result in a 60% reduction, as noted by Fagnant & Kockelman (2015). Bischoff and Maciejewski (2016) conducted a study in Berlin where AVs were distributed based on population density, and they found that waiting times varied in urban and suburban areas. While waiting times in the city center remained constant, some regions experienced waits of up to 20 minutes. These areas also had low shared car usage and long acceleration distances, resulting in 45% of empty car rides. The study showed that one AV could meet the same demand as 11 conventional private vehicles. In the study of Dündar et al., (2021), it was observed that as AV penetration increased, the number of vehicles passing through the lane increased and the headways in the traffic flow were shortened. Again, according to the findings of the same study, it was observed that 70% AV penetration increased the strip capacities by an average of 35%.

There are varying opinions on the impact of SAVs on traffic congestion. Some argue that ride-sharing systems could increase congestion (Alam & Habib, 2018; Zhao & Kockelman, 2018), while others believe that they will reduce it (Alazzawi et al., 2018; Martinez & Viegas, 2017). According to Alazzawi et al. (2018), ridesharing can reduce traffic congestion by at least 50%. However, Narayanan et al. (2020) suggest that the positive impact of ride-sharing depends on several factors, such as average vehicle density, demand density and pattern, network topology, vehicle assignment, and location algorithms. These findings highlight the complex nature of the relationship between AVs and traffic congestion, which requires further investigation.

Shared autonomous vehicles (SAVs) have been found to have a significant impact on mobility, according to study conducted by Fagnant & Kockelman (2014). This study found that SAVs can reduce waiting times by repositioning themselves for the next driver, leading to fewer vehicles needed to make the same number of trips. Additionally, SAVs used in a pooling system can replace up to 10 conventional vehicles during peak hours. As the market share of AVs increases, road capacity is expected to increase as well due to lower following headways, as predicted by several studies (Li et al., 2020; Mena-Oreja et al., 2018; Salazar et al., 2018; Talebpour & Mahmassani, 2016).

Moreover, SAVs have the potential to significantly increase sharing mobility as demonstrated by a simulation of Austin, which found that each SAV in the pooling system (with 3.02 passengers per trip and less than 5 minutes waiting time during peak hours) can replace 10 conventional vehicles. AVs may also enable young people to obtain a license later than previous generations, as revealed by a study conducted by Alessandrini et al. (2015). Furthermore, AVs may increase personal mobility for those with flexible work schedules and jobs not tied to specific locations, including the elderly and their children, who often rely on PT or special modes of transportation. AVs may provide them with more mobility options, as the convenience of AVs eliminates the responsibilities of driving. However, this may also lead to an increase in the number of cars on the road (Duarte & Ratti, 2018).

Millard-Ball's (2019) research suggests that the pursuit of cost reduction in AVs may lead to an unintended consequence of increased traffic congestion, as these vehicles prioritize cruising and actively seek out congested routes. This highlights the importance of considering the broader impacts of AV technology beyond its immediate benefits.

Various studies suggest that AVs can increase road capacity by reducing headways between vehicles (Friedrich, 2015; Tientrakool et al., 2011). Some researchers predict that as the number of AVs on the road increases, road capacity will also increase with lower headways (Li et al., 2020; Talebpour & Mahmassani, 2016). However, there are also studies that suggest road capacity may decrease by up to 20% at a certain AV penetration rate, after which it is expected to increase by Mena-Oreja et al. (2018), To achieve high traffic volume and fuel savings, some researchers suggest using constant headway values smaller than 2.0 Nowakowski et al. (2016). AVs can also reduce the use of lanes on narrow roads by sharing opposite direction lanes with smaller headway values (Schlossberg et al., 2018). Additionally, the reduced use of lanes can increase demand, as noted by Millard-Ball (2018).

Previous research indicates that when AVs are connected, there can be a positive impact on traffic flow. AVs come equipped with adaptive cruise control and the ability to communicate with each other (V2V), allowing for a safe following distance. This leads to a more stable traffic flow (Naus et al., 2010; Swaroop et al., 1994; Swaroop & Rajagopal, 2001). According to Olia et al. (2018), AVs without connectivity may slightly increase road capacity, but with connectivity, there is a significant increase in road capacity. However, studies have shown that when headways are less than 2.0 seconds and there is no vehicle-to-vehicle or vehicle-to-infrastructure communication, there is an imbalance in traffic flow despite reduced time spent in traffic due to speed and acceleration sharing among vehicles (Ploeg et al., 2011).

There have been numerous studies conducted on the potential impact of AVs on vehicle miles traveled (VMT) or vehicle kilometers traveled (VKT) due to empty trips (Alam & Habib, 2018; Bischoff & Maciejewski, 2016; Dia & Javanshour, 2017; Fagnant & Kockelman, 2014; Martinez & Crist, 2015; Moavenzadeh & Lang, 2018;

Moreno et al., 2018). While some researchers suggest that reducing congestion and travel times may increase demand for AVs Pakusch et al. (2018), others have found that unused shared AVs may increase the total distance traveled by up to 10% compared to non-shared AVs, but still require fewer vehicles Salazar et al. (2018). In fact, one study even concluded that each AV running in a pooling system could replace 10 conventional vehicles However, it is important to note that depending on whether AVs are shared or not, there may be an increase in vehicle demand between 8% and 14% (Fagnant & Kockelman, 2014; Ostermeijer et al., 2019). Furthermore, it has been suggested that while car sharing in the city may decrease traffic, it could potentially increase in the suburbs due to high demand density Both Moavenzadeh & Lang (2018) and Litman (2018). Despite these potential challenges, some researchers propose that AVs can be oriented in a way that does not increase congestion and significantly increases sharing mobility.

The utilization of AVs has the potential to provide significant benefits to individuals who are elderly, disabled, or unable to drive, by relieving them of the responsibility of operating a vehicle and increasing their mobility. However, the widespread adoption of AVs could also result in an increase in the number of vehicles on the road (Duarte and Ratti, 2018). Nevertheless, through the shared use of AVs, there is the potential to significantly reduce greenhouse gas emissions, which would have a positive impact on the environment (Chester and Horvath, 2009; Chester et al., 2010; Iacobucci et al., 2019; Pakusch et al., 2018; Rashid et al., 2019). Ridesharing apps have already demonstrated their effectiveness in reducing the number of cars on the road in many countries, with each shared vehicle potentially replacing the need for 9 to 13 other vehicles (Ratti & Biderman, 2017). According to the study by Spieser et al. (2014), only 30% of the vehicles in Singapore can be used to meet personal mobility needs with shared driving. Heilig et al. (2017) estimated that pooling-based SAVs services claim to be able to reduce costs while increasing travel lengths. Vosooghi et al. (2019) claimed that SAVs can replace up to 1.7% of vehicles in the network, while Milakis et al. (2017) predicts that SAVs can replace up to 67%-90% of conventional vehicles as they provide more equal mobility. AVs can increase the availability of road transport services by providing mobility to population groups that cannot drive, while also increasing shared mobility.

3.6.1.2 Parking

The impact of parking lots on both pedestrians and drivers, particularly in city centers and roadside parks, has been a subject of concern due to the large areas they occupy. AVs offer the potential for better utilization rates, with up to 75% higher efficiency when optimizing parking (Economist, 2015). This could lead to significant benefits, especially in high-rent areas where parking spaces could be transformed into more dynamic spaces, resulting in reduced per capita energy consumption and overall spending on passenger transport Duarte & Ratti, 2018). Moreover, the reduction of roadside parks and street parking can lead to denser cities and improved road safety (Zhang et al., 2015). The efficient operation of the transportation system is directly related to efficient parking areas, particularly in city centers where roadside parks occupy significant street space (Bruun & Givoni, 2015). This results in increased travel time, pollution, and reduced capacity, as well as decreased road safety due to parking and maneuvering. To improve transportation efficiency, the number of roadside parks should be reduced (Biswas et al., 2017; Herin & Akkara, 2019). It is worth noting that private cars in Europe are parked 95% of the time, and about 30% of traffic in the city center is from drivers seeking free parking (Transport Environment, 2017; SPUR, 2004). Therefore, high parking fees are often used to discourage citizens from driving to the city center.

AVs are anticipated to replace the need for parking lots once they become available on the market. Their parking behavior will differ from that of a human driver. AVs offer more flexible parking than conventional vehicles. AVs can drop passengers almost anywhere and use accessible and inexpensive land for parking, rather than traveling to park (Inci, 2005). In addition, by providing the opportunity to park closer without colliding with the nearby vehicle, they can reduce less space and parking space shortages (Bertencello & Wee, 2015; Grinberg & Wiseman, 2007, 2013). Moreover, they can also solve the problem of occupied parking space due to incorrect parking and make parking management more effective (Filatov & Serykh, 2016). Furthermore, they can park closer because they can park without the doors needing to be opened, assuming AVs drop passengers before they reach the parking lot. Also, the smaller designs of the vehicles will also lead to less space when parked (Capp & Litkouhi, 2014).

According to Nourinejad, et al (2018), AVs are highly maneuverable, which enables them to park in smaller spaces and utilize less land. Additionally, they can navigate around parking lots and park in peripheral areas. However, Kramer & Mandel (2015) argue that this may result in an increase in driving per cruise-trip as the AV waits for passengers, posing a challenge for cities to regulate.

AVs can be programmed to return to their point of departure or park in more affordable spots around the city center, which can lead to new methods and organization of parking spaces (Targa et al., 2018). Furthermore, AVs require less parking space since their access and parking maneuvers are automatic, allowing for more AVs to fit in car parks with the same surface area compared to traditional cars (Ruso et al., 2019; Nourinejad, 2018). The proximity of the car parks to the travel destination for AVs depends on whether they are being used privately or shared (Gavanas, 2019). In a study conducted in Georgia, Zhang & Guhathakurta (2017) simulated AV parking algorithms and found that each AV can reduce vehicle ownership, increase the vehicle occupancy rate by 5%, and eliminate up to 20 parking spaces. These findings highlight the potential benefits of AVs in reducing traffic congestion and optimizing parking utilization.

Car sharing applications have become more common nowadays. SAVs can provide a similar service. Studies show that each SAV can make at least 20 parking spaces unnecessary due to the reduction in the number of vehicles and increased occupancy rates Zhang (2017). In scenarios where all AVs are shared, parking demand can drop by up to 90% (Fagnant & Kockelman, 2014; Martinez & Viegas, 2017; Zhang & Guhathakurta, 2017; Zhang, et al., 2015). SAVs also provide flexibility in parking space allocation, allowing passengers to use the nearest vehicle.

However, there are also studies that predict an increase in parking demand with the use of AVs (Duarte and Ratti, 2018; Grush et al., 2016; Stead and Vaddadi 2019; Zhang et al., 2015). Emberger and Pfaffenbichler's (2020) study suggests that remote parking will increase the distance traveled per vehicle by 48%, indicating that there may be unintended consequences of AVs that need to be considered. Duarte and Ratti (2018) suggest that increasing parking fees may encourage people to use AVs, which can serve multiple users and park farther away from normal vehicles or use cheap parking spaces that have less impact on urban traffic.

Furthermore, AVs have the potential to optimize parking and transform land uses, resulting in more dynamic city centers and public spaces such as parklets (Duarte & Ratti, 2018). However, removing roadside parks can reduce the number of lanes and result in denser cities. Despite these potential drawbacks, AVs can contribute to the reduction of energy consumption due to automobiles per capita and the reduction of travel costs (Bruun & Givoni, 2015). Overall, the research suggests that AVs have the potential to revolutionize parking and transportation systems, but careful consideration is needed to ensure that the benefits outweigh the costs.

High parking fees in city centers can deter travel to these areas, which is why park policies are crucial for their development. SAVs can eliminate parking restrictions or make strategic decisions to reduce costs. For example, they can drop off and pick up passengers from different points in the city and park farther away when not needed, avoiding high parking fees in urban centers Begg's (2014). Studies predict that up to 97% of SAVs will choose to park outside the city center, where land prices are lower (Zakharenko, 2016). Remote parking allows vehicles to leave passengers and go home, returning to the residential parking area either free of charge or for a monthly fee. Such a strategy could double the number of rides per trip. Remote parking also saves users about $18 per day, but the total number of trips increases by 2.5% due to trips between the city center and the parking lot (Harper et al.2018).

Studies suggest that SAVs will significantly reduce parking demand by 67-90%, decreasing the need for roadside parking by at least 50% (Fagnant & Kockelman, 2015). However, some studies predict that SAVs will increase parking demand (Milakis et al., 2017; Zhang et al., 2015). The use of AVs can encourage more dynamic city centers by transforming land use and creating public spaces (DuPuis et al., 2015). Removing parking areas can also contribute to reducing energy consumption and travel costs (Alessandri et al., 2015; Begg, 2014; Heinrichs, 2016).

In the literature, while some studies suggest that AVs will lead to an increase in the need for parking, most predict a decrease. This is since AVs can move without a driver or passenger and can park in remote locations, which are often cheaper and do not need to be close to activities. Several studies, including Dia & Javanshour (2017), Keeney (2017), Martinez & Crist (2015), Zhang et al. (2015), and Zhang & Guhathakurta (2017) suggest that this reduction could be as high as 90% or 83%. However, there are some researchers, such as Grush et al. (2016) and Stead & Vaddadi (2019), who argue that the demand for parking will rise due to AVs, increased vehicle use, and the need for collection and drop-off points (Yigitcanlar et al., 2019). Overall, further research is needed to determine the true impact of AVs on parking demand.

3.6.1.3 Public Transportation

Today, individual vehicle ownership is increasing, leading to an increase in vehicles and traffic congestion on the roads, thus many city governments are investing in large PT vehicles to reduce traffic congestion. While shared vehicle travels and coordinated fleets can increase efficiency, they cannot compete with the capacity of subways or buses (Mitchel et al., 2010; Ratti & Biderman, 2017). AVs offer a potential solution, as they can navigate traffic without the risk of collisions and frequent stops. However, even AVs cannot replace the capacity of a subway car (Stanford, 2015). Instead, AVs can be utilized as a feeder mode, transporting passengers from surrounding areas to PT stations and corridors (Duarte & Ratti, 2018). According to a study by Salazar et al. (2018), the integration of SAVs with PT could lead to a reduction in traffic congestion. Similarly, Moavenzadeh & Lang (2018) suggest that SAVs may eventually replace individual vehicles and PT particularly in suburban areas. This conclusion was drawn after performing a conjoint analysis simulation for Boston, USA.

3.6.1.4 Vehicle Miles/Kilometers Travelled

Several research studies have been conducted to investigate the potential impact of AVs on the total distance traveled in urban areas. It is anticipated that the adoption of AVs by current vehicle users, travels made with more than one person before become an individual travels, the occurrence of empty AV trips, and the decrease in transportation costs and increase in demand will result in an increase in the vehicle miles/ kilometers travelled (VMT/VKT) (Bahamonde-Birke et al., 2018; Medina-Tapia & Robusté, 2019; Pakusch et al., 2018; Plumer, 2013; Sivak & Schoettle, 2015; Smith, 2012). However, some studies suggest that AVs will reduce the total distance traveled due to the replacement of the existing taxi system with car sharing, the decline in private vehicle ownership, and service-oriented mobility (Levinson & Krizek, 2015; Lokhandwala & Cai, 2018). Furthermore, the marginal cost of each vehicle trip may increase, leading to reduced vehicle travels due to time and distance-based costs of accessing the SAV fleet and replacing fixed vehicle ownership costs (Zhang et al., 2015).

3.6.1.5 Traffic Safety

According to the research conducted by Fagnant and Kockelman in 2015, AVs have the potential to significantly reduce the number of accidents caused by factors such as alcohol use, fatigue, and distraction, which currently contribute to over 40% of accidents. It is projected that fatal accidents could decrease by up to 40%, while Keeney (2017) goes as far as suggesting that accidents could decrease by as much as 80% with increased vehicle automation. It is worth noting, however, that machine faults can still occur, which means accidents cannot be completely eliminated (Teoh & Kidd, 2017). Hayes (2011) claims that self-driving cars could potentially reduce fatal accidents by up to 99%, and by taking on the driving responsibilities, AVs could also allow passengers to engage in other activities during travel without having to focus on the road.

3.6.2 Urbanization and Land Use

Transportation networks are the largest land use type in urban areas, covering between 25-35% of the land (Yiğitcanlar et al., 2019). They play a crucial role in shaping the urban form and have become more compatible with the widespread use of automobiles. This has led to the construction of wider, straighter, and longer roads, which often force pedestrians to use under/overpasses to avoid disrupting traffic flow (Duarte & Ratti, 2018). However, promoting pedestrian and bicycle mobility is essential for creating livable cities, alongside efficient use of highways.

The emergence of AVs will likely impact road infrastructure, transportation, and urban planning. Understanding these changes and opportunities can positively impact social, economic, and environmental aspects of urban development. City planners need to evaluate the specific effects of AVs on cities and their relationship with sustainable development, to be better prepared for these changes (Gavanas, 2019).

3.6.2.1 Clearing Parking Spaces

In the United States, where 94.5% of the population uses private cars, parking areas cover 4,400 km2 (Ben-Joseph, 2012). Parking spaces are equivalent to 76% of the city center in Melbourne (Lipson & Kurman, 2016). In Los Angeles, 110,000 roadside parking garages cover 331 hectares, which corresponds to 81% of the city center (Tachet, et al, 2017). As a result, transportation networks are the largest land use type in urban areas, covering between 25-35% of the land. They play a crucial role in shaping the urban form and have become more compatible with the widespread use of automobiles. This has led to the construction of wider, straighter, and longer roads, which often force pedestrians to use under/overpasses to avoid disrupting traffic flow. However, promoting pedestrian and bicycle mobility is essential for creating livable cities, alongside efficient use of highways.

The rise of AVs is expected to have a significant impact on road infrastructure, transportation, and urban planning. By understanding these changes and opportunities, we can positively influence the social, economic, and environmental aspects of urban development. City planners should assess the specific effects of AVs on cities and their relationship with sustainable development to prepare for these changes (Gavanas, 2019). Studies indicate that the number of vehicles on the road and the demand for parking spaces will decrease with the prevalence of AVs. Therefore, parking lots, which are part of the urban transportation infrastructure, can be repurposed as green spaces, additional traffic lanes, or alternative public spaces for cyclists and pedestrians (Silva et al., 2021).

Studies predict that current parking areas will be emptied and repurposed in urban areas, leading to a more pedestrian-friendly city center while reducing urban sprawl in peripheral metropolitan areas (Anderson et al., 2014; Fagnant & Kockelman, 2015; Levinson, 2015; Milakis et al., 2017). Another study suggests that repurposing former parking lots or road lanes will allow for better transportation options, green spaces, and wider sidewalks, ultimately improving quality of life (Kirschner & Lanzendorf, 2020). Additionally, the reduced need for parking in the city center due to shorter wait times for AVs in designated areas could increase urban density and raise real estate prices in outlying settlements (Bagloee et al., 2016; Heinrichs, 2016; Levine et al., 2017; Rubin, 2016; Snyder, 2016).

3.6.2.2 Reuse of Roads

The utilization of transportation networks in urban regions has been a contentious issue, with the road network occupying a significant amount of space. Unfortunately, individual motorized transport often takes precedence over sustainable modes of transportation due to the uneven road network (Silva et al., 2019). However, by employing various modes of transportation and mobility options within the limited transportation network area, we can reduce accidents, air pollution, noise, and improve urban livability (Silva et al., 2019). According to a study by Millard-Ball (2019), optimizing the use of highways can improve the local economy and the quality of life in the area. Although the use of AVs may cause urban sprawl, they can also provide an opportunity to redesign streets for walking and cycling paths. Depending on the location of drop-off points and park-and-ride systems, AVs can increase the use of PT, walking, and cycling, as suggested by González-González et al. (2020). However, Soteropoulos et al. (2019) predict that AVs may increase the distance traveled per vehicle and decrease the use of PT, walking, and cycling. Nevertheless, AVs can provide empty spaces for city planners by utilizing highways more efficiently through platooning technology, which can transform highways into boulevards and offer better quality roads for both vehicles and pedestrians, thereby enhancing urban life (Yigitcanlar et al., 2017, 2019).

3.6.2.3 Livability and Quality of Urban Life

The livability of cities is determined by their form, functions, and requirements (Kovacs-Györi et al, 2019). Urban residents' satisfaction with the services provided indicates the quality of city life. Unfortunately, the quality of life in cities has been declining due to factors such as rising individual vehicle ownership, more traffic accidents, traffic congestion, and longer travel times (Silva et al., 2021).

The integration of AVs into urban areas has the potential to significantly impact urban development, with implications for land use, mobility, and quality of life. AVs are expected to adhere to traffic regulations, leading to safer and more livable cities. The distribution of parking lots in high-density areas plays a crucial role in urban planning, and the use of AVs can facilitate efficient parking management. This can eliminate the need for free parking lots, allowing for the conversion of on-street parking spaces into wider sidewalks, street cafes, and other public spaces (Alessandrini et al., 2015; González-González, et al, 2020; Heinrichs, 2016). Even if AVs continue to park like human-driven vehicles, this can be achieved, as noted by Millard-Ball (2019). Additionally, Schlossberg et al. (2018) suggest that AVs have the potential to contribute to better parking management and compliance with traffic regulations, thereby promoting safer and more livable cities.

By repurposing parking lots and road lanes, new public spaces can be created to promote sustainable transportation, greenery, and wider sidewalks. A study in Portugal recommended enhancing the quality of green spaces, ensuring their cleanliness and maintenance, and prioritizing investments in small public areas to improve livability (Madureira et al., 2018). Former parks can be transformed into extra sidewalk space, cultural venues, or commercial seating for businesses, generating revenue for further public projects.

3.6.2.4 Land Use

The impact of AVs on existing infrastructure remains uncertain, as changes in land use are typically slow and require years of observation before their full impact can be determined (Duarte & Ratti, 2018). Nevertheless, AVs will have a significant impact on the way cities are planned. To ensure that mobility, public space, and environmental concerns are balanced, the concept of multifunctional streets should be adopted. This will lead to urban transformations that improve the environment and encourage sustainable forms of mobility (Cartenì, 2020). Additionally, the reduction in required road capacity means that public space can be repurposed for land use planning, particularly in densely populated urban areas. Furthermore, AVs' ability to navigate roads with narrow geometry can improve access to less reachable urban areas, which could have implications for urbanization (Gavanas, 2019). For instance, studies suggest that AVs used in demand-sensitive and flexible PT contexts could increase urbanization, particularly in cities where urban development is closely tied to PT, such as European cities (European Commission, 2006; Hawkins & Habib, 2019).

Recent academic research conducted by Stead & Vaddadi (2019) and Duarte & Ratti (2018) proposes various strategies that could enhance the quality of the built environment in urban areas. These include recentralization, reorganization, re-densification, land-use conversion to green areas, and the widespread implementation of AVs. AVs have the potential to reduce the number of cars on the road, thus, transforming CBD into more pedestrian-friendly areas that appeal to new resident. Furthermore, AVs could enhance safety and livability in cities by being programmed to follow traffic regulations, look out for pedestrians, and adhere to speed limits. This could lead to fewer accidents and less noise and air pollution, ultimately making urban areas more attractive to people. Beraldi (2007) propose that regulations should be established to permit AVs to navigate in specific areas of urban areas, such as old settlements, regions with chronic traffic congestion, and narrow, difficult-to-navigate areas.

3.6.2.5 Urban Sprawl

Many factors such as time, cost and access can affect the location choices of households and companies in cities. For example, in America, where cars became widespread at the beginning of the XX century, the decrease in the value of time and the increase in accessibility also affected the location choices and caused urban sprawl. A similar situation was observed in Europe, which has more compact cities compared to America, after the 1950s (Piao, 2016). The use of AVs in urban areas can lead to transformative changes in mobility and accessibility conditions in urban areas and affect urban development. Widespread implementation of AVs will affect the location choices of households and firms, the availability of public space, and access to areas with poor road features. This will allow the reorganization of land uses.

Stead & Vaddadi (2019) argue that the built environment can be reshaped in line with the needs of AVs and users, comfortable travels can trigger urban sprawl, and therefore suburbanization will increase. Similarly, Duarte & Ratti (2018) also argue that these programs can increase driving because they can increase car users. It is suggested that AVs can move to even more distant suburbs after they are freed from the burden, thus enabling AVs to move away from the American ideal city center to detached houses with gardens, which can create low-density dispersed suburban areas (Anderson et al., 2014).

Recent research has highlighted the potential impacts of AVs on urban development and transportation. Studies by Guerra (2016) and Litman (2017) have shown that lower-priced AVs can increase road capacity and improve accessibility, potentially leading to changes in spatial distribution and rendering PT unnecessary. However, Zhang et al. (2015) found that AVs would not cause urban sprawl but could instead lead older people to move closer to city centers while younger generations moved away in a limited way.

The implications of AVs for urban planning and development can be complex and multifaceted. While AVs offer potential benefits such as reduced driving and more pedestrian-friendly cities, they may also contribute to urban sprawl and suburbanization, increase real estate prices and infrastructure costs, decrease PT use, and potentially lead to densely populated cities with increased air and water pollution and decreased livability. Furthermore, AVs may cause denser urbanization in city centers while leading to dispersed and low-density settlements in urban peripheries and suburbs. As such, urban planners must carefully consider the potential impacts of AVs on location choices for households and firms to prioritize urban development initiatives.

3.6.3 Environment

In contemporary society, one of the most pressing issues confronting urban areas is environmental degradation. With the population steadily increasing, both traffic congestion and production activities are on the rise, exacerbating the negative impact on the environment. In nations like China, air pollution resulting from production, transportation, and traffic has risen to hazardous levels that pose a threat to human life. In the future, the adoption of AVs is anticipated to feature electric power, which many believe will significantly reduce their environmental impact by decreasing traffic and emissions.

Academic research has indicated that improving the utilization of road space can have a positive impact on the local economy and the overall quality of life. However, the construction and maintenance of infrastructure, as well as the use of parking facilities, can lead to harmful environmental pollutants such as carbon dioxide (CO_2) and sulfur dioxide (SO_2) (Chester et al., 2010; Chester & Horvath, 2009). Minimizing emissions and reducing parking demand and vehicle numbers on the road is crucial to mitigating these negative effects (Silva et al., 2019). Electric vehicles charged with renewable energy sources have the potential to significantly reduce emissions and maximize environmental benefits (Iacobucci et al., 2019). Additionally, research has shown that shared SAVs can further reduce energy consumption and emissions of greenhouse gases, nitrogen oxides, volatile organic compounds, and particulate matter emissions smaller than 10µm. These findings highlight the potential for innovative transportation technologies to play a critical role in addressing environmental challenges (Fagnant & Kockelman, 2015; Moreno et al., 2018).

Various studies have suggested that incorporating electric and SAVs could significantly reduce energy consumption (Arbid & Seba, 2017; Bauer et al., 2018; Fagnant & Kockelman, 2014). The use of electric SAVs can help cut down on emissions, reduce traffic congestion, and lower transportation costs (Salazar et al., 2018). Moreover, driving efficiently can also lead to reduced fuel costs, increased average travel speed, and lower overall travel expenses (Medina-Tapia & Robusté, 2019). AVs are expected to aid in fuel efficiency, thereby decreasing environmental harm. Bullis (2017) discovered that AVs can improve fuel efficiency by 10-15%. Anderson et al. (2014) also suggested that communication between vehicles and infrastructure (V2V and V2I) can further enhance fuel efficiency by 10%. Additionally, AVs can save up to 10% in fuel consumption when they travel in platoons (Waldrop, 2015).

Milakis et al. (2017) suggest that although AVs can offer short-term benefits such as fuel savings and reduced emissions, their long-term impact remains uncertain. Moreover, Wilson & Chakraborty (2013) predict that AVs may contribute to urban sprawl, necessitating the expansion of physical infrastructure including roads, water, sewage, and waste disposal systems. This could result in increased energy consumption and decreased air and water quality (Wilson & Chakraborty, 2013). To address this issue, the Partnership for Sustainable Communities project in the USA recommends investments in housing, transportation, water use, and other infrastructures to promote compact settlements and encourage proximity to work. This approach could lead to significant savings in time and fuel cost, as well as a reduction in pollution (Sustainable Communities, 2015).

The successful integration of AVs into our transportation systems requires the development of effective policies that consider both the environmental benefits and potential negative impacts. One approach to reducing emissions and maximizing efficiency is the adoption of electric, shared AVs with simultaneous route planning. However, it is also critical to consider the end-of-life implications of AV technology, particularly the potential for hazardous waste from batteries. Additionally, the widespread use of AVs may exacerbate traffic demand and contribute to urban sprawl, leading to increased pollution levels. These factors highlight the need for careful planning and thoughtful policy decisions to ensure that the benefits of AV technology are realized while minimizing its negative effects on the environment.

3.6.4 Security

Traffic accidents often result in severe injuries or fatalities, with many being attributed to human errors such as distracted driving, lack of skill, and failure to adhere to traffic rules. In addition, vehicle malfunctions and environmental factors can also contribute to the occurrence of accidents. To mitigate the impact of human error, automakers have integrated automation features such as cruise control, driver assistance, and self-parking capabilities into vehicles. The development of AVs holds the potential to revolutionize the transportation industry by enabling communication-enabled, rule-compliant vehicles that are immune to human-related accidents. Nonetheless, safety and security concerns associated with AV development must be addressed to prevent potential attacks or component failures that could compromise the vehicle network and jeopardize traffic safety (Cui et al., 2019). Moreover, incorrect GPS data caused by errors or attacks can also affect AV localization, leading to the dissemination of false information and a significant loss of safety (Cui & Sabaliauskaite, 2018). Recent fatal accidents involving Tesla cars with autopilot mode have raised concerns about the readiness of technology and society for the widespread deployment of AVs (Shepardson, 2022; The Associated Press, 2022).

Numerous studies have explored the safety implications of AVs. Fagnant & Kockelman (2015) proposed that 90% of traffic accidents in the USA are caused by human error, which highlights the need to eliminate human intervention. In a California-based study, AVs were found to be free from any fault related to collisions, and the overall severity of injuries was lower than that caused by vehicles operated by humans (Sivak & Schoettle, 2015). Kockelman et al. (2016) predicted in their research that defining AV behavior as less aggressive than that of human drivers would lead to increased road and intersection capacity, shorter routes, and less risk-taking in the long run. Tian et al. (2016) demonstrated that platoon driving, which involves vehicles moving in groups, could significantly reduce chain accidents, and the severity of the accident would also decrease. In their study, Morando et al. (2018) concluded that as the percentage of Level 4 AVs increases, the crash rate will decrease. Additionally, both Morando et al. (2018) and Koopman and Wagner (2016) suggest that AVs must have a significant market share to realize positive security effects.

In academic literature, conflicting studies abound concerning the impact of AVs on driving safety. While some propose that AVs have the potential to enhance driving safety, others assert that these vehicles may indeed pose safety risks. For instance, Dixit et al. (2016) have suggested that high-end AVs might not necessitate driver intervention under normal conditions, but they may still require driver intervention in specific malfunction scenarios. Conversely, Koopman & Wagner (2017) contend that the demonstration of AVs' safety in urban traffic necessitates statistically significant data gathered in accordance with specific standards. Their study concludes that potential cyber-attacks could lead to considerable security issues arising from vehicle communication, while also highlighting the vulnerability of personal data held by AVs to privacy sharing and malicious attacks (Taeihagh & Lim, 2019).

Petit and Shladover (2014) contend that the transmission of erroneous and deceptive messages to the Global Navigation Satellite System has the potential to cause erratic and imprecise vehicle maneuvers, as well as the manipulation of maps. Milakis et al. (2017) suggest that the adaptation of human behavior, human-machine interaction, and the limited market adoption of vehicle automation may pose a threat to the advancement of traffic safety. However, the utilization of advanced technologies such as sensors, communication capabilities, and AI is expected to enhance the safety of AVs.

The research conducted by Bonnefon et al. (2016) delved into the complex decision-making processes of AVs in the event of an accident. AVs are often faced with the ethical and moral dilemma of choosing between sacrificing a passing pedestrian, multiple pedestrians, or the passengers in the vehicle to minimize casualties. This highlights the need for a deeper understanding of the social, ethical, and moral implications of AVs.

Despite the potential benefits of AVs in reducing fatalities and injuries in accidents with proper infrastructure and communication, there are still questions about accountability in case of accidents, emergency response protocols, communication with the surrounding environment, and data security. Furthermore, concerns about cyber security and the potential for hacking continue to be relevant and ongoing.

3.6.5 Infrastructure

Urban infrastructure encompasses the necessary components and resources vital for a city's operation. Although urban infrastructure and planning have traditionally been treated as separate entities, contemporary discussions approach them holistically to address urban challenges (Şahin, 2018). The advent of AVs is expected to result in significant changes in urban infrastructure, affecting both AVs and other road users. This change necessitates the implementation of novel safety standards and infrastructure requirements (Albino et al., 2015; Bösch et al., 2018) that can be correlated with the move towards smart cities. However, the integration of AV infrastructure into smart city infrastructure poses significant obstacles for urban planning (Gavanas, 2019). Consequently, the design of pick-up and drop-off areas for AVs is a critical facet of urban infrastructure, requiring careful consideration of occupant safety, comfort, and accessibility to surrounding land use (Gavanas, 2019).

Litman (2017) proposed the creation of special lanes to improve traffic flow and enable automated infrastructure in support of AVs. However, issues of fairness and cost may arise with this proposal. An alternative suggestion by Glancy (2015) involves designated lanes for AVs with reduced following headways and narrower widths. Nevertheless, the infrastructure costs associated with this proposal are still controversial (Duarte & Ratti, 2018). Tachet et al. (2017) argue that AVs can communicate their location, speed, and direction with each other, rendering traffic signals unnecessary. Depending on their communication capabilities, roadside processing units and antennas may not be required. Nonetheless, AVs may still require advanced beacons or sensor reflectors to aid in autonomous operations. Nunes et al. (2016) also emphasize the necessity of charging stations, despite the elimination of gas stations with AVs.

In the study of Ulu & Erdin (2023), the studies that deal with the features, effects and spatial reflections of AVs in the literature are discussed as in the Table 3.3.

Table 3.3 Autonomous vehicles' features, effects, and spatial results (Ulu & Erdin, 2023)

Title	Subtitle	Autonomous Vehicle Features	References	Possible Effects	Spatial Results
Transportation	Traffic	Communication	Naus et al., 2010; Swaroop et al., 1994; Swaroop & Rajagopal, 2001	More stable traffic flow	Cities with less traffic congestion
			Olia et al., 2018	Increase in road capacity	
		Lower Headways	Nowakowski et al., 2016; Schlossberg et al., 2018; Tientrakool et al., 2011		
			Nowakowski et al., 2016	Fuel Saving	Less air pollution
			Millard-Ball, 2018	Increasing travel demand	Traffic jam Increased travel time
	Public Transport	Alternative to PT	Stanford, 2015; Moavenzadeh & Lang, 2018	Reducing public transport use	
			Salazar et al., 2018	Decrease Traffic	Less traffic and air pollution
		Feeder to PT	Duarte & Ratti, 2018	Increasing accessibility to areas without access to PT lines	Higher accessible cities
	Travel Demand, Travel Time	No age and license restrictions	Alessandrini et al., 2015	Transportation for the elderly, children, and the disabled	More urban mobility
		No need for driver's liability	Duarte & Ratti, 2018	Increase in road use	Increased traffic congestion and time spent in traffic
		Easy access/use to vehicles	Alazzawi et al., 2018; Martinez & Viegas, 2017; Zhao & Kockelman, 2018	Increase in traffic congestion	
			Lokhandwala & Cai, 2018	Replacing the existing taxi system	
			Pakusch et al., 2018	Decrease congestion	Increase travel demand

Table 3.3 Continued

Title	Subtitle	Autonomous Vehicle Features	References	Possible Effects	Spatial Results
Transportation	Travel Demand, Travel Time	Ride-Sharing/Car Sharing	Bischoff & Maciejewski, 2016; Fagnant & Kockelman, 2014; Levinson & Krizek, 2015; Milakis et al., 2017; Ratti & Biderman, 2017; Spieser et al., 2014; Vosooghi et al., 2019	Decreased number of cars in circulation	Less traffic congestion Reduction in air pollution Decreased time spent in traffic Reduction in individual travel fees
			Plumer, 2013; Sivak & Schoettle, 2015	Reduction in individual vehicle ownership	
			Medina-Tapia & Robusté, 2019	Decreased distance per vehicle	
			Bahamonde-Birke et al., 2018; Bischoff & Maciejewski, 2016; Fagnant & Kockelman, 2014; Martinez & Crist, 2015; Moavenzadeh & Lang, 2018; Moreno et al., 2018; Pakusch et al., 2018	Increase in VMT/VKT due to empty trips	Increased congestion Increase in the number of vehicles in circulation Increased emissions and environmental pollution With less space dedicated to vehicles (roadways and parking),
			Bahamonde-Birke et al., 2018	Increase in travel demand	
	Parking	Self-parking	Keeney, 2017; Martinez & Crist, 2015; Zhang et al., 2015; Zhang & Guhathakurta, 2017	Decreased parking space requirement	Gaining public space in the city center Cities with more compact uses
			Zhang et al., 2015	Making roadside parking redundant	
			Yigitcanlar et al., 2019	Finding cheaper parking spaces	

Table 3.3 Continued

Title	Subtitle	Autonomous Vehicle Features	References	Possible Effects	Spatial Results
Urbanization	Traffic safety	No human intervention	Keeney, 2017	Fewer accidents	Safer and livable cities
		Perceiving the environment with artificial intelligence and sensors	Duarte & Ratti, 2018; Fagnant & Kockelman, 2015	Following the traffic regulations	
	Accessibility		Beraldi, 2007	Less lane use and maneuvering space	Improving transportation in old settlements, narrow and difficult-to-navigate areas
		Lower prices	Guerra, 2016; Litman, 2017	Improved accessibility	Urban Sprawl
	Land Use	Automated mobility	Grush et al., 2016	Increase in demand	Increase in the need for parking
			Stead & Vaddadi, 2019		Need for drop-off points
		Platooning	Stead & Vaddadi, 2019; Yigitcanlar et al., 2017, 2019	Empty spaces in urban areas	Quality of the built environment will increase with the recentralization or reorganization of inner areas, re-densification, land use change to new green area
		No need for vehicle driving responsibility.	Duarte & Ratti, 2018	Decrease in trips	Pedestrian-friendly CBD
	Urban form		Anderson et al., 2014; Duarte & Ratti, 2018; Stead & Vaddadi, 2019	Site selection from suburban areas	Urban sprawl
			Wilson & Chakraborty, 2013		Increasing energy use, reducing water and air quality Increasing infrastructure investments and costs
	Land value		Bagloee et al., 2016; Heinrichs, 2016; Rubin, 2016; Snyder, 2016		Rising real estate prices in the suburbs

Table 3.3 Continued

Title	Subtitle	Autonomous Vehicle Features	References	Possible Effects	Spatial Results
Infrastructure	Traffic signalization	Communication	Tachet et al., 2017	No need for traffic signaling	Extra urban area gain
			Glancy, 2015	Antennas and roadside processing units' requirement	Requires additional investments
	Highway operators	Automatic transitions	Litman, 2017	Special lane requirement	
	Energy	Working with electricity	Nunes et al., 2016	Charging stations requirement	
Security	Pedestrian and Traffic Security	No human intervention	Dixit et al., 2016	Require human intervention in some malfunction situations.	The dangerous urban environment created by careless users
			Morando et al., 2018. Fagnant & Kockelman, 2015	Reduction of human-induced accidents	Reduction in fatal and severe injury accidents
		ADAS	Rosén et al., 2010 Sivak & Schoettle, 2015	Reduce collision severity	
			Gavrila et al., 2003; Hannawald & Kauer, 2004; Rosén & Sander, 2009;		Safer driving in cities
		Communication	Tian et al., 2016	Platooning	Reduction of chain accident risk and accident severity

Table 3.3 Continued

Title	Subtitle	Autonomous Vehicle Features	References	Possible Effects	Spatial Results
Environment	Build Environment	Integration with infrastructure	Wilson & Chakraborty, 2013	Urban Sprawl	Expansion of infrastructure due to urban sprawl and its negative effects on the environment
	Air Pollution	Soft acceleration/ declarations, optimal control strategies, and energy management	Bahamonde-Birke et al., 2018; Martínez-Díaz & Soriguera, 2018; Pakusch et al., 2018; Wadud, 2017	Compact and mixed-use land use	Decrease in environmental pollution Lower emissions
		Communication	Fagnant & Kockelman, 2014	Platooning	
			Anderson et al., 2014	Fuel-saving	
	Fuel Consumption		Medina-Tapia & Robusté, 2019	Finding a parking area in a shorter time	
		Integration of Public Transport and SAVs	Salazar et al., 2018	Reduced emissions Reducing traffic congestion	
		Intelligent steering and movement	Walker & Crofton, 2014		
		Integration of EV and SAVs	Fagnant & Kockelman, 2014; Greenblatt & Saxena, 2015; Lokhandwala & Cai, 2018; Martinez & Viegas, 2017; Salazar et al., 2018; Vleugel & Bal, 2018; Zhang et al., 2015	Less fuel consumption	
		Design	Capp & Litkouhi, 2014	Reduction in vehicle weight	

In summary, AVs have the potential to improve urban transportation when operated correctly, but they necessitate the renewal and improvement of urban infrastructure. Debates persist concerning the number of specialized facilities required, such as charging stations, data collectors and distributors, designated lanes, beacons, and sensors. Moreover, the ownership of these infrastructure areas, how their costs will be covered, and who will bear these costs remain ongoing issues.

3.7 Barriers to Implementation

There are many expected benefits after the use of AVs is introduced. However, there are still some obstacles to the implementation of this technology. Rajasekhar & Jaswal (2015) summarized these challenges as follows:

• High manufacturing costs of vehicles: For example, Google's high fees, such as $ 80000 to add an AV module to its vehicle, make AVs far from accessible.
• Technological challenges: Although many major automakers state that they are technologically ready to produce level 3 AVs, the infrastructure of many countries is not ready for this. Also, this technology still needs to be researched and tested.
• Removal of traditional cars from the market: Combining AVs with conventional cars after their release may have unpredictable results. Upgrading old cars technologically or replacing them with AVs may be the solution, but this is costly.
• Unemployment problem: after the proven and smooth launch of AVs technology, people with chauffeuring profession will face the problem of unemployment.
• Security and privacy concerns: AVs can be an instrument of malicious activity, leading to privacy breaches and vulnerabilities.
• Standards and regulations: governments should prepare standards and laws to ensure that AVs can travel, protect large amounts of personal data, and that AVs are not a danger.

CHAPTER FOUR
MODELLING TRANSPORTATION WITH AUTONOMOUS VEHICLES

The strategic planning of transportation and land use in urban areas has a significant impact on the mobility of individuals. Common issues in cities include traffic congestion, air pollution, longer travel times, and less security on the roads. In the past, constructing new roads and opening new areas to settlements consumed a lot of space, making walking more challenging and encouraging driving. However, the current trend is to optimize the current infrastructure by implementing policies and strategies that utilize existing roads and PT more efficiently.

The advent of technology has brought about significant changes to cities and transportation systems. To optimize the efficiency of existing infrastructure, technology-driven systems such as smart cities and smart transportation systems have been implemented. Additionally, transportation vehicles have undergone significant changes due to technological advancements, with the emergence of AVs expected to transform urban transportation systems. The impact of this transformation on transportation systems and urban planning is anticipated to be comparable to that of automobiles almost a century ago.

The proliferation of technology has had a significant impact on cities and transportation systems. The development of smart cities and smart transportation systems, which leverage technology to optimize existing infrastructure, has been a key trend. Furthermore, transportation vehicles have been heavily influenced by technology, with the advent of AVs poised to transform urban transportation systems. This shift is likely to have a far-reaching impact on transportation systems and urban planning, nearly a century after the widespread adoption of automobiles.

4.1. Study Area

The literature suggests that city centers will be among the urban areas most influenced by AVs, and based on this, Alsancak/ İzmir was selected as the study area for this research. The choice of this area is primarily based on several factors. Firstly, it is situated in the CBD, which typically experiences high levels of traffic and transportation activities. Secondly, the area encompasses diverse mixed-use developments, indicating a combination of residential, commercial, and recreational zones. Lastly, it incorporates various modes of transportation, thereby offering an opportunity to examine the potential effects of AVs on different transportation systems within a high-density urban area.

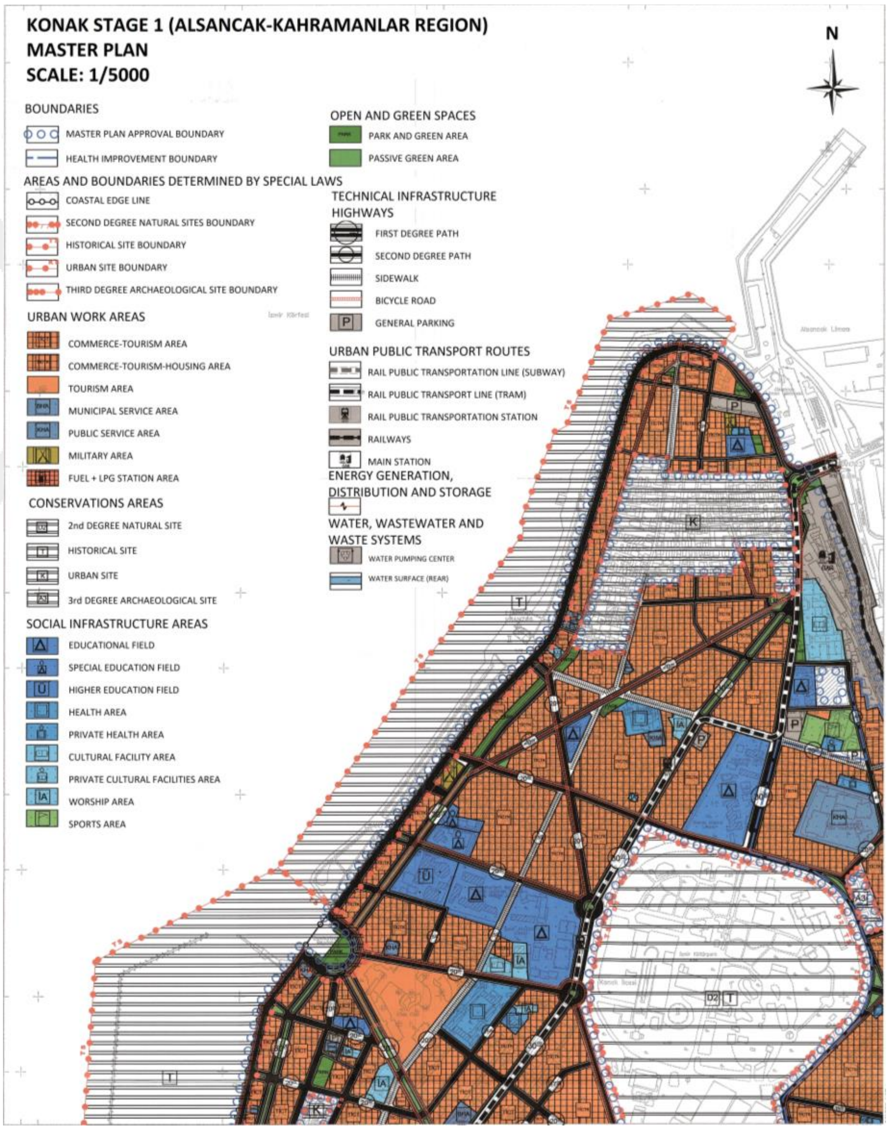


Figure 4.1 Master plan of Alsancak (İzmir Büyüşehir Belediyesi, 2021)

While determining the study area limits, zone 38 from the zones determined in the İzmir Transportation Master Plan was chosen because it is located in the CBD (İzmir

Büyükşehir Belediyesi Ulaşım Şube Müdürlüğü, 2017). However, the south of Gazi boulevard is defined as the Urban Protected Area, and since the areas have a different urban texture and transportation pattern than the northern region, the study limits are limited to the north of the 38th region. The study area and the area limits are given in Figure 4.2.

Figure 4.2 Study area (Google Earth, 2023)

There are many hospitals, schools, tourism areas, museums, hotels, commercial units, restaurants, sports fields in the mixed-use study area. In addition, Alsancak station, which is the intersection point of many transportation modes, is located in the area. Izmir Fair (Kültürpark), on the other hand, hosts many citizens with its activities.

The Study area has an extensive road network that includes multi-lane highways used for PT. Passengers can choose from both buses and the Konak tram in the area. The tram line runs through Gazi Boulevard, Şair Esref Boulevard, Ziya Gökalp Boulevard, and Atatürk Avenue. The trams can carry up to 285 individuals and make stops at 8 stations to pick up and drop off passengers.

Meanwhile, the buses can accommodate 110 people and operate on 3 different routes. The first route is through Mürselpaşa Boulevard and Gazi Boulevard, the second through Cumhuriyet Boulevard, Talatpaşa Boulevard, and Atatürk Avenue, and the third through Mürselpaşa Boulevard, Şair Eşref Boulevard, and Atatürk Avenue. During peak hours, both bus and tram lines have a frequency of 5 minutes from each stop.

Figure 4.3 Public transport routes (Google Earth, 2023)

There are 11 different roadside parking lots with a total capacity of 610 vehicles in the study area. Parking areas are given in Table 4.1 with their names, capacities, width/lengths and hourly occupancy rates. Hourly occupancy rates were created with the data collected on 02.06.2023 via the IZUM website between 08:00 and 09:00, which are the morning peak hours.

Table 4.1 Parking areas (İZUM, 2023)

Park Name	Capacity	Length (m)	Width (m)	Hourly Occupancy Change
Kordon 1	132	4	2.5	%5
Kordon 2	18	4	2.5	%1
Kordon 3	35	4	2.5	%3
Kordon 4	67	4	2.5	%9
Plevne Boulevard	110	4	2.5	%11
Hilton	68	4	2.5	%3
Efes Otel	25	4	2.5	%37
Akdeniz Avenue	27	4	2.5	%37
26. Ağustos	14	4	2.5	%7
Ziya Gökalp	59	4	2.5	%5
Şair Eşref Boulevard	55	4	2.5	%12.7

4.2 Data and Modelling the Network

Simulation softwares are commonly used in transportation engineering to improve transportation networks, assess environmental impact, estimate costs, and evaluate safety. The specific software chosen depends on the region, system, and type of analysis needed. In this study, PTV VISSIM software was selected due to its ability to generate travel demand, create micro-scale models, and conduct static and dynamic analyses. Developed by PTV Planung Transport Verkehr AG in Germany, PTV VISSIM is an integrated software that is easy to use, saves time, reduces expenses, and facilitates reoperation. It was chosen for this study because it allows for simulations, multiple runs, and the creation of various scenarios for traffic conditions that are difficult, time-consuming, and costly to observe in the field.

To achieve simulation results that accurately reflect reality, it is necessary to collect and analyze data. This includes determining the study area and limits, as well as drawing road components based on their geometry, such as length, number of lanes, lane width, intersection radii, and turning angles. Incorporating free speed and traffic limitations is also crucial, as well as adding traffic controllers and signal settings. Defining vehicle characteristics, including model, length, acceleration, maximum speed, maximum deceleration, emission, fuel consumption, vehicle weight, and battery capacity, is then necessary. Once vehicles are defined, their composition in traffic is also established. Finally, traffic demand between links or zones is defined using an origin-destination matrix or special routes.

After the vehicles are defined, the vehicle composition in the traffic is defined. And finally, the traffic demand between the links or between the zones should be defined to the system in the form of an origin-destination matrix or special routes.

When performing a simulation, it is essential to establish variables such as the simulation duration, random seed, resolution, output time, and warm-up period. Scenarios are then developed based on the conditions to be assessed, which can be operated multiple times to obtain desired results. The results of these scenarios are available in various formats, including tables, graphics, and color-coded displays. It is crucial to follow the three fundamental principles of software error control, calibration, and validation when creating the simulation model. Despite being widely used and easy to use, simulation programs must be reliable and have default parameters appropriately adjusted. It is also critical to interpret the results carefully, as inappropriate model parameters can impact simulation accuracy. To improve model accuracy, users should adjust the sensitivity of the model by calibrating its parameters, resulting in a better reflection of reality in the model and its outputs. The road network in the model was created based on the number of lanes and lane width data obtained from Google Earth 2023. The network includes the main arteries and collector roads from the Izmir Transportation Master Plan (Figure 4.4-4.7). In summary, ensuring the accuracy and reliability of simulation programs and their results is essential for effective decision-making.

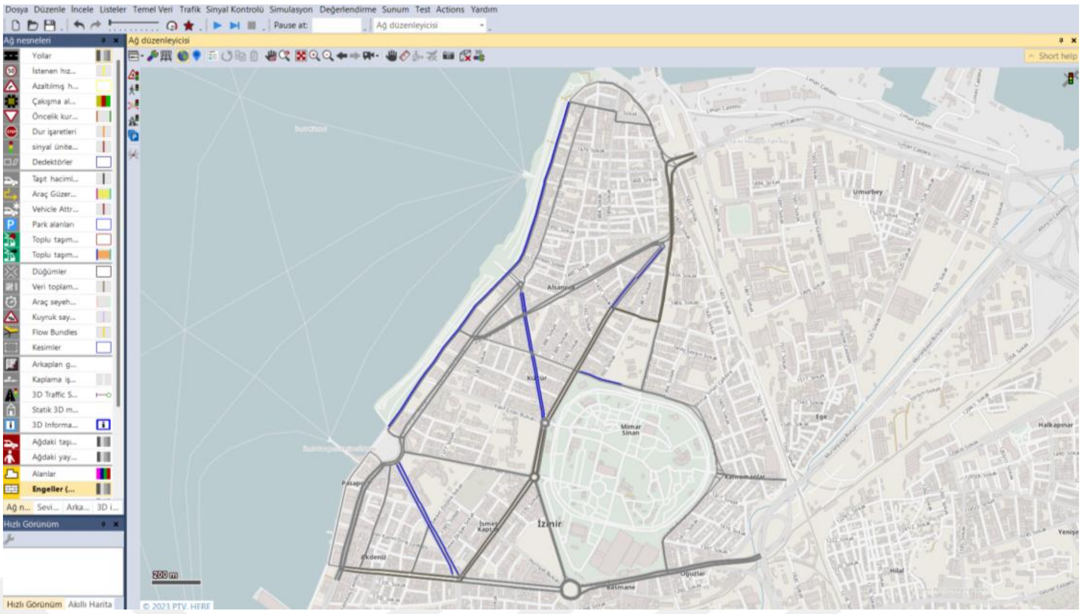


Figure 4.4 Links in simulations model

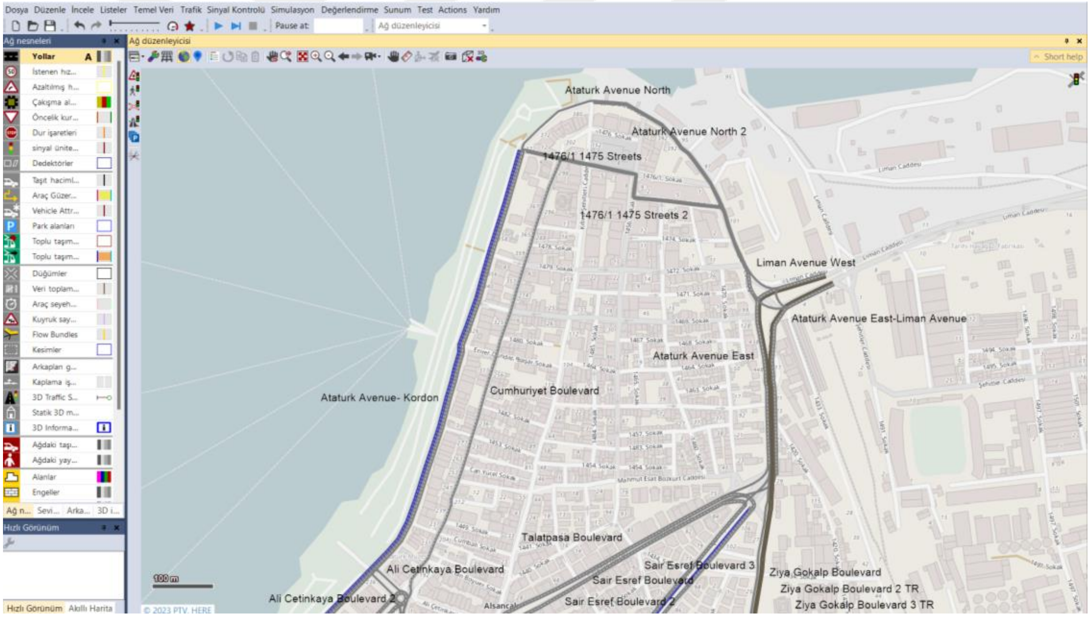


Figure 4.5 Links’ names (north)

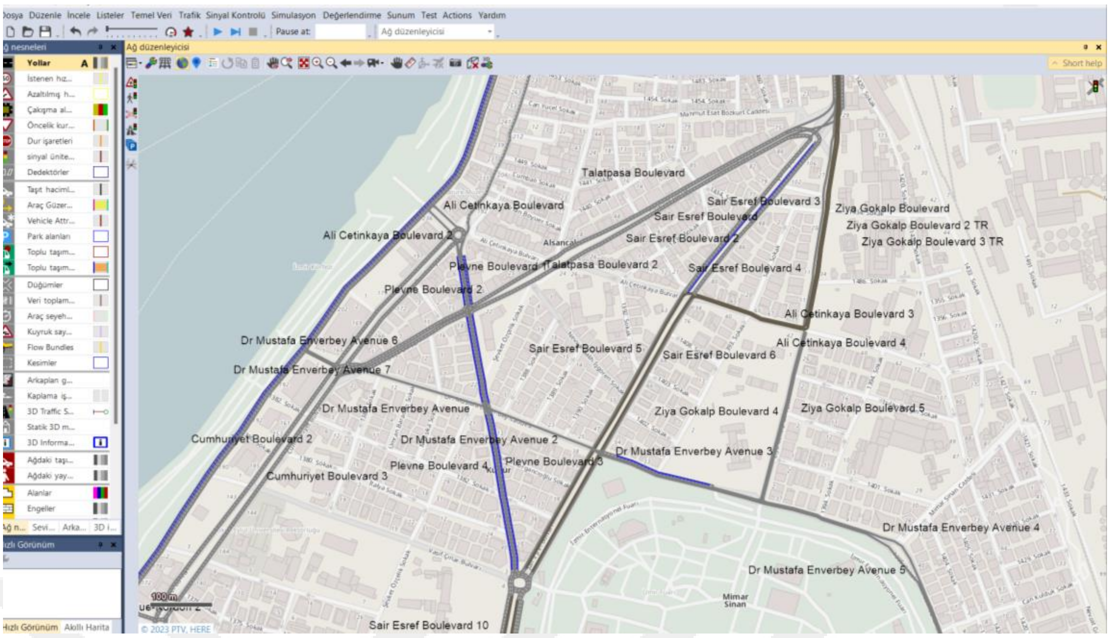


Figure 4.6 Links' names (middle)

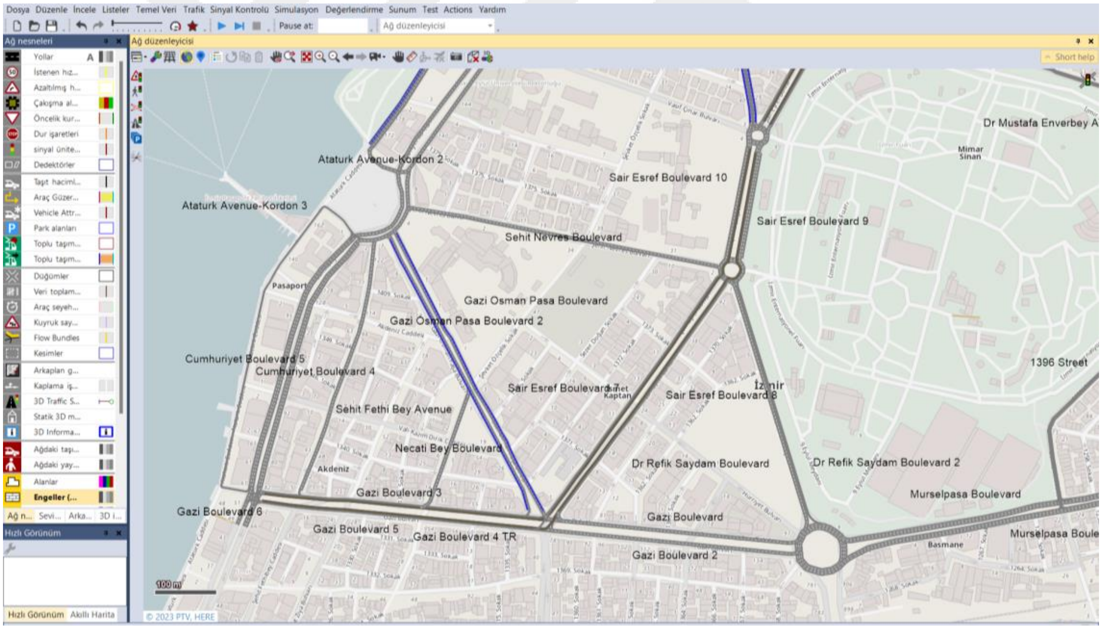


Figure 4.7 Links' names (south)

Table 4.2 Links of simulation model and their geometric properties

Link Numbers and Names	Number of Lanes	Lane Width	Parking Lane Width	Bicycle Lane Width	Tram Lane Width	Parking Lot Capacity
Ataturk Avenue North	1	3				
Ataturk Avenue North 2	1	3				
1476/1 1475 Streets	1	3				
1476/1 1475 Streets 2	1	3				
Ataturk Avenue- Kordon	3	3.5	2.5			252
Cumhuriyet Boulevard	2	3		1.2		
Liman Avenue West	3	3			3	
Ataturk Avenue East	3	3			3	
Ataturk Avenue East-Liman Avenue	3	3			3	
Ali Cetinkaya Boulevard	1	3				
Ali Cetinkaya Boulevard 2	1	3				
Cumhuriyet Boulevard 2	2	3				
Cumhuriyet Boulevard 3	2	3				
Plevne Boulevard 1	2	3.5	2.5			20
Plevne Boulevard 2	2	3.5	2.5			10
Plevne Boulevard 3	2	3	2.5			40
Plevne Boulevard 4	2	3	2.5			40
Talatpasa Boulevard	2	3				
Talatpasa Boulevard 2	2	3				
Sair Esref Boulevard	2	3				
Sair Esref Boulevard 2	3	3	2.5			27
Sair Esref Boulevard 3	3	3	2.5			28
Sair Esref Boulevard 4	2	3				
Ziya Gokalp Boulevard	1	3				
Ziya Gokalp Boulevard 2 TR	1	3			3	
Ziya Gokalp Boulevard 3 TR	1	3			3	
Ziya Gokalp Boulevard 4	1	3				
Ziya Gokalp Boulevard 5	1	3				
Ali Cetinkaya Boulevard 3	1	3			3	
Ali Cetinkaya Boulevard 4	1	3			3	
Sair Esref Boulevard 5	2	3			3	
Sair Esref Boulevard 6	2	3			3	
Dr Mustafa Enverbey Avenue	1	3				
Dr Mustafa Enverbey Avenue 2	1	3				
Dr Mustafa Enverbey Avenue 3	2	3	2.5			14

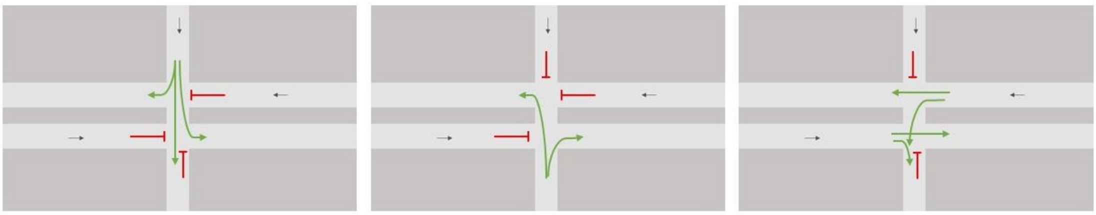
Table 4.2 Continued

Link Numbers and Names	Number of Lanes	Lane Width	Parking Lane Width	Bicycle Lane Width	Tram Lane Width	Parking Lot
Dr Mustafa Enverbey Avenue 4	1	3				
Dr Mustafa Enverbey Avenue 5	1	3				
Dr Mustafa Enverbey Avenue 6	1	3				
Dr Mustafa Enverbey Avenue 7	1	3				
Akıncılar Avenue	1	3.5				
Akıncılar Avenue 2	1	3.5				
1396 Street	1	3				
1396 Street 2	1	3				
Murselpasa Boulevard	3	3				
Murselpasa Boulevard 2	3	3				
Gazi Boulevard	3	3				
Gazi Boulevard 2	3	3				
Gazi Boulevard 3	3	3			3	
Gazi Boulevard 4 TR	3	3			3	
Gazi Boulevard 5	1	3				
Necati Bey Boulevard	2	3				
Sehit Fethi Bey Avenue	2	3				
Cumhuriyet Boulevard 4	3	3				
Cumhuriyet Boulevard 5	3	3				
Ataturk Avenue-Kordon 3	1	3				
Gazi Boulevard 6	1	3				
Gazi Osman Pasa Boulevard	2	3	2.5			46
Gazi Osman Pasa Boulevard 2	2	3	2.5			47
Sair Esref Boulevard 7	2	3			3	
Sair Esref Boulevard 8	2	3			3	
Dr Refik Saydam Boulevard	2	3				
Dr Refik Saydam Boulevard 2	1	3				
Sehit Nevres Boulevard	2	3.5		2.4		
Ataturk Avenue-Kordon 2	2	3				
Sair Esref Boulevard 9	4	3				
Sair Esref Boulevard 10	3	3				

Traffic volumes are taken from the volumes assigned to the links in the Izmir Transportation Master Plan. Since these values are daily volume values, they were converted into hourly volume values (peak) by multiplying with the coefficient of 1/10 by proportioning to the data obtained from IZUM cameras. It is defined that traffic volumes enter the system from Akıncılar Street, Liman Avenue, Atatürk Avenue, and Mürselpaşa Boulevard. After determining the routes according to the traffic volume in the links in the Izmir Transportation Master Plan for vehicles, data collection points were added on each link. In addition, the traffic composition collected during the weekday peak hours and the signal phases at the signalized intersections were obtained from cameras of the Izmir Transportation Center (IZUM). Links and their geometric features are given in Table 4.1.

In the transportation network, both trams and buses are used for the PT system. The tram system route is located along Gazi Boulevard and Alsancak Station and includes 10 opposing tram stations on the Alsancak Station, Atatürk Sports Hall, Hocazade Mosque, Kültürpark and Gazi Boulevard. Trams have been added to the network to pass through stops every 5 minutes and wait 30 seconds at each stop. Since there are a PT routes with buses on the Liman Avenue, Talaşpaşa Boulevard, Şair Eşref Boulevard, Dr Refik Sayfam Boulevard, Cumhuriyet Boulevard, Gazi Boulevard, and Mürselpaşa Avenue, the bus line was defined so that a bus passes every 5 minutes from each stop on these streets and the traffic composition of the network defined as 98% automobile and 2% heavy vehicle.

The signal phases of the signalized intersections in the area were obtained by field work, and signal phase diagrams were created for all intersections as shown in the Figure 4.8 as an example.



40 sec 15 sec 30 sec

Figure 4.8 Signal phase example

To obtain link-based outputs from the created model, data collecting points were added to each link. In this way, detailed outputs such as the number of vehicles passing through each link, queue delays and speeds can be obtained. Data collecting points number and link numbers are given in Table 4.3.

Table 4.3 Links' names and data collecting point no

Links' Names	Data Collecting Point No	Links' Names	Data Collecting Point No
Ataturk Avenue North	1	Dr Mustafa Enverbey Avenue 3	29
Ataturk Avenue North 2	2	Dr Mustafa Enverbey Avenue 4	30
1476/1 1475 Streets	3	Dr Mustafa Enverbey Avenue 5	31
1476/1 1475 Streets 2	4	Akıncılar Avenue	34
Ataturk Avenue- Kordon	5	Akıncılar Avenue 2	35
Cumhuriyet Boulevard	6	1396 Street	36
Liman Avenue West	7	1396 Street 2	37
Ataturk Avenue East	8	Murselpasa Boulevard	38
Ataturk Avenue East-Liman Avenue	9	Murselpasa Boulevard 2	39
Ali Cetinkaya Boulevard	10	Gazi Boulevard	40
Ali Cetinkaya Boulevard 2	11	Gazi Boulevard 2	41
Cumhuriyet Boulevard 2	12	Gazi Boulevard 3	42
Cumhuriyet Boulevard 3	13	Gazi Boulevard 5	43
Plevne Boulevard 1	14	Necati Bey Boulevard	44
Plevne Boulevard 2	15	Sehit Fethi Bey Avenue	45
Plevne Boulevard 3	16	Cumhuriyet Boulevard 4	46
Plevne Boulevard 4	17	Cumhuriyet Boulevard 5	47
Talatpasa Boulevard	18	Ataturk Avenue-Kordon 3	48
Talatpasa Boulevard 2	19	Gazi Osman Pasa Boulevard	50
Sair Esref Boulevard 2	20	Gazi Osman Pasa Boulevard 2	51
Sair Esref Boulevard 3	21	Sair Esref Boulevard 7	52
Ziya Gokalp Boulevard	22	Sair Esref Boulevard 8	53
Ziya Gokalp Boulevard 4	23	Dr Refik Saydam Boulevard	54
Ziya Gokalp Boulevard 5	24	Dr Refik Saydam Boulevard 2	55
Sair Esref Boulevard 5	25	Sehit Nevres Boulevard	56
Sair Esref Boulevard 6	26	Sair Esref Boulevard 9	58
Dr Mustafa Enverbey Avenue	27	Sair Esref Boulevard 10	59
Dr Mustafa Enverbey Avenue 2	28		

4.2.1 Calibration and Validation of Model

Calibration of the model in the simulation is one of the most important steps to ensure the accuracy and reliability of the model outputs. Calibration of the model in a traffic simulation program is a process by changing and correcting some model parameters (Chaudhry & Ranjitkar, 2009; Giuffrê et al., 2016).

Developing a comprehensive traffic model that takes all possible variables into account presents a significant challenge, as real-world traffic conditions can be overlooked. It is crucial to adjust each model to local conditions, research, and dataset, as it is impossible for a single model to contain all the variables. Therefore, calibration is a crucial step in the process (Yiğit, 2019). Traffic simulation programs typically offer user-adjustable parameters that enable calibration of the model to local conditions. In the calibration step, routes were created for the vehicles entering the network according to the volumes assigned for the links in the Transportation master plan. In addition, 50km/h, which is the average speed limit in the study area, has been defined for speed values.

Besides the calibration step, the validation process is also very important. Validation is defined as the process in which the researcher tries to reduce the difference between the model predicted for the road network and the current conditions (Yiğit, 2019). In other words, validation is the process of determining whether the model calibration result is valid or not. Therefore, the calibration and validation processes are highly interconnected and work better together for the sensitivity of the model.

Suggested parameters for calibration and validation are statistical parameters that can be used frequently in research. Geoffrey E. Havers (GEH) were used for these two processes in this research.

The GEH parameter is used in traffic engineering forecasting and modeling to compare two separate traffic data sets. The GEH formula is named after Geoffrey E.

Havers, who worked on transport planning in London, England in the 1970s. Although its mathematical form is similar to the chi-square test, it is not a real statistical test (Yiğit, 2019). It is an empirical formula used for various traffic analyses and has proven to be useful. The GEH parameter avoids errors that occur when using simple percentages to compare two data sets. For example, the volumes carried by a highway line and any urban highway section are different from each other. The GEH parameter reduces this problem. Since the GEH value is not linear, the acceptance threshold based on the GEH value can be used in a wide range of traffic volumes (Yiğit, 2019).

GEH, as mentioned, is a value used in traffic engineering to compare two sets of data. The Economic Evaluation Manual (EEM-I) present the GEH concept for transportation model validation. The GEH value is also used as a criterion for the acceptance or rejection of a model. The fact that each simulation value is less than 5 according to each observation measurement proves that the model is strong. Equation 4.1 contains the empirical formula used to calculate the GEH value. The Q_{model} and $Q_{observation}$ values in the formula are the volume values of the model and observation data. Although the GEH value is accepted without a unit, since the Q volume values used are vehicles/hour, it can also be accepted as 0.5 (vehicle/hour) for the GEH (Feldman, 2012).

$$GEH = \sqrt{\frac{2 * (Q_{model} - Q_{observation})^2}{(Q_{model} + Q_{observation})}} \tag{4.1}$$

The acceptance conditions of the value are as follows;
0-5 A good model has been established.
5-10 Requires more research.
> 10 Models are unacceptable.

Table 4.4 Hourly traffic volumes obtained from microsimulation model and transportation master plan and GEH values obtained from data collecting points

Data Collecting Point	Model Volume (veh/h)	Assigned Volume (veh/h)	GEH
5	1059	908	4.81
15	196	215	1.31
25	483	551	2.95
35	417	431	0.66
45	1284	1325	1.13
55	504	508	0.15

The volume assigned to the links in the transportation master plan and the volume values obtained from the data collection points in the simulation model and the GEH values calculated are given in the Table 4.3. All values below 5 indicate that the model is acceptable and realistic.

4.3 Scenarios

Simulation software provides the opportunity to develop scenarios and construct models for testing challenging and expensive situations within the transportation network. This capability proves invaluable in addressing present issues and preparing for the future. When formulating these scenarios, it becomes possible to create hypothetical models by altering various parameters, including road infrastructure, traffic volume, vehicle composition, driver behaviors, and signal phases. These models can then be compared with the existing conditions and other scenarios.

After testing the validity of the model with the calibration and validation processes, 5 different scenarios were created in this section, and the network performance results and data collecting point results obtained from each scenario were evaluated. A warm-up time of 900 seconds is defined as a run-time of 3600 seconds while each simulation is run. In addition, each simulation was run with 10 seeds and evaluated by taking the average.

Default values in the software are used for both human and autonomous driving behavior. Within the software, three different driver types were defined for AVs:

cautious, normal, and aggressive. For this study, the behavior of a normal AVs behavior was assumed, and a comparison of the parameters pertaining to AVs and human driver behavior is presented in Appendix 1.

The definitions of the findings obtained from the simulation results are as follows:

- Average Delay: Average delay per vehicle:
- Average Stop: Average number of stops per vehicle:
- Average Speed: Average speed [km/h]
- Delay Stop: Total standstill time of all vehicles that are in the network or have already arrived.
- Total Distance: total distance traveled by vehicles moving or leaving the system
- Total Travel Time: Total travel time of vehicles moving in the system or leaving the system
- Vehicle (Active): Number of vehicles moving in the system at the end of the simulation
- Vehicle (Arrived): Total number of vehicles arriving at destination or leaving the system
- Queue Delay: Total time in [s] that the vehicles have spent so far stuck in a queue, if the queue conditions are met.

4.3.1 Scenario 1: Base Scenario

The base scenario is based on the question of what would happen if the existing vehicles were replaced by AVs. While creating the scenario, the volume of vehicles entering the system was replaced by AVs with 10% intervals. As a result of the scenario, the impact of AVs on the existing traffic gradually was evaluated. Network performance results are given in Table 4.5.

Table 4.5 Scenario 1: Base Scenario network performance results

Autonomous Vehicles %	Average Delay (sec)	Average Stop	Average Speed (km/h)	Delay Stop (sec)	Total Distance (km)	Total Travel Time (sec)	Vehicle (Active)	Vehicle (Arrived)
0%	49.94	1.61	34.05	31.09	20944	2230021	2632	12854
10%	47.10	1.55	34.76	29.08	20984	2185181	2571	12878
20%	44.90	1.49	35.35	27.33	20996	2149689	2533	12884
30%	43.13	1.46	35.82	25.45	21016	2120770	2496	12894
40%	40.77	1.39	36.47	23.30	21078	2086946	2451	12923
50%	38.47	1.33	37.13	21.33	21112	2051667	2394	12943
60%	37.73	1.34	37.34	20.48	21124	2040346	2398	12941
70%	35.96	1.30	37.88	18.54	21159	2013815	2353	12953
80%	35.62	1.32	37.99	17.51	21171	2009387	2351	12957
90%	34.66	1.32	38.29	16.47	21187	1994184	2323	12967
100%	34.52	1.37	38.36	15.66	21247	1996628	2325	12965

According to the network performance results, the average speeds increase as the number of AVs included in the system increases. The average speed of every 10% AVs included in the system increases by 1.20% (Figure 4.9). In addition, delays per vehicle decreased by 3.61% on average with the addition of 10% AVs (Figure 4.10).

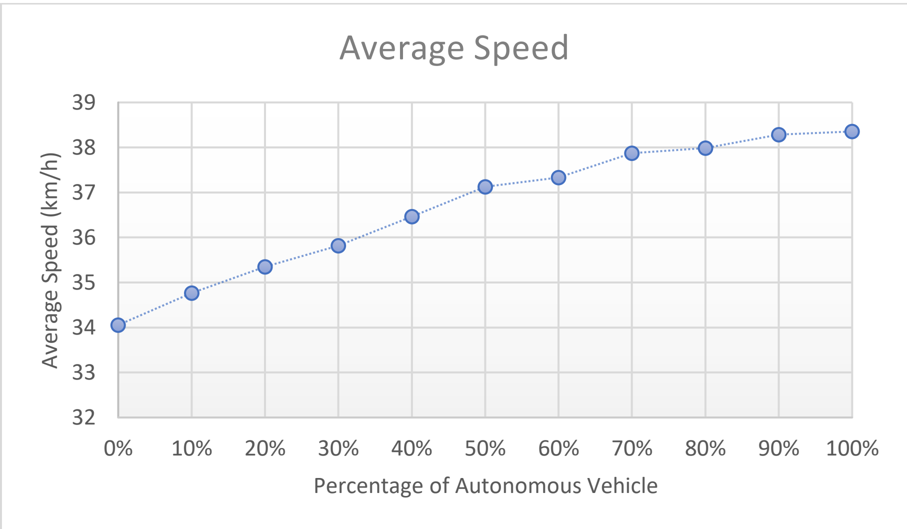


Figure 4.9 Scenario 1: Base scenario average speeds of the network

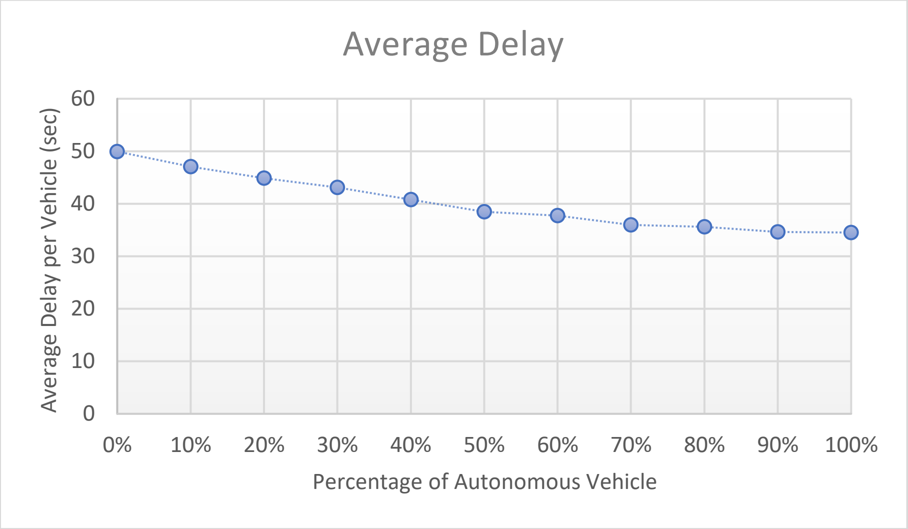


Figure 4.10 Scenario 1: Base scenario average delays of the network

When the average stops are examined, it is seen that the stops decrease up to 70% AVs but increase after 70% (with a relatively less increase) (Figure 4.11). It is observed that AVs reduce average stops by 1.55% on average. However, despite this, it is seen that Delay Stops are gradually decreasing. A change of 6.61% was obtained for each sub-scenario (Figure 4.12).

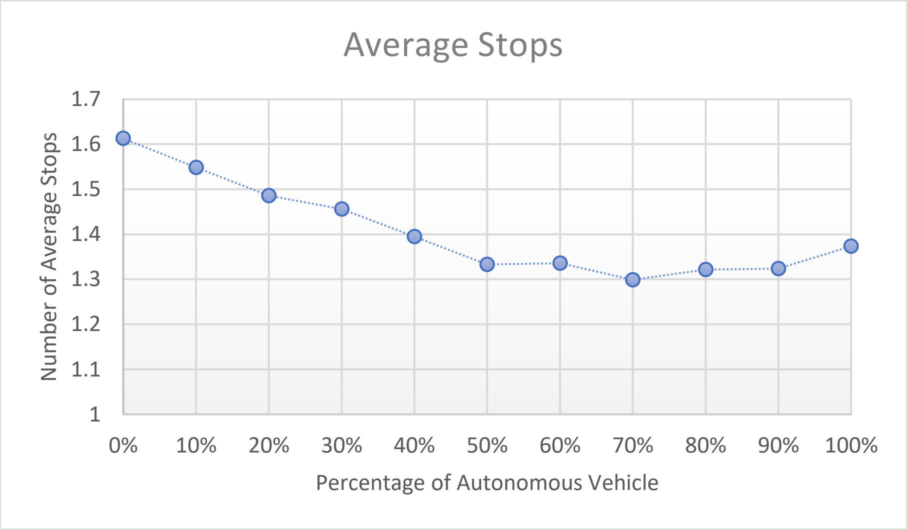


Figure 4.11 Scenario 1: Base scenario average number of stops of the network

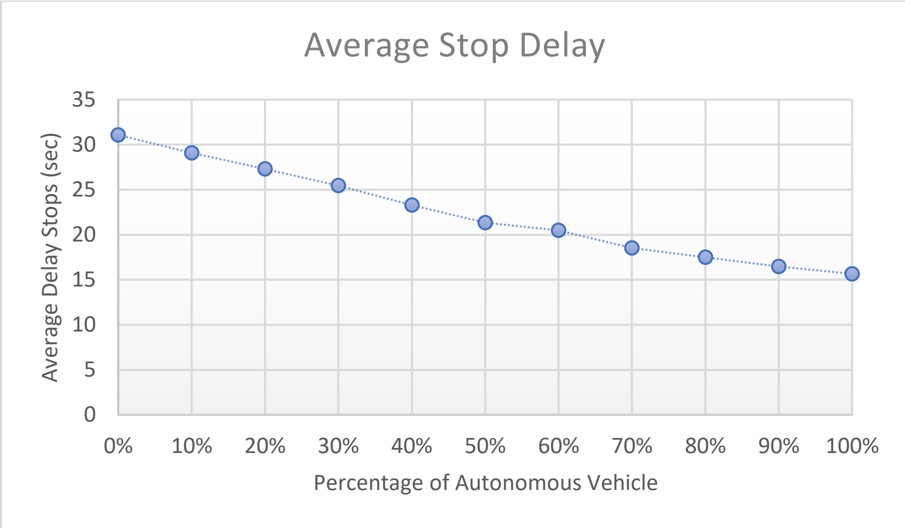


Figure 4.12 Scenario 1: Base scenario average stop delays of the network

When the results are examined, it is seen that the total travel time is gradually decreasing. The reasons for this are increased average speeds, reduced delays, and reduced stops. Moreover, the total travel time decreased by an average of 1.10% with the 10% AVs change in the system (Figure 4.13). It is also seen that the total distance is gradually increasing. The reason for this is that as the percentage of AVs increases during the simulation time, the number of vehicles that complete their route and leave the system increases (Figure 4.14). It is seen that the total distance decreased by an average of 0.14% in each sub-scenario.

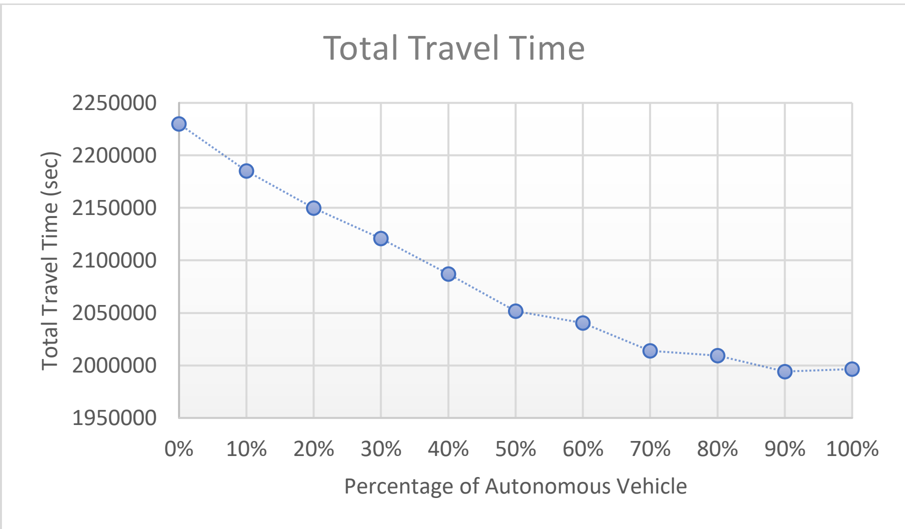


Figure 4.13 Scenario 1: Base scenario total travel time of the network

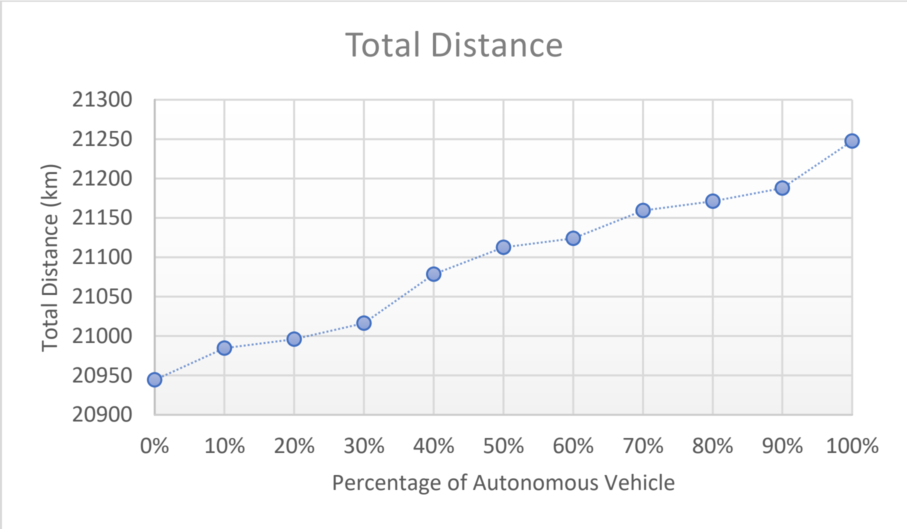
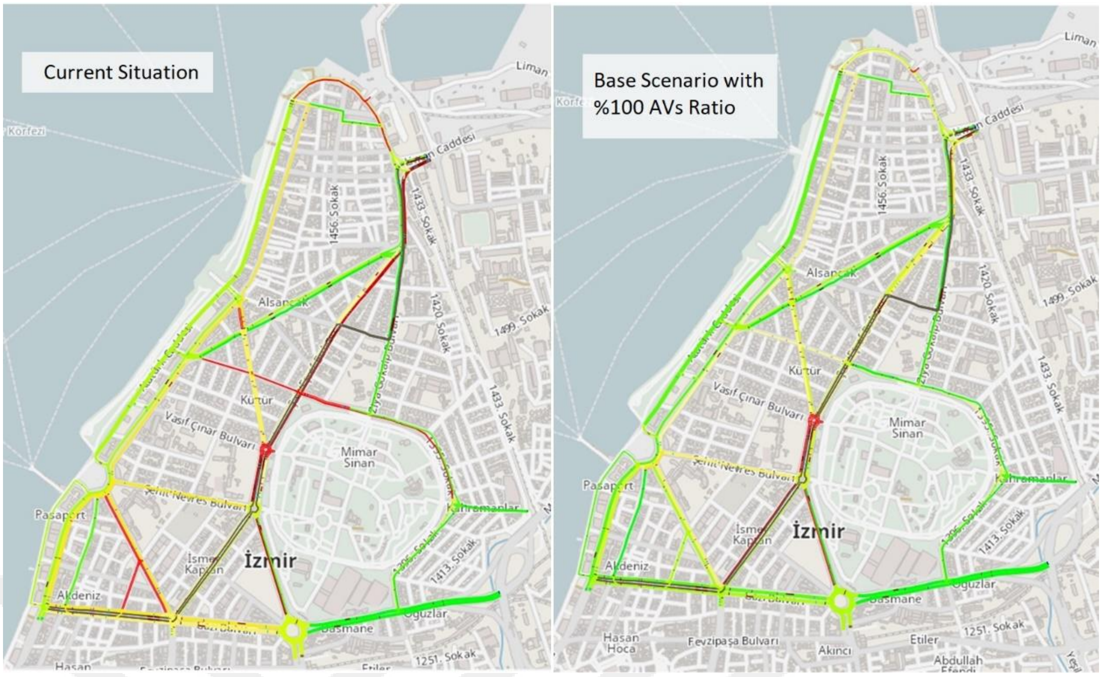


Figure 4.14 Scenario 1: Base scenario total distance of the network

These results show that the inclusion of AVs in the system increases average speeds, reduces delays, reduces the time spent in traffic, and leads to a decrease in both the number of stops and the duration of stops. This situation will contribute to the reduction of traffic congestion, as well as reduce environmental pollution and increase the quality of urban life.

The scenario results obtained from the data collection points assigned for each link are given in Appendix 2-4. Based on these findings, the current traffic congestion in the system and the traffic congestion in the case of all vehicles in the system are autonomous are mapped with queue delay values. In both cases congestion maps are given in Figure 4.15. In each map, the links with the least queue delay are colored in dark green, those with the most in dark red.



a) Current situation b) Base scenario

Figure 4.15 Scenario 1 traffic congestion maps

According to the findings, the inclusion of AVs in the system has a reducing effect on traffic congestion on all roads in the system. However, remarkable improvements are observed especially in the congestion of the collector roads merging to the main road. In line with many studies in the literature, it is seen that the introduction of AVs into the system can partially provide a solution to the existing transportation-related problems.

4.3.2 Scenario 2: Autonomous Public Transport

PT, which is an important part of urban mobility, is also associated with traffic congestion in the city. Automation in the automotive sector continues with the automation of PT vehicles. APT can offer lower error and accident rates, lower waiting times, shorter headways, and more punctual service (Pakusch & Bossauer, 2017).

In this scenario, besides the replacement of traffic demand with AVs with 10% changes, PT vehicles are also defined as autonomous according to percentage changes.

Table 4.6 Scenario 2: Autonomous public transport network performance results

Autonomous Vehicles%	**Average Delay (sec)**	**Average Stop**	**Average Speed (km/h)**	**Delay Stop (sec)**	**Total Distance (km)**	**Total Travel Time (sec)**	**Vehicle (Active)**	**Vehicle (Arrived)**
0%	49.94	1.61	34.05	31.08	20944.23	2230021	2632	12854
10%	44.94	1.44	35.33	28.14	21019.4	2151661	2523	12894
20%	44.02	1.44	35.57	26.89	21039.99	2138404	2525	12895
30%	43.47	1.46	35.74	25.88	21027.96	2127568	2510	12896
40%	41.05	1.41	36.40	23.53	21051.67	2089020	2469	12912
50%	37.97	1.29	37.27	21.25	21086.34	2040756	2407	12926
60%	37.68	1.33	37.36	20.79	21110.21	2037793	2410	12938
70%	35.62	1.28	37.98	18.55	21139.59	2005352	2349	12954
80%	33.85	1.25	38.53	16.78	21150.69	1977854	2317	12961
90%	32.88	1.28	38.84	16.19	21161.16	1962644	2293	12967
100%	31.84	1.29	39.21	15.31	21216.33	1949096	2283	12977

The results obtained from the scenario were compared with the base scenario. Although APTs do not make a remarkable difference in average speeds and average delays in the network up to 70% market penetration rate, it is seen that average speeds increase and average delays decrease when more APTs enter the system than 70% market penetration rate (Figure 4.16, 4.17).

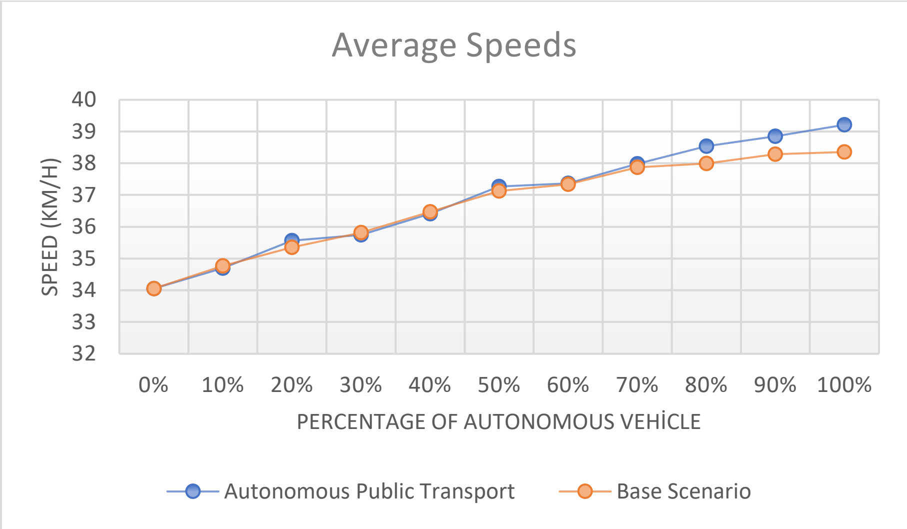


Figure 4.16 Scenario 2 Autonomous public transport average speed of the network

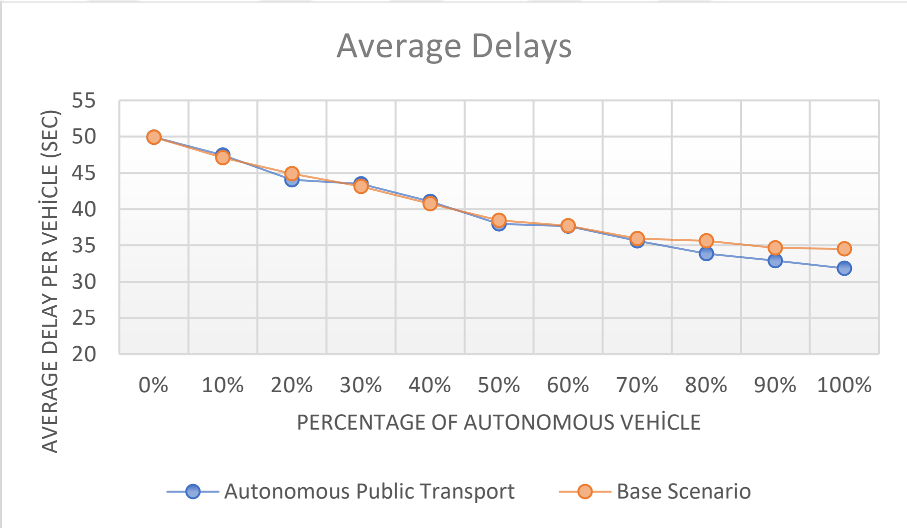


Figure 4.17 Scenario 2 Autonomous public transport average delay of the network

Similarly, it is seen that APT reduces average stances in usages above 70% market penetration (Figure 4.16). Correspondingly, the average stop delays continue to decrease (Figure 4.19).

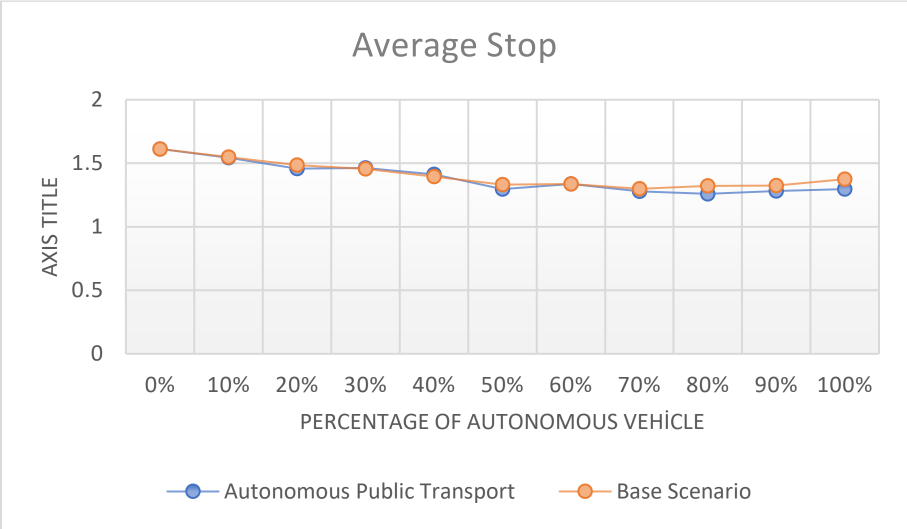


Figure 4.18 Scenario 2 Autonomous public transport average stop of the network

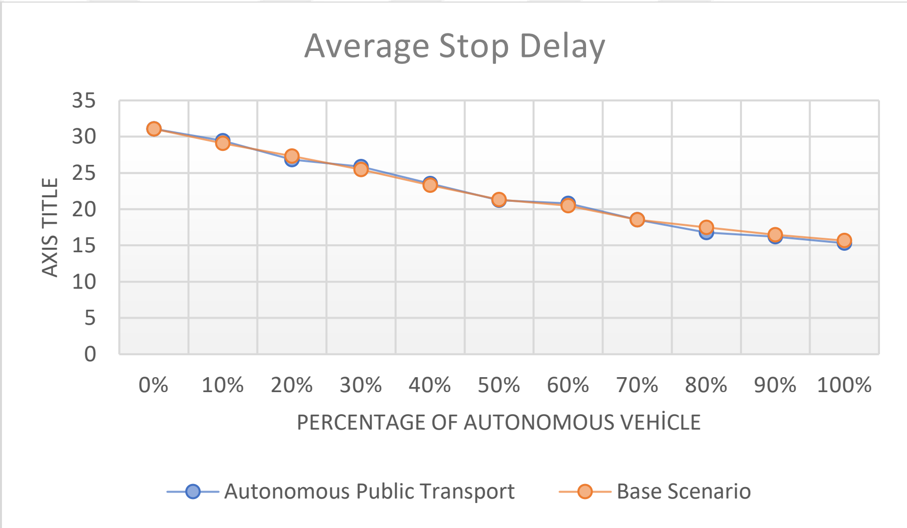


Figure 4.19 Scenario 3 Autonomous public transport average stop delay of the network

It is seen that APT reduces the total distance traveled in the network after 50% market penetration rate. Also, total travel time decreases after 70% market penetration, similar to the other scenario outputs.

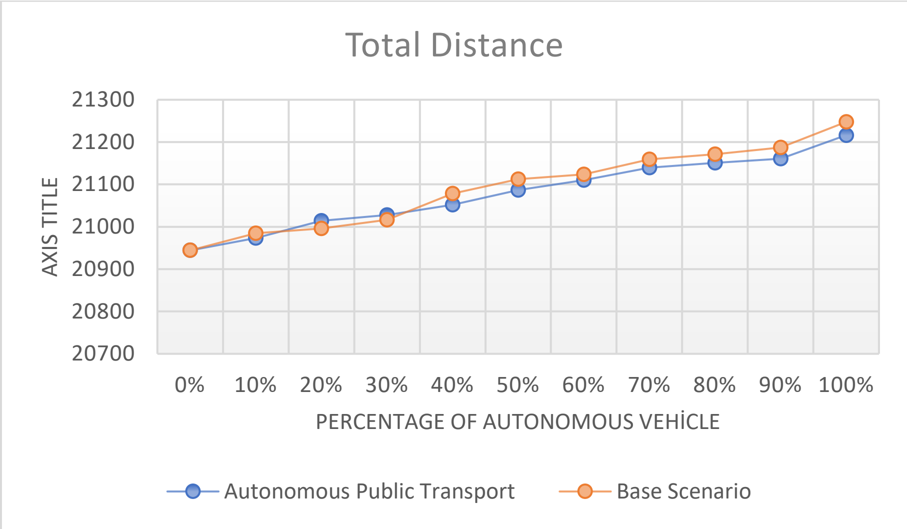


Figure 4.20 Scenario 2 Autonomous public transport total distance of the network

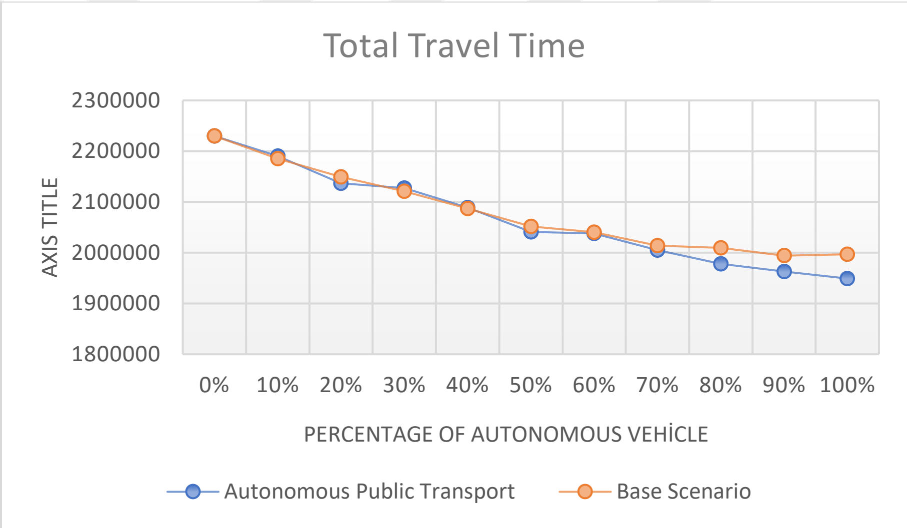


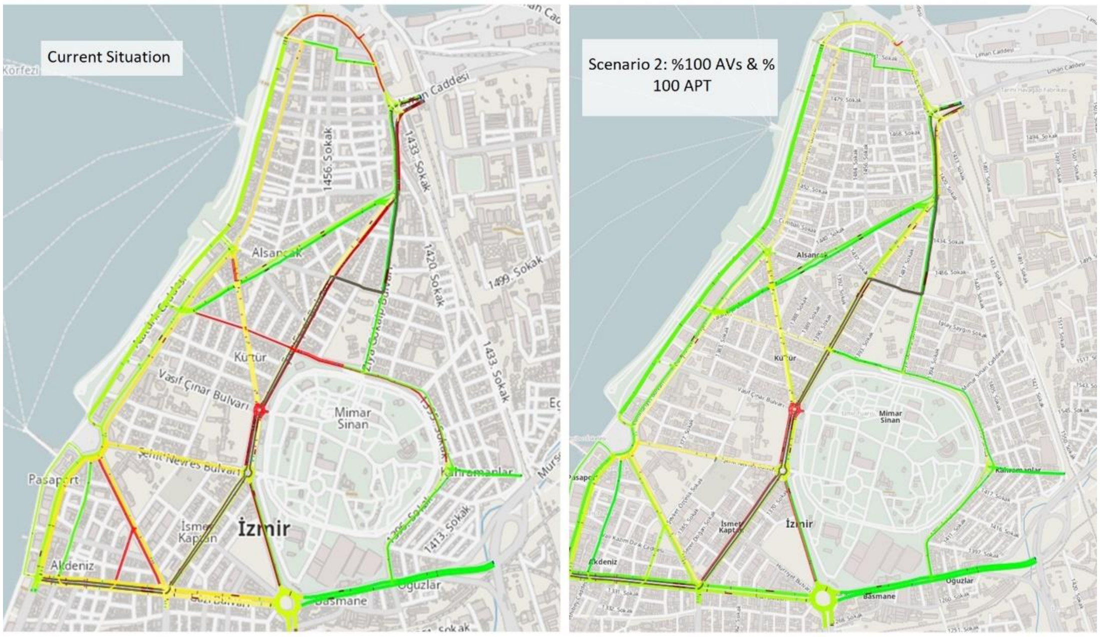
Figure 4.21 Scenario 2 Autonomous public transport total travel time of the network

Considering the scenario results, APTs have a market penetration rate of at least 80% to have an improving effect on the transportation system. In other words, making less than 80% of the vehicle fleet autonomous does not affect it and does not constitute an effective PT investment decision.

When the data collecting point result from the scenario outputs is examined, APT affected 44 of 55 links less than 1% compared to the basic scenario (Appendix 6). At the same time, 10 of the other 11 links on the PT route increased the average speeds.

Compared to the current situation, it is seen that the use of both AVs and APTs can increase average speeds, especially on links on PT routes.

Although both APTs and AVs use led to increased speeds and reduced queue delay, the number of vehicles passing through the links showed a maximum change of 2% compared to the base scenario (only on PT routes) (Appendix 6). The traffic congestion maps are given in Figure 4.22.



a) Current situation b) Scenario 2

Figure 4.22 Scenario 2: Traffic congestion maps

When the queuing delays of links are examined, it is seen that the APTs reduce the queuing delays in almost every link compared to the basic scenario (Appendix 7). Compared to the current situation, the use of APTs and AVs together reduces the queuing delay on all links.

4.3.3 Scenario 3: Autonomous Vehicles as an Alternative to Public Transport

There are many studies in the literature that AVs will change the habits of using PT. For example, Stanford (2015) and Moavenzadeh & Lang (2018) argue that the advantages of AVs can reduce PT use, therefore AVs can be seen as an alternative to PT, which will cause traffic congestion and increase travel time.

In this scenario, the impact of PT users on transportation if they choose AVs is examined. This scenario has been prepared for two sub-scenarios. The reason for this is that the capacity and service frequency of PT systems depend on local decision-making authorities. If PT users choose AVs, the PT capacity may be reduced or the frequency of services may be decreased due to the idle PT capacity, or, on the contrary, the existing system may continue to operate to protect the public welfare. How the transportation system will be affected in these two cases was evaluated through two sub-scenarios: Sub-scenario 1: Change of PT services according to demand and Sub-scenario 2: Continuation of existing PT services, and the results were compared. In each sub-scenario, PT users gradually turned to AV use with 10% changes. In Table 4.17, the transportation type choice of the passengers and PT capacities according to the sub-scenarios are given.

Table 4.7 Scenario 3 Public transport capacity and preferences of passengers

Sub-scenario	Public Transportation Type	Percentage of Passenger Who Changed Travel Type	PT Capacity (passenger/hour)	Number of Passengers who prefer autonomous vehicles (passenger/hour)
Change of PT Services According to Demand	Tram	%0	6480	0
		%10	5832	648
		%20	5184	1296
		%30	4536	1944
		%40	3888	2592
		%50	3240	3240
		%60	2592	3888
		%70	1944	4536
		%80	1296	5184
		%90	648	5832
		%100	No Tram	6480
	Bus	%0	6600	0
		%10	5940	660
		%20	5280	1320
		%30	4620	1980
		%40	3960	2640
		%50	3300	3300
		%60	2640	3960
		%70	1980	4620

Table 4.7 Continued

Sub-scenario	Public Transportation Type	Percentage of Passenger Who Changed Travel Type	PT Capacity (passenger/hour)	Number of Passengers who prefer autonomous vehicles (passenger/hour)
		%80	1320	5280
		%90	660	5940
		%100	No Bus	6600
Continuation of Existing PT Services		%0	6480	0
		%10	6480	648
		%20	6480	1296
		%30	6480	1944
		%40	6480	2592
		%50	6480	3240
		%60	6480	3888
		%70	6480	4536
		%80	6480	5184
		%90	6480	5832
		%100	6480	6480
		%0	6600	0
		%10	6600	660
		%20	6600	1320
		%30	6600	1980
		%40	6600	2640
		%50	6600	3300
		%60	6600	3960
		%70	6600	4620
		%80	6600	5280
		%90	6600	5940
		%100	6600	6600

Table 4.8 Scenario 3: Change of PT services according to demand sub-scenario network performance results

Autonomous Vehicles%	**Average Delay (sec)**	**Average Stop**	**Average Speed (km/h)**	**Delay Stop (sec)**	**Total Distance (km)**	**Total Travel Time (sec)**	**Vehicle (Active)**	**Vehicle (Arrived)**
0%	49.94275	1.61275	34.0545	31.08525	20944.23	2230021	2633	12855
10%	81.0605	3.08475	26.9355	48.0785	21198.74	3142148	3745	13624
20%	170.0563	12.57725	16.76475	87.56425	21745.06	5052853	6160	13064
30%	230.2765	21.6305	11.77125	106.963	18443.45	5915758	7071	11775
40%	250.871	27.984	10.53525	110.8343	17505.7	6220213	7458	11282
50%	275.574	30.80425	9.4965	127.6098	16758.27	6701813	8120	10812
60%	293.3913	36.697	8.844	118.4265	16787.24	7274017	8887	10759
70%	307.7695	39.7925	8.4195	119.8578	16641.57	7645945	9323	10622
80%	327.8798	43.993	7.82225	123.551	16202.32	8065989	9804	10311
90%	340.0515	45.70275	7.46975	129.0555	16026.09	8341918	10075	10164
100%	270.966	34.606	10.2915	76.6855	21530.66	7736649	9165	12714

Table 4.9 Scenario 3: Continuation of existing PT services sub-scenario network performance results

Autonomous Vehicles%	Average Delay (sec)	Average Stop	Average Speed (km/h)	Delay Stop (sec)	Total Distance (km)	Total Travel Time (sec)	Vehicle (Active)	Vehicle (Arrived)
0%	49.94	1.61	34.05	31.09	20944.23	2230021.30	2632.60	12854.80
10%	82.53	3.17	26.66	49.18	21035.99	3168624.09	3784.10	13608.20
20%	177.53	13.53	16.20	89.06	21390.47	5163759.36	6286.00	12884.20
30%	233.36	21.80	11.62	109.39	18236.15	5946797.51	7119.10	11670.50
40%	249.53	26.87	10.58	112.57	17528.70	6199583.82	7419.40	11324.00
50%	277.10	29.95	9.42	130.39	16656.10	6730520.30	8160.30	10792.50
60%	297.12	34.39	8.71	128.28	16597.63	7328366.40	8933.70	10690.00
70%	317.38	38.14	8.08	133.73	16304.51	7822879.55	9486.80	10488.00
80%	334.42	42.15	7.63	137.47	15887.88	8156948.20	9836.80	10203.70
90%	340.41	43.75	7.39	139.40	15889.28	8345305.91	10046.50	10228.70
100%	301.76	31.09	9.16	120.85	19529.51	8232595.49	9897.90	11769.60

When the two sub-scenarios are compared with the basic scenario, whether PT capacity changes or not, PT users' giving up on PT and using AV affects the transportation system negatively (Figure 4.22, Figure 4.23). It is seen that average speeds decrease up to 81%, while average delays increase up to 10 times.

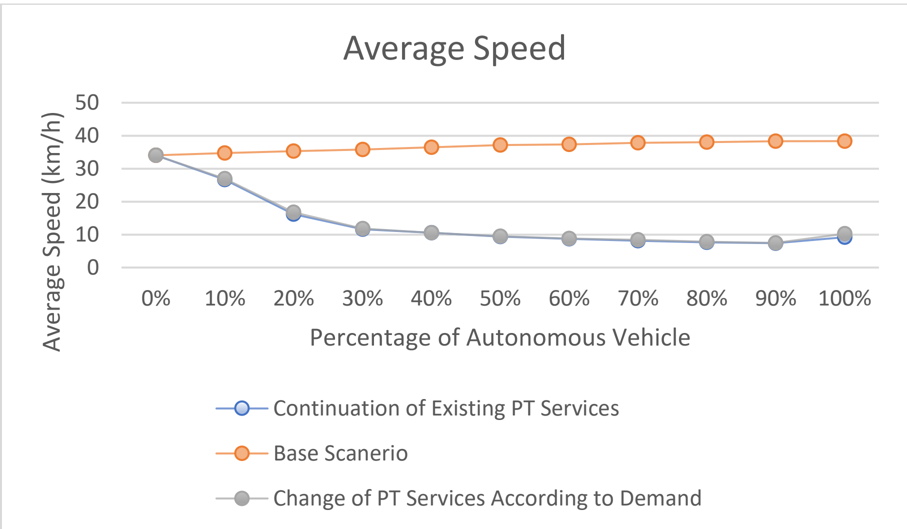


Figure 4.23 Scenario 3: Autonomous vehicles as an alternative to public transport average speed

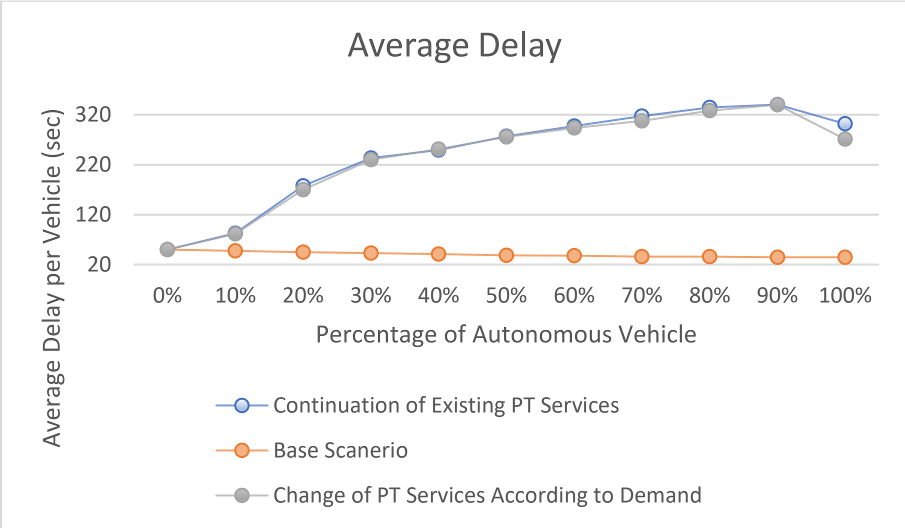


Figure 4.24 Scenario 3: Autonomous vehicles as an alternative to public transport average delay

The increase in the percentage of people who give up using PT and use AV increases both the number of stops and the delays in the network (Figure 4.24, Figure 4.25).

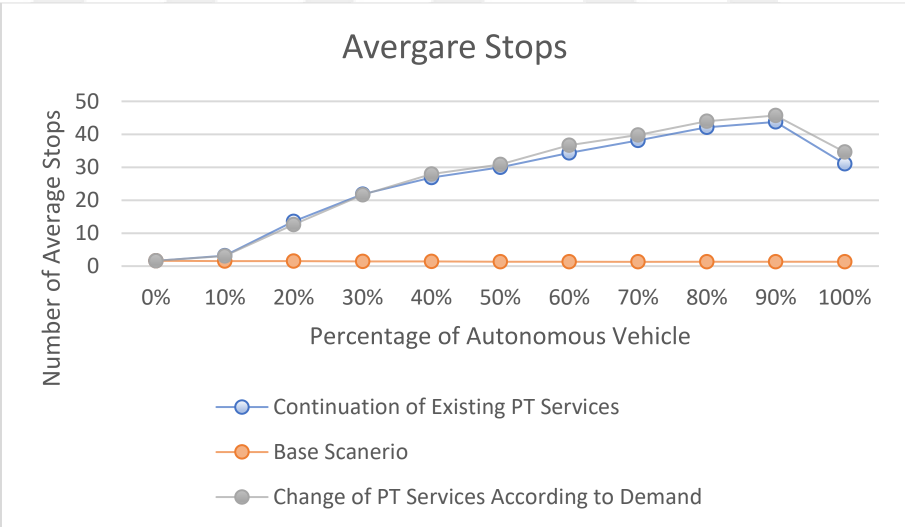


Figure 4.25 Scenario 3: Autonomous vehicles as an alternative to public transport average stop

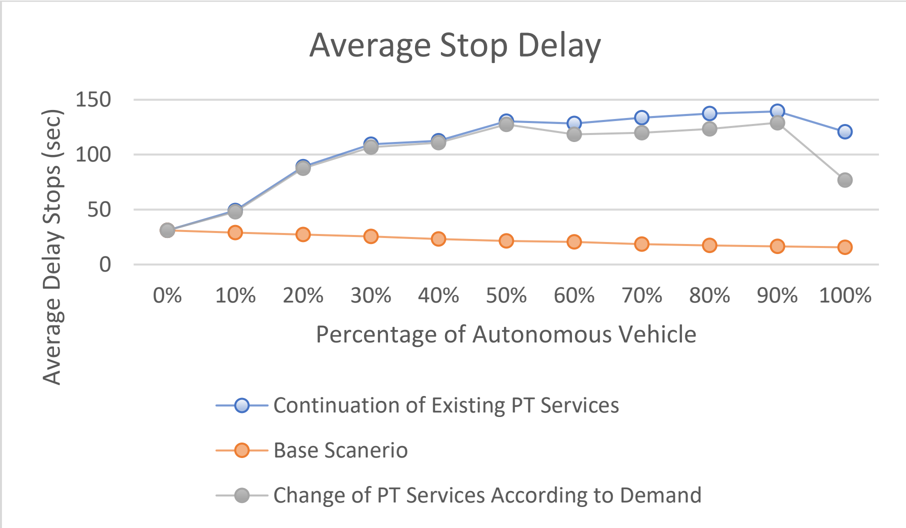


Figure 4.26 Scenario 3: Autonomous vehicles as an alternative to public transport average stop delay

Contrary to expectations, the distance covered decreases as the number of people who give up the use of PT and prefer to use AV increases. The reason for this is that new vehicles cannot enter the system due to the congestion in the network after 20% and the existing ones cannot reach the desired speed due to the congestion. It is seen that the total travel time has increased. This is due to the late departure of the vehicles from the network due to delays and slowdowns.

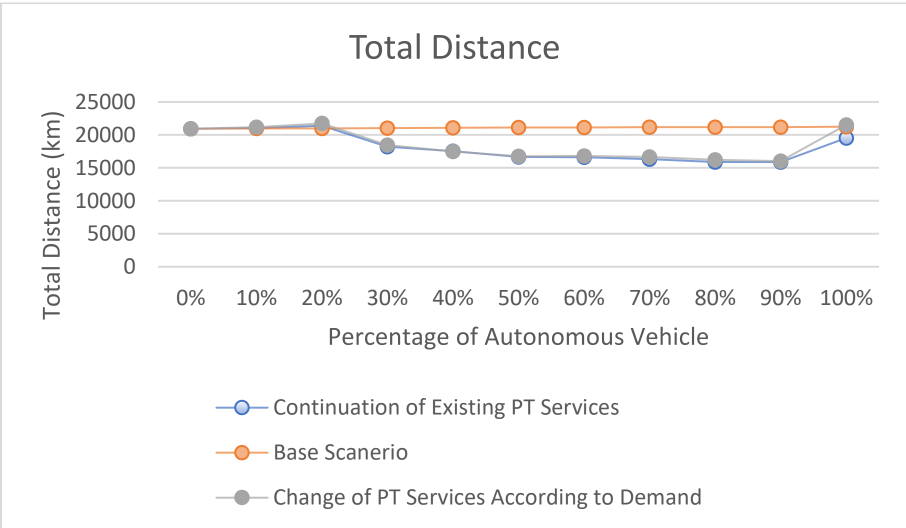


Figure 4.27 Scenario 3: Autonomous vehicles as an alternative to public transport total distance

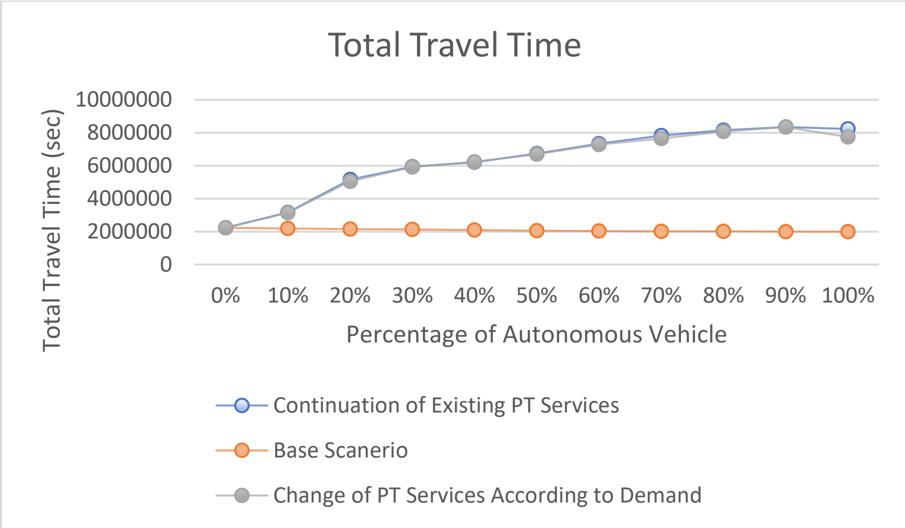
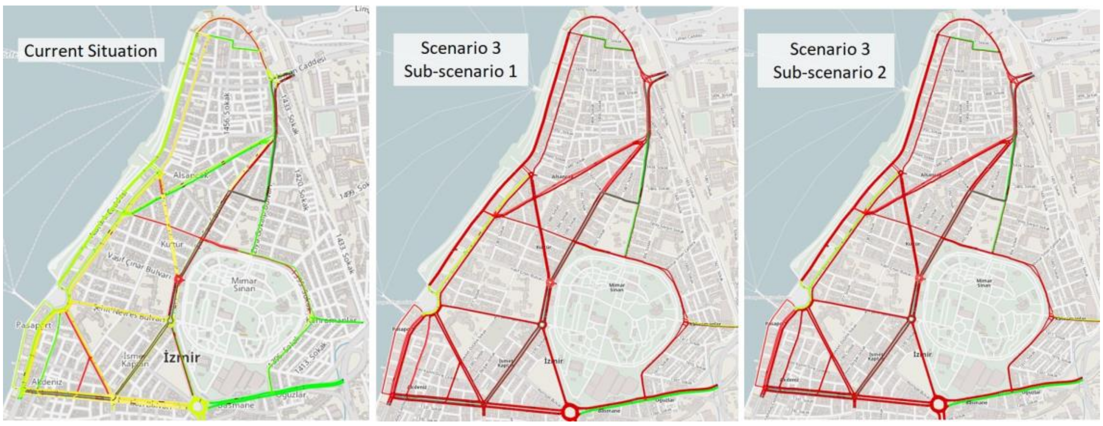


Figure 4.28 Scenario 3: Autonomous vehicles as an alternative to public transport total travel time

According to the findings obtained from data collecting points, in sub-scenario 1, users' giving up on PT and turning to AVs leads to a decrease in speeds, especially on PT routes (Appendix 9). In addition, it is seen that the speeds on the collector roads connected to the main roads where PT routes are located also decrease. Moreover, it is seen that the queuing delays increase in all links at a high rate (Appendix 10). In addition, it is observed that the number of vehicles passing through the links decreased in almost all links due to the congestion, decrease in speeds and queuing delays (Appendix 8).



a) Current situation b) Scenario 3- Sub-scenario 1 c) Scenario 3-Sub-scenario 2

Figure 4.29 Scenario 3: Traffic congestion maps

When the second sub-scenario is examined, it is seen that the number of vehicles passing through the link decreases, the speeds decrease and the queue delay increases, especially on the main roads with PT routes and on the collector roads connected by this way, compared to the first sub-scenario, if the existing PT service continues (Appendix 11-13) (Figure 4.29). However, this change appears as a relatively small difference compared to the current situation. For example, when all users use AV and the PT does not provide service, the queue delay increases by 656% from the current situation, and by 689% when the PT service continues to serve at the current capacity. Therefore, the main reason for this negative situation in the transportation system is the increase in the number of vehicles in the system, and because the existing PT system is not used, leaving it out of service will not provide sufficient improvement.

4.3.4. Scenario 4: Special Lanes for Autonomous Vehicles

In studies examining the possible effects of AVs on infrastructure, it is claimed that AVs may require special lanes, which may lead to new infrastructure investments (Litman, 2017). In this scenario, based on the question of whether separating special lanes for AVs can provide more efficient use of highways when AVs enter traffic, lanes on multiple lane links are reserved for AVs without changing the existing road infrastructure. In this scenario, up to 50% AV penetration rate, 1 lane of 2 and 3 lane roads is reserved for AVs. 2 lanes of 3-lane roads with a penetration rate of 50% and above are reserved for AVs. At the rate of 100% AVs, all lanes are naturally used by AVs. The scenario results are given in Table 4.20.

Table 4.10 Scenario 4: Special lanes for autonomous vehicles network performance results

Autonomous Vehicles%	**Average Delay (sec)**	**Average Stop**	**Average Speed (km/h)**	**Delay Stop (sec)**	**Total Distance (km)**	**Total Travel Time (sec)**	**Vehicle (Active)**	**Vehicle (Arrived)**
0%	49.94	1.61	34.05	31.09	20944.23	2230021.30	2633	12855
10%	193.57	5.35	11.90	151.43	9053.07	2840985.42	3380	7996
20%	202.10	5.88	11.17	152.11	8182.20	2712654.63	3196	7424
30%	217.09	6.42	10.29	157.37	7842.48	2832289.92	3352	7161
40%	229.57	7.55	9.61	156.89	7553.56	2938630.95	3479	7002

Table 4.10 Continued

Autonomous Vehicles%	Average Delay (sec)	Average Stop	Average Speed (km/h)	Delay Stop (sec)	Total Distance (km)	Total Travel Time (sec)	Vehicle (Active)	Vehicle (Arrived)
50%	252.15	6.40	8.59	190.29	7090.84	3049272.03	3736	6280
60%	253.45	6.62	8.64	174.60	7840.69	3432523.38	4142	7183
70%	260.39	9.51	8.46	163.73	7998.98	3608983.21	4323	7391
80%	292.55	11.34	7.48	173.13	7862.82	4142334.74	4948	7425
90%	297.41	13.81	7.43	163.86	7862.53	4241352.89	5058	7468
100%	34.52	1.37	38.36	15.66	21247.67	1996628.97	2325	12965

When the scenario results are examined, reserving lanes for AVs in the existing road network reduces average speeds and increases delays (Figure 4.28, Figure 4.29). The reason for this situation is the congestion due to the increase in the lane change maneuver.

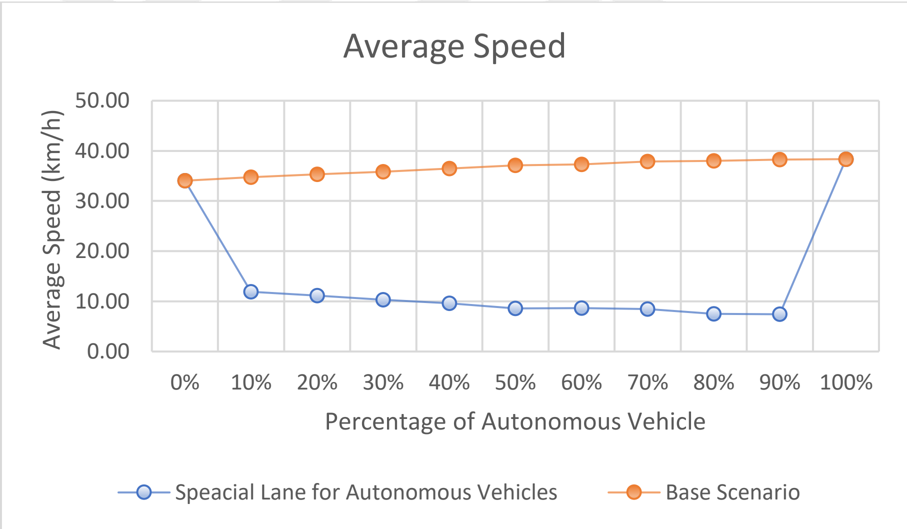


Figure 4.30 Scenario 4: Special lanes for autonomous vehicles average speed

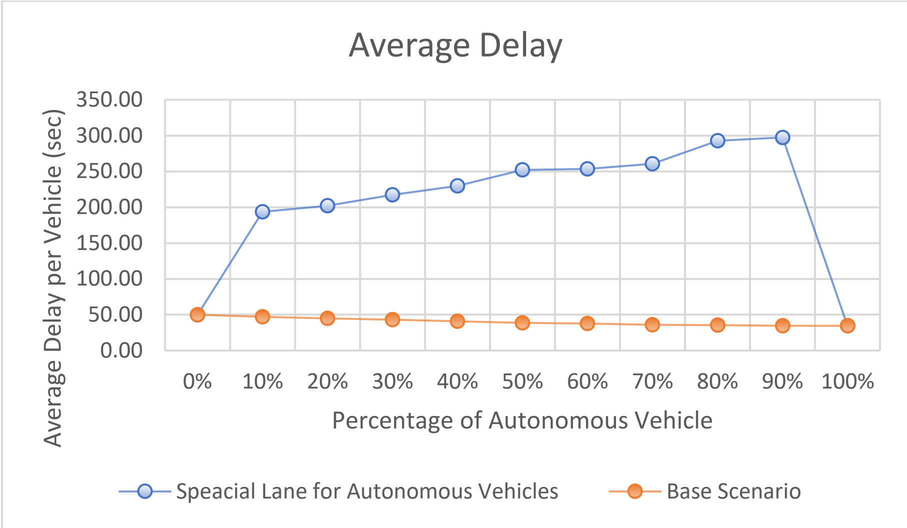


Figure 4.31 Scenario 4: Special lanes for autonomous vehicles average delay

According to the scenario results, even if special lanes are reserved for AVs, average stops and stop delays increase as the market penetration of AVs increases. It is seen that the new lanes reserved for AVs at 50% market penetration reduce the average number of stops, but the number of stops continues to increase as the number of AVs increases (Figure 4.30). However, it is observed that the average stop delays increase with the new lanes (Figure 4.31). The reason for the increase in the average stop and stop delay values is that autonomous and conventional vehicles make a lane change maneuver for the lanes reserved to them, which causes congestion.

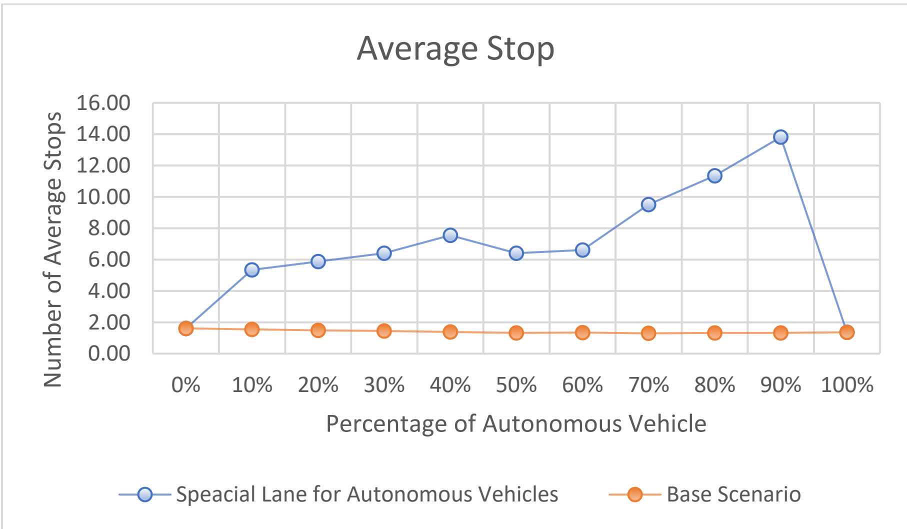


Figure 4.32 Scenario 4: Special lanes for autonomous vehicles average stop

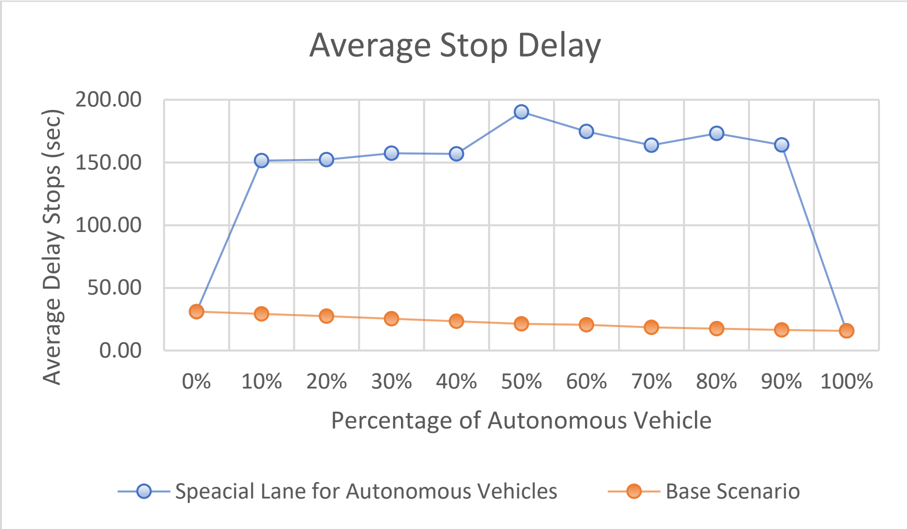


Figure 4.33 Scenario 4: Special lanes for autonomous vehicles average stop delay

The traffic congestion caused by the lane change maneuver of the vehicles on the flows has led to a decrease in the number of vehicles that have completed their travel and left the system. This also resulted in fewer vehicles entering the system than demand (Table 4.20). Thus, although the distance traveled by the vehicles decreases, the total travel time increases (Figure 32, Figure 33).

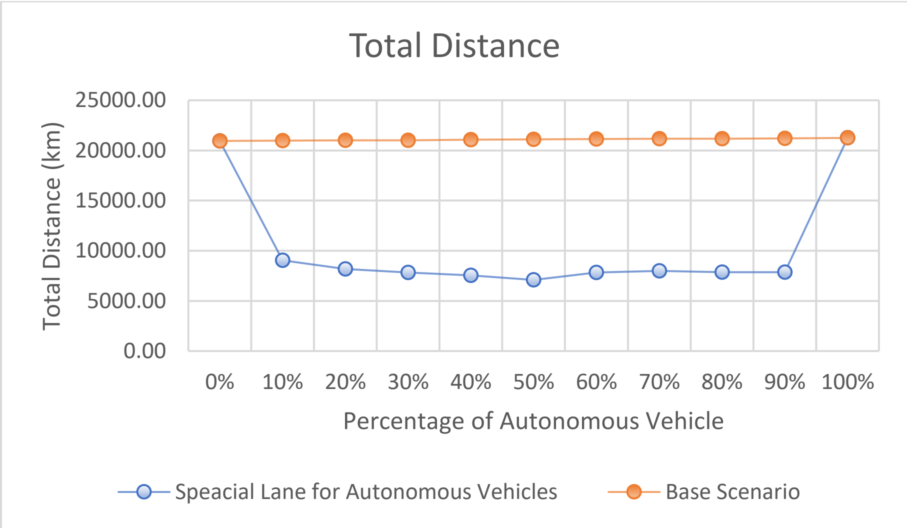


Figure 4.34 Scenario 4: Special lanes for autonomous vehicles total distance

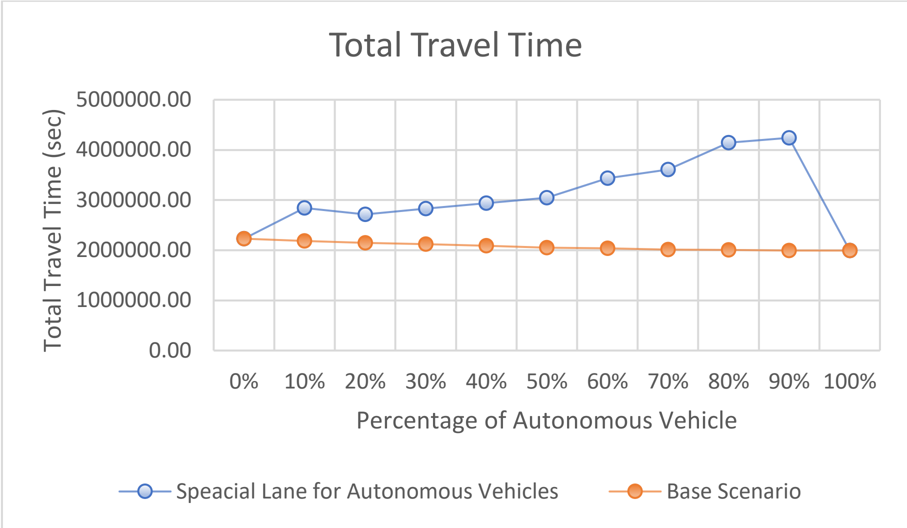
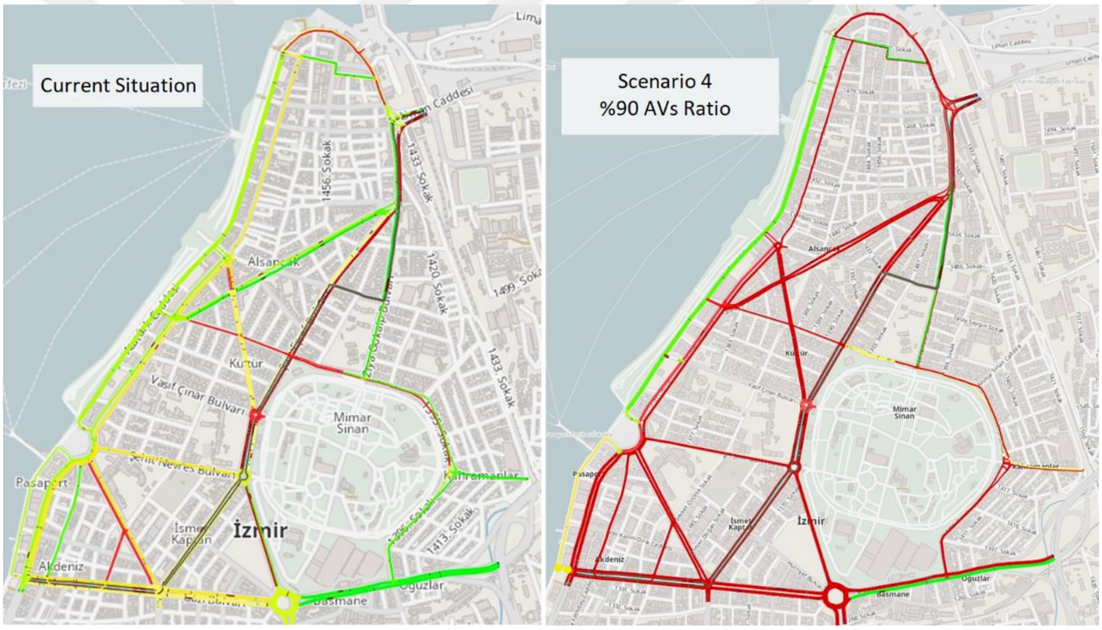


Figure 4.35 Scenario 4: Special lanes for autonomous vehicles total travel time



a) Current situation b) Scenario 4

Figure 4.36 Scenario 4: Traffic congestion maps

When the scenario results are analyzed based on links, the traffic congestion experienced due to lane changes when special lanes are reserved for AVs reduces speeds on almost every link, increases queue delays and reduces the number of vehicles that can pass through the lane (Appendix 14-16) (Figure 4.36). The reason for making comparison with 90% AVs rate in the figure is that delays are reduced since all lanes are already reserved for AVs at 100% AV rate.

4.3.5 Scenario 5: Having Redesignable Urban Areas with Autonomous Vehicles

In the literature, it has been suggested that AVs can travel in narrow lanes, so that AVs can create an advantage in old settlements and areas where it is difficult to move (Beraldi, 2007). In other studies, it has been claimed that AVs will not need parking spaces in the city center and that they can find cheaper parking spaces outside the city center (Yigitcanlar et al., 2019, Zhang et al., 2015).

Based on these assumptions, how much urban area can be gained when AVs are included in the system is examined in this scenario. In the scenario, road widths were limited to 2m and parking areas with a total size of 6100m2 were removed from use.

Table 4.11 Scenario 5: Having redesignable urban areas with autonomous vehicles network performance results

Autonomous Vehicles%	**Average Delay (sec)**	**Average Stop (# of stops)**	**Average Speed (km/h)**	**Delay Stop**	**Total Distance**	**Total Travel Time**	**Vehicle (Active)**	**Vehicle (Arrived)**
0%	168.62	2.63	18.15	139.56	14327.28	3276598.28	4142	9608
10%	162.49	2.41	18.32	134.41	14770.51	3354674.50	4248	10050
20%	144.31	2.81	19.96	110.68	15789.61	3195688.41	4005	10489
30%	143.82	2.72	20.10	108.08	15871.62	3202066.39	4013	10544
40%	115.78	2.75	22.94	77.71	17406.41	2954805.89	3667	11304
50%	109.85	2.55	23.74	71.85	17764.78	2911265.95	3643	11505
60%	96.09	2.60	25.46	57.38	18560.31	2764819.20	3402	11824
70%	87.21	2.35	26.91	49.26	18923.18	2656846.99	3293	11959
80%	73.62	2.36	29.05	35.69	19775.44	2510323.40	3016	12313
90%	55.92	2.02	32.56	23.99	20291.26	2258404.56	2676	12533
100%	34.89	1.37	38.24	15.84	21253.87	2003005.74	2329	12967

In this scenario, unlike the other scenarios, what would happen if the road lanes were narrowed and the roadside parking lots were removed while continuing to use conventional vehicles was examined first. As can be seen from the Figure 4.37-Figure 4.42, even if the roadside parking areas are removed, the delays increase by 2.42 times as a result of narrowing the lanes, and the average speeds decrease by

48%. With the addition of AVs to the system, it is seen that the average speeds gradually increase and the delays decrease.

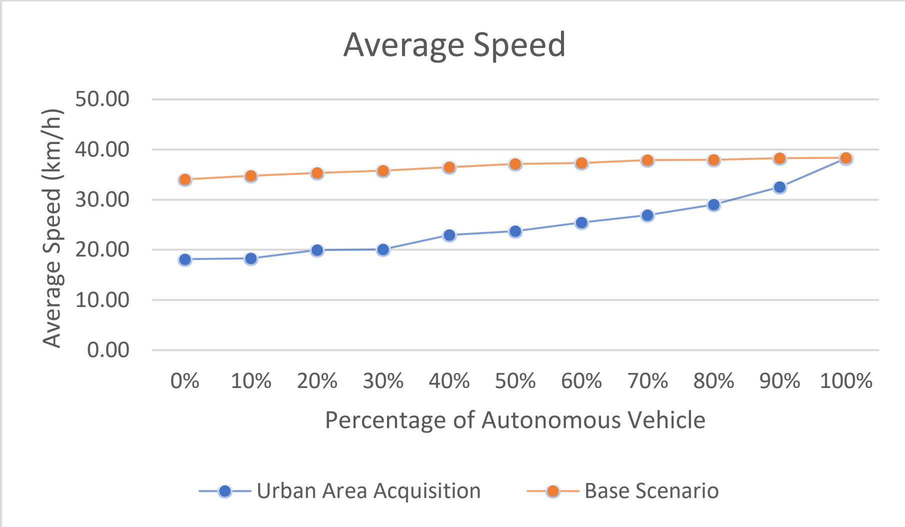


Figure 4.37 Scenario 5: Having redesignable urban areas with autonomous vehicles average speed

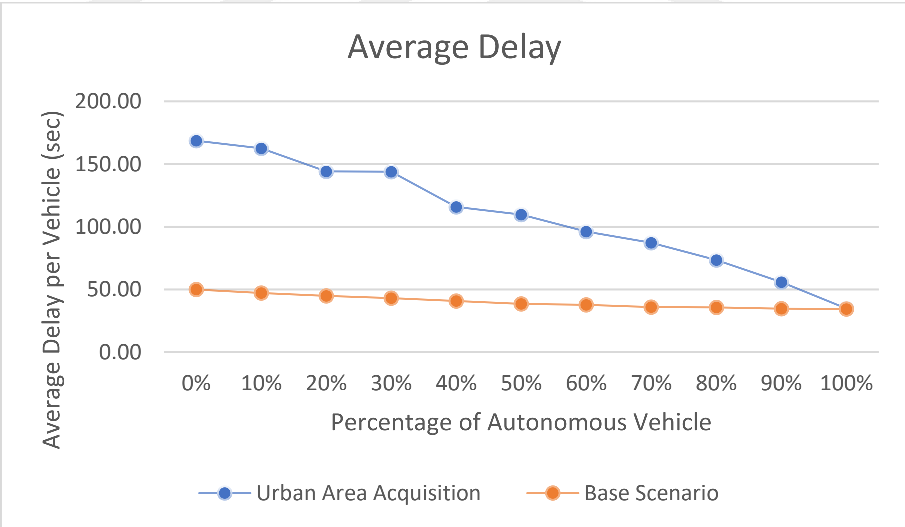


Figure 4.38 Scenario 5: Having redesignable urban areas with autonomous vehicles average delay

Similarly, lane narrowing increases the average stopping and stopping delays, but with the introduction of AVs into the system, the stops and stop delays are gradually reduced (Figure 4.39, Figure 4.40).

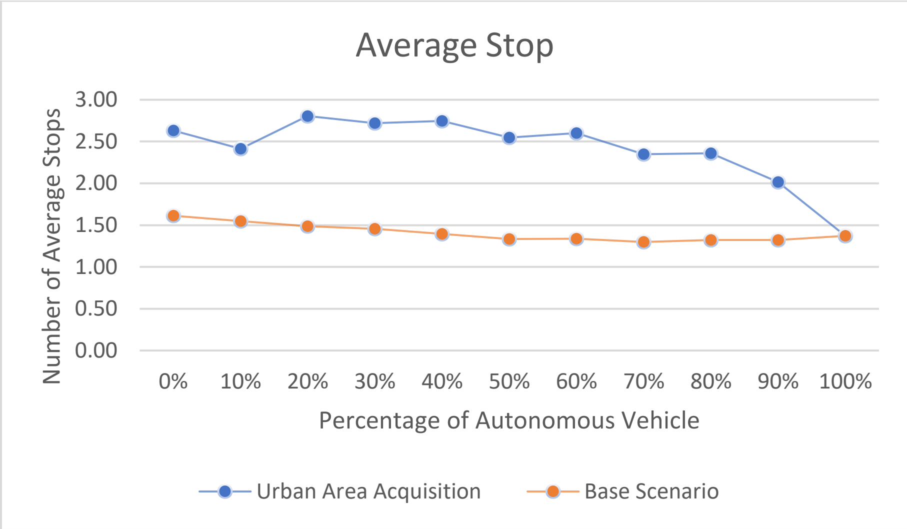


Figure 4.39 Scenario 5: Having redesignable urban areas with autonomous vehicles average stop

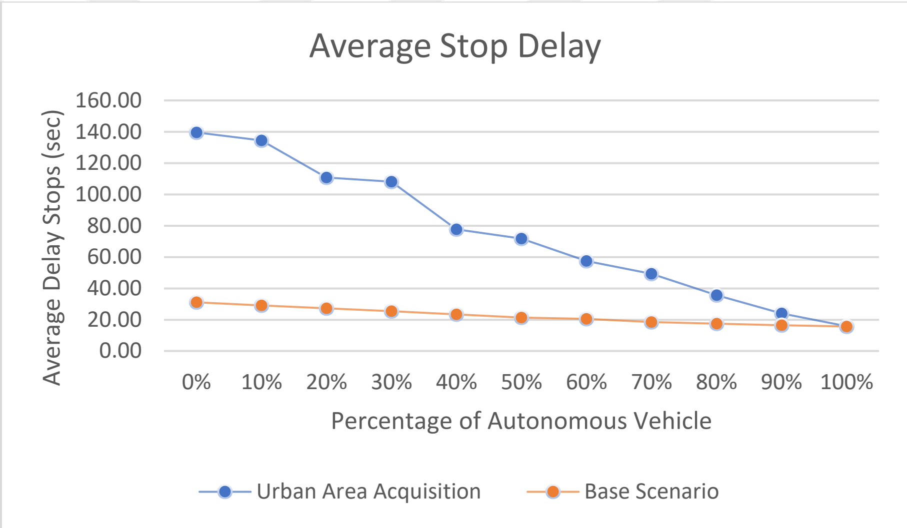


Figure 4.40 Scenario 5: Having redesignable urban areas with autonomous vehicles average stop delay

The scenario results show that narrowing the lanes currently increases the total travel time and reduces the total distance traveled due to congestion. However, this negative effect disappears with the increase in the percentage of AVs.

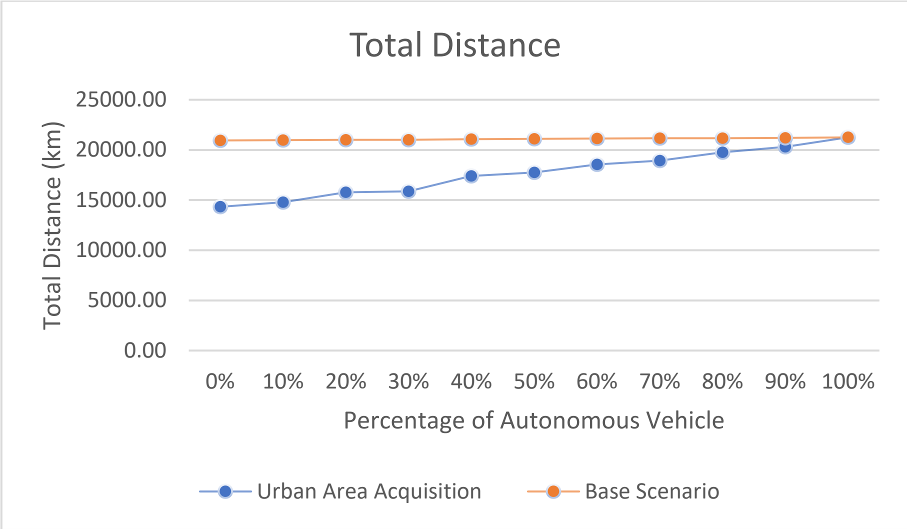


Figure 4.41 Scenario 5: Having redesignable urban areas with autonomous vehicles total distance

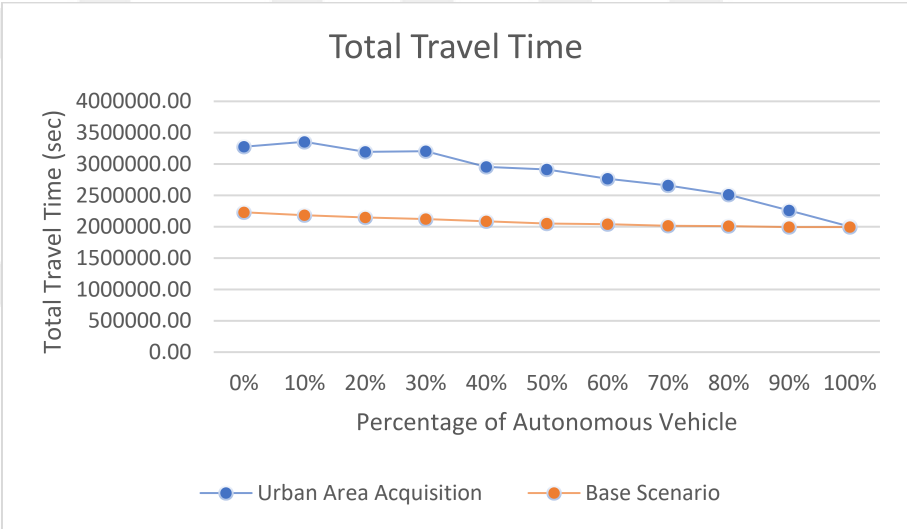
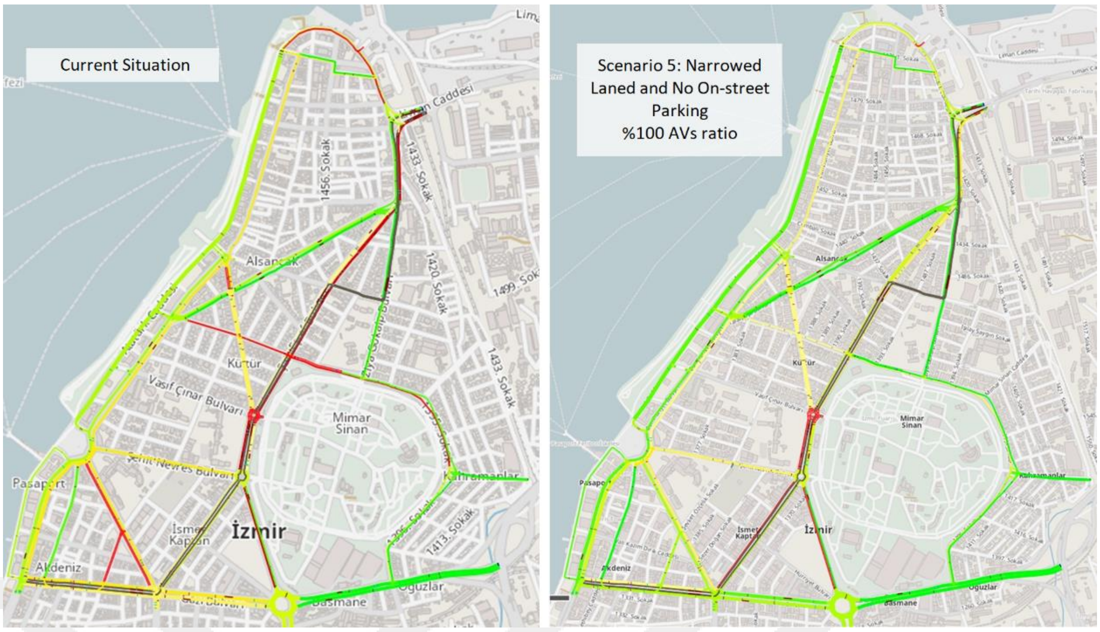


Figure 4.42 Scenario 5: Having redesignable urban areas with autonomous vehicles total travel time

According to the scenario result, narrowing the lanes increases traffic congestion, even if the roadside parking lots are removed in the current situation. However, with the introduction of AVs into the system, this negative effect gradually disappears. In case AVs have 100% market penetration, road use can continue as in the current situation even if all lanes and roadside parking are removed.



a) Current situation b) Scenario 5

Figure 4.43 Scenario 5: Traffic congestion maps

Figure 4.44 presents the current traffic congestion and the traffic congestion in narrowed lanes under conditions with 100% AVs. As can be seen in Figure 4.43, AVs can improve traffic even in narrowed lanes. The AVs reduce congestion, similar to previous scenarios, especially on the collector roads that merge into the main road (Appendix 17-19).

CHAPTER FIVE
EVALUATION AND DISCUSSION

The previous chapter analyzed various scenarios regarding the impact of AVs on urban transportation. This chapter focuses on how these impacts will affect the city.

According to the base scenario, the introduction of AVs leads to an improvement in traffic flow as their market penetration increases. This finding is consistent with previous studies. The addition of AVs to the transportation network results in a more stable traffic flow, reduced travel time, and a safer, more comfortable, and eco-friendly mode of transportation. Furthermore, the examination of CBD revealed improvements in all areas, indicating that AVs use existing infrastructure more efficiently, particularly on collector roads merging with main roads. This improved efficiency can enhance urban mobility and accessibility, especially in areas where quick access is crucial, such as health facilities. However, an increase in demand due to the inclusion of AVs can also negatively impact these positive effects in the long run by causing more congestion in CBD and promoting suburbanization.

In the second scenario, when APTs are included in the system together with AVs, it is seen that they must have a rate of at least 70% to see improvement in the transportation system. This situation may benefit the use of highly APT, especially in urban main arteries where congestion is observed.

In the third scenario, scenarios that may occur if the passengers find AVs more attractive (for reasons such as comfort, transportation time, cost, etc.) and give up on PT are examined. Accordingly, if users choose AVs, it is seen that there is almost no difference in removing or continuing the PT, and almost all the traffic congestions are caused by the extra vehicles that enter the system. In this case, local administrators should follow strategies that encourage the use of PT instead of reducing PT capacity and frequency due to falling PT demand. Increasing traffic congestion in city centers may cause land uses to choose places outside the city center, which may cause both rent increases in the city periphery and the dysfunction of the city centers. In addition, it should be considered that increasing traffic congestion in city centers may increase fuel consumption, create noise pollution and create unsafe areas for pedestrians.

In the fourth scenario, a portion of the lanes on existing multi-lane highways is designated exclusively for AV use. However, upon evaluating the scenario outcomes, it is observed that this approach has a detrimental impact on the transportation system due to increased lane changes. Instead, allocating dedicated urban areas specifically for fully AVs, rather than repurposing existing lanes for different vehicle classes, can enhance the overall transport system. This approach may offer a viable solution for urban areas characterized by chronic congestion or narrow lanes.

In the fifth scenario, how much space can be gained in the city center with the use of AVs is examined. Having redesignable areas in the city center can contribute to the improvement of the quality of the built environment with recentralization and reorganization, the replacement of land uses with green areas, and the creation of pedestrian-oriented CBD. Redesigning urban areas for green spaces, bicycle/micromobility paths, parks, sidewalks, additional PT lanes, social and recreational activities and commercial activities can provide more social, livelier, greener city centers and contribute to the development of the local economy. However, gaining space can also lead to denser urban centers and higher property prices.

When the scenarios prepared are compared, the scenario where the average delays in the network decreases the most is scenario 2: APT. However, it should not be ignored that this decrease can be achieved by more than 70% APT. The scenario that increases the average delays the most is Scenario 3: Continuation of Existing PT Services sub-scenario (Table 5.1, Figure 5.1).

Table 5.1 Average delays of scenarios

Autonomous Vehicle Ratio	Average Delay (sec)					
	Scenario 1	Scenario 2	Scenario 3-1	Scenario 3-2	Scenario 4	Scenario 5
0%	49.94	49.94	49.94275	49.94	49.94	168.62
10%	47.10	44.94	81.0605	82.53	193.57	162.49
20%	44.90	44.02	170.0563	177.53	202.10	144.31
30%	43.13	43.47	230.2765	233.36	217.09	143.82
40%	40.77	41.05	250.871	249.53	229.57	115.78
50%	38.47	37,97	275.574	277.10	252.15	109.85
60%	37.73	37.68	293.3913	297.12	253.45	96.09
70%	35.96	35.62	307.7695	317.38	260.39	87.21
80%	35.62	33.85	327.8798	334.42	292.55	73.62
90%	34.66	32.88	340.0515	340.41	297.41	55.92
100%	34.52	31.84	270.966	301.76	34.52	34.89

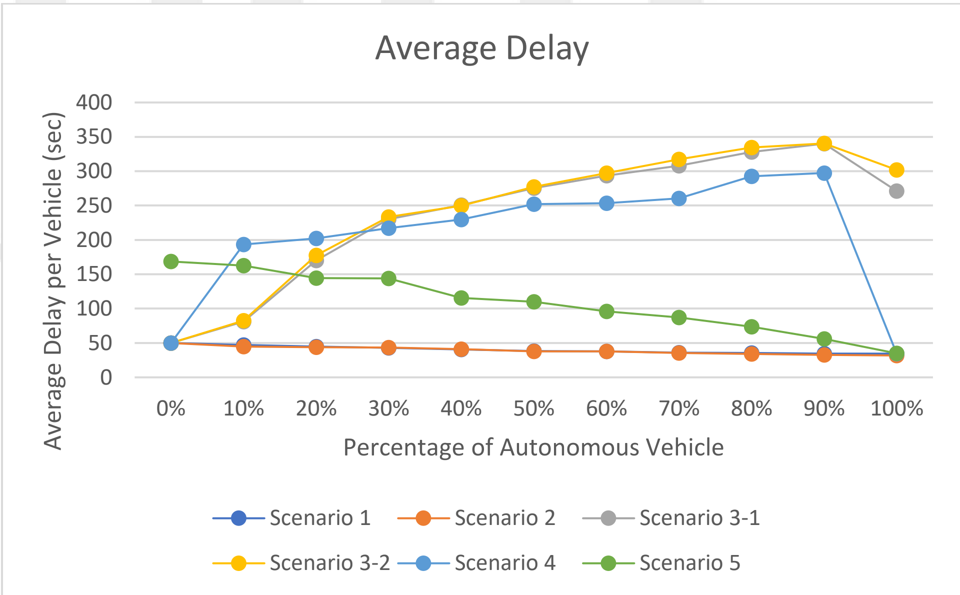


Figure 5.1 Average delays of scenarios

The scenario that increases the average speeds the most is scenario 1: basic scenario. The scenario where the speeds drop the most is Scenario 3: Continuation of Existing PT Services sub-scenario (Table 5.2, Figure 5.2).

Table 5.2 Average speeds of scenarios

Autonomous Vehicle Ratio	Average Speed (km/h)					
	Scenario 1	Scenario 2	Scenario 3-1	Scenario 3-2	Scenario 4	Scenario 5
0%	34.05	34.05	34.0545	34.05	34.05	18.15
10%	34.76	35.33	26.9355	26.66	11.90	18.32
20%	35.35	35.57	16.76475	16.20	11.17	19.96
30%	35.82	35.74	11.77125	11.62	10.29	20.10
40%	36.47	36.40	10.53525	10.58	9.61	22.94
50%	37.13	37,27	9.4965	9.42	8.59	23.74
60%	37.34	37.36	8.844	8.71	8.64	25.46
70%	37.88	37.98	8.4195	8.08	8.46	26.91
80%	37.99	38.53	7.82225	7.63	7.48	29.05
90%	38.29	38.84	7.46975	7.39	7.43	32.56
100%	38.36	39.21	10.2915	9.16	38.36	38.24

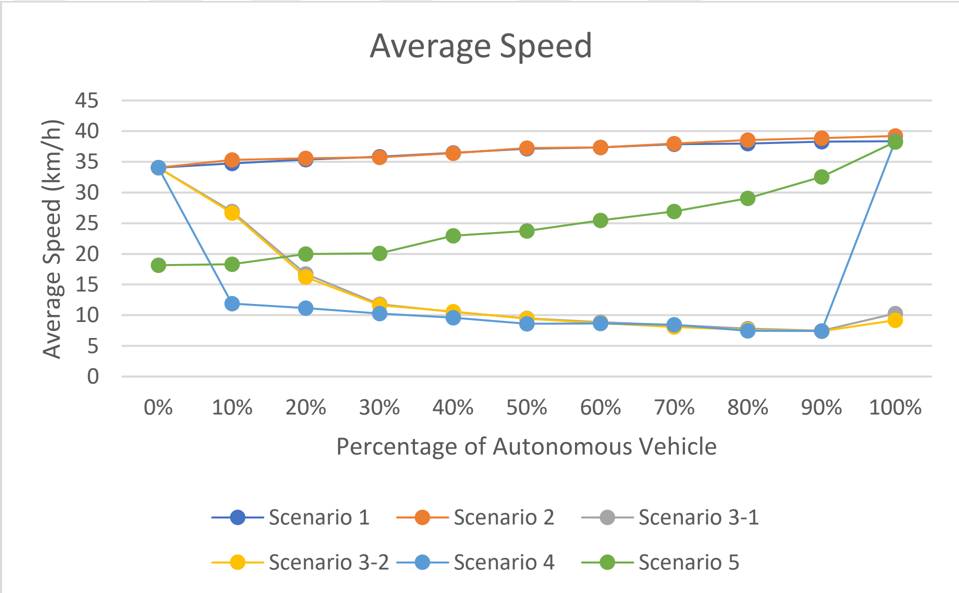


Figure 5.2 Average speed of scenarios

The scenario where average stops and stop delays decrease the most is Scenario 2: APT (Table 5.3, Figure 5.3, Table 5.4, Figure 5.4). The scenario where average stops increase the most is Scenario 3: Change of PT Services According to Demand. The scenario where average stop delays increase the most is Scenario 3: Continuation of Existing PT Services sub-scenario.

Table 5.3 Average stops of scenarios

Autonomous Vehicle Ratio	Average Stop					
	Scenario 1	Scenario 2	Scenario 3-1	Scenario 3-2	Scenario 4	Scenario 5
0%	1.61	1.61	1.61275	1.61	1.61	2.63
10%	1.55	1.44	3.08475	3.17	5.35	2.41
20%	1.49	1.44	12.57725	13.53	5.88	2.81
30%	1.46	1.46	21.6305	21.80	6.42	2.72
40%	1.39	1.41	27.984	26.87	7.55	2.75
50%	1.33	1,29	30.80425	29.95	6.40	2.55
60%	1.34	1.33	36.697	34.39	6.62	2.60
70%	1.30	1.28	39.7925	38.14	9.51	2.35
80%	1.32	1.25	43.993	42.15	11.34	2.36
90%	1.32	1.28	45.70275	43.75	13.81	2.02
100%	1.37	1.29	34.606	31.09	1.37	1.37

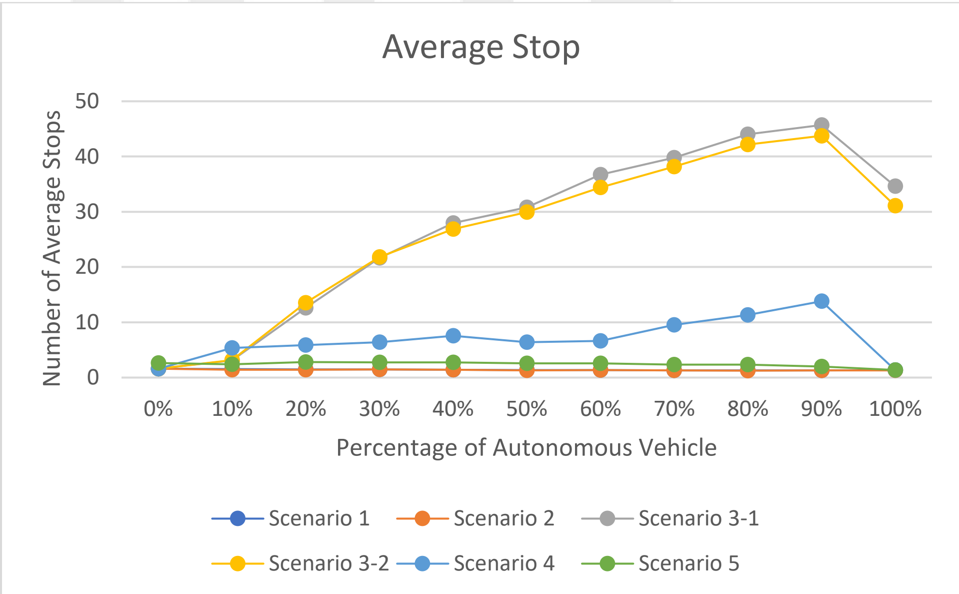


Figure 5.3 Average stops of scenarios

Table 5.4 Average stop delay of scenarios

Autonomous Vehicle Ratio	Average Stop Delay					
	Scenario 1	Scenario 2	Scenario 3-1	Scenario 3-2	Scenario 4	Scenario 5
0%	31.09	31.08	31.08525	31.09	31.09	139.56
10%	29.08	28.14	48.0785	49.18	151.43	134.41
20%	27.33	26.89	87.56425	89.06	152.11	110.68
30%	25.45	25.88	106.963	109.39	157.37	108.08
40%	23.30	23.53	110.8343	112.57	156.89	77.71
50%	21.33	21,25	127.6098	130.39	190.29	71.85
60%	20.48	20.79	118.4265	128.28	174.60	57.38
70%	18.54	18.55	119.8578	133.73	163.73	49.26
80%	17.51	16.78	123.551	137.47	173.13	35.69
90%	16.47	16.19	129.0555	139.40	163.86	23.99
100%	15.66	15.31	76.6855	120.85	15.66	15.84

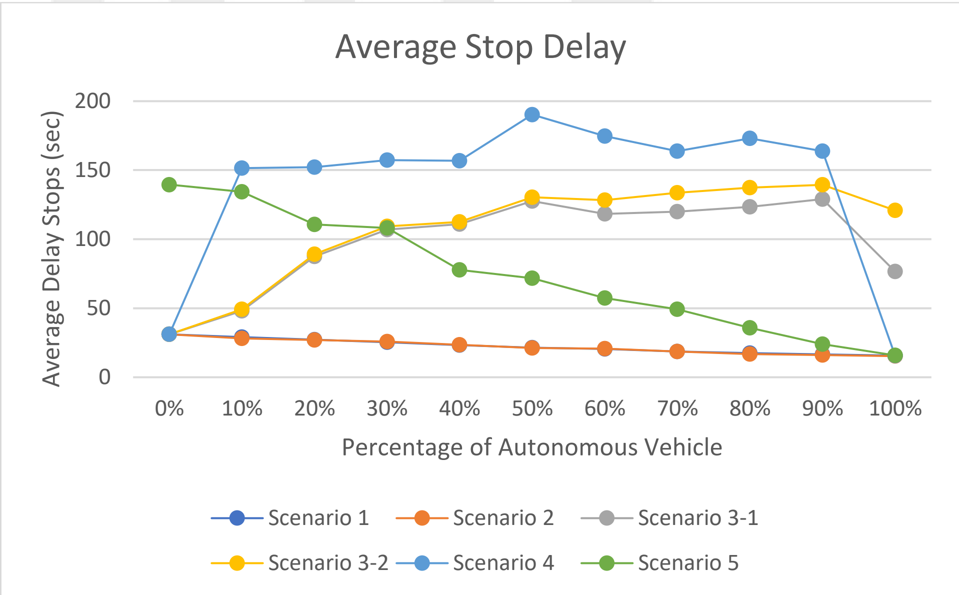


Figure 5.4 Average stop delays of scenarios

It is the scenario where the highest total travel time and the lowest distance traveled are seen due to the congestion in Scenario 3-2 (Table 5.5, Figure 5.5, Table 5.6, Figure 5.6). The reason for the extraordinary change in the scenario where 100% AVs is in circulation and all PT users use AVs in Scenario 3-1 is that all vehicles in the system are autonomous and do not interact with other vehicle types. The scenario that reduces the total travel time the most is scenario 2.

Table 5.5 Total distance of scenarios

Autonomous Vehicle Ratio	Total Distance					
	Scenario 1	Scenario 2	Scenario 3-1	Scenario 3-2	Scenario 4	Scenario 5
0%	20944	20944.23	20944.23	20944.23	20944.23	14327.28
10%	20984	21019.4	21198.74	21035.99	9053.07	14770.51
20%	20996	21039.99	21745.06	21390.47	8182.20	15789.61
30%	21016	21027.96	18443.45	18236.15	7842.48	15871.62
40%	21078	21051.67	17505.7	17528.70	7553.56	17406.41
50%	21112	21086,34	16758.27	16656.10	7090.84	17764.78
60%	21124	21110.21	16787.24	16597.63	7840.69	18560.31
70%	21159	21139.59	16641.57	16304.51	7998.98	18923.18
80%	21171	21150.69	16202.32	15887.88	7862.82	19775.44
90%	21187	21161.16	16026.09	15889.28	7862.53	20291.26
100%	21247	21216.33	21530.66	19529.51	21247.67	21253.87

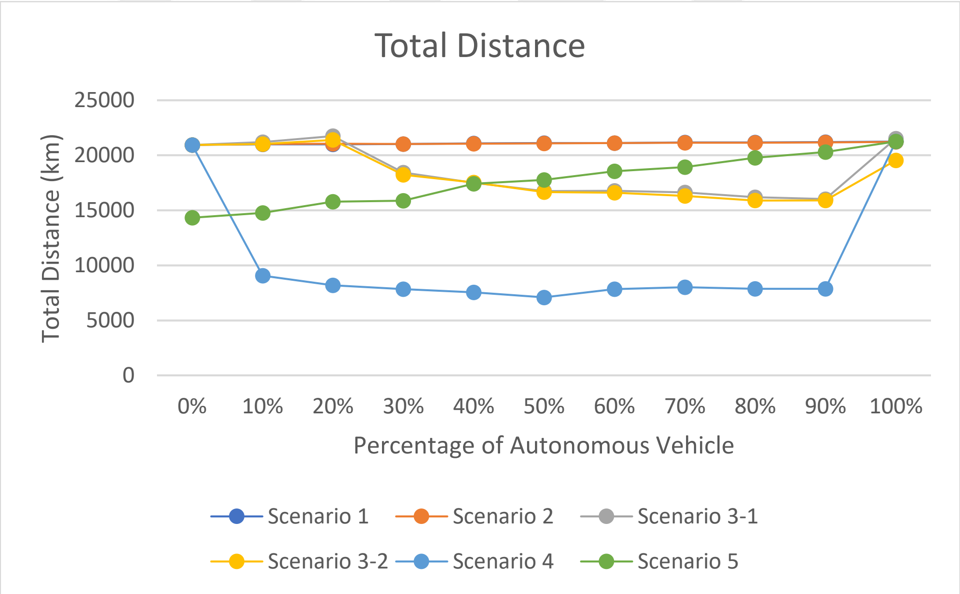


Figure 5.5 Total distance of scenarios

Table 5.6 Total travel time of scenarios

Autonomous Vehicle Ratio	Total Travel Time					
	Scenario 1	Scenario 2	Scenario 3-1	Scenario 3-2	Scenario 4	Scenario 5
0%	2230021	2230021	2230021	2230021.30	2230021.30	3276598.28
10%	2185181	2151661	3142148	3168624.09	2840985.42	3354674.50
20%	2149689	2138404	5052853	5163759.36	2712654.63	3195688.41
30%	2120770	2127568	5915758	5946797.51	2832289.92	3202066.39
40%	2086946	2089020	6220213	6199583.82	2938630.95	2954805.89
50%	2051667	2040756	6701813	6730520.30	3049272.03	2911265.95
60%	2040346	2037793	7274017	7328366.40	3432523.38	2764819.20
70%	2013815	2005352	7645945	7822879.55	3608983.21	2656846.99
80%	2009387	1977854	8065989	8156948.20	4142334.74	2510323.40
90%	1994184	1962644	8341918	8345305.91	4241352.89	2258404.56
100%	1996628	1949096	7736649	8232595.49	1996628.97	2003005.74

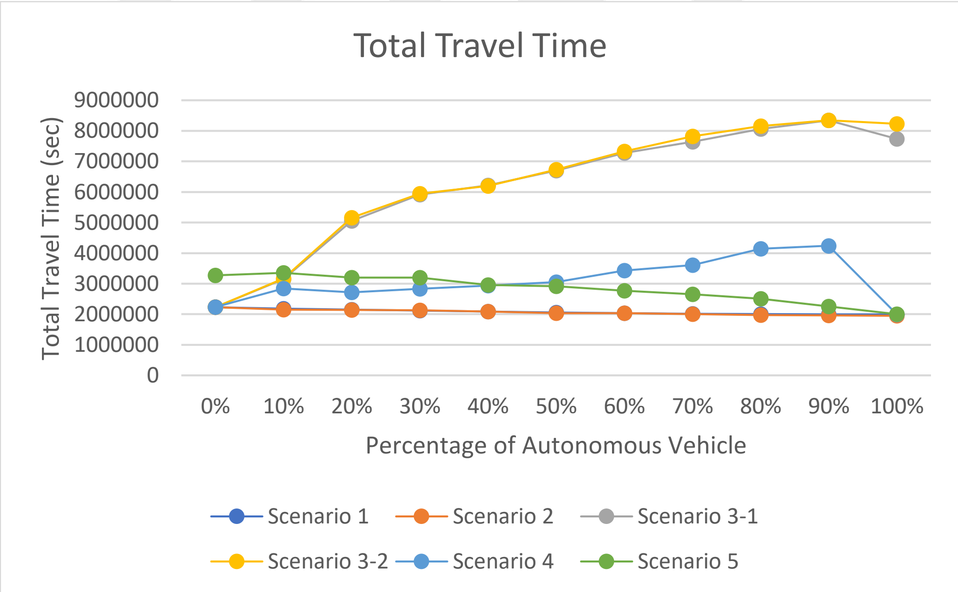


Figure 5.6 Total Travel Time of Scenarios

When the scenario results are evaluated spatially, it is seen that AVs provide improvement especially on roads such as Talatpaşa Boulevard and Şehit Nevres Boulevard, where access is not blocked due to congestion, such as health institutions, and land use where every second is urgent in access. In addition, the reduction of congestion on main roads can reduce delays in accessing health institutions and enable more effective use of institutions.

In the study area, various public and educational institutions generate travel demand and increase traffic during peak hours, necessitating the provision of large parking lots. However, the implementation of AVs can alleviate congestion on the roads serving these land uses and eliminate the need for parking. AVs, autonomous shuttles, and APT options can also help reduce delays caused by high demand for individuals working or studying in these areas.

In the study area, there are many touristic areas and commercial units such as many hotels, museums, historical buildings, squares, art centers. Access to these areas and parking problems can be improved with AVs. In addition, facilitating access to these areas can increase the preferability of areas and contribute to the local economy as well as contribute to the cultural development of the citizens.

AVs can improve traffic flow on main roads with PT routes and collector roads. Nevertheless, they should not be an alternative for PT but rather serve as a complementary mode of transport. Research reveals that AVs can navigate narrower lanes and do not require designated parking areas, freeing up space in city centers. This can result in the redesign of urban areas as new commercial units, tourism spots, green belts, and recreational zones. Certain road sections can also be made pedestrian-only or reserved for micromobility use, or solely accessible to AVs/SAVs in specific parts of the city. In urban areas where physical intervention is limited, the mobility opportunity created by AVs can be an advantage. However, if these areas transform into land uses that necessitate more travel, it can lead to increased land values, higher density in the city center, traffic congestion, air pollution, and urban sprawl.

The Izmir Fair (Kültürpark), situated in the study area, attracts many residents and tourists with various events throughout the year, resulting in high travel demand that adversely affects transportation networks. AVs/SAVs can help facilitate access to land uses with high travel demand and reduce the need for parking and traffic congestion.

As a result, AVs, which have the potential to increase transportation problems when not operated correctly, can become an advantage for all citizens and urban regions with the right planning and policies for each urban region and road section, considering each land use and the preferences of the citizens.

CHAPTER SIX
CONCLUSION

The transportation system has long been a crucial aspect of urban development, and it continues to be impacted by technological advances. Historically, rail systems facilitated the growth of linear cities, while the advent of automobiles allowed urban areas to expand even further and provided greater transport options. Today, the development of AVs promises to revolutionize transportation systems. These vehicles will be capable of transporting passengers from one point to another without requiring human intervention, and because they will have different driving behaviors than human drivers, they are expected to have a significant impact on transportation systems. Research suggests that AVs will increase road capacity, reduce travel time and traffic congestion, enhance traffic safety, decrease environmental pollution, and improve city livability. However, it is also predicted that they could increase transportation demand, create security problems, and encourage urban sprawl.

In this study, the potential impacts of AVs on the urban transportation system and urban utilization were examined through various scenarios. The findings of the study can be summarized as follows:

The introduction of AVs has the potential to address some of the transportation issues, but it alone cannot provide a complete solution. While the advancements in transportation systems brought about by AVs may alleviate certain challenges, they may also contribute to increased travel demand and urban sprawl.

To observe the positive effects of integrating autonomous technology into PT and the overall vehicle demand, a minimum of 70% of the PT fleet needs to be automated.

If users of PT switch to AVs, simply reducing the existing PT system based on demand will not effectively address the growing transportation issues. Instead, it is crucial to maintain and enhance PT services to make them more appealing than individual AVs use, to protect public welfare.

Allocating specific lanes within the current transportation network for AVs negatively affect traffic flow. Conversely, designating certain areas of the city exclusively for AVs could yield more efficient results. For instance, permitting the use of AVs solely in restricted or congested zones, where altering the road infrastructure should be avoided or environmental damage must be minimized (e.g., urban and archaeological sites), may generate more positive outcomes.

Especially in urban centers where it is difficult to find new areas and where there is dense land use, lanes can be narrowed and roadside parking lots can be removed with the use of AVs. Thus, the new areas in the city center can be used for green areas, parks, social and cultural facilities, commercial units, micromobility vehicle roads, pedestrian paths. At this point, more livable, accessible and lively cities can be obtained if planning is made by considering the quality of urban life instead of the rent that can be obtained from the newly redesignable areas.

The effects of AVs on the transportation network and the city, as revealed by the scenarios, vary depending on their usage, user preferences, and operational procedures. By implementing appropriate transportation and urban planning strategies following the introduction of these vehicles, autonomous technology can be leveraged as an opportunity to address contemporary transportation challenges.

This study not only analyzes the current state but also identifies crucial areas that could serve as a foundation for future research and efforts. The goals of mitigating climate change and reducing carbon emissions further underscore the role of AV technology in urban transportation systems. In this context, the development of guidelines or standards that address environmental impacts at the road cross-section level and human-centered solutions in urban design could be a significant component of future research endeavors.

This study utilized default values in the simulation rather than local driver behaviors due to limited data. Future research could investigate the use of local driver behavior parameters that have a more direct impact on traffic flow. Additionally, it would be worthwhile to examine the potential for AVs to integrate into public transportation as a feeder mode. The environmental impact of electric AVs should also be thoroughly studied. Furthermore, it is crucial to consider the effects of these vehicles in various areas of the city, including industrial zones, suburban areas, and the periphery.

Additionally, formulating strategies in urban planning and design that account for the effects of AVs could ensure cities' sustainable growth in harmony with this technological transformation. Subsequent research could encompass more detailed road cross-section proposals and designs, thereby encompassing critical aspects such as traffic flow management, pedestrian safety, and environmental considerations within urban spaces. Ultimately, unlocking the full potential of AVs in urban transportation and environmental sustainability demands multifaceted and interdisciplinary approaches.

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APPENDIX 1: Driving Behavior Parameters of Human Driver and Autonomous Vehicles

Parameters	Subtitles	Human Driver Behavior		Autonomous Vehicles Behavior	
Following					
Look ahead distance	Minimum	30m		30	
	Maximum	250m		250	
	Number of interaction objects	4		2	
	Number of interaction vehicles	99		1	
Look back distance	Minimum	30		30	
	Maximum	150		150	
Behavior during recovery from speed breakdown	Slow recovery	X		X	
	Speed	60%		60%	
	Acceleration	40%		40%	
	Safety distance	110%		110%	
	Distance	2000m		2000m	
Standstill distance for static obstacles		X		X	
Jerk limitation		X		✓	
Car Following Model					
Following model		Wiedemann 74		Wiedeman 99	
Avarage standstill distance		2m		1.5	
Additive part of safety distance		2m		2:0.9s	
Multiplic. Part of safety distance		3m		0.00m	
Lane Change					
General behavior		Free lane selection		Free lane selection	
Necessary lane change (route)		Vehicle	Following vehicle	Vehicle	Following vehicle
	Minimum deceleration	-4.00m/s2	-3.00m/s2	-4.00m/s2	-3.00m/s2
	-ft/s2 per distance	100m	100m	100m	100m
	Accepted deceleration	-1.00m/s2	-1,00m/s2	-1.00m/s2	-1,00m/s2
Waiting time before diffusion		60.00s		60.00s	
Minimum clearance (front/rear)		0.50m		0.50m	
To slover lane if collosion time is above		11.00s		11.00s	
Safety distance reduction factor		0.60		0.60	
Minimum deceleration for cooperative braking		-3.00m/s2		-3.00m/s2	
Overtake reduced speed areas		X		X	
Advanced merging		✓		✓	
Vehicle routing desicion look ahead		✓		✓	
Cooperative lane change		X		Max speed difference: 10.80km/h Max collision speed: 10.00s	
Rear correction of lateral position		Max speed: 3km/h		X	

Parameters	Subtitles	Human Driver Behavior	Autonomous Vehicles Behavior
Lateral			
Desired position at free flow		Any	Middle of the lane
Observe adjacent lane		✓	X
Diamond queuing		X	X
Consider next turn		✓	X
Consider time gain		2.00s	2.00s
Minimum longitudinal speed		1.00km/h	1.00 km/h
Time between direction changes		0s	0s
Default behavior when overtaking vehicles on the same lane or on adjacent lanes	Overtake on same lane	✓	X
	Minimum lateral distance	Stopping distance:0.70m (at 0km/h) Driving distance 0.70m (at 50 km/h)	Stopping distance:0.20m (at 0km/h) Driving distance 1.00m (at 50 km/h)
Signal Control			
Reaction after end of green	Behavior at amber signal	Continuous control	One time decision
	Possibility factor	X	1.59
			-0.26
			0.27
Reaction after end of red	Behavior at red/amber signal	Go (same as Green)	Stop (same as red)
	Reaction time distribution	-	-
reduced safety distance near a stop	Factor	0.60	1.00
	Start of stop line entrance flow	100.00m	100.00m
	End of stop line output flow	100.00m	100.00m
Autonomous driving			
Enforce absolute braking distance		X	X
Use implicit stochastics		X	X
Platooning	Max number of vehicle	X	7
	Max desired speed		80km/h
	Max distance for cathing up to a platoon		25.00m
	Gap time		0,60s
	Minimum clearance		2,00m

APPENDIX 2: Scenario 1 Change in the Number of Vehicles According to the Rate of Autonomous Vehicles Based on Links

Data Collecting Point	Number of Vehicles											Change (%)	Data Collecting Point	Number of Vehicles											Change (%)
	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%			0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	
1	743	744	744	745	746	743	750	749	750	750	750	0.94%	31	187	188	188	188	188	187	191	188	188	189	191	2.14%
2	396	395	394	396	397	396	398	399	399	399	400	0.98%	34	586	586	587	587	587	586	587	587	588	588	588	0.27%
3	557	557	557	557	557	557	557	557	557	557	557	0.00%	35	417	418	417	418	417	417	418	418	418	418	419	0.38%
4	397	397	395	397	398	397	399	400	400	400	400	0.88%	36	541	541	541	541	542	541	544	543	542	543	544	0.65%
5	1059	1060	1059	1060	1062	1058	1064	1065	1065	1065	1066	0.65%	37	542	541	542	542	542	542	542	542	542	542	542	-0.02%
6	381	381	380	381	382	381	383	384	384	384	385	1.02%	38	1846	1846	1846	1846	1846	1846	1846	1846	1846	1846	1846	0.01%
7	1133	1133	1133	1131	1134	1131	1132	1134	1135	1134	1135	0.17%	39	3257	3257	3257	3257	3257	3257	3258	3257	3258	3258	3258	0.02%
8	1254	1255	1252	1248	1260	1258	1256	1262	1262	1262	1262	0.65%	40	1296	1297	1299	1299	1300	1297	1302	1301	1302	1302	1303	0.52%
9	1562	1569	1571	1578	1589	1555	1603	1605	1605	1607	1610	3.10%	41	2362	2369	2370	2370	2376	2361	2372	2384	2387	2389	2393	1.31%
12	1177	1176	1172	1170	1176	1179	1174	1178	1178	1178	1180	0.22%	42	559	558	555	559	562	555	565	560	557	556	568	1.72%
13	1156	1160	1161	1161	1161	1155	1177	1164	1164	1167	1184	2.39%	43	1315	1338	1363	1376	1396	1306	1434	1472	1500	1546	1594	21.23%
14	389	389	390	390	391	390	392	392	392	392	393	0.98%	44	786	792	800	803	807	784	809	810	811	811	811	3.22%
15	196	197	197	198	197	196	200	197	197	198	200	1.99%	45	1284	1287	1288	1288	1289	1283	1291	1290	1291	1290	1290	0.43%
16	283	284	284	285	285	283	285	286	286	286	287	1.27%	46	857	861	859	860	859	856	876	861	861	862	876	2.22%
17	340	341	341	341	341	341	343	341	342	342	344	1.09%	47	674	673	671	671	677	674	678	677	679	677	678	0.62%
18	689	689	684	680	691	695	689	693	694	694	697	1.13%	48	192	192	191	191	193	192	192	192	193	193	193	0.42%
19	727	727	727	728	728	727	728	727	728	728	728	0.01%	49	192	192	191	191	193	192	192	192	193	193	193	0.63%
20	533	532	527	524	532	536	530	533	534	534	537	0.79%	50	952	953	954	954	955	951	956	958	959	959	962	1.06%
21	823	831	834	843	852	821	869	870	870	873	876	6.35%	51	409	412	415	415	418	409	419	420	420	420	420	2.89%
22	33	33	33	33	33	33	33	33	33	33	33	0.00%	52	508	510	512	514	519	507	515	529	533	535	540	6.26%
23	33	33	33	33	33	33	33	33	33	33	33	0.00%	53	558	560	561	561	562	557	562	565	564	565	567	1.65%
24	32	32	32	32	32	31	32	32	32	32	32	2.54%	54	349	349	351	353	357	349	353	365	366	369	373	6.85%
25	484	485	491	492	501	483	490	521	525	530	538	11.22%	55	505	505	506	505	506	504	506	506	507	506	507	0.42%
26	842	852	854	866	874	842	889	891	888	891	894	6.21%	56	659	661	661	662	664	658	664	666	667	668	669	1.58%
27	307	308	308	308	308	308	312	308	308	309	313	1.89%	57	365	367	364	365	369	366	371	367	370	368	369	1.01%
28	306	307	307	307	307	306	311	308	308	309	312	1.89%	58	1288	1290	1291	1291	1289	1288	1298	1288	1286	1287	1280	-0.67%
29	324	330	333	336	341	323	347	347	347	347	347	7.22%	59	809	811	814	820	827	807	822	849	851	859	869	7.37%
30	342	344	346	345	348	342	348	348	348	348	348	1.87%													

APPENDIX 3: Scenario 1 Change of Speeds According to the Rate of Autonomous Vehicles Based on Links

Data Collecting Point	Speeds (km/h)											Change (%)	Data Collecting Point	Speeds (km/h)											Change (%)
	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%														
1	49.75	50.05	50.16	50.51	50.48	49.76	49.88	51.37	51.64	51.79	52.02	5%	31	52.11	52.09	51.94	51.99	52.05	52.12	52.18	52.19	52.14	52.22	52.15	0%
2	48.95	49.14	49.70	49.43	49.61	49.31	49.57	49.26	49.31	48.95	49.42	1%	34	31.40	31.95	32.65	33.16	33.50	31.40	34.38	34.48	34.73	34.77	34.78	11%
3	52.95	52.90	52.86	52.83	52.80	52.95	52.77	52.76	52.77	52.79	52.80	0%	35	51.98	51.99	51.92	52.05	52.05	51.99	52.13	52.16	52.29	52.37	52.37	1%
4	50.80	51.02	51.14	51.16	51.21	50.84	51.33	51.61	51.64	51.63	51.93	2%	36	51.22	51.28	51.36	51.40	51.46	51.28	51.68	51.86	51.95	52.23	52.45	2%
5	51.90	51.94	51.92	51.93	51.95	51.86	51.97	51.97	51.97	51.98	52.07	0%	37	52.07	52.04	52.03	52.05	52.10	52.04	52.19	52.25	52.33	52.42	52.45	1%
6	50.99	51.09	50.81	51.05	51.19	51.00	51.32	51.64	51.60	51.76	52.01	2%	38	52.09	52.14	52.24	52.28	52.37	52.07	52.51	52.57	52.63	52.69	52.76	1%
7	33.25	32.08	31.18	30.94	30.98	33.29	32.76	32.82	33.04	34.00	35.18	6%	39	50.90	50.94	50.99	51.03	51.06	50.92	51.14	51.18	51.22	51.25	51.28	1%
8	45.70	43.99	42.75	43.85	45.24	46.30	44.91	48.88	50.35	50.88	51.42	13%	40	49.90	50.08	50.22	50.41	50.58	49.88	50.79	51.05	50.95	50.94	51.18	3%
9	46.27	46.70	46.45	46.65	47.11	46.36	47.40	47.76	48.38	49.09	49.39	7%	41	46.18	48.53	49.86	49.94	50.28	45.88	50.88	51.66	50.67	52.01	52.15	13%
12	51.82	51.80	51.72	51.67	51.59	51.80	51.66	51.04	51.09	50.77	50.74	-2%	42	48.39	49.01	49.13	49.28	49.51	48.66	49.41	49.32	49.38	48.96	48.58	0%
13	50.40	50.64	50.63	50.68	50.78	50.47	50.97	51.08	51.00	51.00	51.16	2%	43	43.96	44.37	44.49	44.38	44.37	44.01	43.67	42.60	41.98	40.85	39.59	-10%
14	45.36	45.97	46.30	46.74	47.33	45.57	48.21	49.20	49.87	50.71	51.58	14%	44	49.96	50.18	50.31	50.26	50.25	49.99	50.60	50.62	50.65	50.72	50.81	2%
15	47.33	47.73	48.08	47.90	47.90	47.65	47.84	47.79	47.33	47.23	46.95	-1%	45	50.81	51.57	52.28	52.51	52.64	50.35	52.70	52.77	52.78	52.81	52.87	4%
16	52.66	52.67	52.49	52.61	52.59	52.48	52.71	52.69	52.74	52.74	52.65	0%	46	52.44	52.38	52.43	52.39	52.51	52.45	52.42	52.53	52.47	52.50	52.56	0%
17	51.84	51.94	52.08	52.00	52.21	51.89	52.31	52.40	52.48	52.55	52.77	2%	47	52.13	52.21	52.19	52.18	52.21	52.18	52.14	52.23	52.17	52.17	52.24	0%
18	51.53	51.65	51.66	51.74	51.79	51.66	51.67	51.83	51.77	51.53	51.46	0%	48	52.43	52.43	52.48	52.57	52.48	52.49	52.49	52.45	52.57	52.66	52.62	0%
19	51.63	51.62	51.65	51.67	51.75	51.61	51.81	51.83	52.00	52.16	52.30	1%	49	52.37	52.36	52.35	52.48	52.39	52.39	52.46	52.40	52.48	52.53	52.50	0%
20	51.76	51.69	51.67	51.76	51.82	51.62	51.73	51.97	52.17	52.48	52.73	2%	50	51.16	51.31	51.42	51.50	51.70	51.13	52.31	52.73	53.03	53.51	53.76	5%
21	48.85	49.17	49.34	49.18	49.17	48.95	48.23	47.92	47.43	46.40	44.84	-8%	51	52.21	52.27	52.23	52.31	52.30	52.24	52.42	52.50	52.57	52.57	52.77	1%
22	52.29	52.34	52.42	52.44	52.48	52.29	52.57	52.62	52.70	52.75	52.79	1%	52	36.62	35.67	35.43	35.57	35.01	36.20	34.95	33.23	31.81	31.88	30.52	-17%
23	52.77	52.78	52.71	52.68	52.76	52.75	52.73	52.73	52.75	52.74	52.76	0%	53	51.87	51.99	51.91	51.95	51.99	51.90	51.93	52.15	52.16	52.10	52.20	1%
24	53.08	52.92	52.96	52.90	53.02	53.10	52.98	52.95	52.88	52.97	53.02	0%	54	48.54	48.70	49.07	49.34	49.05	48.97	48.76	48.42	47.88	47.20	46.33	-5%
25	40.81	42.41	43.76	44.94	45.41	40.95	45.22	42.30	40.28	37.42	33.89	-17%	55	52.09	52.11	52.10	52.13	52.17	52.15	52.25	52.32	52.45	52.53	52.58	1%
26	49.73	50.29	50.16	50.40	50.82	49.55	51.02	51.95	52.16	52.91	52.75	6%	56	48.44	48.37	49.42	49.52	49.86	48.65	50.51	50.63	50.63	51.09	51.35	6%
27	52.52	52.58	52.46	52.58	52.48	52.72	52.65	52.56	52.58	52.58	52.57	0%	57	52.05	52.11	52.10	52.12	52.16	52.09	52.16	52.18	52.10	52.20	52.12	0%
28	51.88	51.95	51.83	51.98	51.91	51.99	52.14	52.03	51.98	51.94	51.93	0%	58	45.91	46.32	46.87	47.41	47.93	45.83	47.77	48.40	48.47	48.77	48.79	6%
29	33.76	36.24	38.04	41.01	43.09	33.77	49.89	50.36	50.63	51.12	50.69	50%	59	47.20	47.39	47.41	47.25	46.87	47.32	47.53	45.98	45.91	45.37	45.20	-4%
30	50.46	51.02	51.36	51.42	52.32	50.59	52.38	52.35	52.40	52.47	52.53	4%													

APPENDIX 4: Scenario 1 Change of Queue Delays According to the Rate of Autonomous Vehicles Based on Links

Data Collecting Point	Queue Delays (sec)											Change (%)	Data Collecting Point	Queue Delays (sec)											Change (%)
	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%			0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	
1	38.39	37.46	35.37	33.85	32.23	38.07	27.41	25.53	24.30	22.78	22.37	-42%	31	81.01	75.92	70.97	66.00	63.49	81.21	60.43	58.53	58.01	56.03	53.68	-34%
2	68.00	67.52	69.16	68.84	65.35	67.84	63.85	59.70	60.10	57.64	54.78	-19%	34	7.28	6.01	4.12	3.41	2.63	7.28	1.70	1.43	1.19	0.98	0.87	-88%
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-	35	11.87	11.15	10.89	9.95	9.72	12.00	9.19	8.99	8.58	8.41	8.29	-30%
4	67.74	67.35	69.05	68.70	65.23	67.62	63.71	59.51	59.98	57.59	54.72	-19%	36	36.89	34.44	30.97	28.91	27.08	37.13	25.12	24.02	23.56	22.55	21.61	-41%
5	26.24	25.60	24.17	23.11	22.04	25.88	18.79	17.53	16.72	15.44	15.42	-41%	37	0.19	0.36	0.26	0.25	0.19	0.33	0.17	0.19	0.15	0.20	0.17	-8%
6	68.97	68.80	70.54	70.37	66.59	68.95	65.28	61.16	61.61	58.84	56.30	-18%	38	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	-
7	10.07	10.08	9.72	9.65	9.66	9.94	10.54	6.70	5.99	5.45	4.48	-55%	39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
8	19.68	22.33	23.64	24.63	19.52	19.15	21.63	16.32	15.24	14.26	13.82	-30%	40	21.23	20.42	18.93	18.66	17.32	21.89	16.23	15.57	15.31	14.70	14.31	-33%
9	115.04	107.41	103.73	97.05	89.97	115.09	75.94	71.62	69.24	67.08	66.27	-42%	41	26.22	24.30	24.20	24.01	23.37	26.45	22.79	21.64	21.96	20.92	20.93	-20%
12	20.44	23.91	26.51	25.74	23.84	20.04	24.47	19.69	18.02	17.74	16.19	-21%	42	68.50	62.69	56.74	53.86	49.42	69.76	44.70	43.96	44.06	42.44	41.69	-39%
13	69.12	63.66	58.19	56.15	52.97	69.93	49.08	47.01	46.52	44.64	43.32	-37%	43	53.13	45.58	40.35	38.61	36.15	54.52	32.61	30.59	31.27	29.00	28.60	-46%
14	69.27	69.31	70.94	70.53	66.92	68.94	65.39	61.37	61.77	59.10	56.43	-19%	44	84.78	72.55	55.86	50.12	41.71	88.25	32.90	30.72	28.27	26.39	23.96	-72%
15	72.65	65.96	60.77	59.02	54.56	71.98	52.03	47.96	46.31	46.19	45.35	-38%	45	17.10	15.49	13.49	12.96	11.22	18.19	10.38	10.10	9.71	9.28	8.95	-48%
16	51.26	47.85	46.89	47.29	44.51	51.12	43.05	41.57	43.33	41.04	39.26	-23%	46	69.76	62.08	55.59	53.07	48.79	71.00	44.73	42.82	41.93	40.33	39.01	-44%
17	59.71	55.93	52.96	51.97	49.27	59.62	47.46	45.11	43.76	43.48	43.12	-28%	47	24.53	26.39	26.98	26.77	24.64	24.16	24.20	20.15	19.07	18.16	17.35	-29%
18	29.73	36.84	43.24	42.72	38.43	28.95	39.13	29.17	25.82	24.38	20.97	-29%	48	24.42	25.32	26.20	24.31	23.25	23.00	22.26	19.90	19.40	16.55	16.45	-33%
19	9.79	9.67	9.52	9.25	9.11	9.71	8.69	8.40	8.17	7.90	7.69	-21%	49	24.43	25.17	26.05	24.14	23.24	22.94	22.13	19.84	19.40	16.56	16.46	-33%
20	42.22	49.81	57.63	58.62	53.84	40.75	53.08	42.00	39.40	36.15	32.54	-23%	50	65.59	65.28	63.72	62.87	61.65	66.25	58.74	56.97	56.53	54.57	54.20	-17%
21	138.69	126.83	120.31	107.32	95.59	139.65	69.38	63.94	60.87	56.35	56.30	-59%	51	84.84	72.67	57.13	48.82	41.27	88.09	32.58	30.21	27.49	25.73	24.96	-71%
22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-	52	120.35	121.72	121.41	119.28	115.72	120.45	114.02	106.75	106.00	102.41	101.20	-16%
23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-	53	39.52	34.29	32.88	33.23	31.51	39.64	31.60	28.33	30.74	27.42	28.96	-27%
24	32.25	20.76	17.51	16.54	9.52	25.68	8.35	7.58	7.52	7.27	7.24	-78%	54	112.09	112.10	114.99	113.76	108.38	110.72	107.32	97.69	93.17	92.97	90.73	-19%
25	48.57	53.94	60.12	59.90	55.11	47.11	55.06	44.27	42.19	40.37	38.79	-20%	55	15.22	14.41	13.27	12.35	10.95	15.76	11.19	10.33	10.61	9.78	8.81	-42%
26	137.67	125.83	119.44	106.08	94.15	138.42	67.61	62.13	59.00	54.08	53.35	-61%	56	69.13	68.25	65.85	63.47	61.80	70.31	58.66	57.20	56.16	54.12	53.88	-22%
27	70.57	65.69	59.63	57.25	53.77	72.40	51.08	49.46	48.23	45.26	44.59	-37%	57	29.61	29.50	27.74	26.69	25.30	29.24	21.62	20.67	20.03	17.30	18.46	-38%
28	70.49	65.64	59.73	57.21	53.74	72.17	50.98	49.49	48.19	45.22	44.56	-37%	58	43.85	41.41	39.71	38.85	37.04	44.29	35.99	34.12	35.19	32.53	32.90	-25%
29	70.78	50.19	45.14	31.07	18.95	71.18	7.22	6.69	6.35	6.14	5.87	-92%	59	100.10	101.22	103.73	102.57	98.20	99.37	97.64	88.75	85.65	84.04	81.63	-18%
30	19.68	14.86	12.63	12.62	8.64	17.76	7.65	7.34	6.98	6.76	6.48	-67%													

APPENDIX 5: Scenario 2 Change in the Number of Vehicles According to the Rate of Autonomous Vehicles Based on Links

Data Collecting Point	Number of Vehicles											Change (%)	Data Collecting Point	Number of Vehicles											Change (%)
	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%			0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	
1	743	745	743	745	747	744	749	748	750	751	751	1%	31	187	187	188	188	188	187	191	188	189	189	191	2%
2	396	398	396	395	397	396	397	399	400	401	402	1%	34	586	586	587	587	587	586	587	587	588	588	588	0%
3	557	557	557	557	557	557	557	557	557	557	557	0%	35	417	418	417	418	418	417	419	418	418	418	419	0%
4	397	399	397	396	397	397	398	400	400	401	402	1%	36	541	542	541	542	542	540	544	542	543	543	544	1%
5	1059	1061	1058	1061	1063	1059	1065	1063	1066	1065	1067	1%	37	542	542	542	542	542	542	542	542	542	542	542	0%
6	381	382	381	380	382	381	382	384	384	385	385	1%	38	1846	1846	1846	1846	1846	1846	1846	1846	1846	1846	1846	0%
7	1133	1131	1128	1130	1132	1126	1124	1132	1127	1125	1123	-1%	39	3257	3257	3257	3257	3257	3257	3258	3257	3258	3258	3258	0%
8	1254	1258	1253	1244	1246	1247	1244	1252	1248	1245	1240	-1%	40	1296	1297	1299	1300	1298	1296	1302	1302	1301	1302	1303	1%
9	1562	1573	1574	1580	1587	1562	1604	1607	1609	1607	1614	3%	41	2362	2371	2371	2375	2374	2366	2377	2385	2388	2391	2394	1%
12	1177	1181	1175	1169	1171	1175	1171	1175	1175	1178	1178	0%	42	559	559	554	551	555	549	553	542	555	544	552	-1%
13	1156	1160	1158	1163	1160	1157	1177	1165	1166	1164	1183	2%	43	1315	1335	1359	1380	1396	1311	1441	1474	1513	1548	1598	22%
14	389	391	391	390	391	390	391	391	393	393	394	1%	44	786	794	801	805	807	785	809	810	811	811	811	3%
15	196	197	197	198	197	197	199	198	198	197	200	2%	45	1284	1287	1288	1289	1289	1284	1290	1291	1290	1290	1290	0%
16	283	284	284	285	285	283	285	286	286	286	287	1%	46	857	859	858	863	858	857	876	861	861	859	876	2%
17	340	341	341	342	341	341	343	342	342	342	344	1%	47	674	678	675	674	673	672	672	678	674	674	675	0%
18	689	694	689	681	684	690	684	691	689	694	694	1%	48	192	192	192	192	192	192	191	193	192	193	194	1%
19	727	727	727	728	728	728	728	727	728	728	728	0%	49	192	192	193	191	192	192	192	193	192	193	194	1%
20	533	536	530	524	525	532	526	531	532	531	534	0%	50	952	953	955	955	955	954	957	959	959	960	963	1%
21	823	833	838	841	852	825	869	869	873	873	878	7%	51	409	413	415	417	418	409	419	420	420	420	420	3%
22	33	33	33	33	33	33	33	33	33	33	33	0%	52	508	513	512	512	514	509	513	524	524	526	527	4%
23	33	33	33	33	33	33	33	33	33	33	33	0%	53	558	560	560	561	562	559	562	565	566	566	568	2%
24	32	32	32	32	32	32	32	32	32	32	32	3%	54	349	354	354	356	359	356	358	366	368	372	375	8%
25	484	492	494	495	499	492	494	516	521	524	527	9%	55	505	505	505	506	505	505	506	506	506	506	507	0%
26	842	855	858	863	874	846	889	888	894	894	897	7%	56	659	661	662	664	664	660	666	667	667	668	670	2%
27	307	308	308	309	308	308	312	309	309	308	313	2%	57	365	368	369	370	368	366	369	371	368	367	371	2%
28	306	307	308	308	307	307	311	308	308	307	313	2%	58	1288	1290	1291	1288	1289	1288	1299	1284	1287	1287	1286	0%
29	324	330	333	336	341	326	347	347	347	347	347	7%	59	809	819	818	820	825	818	824	844	846	852	857	6%
30	342	343	346	348	348	344	348	348	348	348	348	2%													

APPENDIX 6: Scenario 2 Change in the Speeds According to the Rate of Autonomous Vehicles Based on Links

Data Collecting Point	Speeds (km/h)											Change (%)	Data Collecting Point	Speeds (km/h)											Change (%)
	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%		0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%		
1	49.75	49.66	49.56	50.38	50.66	49.50	49.90	51.36	51.54	51.88	52.09	5%	31	52.11	51.95	51.69	52.02	51.93	52.03	52.00	52.07	52.08	52.29	52.38	1%
2	48.95	49.41	48.68	49.67	49.62	49.15	49.77	49.40	49.13	49.06	49.18	0%	34	31.40	31.97	25.50	33.16	33.48	31.39	34.38	34.50	34.71	34.77	34.79	11%
3	52.95	52.90	52.69	52.83	52.80	52.95	52.77	52.76	52.77	52.79	52.80	0%	35	51.98	51.93	51.78	52.01	51.97	51.99	52.11	52.25	52.24	52.43	52.56	1%
4	50.80	51.05	51.03	51.16	51.22	50.89	51.41	51.41	51.50	51.55	51.83	2%	36	51.22	51.27	51.11	51.42	51.47	51.23	51.66	51.76	51.97	52.22	52.50	2%
5	51.90	51.90	51.77	51.99	51.93	51.82	51.93	51.97	51.95	52.00	52.03	0%	37	52.07	51.98	51.84	52.04	52.09	52.02	52.19	52.24	52.34	52.40	52.46	1%
6	50.99	50.99	50.66	51.11	51.06	51.02	51.36	51.45	51.68	51.63	51.90	2%	38	52.09	52.22	52.10	52.32	52.40	52.13	52.53	52.57	52.67	52.73	52.80	1%
7	33.25	33.15	20.00	29.92	30.51	30.64	30.80	31.16	32.22	33.03	33.42	1%	39	50.90	50.94	50.89	51.02	51.07	50.92	51.14	51.18	51.22	51.25	51.28	1%
8	45.70	46.42	38.43	42.47	45.46	45.28	44.63	50.42	51.39	51.84	52.89	16%	40	49.90	50.15	49.03	50.35	50.52	49.99	50.80	50.99	51.01	51.21	51.15	2%
9	46.27	47.22	38.52	47.20	47.18	46.95	48.55	47.98	49.25	50.00	50.88	10%	41	46.18	49.35	47.77	50.42	49.77	46.02	51.25	51.39	52.02	52.26	52.37	13%
12	51.82	51.79	51.61	51.69	51.61	51.82	51.70	51.30	51.21	51.17	51.09	-1%	42	48.39	49.08	47.53	49.57	49.81	49.01	49.64	49.61	49.50	49.54	49.00	1%
13	50.40	50.77	49.47	50.81	50.96	50.55	51.04	51.05	51.10	51.10	51.28	2%	43	43.96	44.35	36.02	44.70	44.37	43.99	43.88	42.70	42.19	41.25	39.77	-10%
14	45.36	45.85	44.44	46.56	47.11	45.56	48.40	48.98	49.97	50.54	51.48	13%	44	49.96	50.17	49.91	50.34	50.31	50.03	50.59	50.79	50.48	50.73	50.84	2%
15	47.33	47.48	46.05	47.65	48.03	47.45	47.53	47.59	47.30	47.08	46.94	-1%	45	50.81	51.69	51.90	52.50	52.63	50.45	52.73	52.74	52.79	52.82	52.84	4%
16	52.66	52.56	52.42	52.55	52.69	52.62	52.72	52.64	52.66	52.62	52.65	0%	46	52.44	52.43	52.21	52.40	52.48	52.43	52.39	52.40	52.48	52.47	52.61	0%
17	51.84	52.03	51.90	51.98	52.18	51.86	52.25	52.47	52.44	52.69	52.81	2%	47	52.13	52.13	52.07	52.19	52.21	52.15	52.13	52.21	52.13	52.12	52.15	0%
18	51.53	51.68	51.60	51.80	51.83	51.61	51.83	51.77	51.88	51.74	52.06	1%	48	52.43	52.52	52.28	52.52	52.60	52.42	52.53	52.50	52.50	52.56	52.47	0%
19	51.63	51.61	51.39	51.73	51.76	51.63	51.76	51.85	51.94	52.15	52.33	1%	49	52.37	52.46	52.19	52.35	52.48	52.32	52.49	52.39	52.41	52.44	52.39	0%
20	51.76	51.70	51.50	51.73	51.78	51.79	51.83	51.94	52.38	52.53	52.91	2%	50	51.16	51.25	51.21	51.52	51.79	51.26	52.25	52.77	53.06	53.45	53.88	5%
21	48.85	49.42	48.39	49.28	49.15	49.04	48.85	47.86	48.03	47.53	46.55	-5%	51	52.21	52.25	52.11	52.29	52.30	52.28	52.45	52.47	52.56	52.59	52.62	1%
22	52.29	52.34	52.25	52.44	52.48	52.29	52.57	52.62	52.70	52.75	52.79	1%	52	36.62	36.27	24.70	36.02	35.74	36.59	35.66	34.29	34.39	33.93	34.35	-6%
23	52.77	52.78	52.54	52.73	52.76	52.73	52.72	52.73	52.75	52.74	52.76	0%	53	51.87	51.98	50.92	51.99	51.92	51.90	52.08	51.94	52.13	52.16	52.14	1%
24	53.08	52.97	52.92	53.05	52.97	53.03	52.89	53.06	52.95	52.81	52.95	0%	54	48.54	49.13	46.82	49.29	49.19	48.86	48.62	48.30	47.92	47.39	46.10	-5%
25	40.81	42.77	35.92	45.59	46.01	40.93	46.37	43.54	41.66	39.23	36.42	-11%	55	52.09	52.12	51.92	52.08	52.15	52.09	52.21	52.30	52.38	52.51	52.56	1%
26	49.73	50.80	49.14	50.59	50.87	50.11	51.62	51.46	52.40	53.27	54.09	9%	56	48.44	48.65	48.15	49.49	49.88	48.58	50.53	50.52	50.68	51.00	51.25	6%
27	52.52	52.48	52.26	52.52	52.44	52.50	52.51	52.52	52.47	52.62	52.62	0%	57	52.05	52.06	52.00	52.11	52.19	51.95	52.13	52.09	52.02	52.05	51.96	0%
28	51.88	51.86	51.55	51.86	51.93	51.87	51.96	52.04	51.93	52.02	51.89	0%	58	45.91	46.91	43.65	47.45	47.88	46.50	48.28	48.30	48.84	49.01	49.18	7%
29	33.76	37.00	34.81	39.20	43.70	34.26	49.09	50.11	50.66	51.04	50.64	50%	59	47.20	47.50	43.80	47.64	47.66	47.45	48.13	47.20	47.37	47.44	48.44	3%
30	50.46	51.05	51.00	51.63	52.16	51.11	52.39	52.36	52.44	52.47	52.52	4%													

APPENDIX 7: Scenario 2 Change in the Queue Delays According to the Rate of Autonomous Vehicles Based on Links

Data Collecting Point	Queue Delays (sec)											Change (%)	Data Collecting Point	Queue Delays (sec)											Change (%)
	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%			0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	
1	38.39	34.66	36.28	36.17	32.83	40.56	30.51	27.30	24.87	23.01	22.93	-40%	31	81.01	72.56	70.31	68.79	64.42	84.03	58.52	56.70	56.80	53.43	52.28	-35%
2	68.00	65.42	66.20	69.60	65.46	71.05	64.98	60.61	55.60	55.01	52.12	-23%	34	7.28	6.00	4.12	3.41	2.66	7.33	1.69	1.43	1.19	0.98	0.87	-88%
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-	35	11.87	11.28	10.49	10.57	9.60	12.55	9.27	8.46	8.94	8.27	8.29	-30%
4	67.74	65.20	66.13	69.56	65.36	70.81	64.90	60.57	55.49	54.87	52.05	-23%	36	36.89	33.30	30.98	29.30	27.55	37.51	24.50	23.76	22.98	21.78	21.16	-43%
5	26.24	23.77	24.92	24.66	22.55	27.77	20.89	18.58	17.13	15.87	15.84	-40%	37	0.19	0.23	0.24	0.17	0.16	0.16	0.22	0.13	0.15	0.17	0.15	-20%
6	68.97	66.85	67.78	71.04	67.08	72.32	66.15	61.66	57.01	56.37	53.39	-23%	38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
7	10.07	9.35	11.32	11.56	10.16	13.80	13.85	9.60	8.35	6.88	7.03	-30%	39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
8	19.68	19.01	21.23	25.86	21.89	23.79	23.92	16.72	15.23	14.82	14.16	-28%	40	21.23	19.49	19.38	18.19	17.58	21.29	15.88	15.31	14.61	14.28	13.61	-36%
9	115.04	103.51	100.09	98.02	90.34	113.46	74.61	72.01	67.24	63.26	60.94	-47%	41	26.22	23.43	24.03	24.45	23.73	27.80	23.53	21.57	20.78	20.81	20.21	-23%
12	20.44	20.26	23.74	29.34	24.56	23.19	26.49	18.37	15.76	15.64	13.18	-36%	42	68.50	61.75	56.29	53.05	49.02	69.68	43.91	42.63	41.03	39.42	38.98	-43%
13	69.12	62.47	58.48	56.31	53.25	70.60	48.24	47.33	44.63	43.60	42.95	-38%	43	53.13	43.59	40.85	38.84	36.59	55.59	32.26	30.62	29.10	28.22	27.62	-48%
14	69.27	67.27	67.94	71.37	67.27	72.50	66.24	61.92	57.15	56.41	53.56	-23%	44	84.78	70.20	57.51	49.45	42.17	87.41	33.05	30.11	27.59	25.94	24.71	-71%
15	72.65	63.90	60.03	60.56	55.88	72.62	47.84	48.61	42.53	45.54	43.74	-40%	45	17.10	15.64	13.83	12.60	11.86	17.75	10.35	9.80	9.48	8.96	9.00	-47%
16	51.26	47.22	46.15	46.45	45.48	54.07	43.16	43.22	38.22	38.28	37.50	-27%	46	69.76	61.14	55.78	53.12	49.47	71.54	43.80	43.01	40.96	39.43	39.34	-44%
17	59.71	54.34	52.43	52.61	49.39	59.60	45.34	45.18	41.98	43.17	42.28	-29%	47	24.53	24.22	26.32	29.31	25.21	26.78	25.84	20.00	17.45	17.16	15.68	-36%
18	29.73	30.28	36.75	49.39	40.40	35.79	44.22	27.19	22.77	22.66	17.75	-40%	48	24.42	24.39	24.43	27.86	24.12	24.58	24.17	19.02	17.68	16.70	14.53	-40%
19	9.79	9.51	9.66	9.30	9.07	9.72	8.76	8.48	8.21	7.88	7.52	-23%	49	24.43	24.42	24.31	27.63	24.09	24.59	24.12	18.98	17.57	16.62	14.54	-40%
20	42.22	42.63	51.10	63.31	55.36	47.89	58.42	41.48	35.77	35.07	29.30	-31%	50	65.59	63.64	63.88	62.44	61.23	65.87	58.30	56.64	54.32	53.48	52.04	-21%
21	138.69	122.66	115.33	111.93	96.50	136.24	70.03	63.33	58.69	53.90	52.70	-62%	51	84.84	69.29	56.99	48.97	42.87	87.98	33.25	30.12	28.53	26.08	24.23	-71%
22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-	52	120.35	117.30	116.63	123.19	114.79	121.92	112.93	101.65	94.48	92.85	86.66	-28%
23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-	53	39.52	32.07	32.66	31.69	33.36	41.44	31.09	29.76	27.83	26.72	26.39	-33%
24	32.25	22.44	16.25	14.04	10.81	23.09	8.24	7.46	7.41	7.40	7.39	-77%	54	112.09	108.89	112.69	117.60	108.84	114.39	109.39	96.11	90.38	90.74	86.00	-23%
25	48.57	47.41	53.35	64.65	55.84	54.49	59.23	42.25	37.57	37.59	33.11	-32%	55	15.22	13.46	13.55	12.78	11.92	15.57	9.94	10.53	9.56	8.97	8.51	-44%
26	137.67	122.14	114.65	111.13	95.07	135.21	68.64	61.74	57.09	52.15	51.47	-63%	56	69.13	66.43	65.03	63.07	61.94	69.27	58.37	56.63	55.04	53.00	52.21	-24%
27	70.57	63.37	60.86	58.92	54.68	73.24	49.07	48.39	47.00	44.68	44.42	-37%	57	29.61	28.29	29.37	29.16	25.95	31.14	24.56	21.02	19.86	18.58	18.32	-38%
28	70.49	63.24	60.90	58.90	54.64	73.23	48.99	48.33	46.85	44.67	44.46	-37%	58	43.85	39.90	39.63	38.18	38.36	45.29	34.88	35.18	32.88	31.46	30.89	-30%
29	70.78	54.06	41.97	33.56	20.35	66.83	7.31	6.89	6.36	6.11	5.92	-92%	59	100.10	97.41	99.82	106.52	98.69	103.24	99.47	87.31	81.80	82.19	78.02	-22%
30	19.68	15.62	12.28	10.70	8.68	17.06	7.69	7.27	6.97	6.72	6.48	-67%													

APPENDIX 8: Scenario 3 Change of PT Services According to Demand Sub-scenario: Change in the Number of Vehicles according to the Rate of Users' Preferences Based on Links

Data Collecting Point	Number of Vehicles											Change (%)	Data Collecting Point	Number of Vehicles											Change (%)
	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%														
1	743	528	181	117	79	57	63	82	81	81	250	-66%	31	187	185	160	107	87	68	55	52	45	42	115	-39%
2	396	367	257	155	125	112	133	138	132	120	266	-33%	34	586	586	409	205	157	120	141	163	196	225	532	-9%
3	557	557	557	557	557	557	557	557	557	557	557	0%	35	417	416	340	93	31	17	15	12	12	10	290	-30%
4	397	367	257	163	131	119	134	140	132	120	266	-33%	36	541	539	365	149	100	66	83	94	116	139	414	-23%
5	1059	852	512	450	414	392	399	417	416	416	580	-45%	37	542	542	442	111	31	14	8	7	6	3	387	-29%
6	381	357	254	162	135	119	133	141	130	119	260	-32%	38	1846	2110	2044	1091	839	806	698	639	610	566	1600	-13%
7	1133	1349	1142	1016	1023	1052	1041	1013	1059	1082	1121	-1%	39	3257	3257	3257	3257	3257	3257	3258	3257	3258	3258	3258	0%
8	1254	1665	1676	1288	1258	1259	1312	1375	1378	1413	1595	27%	40	1296	1294	950	293	119	62	71	70	80	91	912	-30%
9	1562	2072	2251	2153	1969	1806	1930	1971	1981	1943	2288	47%	41	2362	2392	2363	2419	2367	2208	2166	1967	1758	1594	2286	-3%
12	1177	1206	1143	800	776	769	802	843	827	838	994	-16%	42	559	932	969	837	835	843	821	805	777	773	972	74%
13	1156	1271	1237	1057	1076	984	894	908	937	898	1255	9%	43	1315	1403	1441	1491	1482	1300	1255	1062	892	810	1515	15%
14	389	360	256	164	137	121	135	143	130	122	264	-32%	44	786	792	777	721	707	698	666	565	424	433	758	-4%
15	196	193	164	108	89	70	59	54	46	45	118	-40%	45	1284	1287	1245	1150	1128	1120	1111	1060	894	903	1214	-5%
16	283	270	202	133	110	96	105	103	92	84	198	-30%	46	857	987	1023	983	1069	1169	1115	1089	1083	1009	1144	34%
17	340	337	298	219	157	108	102	102	83	87	194	-43%	47	674	713	659	386	361	351	368	385	384	384	486	-28%
18	689	702	598	229	202	191	230	283	264	276	461	-33%	48	192	165	117	100	93	90	94	99	98	99	128	-33%
19	727	847	879	877	720	603	643	694	710	705	861	18%	49	192	165	117	100	93	90	94	99	98	98	128	-33%
20	533	576	361	150	125	117	143	188	169	180	332	-38%	50	952	904	660	233	114	69	75	77	86	94	632	-34%
21	823	929	858	666	629	656	629	591	552	546	752	-9%	51	409	412	404	378	371	367	360	311	236	244	397	-3%
22	33	33	33	33	33	33	33	33	33	33	33	0%	52	508	744	764	770	775	762	775	782	788	788	807	59%
23	33	33	33	33	33	33	33	33	33	33	33	0%	53	558	897	1163	1332	1342	1253	1344	1319	1273	1228	1391	149%
24	32	31	24	10	5	4	4	5	5	7	27	-16%	54	349	243	161	127	97	70	84	96	87	96	185	-47%
25	484	784	804	866	917	928	946	958	982	995	996	106%	55	505	636	605	421	437	529	483	436	409	418	518	3%
26	842	1305	1475	1442	1419	1404	1415	1408	1394	1394	1588	89%	56	659	630	470	188	111	77	82	79	80	87	447	-32%
27	307	303	260	178	146	113	93	85	74	68	192	-38%	57	365	288	151	130	112	101	106	114	116	112	178	-51%
28	306	303	259	178	146	113	93	85	74	68	191	-38%	58	1288	1755	1786	1685	1669	1642	1673	1645	1589	1560	1875	46%
29	324	311	265	119	84	67	71	76	87	93	287	-12%	59	809	1050	980	991	978	944	966	975	979	997	1081	34%
30	342	340	260	96	57	38	42	48	59	67	282	-18%													

APPENDIX 9: Scenario 3 Change of PT Services According to Demand Sub-scenario: Change in the Speeds According to the Rate of Users' Preferences Based on Links

Data Collecting Point	Speeds (km/h)											Change (%)	Data Collecting Point	Speeds (km/h)											Change (%)
	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%			0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	
1	49.75	51.16	52.59	52.84	53.00	53.29	52.78	53.09	52.99	52.73	52.63	6%	31	52.11	52.00	51.88	51.64	52.20	52.25	52.16	52.43	51.40	52.67	52.68	1%
2	48.95	49.62	50.00	46.69	47.23	47.38	51.27	50.32	51.92	52.12	50.96	4%	34	31.40	31.90	15.90	14.53	12.41	10.44	12.67	12.12	14.03	16.57	32.21	3%
3	52.95	52.90	52.69	52.83	52.80	52.95	52.77	52.76	52.77	52.79	52.80	0%	35	51.98	51.91	51.81	52.32	40.84	32.70	45.02	33.21	38.28	40.03	52.82	2%
4	50.80	51.03	51.26	50.26	49.37	51.51	51.93	51.29	52.28	52.39	51.74	2%	36	51.22	51.29	18.52	12.24	11.58	12.06	12.01	11.96	12.32	13.88	37.37	-27%
5	51.90	52.19	52.48	52.70	52.77	52.67	52.82	52.86	52.89	52.87	52.73	2%	37	52.07	52.05	51.81	52.22	38.38	23.72	17.24	17.29	18.28	14.62	52.66	1%
6	50.99	51.10	51.27	51.95	52.35	52.02	52.00	52.15	52.30	52.39	51.81	2%	38	52.09	52.03	22.87	12.09	6.80	6.43	5.62	4.74	4.00	5.34	10.07	-81%
7	33.25	27.09	9.72	9.33	9.01	8.49	9.00	9.10	9.24	9.41	11.23	-66%	39	50.90	50.94	50.89	51.02	51.06	50.92	51.14	51.18	51.21	51.25	51.28	1%
8	45.70	41.01	30.62	14.68	11.88	12.52	12.91	15.58	13.51	15.70	39.33	-14%	40	49.90	50.24	50.81	52.15	53.01	48.95	48.92	47.60	47.31	44.76	44.65	-11%
9	46.27	28.05	12.97	17.29	14.14	13.56	12.81	12.87	12.68	12.76	15.60	-66%	41	46.18	48.28	44.11	48.26	49.89	44.68	51.74	48.02	44.44	37.91	52.23	13%
12	51.82	51.90	51.89	52.39	52.43	52.48	52.38	52.24	52.26	52.19	51.83	0%	42	48.39	41.32	34.33	33.66	32.82	32.42	32.03	30.87	29.81	30.14	24.82	-49%
13	50.40	49.12	47.68	49.95	46.88	21.62	8.33	7.54	6.69	6.77	9.11	-82%	43	43.96	44.20	34.36	45.02	45.21	45.05	43.27	36.44	29.44	27.04	37.88	-14%
14	45.36	46.69	46.48	49.73	50.26	49.74	50.12	50.62	51.01	51.15	50.40	11%	44	49.96	50.29	49.58	50.71	50.78	50.53	50.32	42.30	34.47	31.65	38.17	-24%
15	47.33	48.14	47.68	50.03	50.22	50.43	49.91	49.30	50.18	48.99	47.30	0%	45	50.81	51.63	52.50	52.95	53.00	53.01	52.19	51.49	47.89	45.26	52.73	4%
16	52.66	52.65	52.54	52.89	53.19	53.04	52.82	53.03	51.68	52.62	52.87	0%	46	52.44	52.40	52.31	52.55	52.44	51.38	35.75	23.42	16.74	12.87	11.97	-77%
17	51.84	51.90	49.52	52.28	52.45	52.27	52.45	52.72	52.56	52.88	52.74	2%	47	52.13	52.27	52.30	52.72	52.69	52.69	52.58	52.57	52.60	52.55	52.53	1%
18	51.53	51.96	52.27	52.47	52.42	52.64	52.31	52.41	52.48	52.63	52.38	2%	48	52.43	52.54	52.60	52.78	52.76	52.75	52.61	52.84	52.76	52.85	52.69	0%
19	51.63	45.62	23.10	22.02	15.72	13.23	12.36	12.33	12.59	12.32	12.97	-75%	49	52.37	52.44	52.51	52.69	52.74	52.71	52.62	52.78	52.73	52.80	52.64	1%
20	51.76	51.73	51.63	51.54	50.76	48.89	49.15	51.86	52.14	51.36	52.76	2%	50	51.16	51.29	51.51	52.52	52.99	53.17	52.93	53.16	52.75	53.15	53.50	5%
21	48.85	48.50	48.35	49.78	49.60	47.16	49.45	49.48	48.77	46.15	26.75	-45%	51	52.21	52.27	52.17	52.32	52.30	52.31	52.59	52.49	44.76	46.25	52.75	1%
22	52.29	52.34	52.25	52.44	52.48	52.29	52.57	52.62	52.70	52.75	52.79	1%	52	36.62	23.80	15.88	20.61	19.95	19.88	19.48	19.49	19.28	19.18	19.18	-48%
23	52.77	52.77	52.52	52.73	52.76	52.75	52.73	52.73	52.75	52.74	52.76	0%	53	51.87	40.58	24.41	27.39	31.19	27.07	30.11	33.53	33.10	31.67	32.93	-37%
24	53.08	52.74	51.76	38.87	28.11	19.93	20.94	21.28	27.74	36.06	50.50	-5%	54	48.54	50.49	50.95	51.84	52.01	52.55	51.96	51.82	52.09	51.32	49.22	1%
25	40.81	34.20	13.66	21.41	23.43	24.61	23.65	24.24	23.12	23.02	23.03	-44%	55	52.09	51.90	41.75	52.65	52.78	50.46	34.31	32.19	32.00	30.03	33.12	-36%
26	49.73	33.56	17.31	27.05	27.12	27.05	28.66	28.76	28.52	28.43	26.36	-47%	56	48.44	48.84	49.80	52.10	52.85	52.95	53.07	52.88	52.72	52.97	51.88	7%
27	52.52	52.51	52.42	52.71	52.79	52.91	52.52	52.60	52.87	52.86	52.77	0%	57	52.05	52.31	52.53	52.91	52.87	52.83	52.61	52.77	52.78	52.75	52.49	1%
28	51.88	52.01	51.81	52.28	52.39	52.41	52.21	52.39	52.69	52.69	52.20	1%	58	45.91	37.27	11.15	15.67	16.23	17.67	14.97	14.67	14.59	13.47	16.11	-65%
29	33.76	31.17	33.65	51.99	52.27	52.34	52.41	52.50	52.42	52.48	45.44	35%	59	47.20	31.08	12.21	23.32	23.57	22.50	22.50	23.34	22.64	22.30	26.00	-45%
30	50.46	50.36	52.20	52.42	47.32	35.27	39.18	35.59	39.69	44.95	52.60	4%													

APPENDIX 10: Scenario 3 Change of PT Services According to Demand Sub-scenario: Change in the Queue Delays According to the Rate of Users' Preferences Based on Links

Data Collecting Point	Queue Delays (sec)											Change (%)	Data Collecting Point	Queue Delays (sec)											Change (%)
	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%			0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	
1	38.39	90.81	316.46	460.40	648.95	780.21	783.28	631.09	584.29	649.02	358.26	833%	31	81.01	83.16	170.62	192.58	153.42	357.96	683.45	890.81	1002.81	1171.96	1042.06	1186%
2	68.00	78.59	278.79	467.52	359.55	361.92	355.18	292.66	325.50	388.50	322.44	374%	34	7.28	6.03	162.56	618.85	841.14	738.81	570.16	536.66	478.58	370.93	22.24	206%
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-	35	11.87	11.71	111.22	550.80	591.71	699.64	754.77	543.14	673.20	867.88	486.78	4000%
4	67.74	78.57	280.15	438.72	357.74	412.76	360.51	298.03	326.05	388.80	322.89	377%	36	36.89	36.09	333.46	1000.94	1200.86	1202.28	1045.51	899.67	702.49	699.00	259.63	604%
5	26.24	53.76	107.69	109.17	110.82	101.05	114.19	108.40	99.43	107.41	152.06	480%	37	0.19	0.27	98.05	510.91	686.13	506.76	236.12	264.03	340.24	317.12	402.01	215165%
6	68.97	78.59	282.84	439.33	387.53	420.43	359.74	300.87	323.64	391.06	326.24	373%	38	0.00	0.00	52.44	247.64	364.21	360.46	375.70	475.89	545.72	422.18	271.37	-
7	10.07	25.44	50.42	91.35	95.93	98.85	93.97	93.77	93.56	94.27	91.51	809%	39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-100%
8	19.68	28.36	63.86	217.02	236.94	231.82	213.92	184.25	193.97	183.41	86.02	337%	40	21.23	23.90	256.86	909.04	1517.22	1566.17	1500.51	1357.17	1206.78	1077.93	529.55	2394%
9	115.04	163.39	365.69	558.26	707.82	838.88	877.98	890.65	924.51	958.33	839.45	630%	41	26.22	22.83	52.89	98.85	115.56	94.90	64.69	96.49	113.76	176.38	85.23	225%
12	20.44	29.72	40.87	64.59	65.19	56.66	63.79	63.43	61.71	57.36	32.44	59%	42	68.50	220.45	554.96	844.50	849.72	845.94	843.62	868.55	914.37	907.28	660.22	864%
13	69.12	61.67	125.20	116.57	78.74	219.65	540.16	760.31	860.70	1004.39	949.82	1274%	43	53.13	43.96	72.91	135.56	161.64	146.76	98.10	177.88	214.02	335.83	142.92	169%
14	69.27	78.72	290.75	448.99	393.69	429.66	379.60	306.40	351.95	399.39	334.83	383%	44	84.78	73.36	66.08	55.10	40.08	42.62	45.06	87.60	103.97	213.37	164.16	94%
15	72.65	70.85	158.47	216.09	165.24	362.21	705.31	888.70	1083.54	1182.50	1024.18	1310%	45	17.10	16.18	32.45	29.16	17.50	11.60	12.82	16.22	15.10	36.31	93.85	449%
16	51.26	59.79	334.65	464.75	395.52	441.87	383.12	341.23	359.16	581.27	409.11	698%	46	69.76	54.92	91.33	70.64	46.10	34.51	108.10	180.89	219.92	318.96	478.54	586%
17	59.71	58.18	117.40	156.65	168.11	341.13	559.18	652.38	835.63	846.00	652.42	993%	47	24.53	45.73	70.91	105.43	113.53	94.21	112.22	102.01	100.69	100.65	82.85	238%
18	29.73	43.99	73.06	342.01	395.47	421.85	347.04	257.28	276.58	252.08	73.55	147%	48	24.42	40.97	60.20	84.85	68.83	73.01	93.13	73.79	80.07	69.07	85.29	249%
19	9.79	21.26	128.27	238.80	429.00	697.18	853.08	951.91	1137.42	1233.13	993.47	10051%	49	24.43	40.63	60.10	84.65	69.02	73.08	93.15	73.68	80.21	68.44	85.40	250%
20	42.22	58.80	88.71	395.64	384.18	390.29	309.19	261.13	344.26	234.77	84.33	100%	50	65.59	84.09	314.71	870.29	1152.62	1229.05	1233.05	1148.06	1162.04	1146.26	575.94	778%
21	138.69	162.71	371.75	598.78	754.54	844.55	944.54	1012.90	1013.63	1050.17	635.35	358%	51	84.84	72.58	65.89	53.37	36.98	44.03	39.71	63.56	75.43	130.40	126.76	49%
22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-	52	120.35	372.25	788.43	970.47	964.62	966.46	956.53	931.73	932.07	923.18	736.15	512%
23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-	53	39.52	20.89	56.59	136.08	119.68	154.91	120.69	120.11	123.72	146.46	121.05	206%
24	32.25	33.13	131.53	354.02	349.80	207.49	176.75	83.90	153.76	233.15	133.13	313%	54	112.09	166.85	433.79	393.61	346.88	434.44	547.74	573.82	626.66	623.02	512.08	357%
25	48.57	54.45	246.74	483.08	480.63	452.44	441.94	403.94	420.19	405.16	176.09	263%	55	15.22	17.01	226.70	651.33	862.92	886.84	1082.19	1161.51	1303.83	1223.68	649.89	4169%
26	137.67	129.00	332.44	532.17	575.41	653.81	664.98	643.97	594.21	607.73	470.27	242%	56	69.13	84.39	283.29	655.68	709.28	621.90	721.30	697.14	889.10	880.18	521.60	654%
27	70.57	72.00	165.84	184.17	164.16	352.22	695.61	907.68	1059.27	1189.32	1039.08	1372%	57	29.61	66.33	145.00	156.99	172.72	151.81	197.77	164.74	150.40	166.45	202.40	584%
28	70.49	71.84	163.51	184.91	164.79	348.95	690.70	896.83	1057.38	1185.15	1037.80	1372%	58	43.85	41.65	246.80	428.59	447.82	535.90	532.21	494.06	464.75	484.46	382.13	771%
29	70.78	93.14	138.60	285.40	266.88	166.37	167.90	134.63	156.65	156.04	130.99	85%	59	100.10	126.33	438.60	614.33	614.27	613.73	625.72	586.83	616.57	613.66	427.63	327%
30	19.68	20.83	134.04	654.52	829.29	675.46	520.55	479.60	410.56	405.27	154.09	683%													

APPENDIX 11: Scenario 3 Continuation of Existing PT Services Sub-scenario: Change in the Number of Vehicles According to the Rate of Users' PT Preferences Based on Links

Data Collecting Point	Number of Vehicles											Change (%)	Data Collecting Point	Number of Vehicles											Change (%)
	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%			0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	
1	743	526	173	112	84	57	66	81	80	98	287	-61%	31	187	185	155	107	84	66	54	46	39	31	68	-64%
2	396	366	254	143	131	113	132	133	126	129	233	-41%	34	586	586	399	192	150	126	143	166	205	230	516	-12%
3	557	557	557	557	557	557	557	557	557	557	557	0%	35	417	416	319	89	31	17	11	12	9	7	263	-37%
4	397	366	254	153	137	118	136	134	127	128	234	-41%	36	541	539	352	140	95	70	78	96	120	137	375	-31%
5	1059	850	505	446	419	392	401	415	415	432	616	-42%	37	542	542	412	104	30	14	7	7	5	3	365	-33%
6	381	356	251	156	138	117	136	133	125	126	228	-40%	38	1846	2112	1953	1064	829	806	668	632	581	552	1508	-18%
7	1133	1347	1139	1029	1039	1029	1026	1050	1057	1069	1122	-1%	39	3257	3257	3257	3257	3257	3257	3258	3257	3258	3258	3258	0%
8	1254	1667	1678	1271	1283	1252	1338	1338	1401	1452	1508	20%	40	1296	1293	896	274	112	63	62	69	83	89	851	-34%
9	1562	2072	2168	2091	1984	1798	1913	1924	1967	2023	2330	49%	41	2362	2389	2341	2413	2373	2200	2119	1948	1644	1522	1792	-24%
12	1177	1204	1143	794	795	773	824	818	845	878	983	-17%	42	559	926	949	841	837	843	809	789	756	746	772	38%
13	1156	1271	1212	1050	1053	947	856	826	791	729	870	-25%	43	1315	1400	1419	1489	1488	1285	1187	1026	827	798	1002	-24%
14	389	361	252	159	140	120	137	134	125	126	231	-41%	44	786	793	771	719	707	688	624	537	435	441	440	-44%
15	196	193	159	106	87	68	55	49	43	33	72	-63%	45	1284	1286	1236	1148	1127	1119	1083	1023	910	903	921	-28%
16	283	270	199	130	110	95	103	98	85	80	167	-41%	46	857	985	1009	981	1071	1145	1065	1002	928	835	793	-7%
17	340	337	287	214	154	106	105	99	95	98	172	-49%	47	674	712	657	384	373	352	379	378	391	406	496	-26%
18	689	700	599	222	223	195	257	252	283	324	446	-35%	48	192	163	116	98	95	90	95	98	100	103	131	-32%
19	727	852	836	850	720	587	656	670	697	768	880	21%	49	192	163	116	98	95	90	96	98	100	103	131	-32%
20	533	575	357	142	142	123	164	164	185	214	315	-41%	50	952	902	625	221	109	69	71	76	87	94	580	-39%
21	823	929	850	656	624	654	606	588	534	519	697	-15%	51	409	412	402	377	371	363	338	294	242	238	245	-40%
22	33	33	33	33	33	33	33	33	33	33	33	0%	52	508	735	757	764	774	760	773	777	768	765	692	36%
23	33	33	33	33	33	33	33	33	33	33	33	0%	53	558	896	1148	1321	1361	1254	1335	1315	1241	1221	1276	129%
24	32	31	22	9	5	4	4	5	7	7	25	-20%	54	349	238	158	123	97	69	87	91	93	105	153	-56%
25	484	783	811	862	904	918	927	951	964	969	895	85%	55	505	636	589	414	432	523	457	441	405	399	484	-4%
26	842	1308	1464	1423	1420	1397	1402	1391	1377	1378	1526	81%	56	659	628	448	180	107	77	76	76	81	84	397	-40%
27	307	303	253	176	141	111	89	74	66	52	116	-62%	57	365	286	147	127	115	101	107	114	116	119	193	-47%
28	306	302	253	176	141	111	88	74	66	52	115	-62%	58	1288	1747	1767	1670	1672	1628	1650	1618	1557	1548	1755	36%
29	324	314	256	115	81	69	71	78	87	94	275	-15%	59	809	1036	985	977	968	936	949	968	966	974	954	18%
30	342	338	247	91	53	40	42	50	61	68	269	-21%													

APPENDIX 12: Scenario 3 Continuation of Existing PT Services Sub-scenario: Change in the Speeds According to the Rate of Users' PT Preferences Based on Links

Data Collecting Point	Speeds (km/h)											Change (%)	Data Collecting Point	Speeds (km/h)											Data Collecting Point
	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%			0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	
1	49.75	51.21	52.70	52.87	53.16	53.20	53.05	53.05	52.94	52.83	52.54	6%	31	52.11	52.02	51.94	52.30	52.22	52.52	52.21	52.42	50.03	51.30	50.01	-4%
2	48.95	49.59	50.09	45.89	48.12	48.62	49.99	50.56	51.64	52.06	50.39	3%	34	31.40	31.90	15.19	14.77	11.76	11.54	12.56	12.53	14.10	16.68	31.56	1%
3	52.95	52.90	52.69	52.83	52.80	52.95	52.77	52.76	52.77	52.79	52.80	0%	35	51.98	52.04	51.97	52.44	43.77	36.70	34.02	34.20	34.43	39.71	51.84	0%
4	50.80	51.00	51.23	50.05	50.63	51.86	52.01	51.88	52.45	52.39	51.91	2%	36	51.22	51.29	17.10	12.21	11.06	12.26	12.61	13.01	12.14	13.58	42.29	-17%
5	51.90	52.20	52.50	52.71	52.78	52.65	52.84	52.86	52.88	52.88	52.65	1%	37	52.07	52.04	51.84	52.37	34.61	23.73	13.20	17.19	19.66	14.62	51.45	-1%
6	50.99	50.89	51.13	52.05	52.10	51.96	52.25	52.35	52.47	52.40	52.00	2%	38	52.09	52.01	19.32	12.42	7.17	6.42	6.22	5.47	4.81	5.28	15.20	-71%
7	33.25	27.13	9.89	9.35	9.45	8.84	9.28	9.41	9.41	9.46	12.26	-63%	39	50.90	50.94	50.88	51.02	51.06	50.92	51.14	51.18	51.21	51.25	51.28	1%
8	45.70	41.01	29.86	14.01	12.34	12.95	13.78	14.28	16.47	20.42	38.06	-17%	40	49.90	50.25	50.37	52.01	51.55	53.00	42.28	46.11	45.35	47.55	39.95	-20%
9	46.27	27.93	12.33	16.56	14.25	13.45	12.82	12.97	12.89	13.10	18.23	-61%	41	46.18	48.59	40.30	45.72	50.54	44.27	51.47	47.74	39.41	33.26	35.47	-23%
12	51.82	51.80	51.89	52.36	52.39	52.47	52.36	52.21	52.15	52.05	51.92	0%	42	48.39	41.41	34.38	33.84	32.78	32.47	31.35	30.59	28.63	29.41	24.32	-50%
13	50.40	48.96	48.35	49.84	42.56	20.55	8.31	7.64	7.66	7.24	11.69	-77%	43	43.96	44.25	34.17	45.18	45.30	44.85	40.44	34.68	28.35	26.54	33.49	-24%
14	45.36	46.29	47.38	49.68	49.96	49.59	50.43	50.62	51.26	51.47	50.22	11%	44	49.96	50.15	49.27	50.69	50.72	50.48	48.27	40.21	34.79	28.37	27.90	-44%
15	47.33	47.83	48.29	50.03	50.27	50.14	50.30	50.31	47.35	46.10	45.74	-3%	45	50.81	51.60	52.45	52.97	52.98	52.91	51.81	50.70	43.16	44.72	42.96	-15%
16	52.66	52.77	52.64	53.08	52.96	52.98	52.87	53.04	53.01	50.35	52.92	0%	46	52.44	52.38	52.34	52.54	52.44	49.60	32.84	22.55	16.46	14.41	14.56	-72%
17	51.84	51.89	51.38	52.28	52.42	52.16	52.65	52.76	52.67	50.00	52.07	0%	47	52.13	52.28	52.29	52.66	52.76	52.67	52.62	52.67	52.63	52.57	52.45	1%
18	51.53	51.91	52.23	52.35	52.47	52.56	52.55	52.38	52.32	52.58	52.48	2%	48	52.43	52.55	52.52	52.86	52.70	52.78	52.86	52.86	52.75	52.75	52.75	1%
19	51.63	46.20	20.48	21.65	15.79	13.18	12.61	14.02	13.26	14.68	15.95	-69%	49	52.37	52.39	52.41	52.90	52.66	52.73	52.86	52.82	52.72	52.71	52.68	1%
20	51.76	51.68	51.61	50.24	48.91	51.26	51.72	52.18	52.14	52.51	49.83	-4%	50	51.16	51.19	51.30	52.37	52.98	52.89	53.01	53.40	53.19	53.07	47.99	-6%
21	48.85	48.44	47.53	49.61	49.46	48.91	49.18	48.98	48.55	47.52	30.02	-39%	51	52.21	52.19	52.08	52.33	52.28	52.30	52.50	51.34	48.67	46.34	51.50	-1%
22	52.29	52.34	52.25	52.44	52.48	52.29	52.57	52.62	52.70	52.75	52.79	1%	52	36.62	23.66	16.40	20.46	20.00	19.79	19.61	19.45	19.39	19.22	17.99	-51%
23	52.77	52.78	52.52	52.72	52.77	52.74	52.73	52.73	52.75	52.73	52.76	0%	53	51.87	40.52	21.57	27.43	31.44	26.88	31.90	31.85	32.62	32.26	32.26	-38%
24	53.08	52.84	51.56	36.56	22.62	22.65	21.24	23.95	27.89	34.60	48.93	-8%	54	48.54	50.69	50.52	52.16	52.34	52.51	52.24	51.94	51.39	51.07	48.17	-1%
25	40.81	33.88	14.24	21.24	23.39	24.80	23.62	23.37	22.42	21.14	21.67	-47%	55	52.09	51.95	47.02	52.68	52.80	47.53	31.52	31.09	30.82	28.73	38.80	-26%
26	49.73	33.61	18.06	27.23	27.14	27.12	28.09	28.62	28.38	27.44	25.74	-48%	56	48.44	48.69	50.02	52.32	52.68	52.76	52.69	53.22	53.14	52.87	51.94	7%
27	52.52	52.52	52.40	52.56	52.78	52.90	52.75	52.53	53.00	52.88	52.79	1%	57	52.05	52.28	52.57	52.79	52.75	52.78	52.75	52.88	52.78	52.81	52.45	1%
28	51.88	51.96	51.75	52.17	52.32	52.29	52.41	52.23	52.68	52.48	51.66	0%	58	45.91	37.15	10.81	15.96	16.52	17.63	14.44	13.30	13.76	12.78	17.08	-63%
29	33.76	32.49	39.39	52.07	52.39	52.39	52.46	52.46	52.45	52.50	44.10	31%	59	47.20	30.44	12.06	23.06	23.17	22.36	23.03	23.12	22.36	22.57	26.32	-44%
30	50.46	49.94	52.43	52.53	44.86	42.23	31.65	38.31	36.89	46.25	49.81	-1%													

APPENDIX 13: Scenario 3 Continuation of Existing PT Services Sub-scenario: Change in the Queue Delays According to the Rate of Users' PT Preferences Based on Links

Data Collecting Point	Queue Delays (sec)											Change (%)	Data Collecting Point	Queue Delays (sec)											Change (%)
	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%			0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	
1	38.39	86.07	348.88	509.00	581.36	735.28	723.30	654.17	682.57	610.66	330.21	760%	31	81.01	80.66	182.27	185.57	173.56	387.43	709.49	1009.56	1113.73	1267.69	1099.42	1257%
2	68.00	80.64	302.03	419.72	365.80	411.27	319.56	375.68	353.49	354.57	324.06	377%	34	7.28	6.10	182.45	719.84	909.82	1002.43	487.78	492.94	466.01	370.36	23.46	222%
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-	35	11.87	11.34	138.94	607.52	770.09	842.64	693.76	664.52	735.66	937.22	428.71	3511%
4	67.74	80.62	302.85	420.79	372.15	418.32	323.69	359.71	357.18	355.05	326.68	382%	36	36.89	35.39	366.24	967.78	1197.95	1408.21	906.80	937.90	807.30	826.22	210.81	471%
5	26.24	51.41	114.76	116.19	106.94	97.89	108.98	114.10	115.49	114.17	144.98	453%	37	0.19	0.33	123.71	582.72	643.99	512.54	136.41	309.79	401.65	311.42	320.54	171540%
6	68.97	80.44	304.82	440.68	362.00	422.91	324.97	357.92	358.59	363.50	328.01	376%	38	0.00	0.00	68.37	236.46	365.00	361.67	367.87	456.02	529.16	462.31	231.92	-
7	10.07	25.70	50.41	93.05	88.99	97.09	93.24	91.92	93.23	89.47	88.96	783%	39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-100%
8	19.68	28.49	61.32	223.02	215.38	229.90	198.50	198.59	174.64	146.82	95.21	384%	40	21.23	24.01	298.62	987.12	1489.02	1756.42	1231.47	1400.88	1144.03	1232.35	437.26	1959%
9	115.04	163.93	411.13	582.28	693.28	846.25	864.05	912.52	920.02	918.47	757.97	559%	41	26.22	23.71	60.25	97.79	114.04	93.74	64.52	70.84	133.31	188.39	190.13	625%
12	20.44	29.56	40.58	61.69	65.63	57.72	61.76	57.22	57.61	51.43	29.87	46%	42	68.50	232.62	555.44	833.77	839.14	847.58	865.47	897.68	916.81	903.07	781.82	1041%
13	69.12	63.41	131.92	112.16	80.58	253.92	594.47	849.03	985.57	1138.40	1096.40	1486%	43	53.13	44.72	84.72	139.91	158.56	146.79	119.68	177.38	354.98	329.55	377.22	610%
14	69.27	80.74	314.83	448.93	370.84	430.77	332.00	363.91	362.03	370.78	341.95	394%	44	84.78	74.49	67.24	48.35	37.28	47.18	60.53	115.06	250.31	241.93	459.94	443%
15	72.65	74.06	169.81	186.53	187.71	385.78	744.29	986.01	1176.26	1190.62	1132.47	1459%	45	17.10	16.33	31.86	25.92	15.95	13.93	15.64	19.07	37.36	33.17	155.74	811%
16	51.26	61.30	365.47	462.38	376.74	438.05	337.79	400.07	520.44	514.20	480.53	837%	46	69.76	56.11	94.42	68.36	43.00	40.39	141.94	252.59	334.47	385.07	632.58	807%
17	59.71	60.30	130.36	145.61	177.65	360.46	535.98	665.19	749.02	562.97	526.82	782%	47	24.53	43.99	72.50	111.31	110.33	98.50	99.25	105.71	100.57	89.48	83.58	241%
18	29.73	44.29	70.68	388.32	351.01	389.97	307.79	294.29	240.31	173.57	81.47	174%	48	24.42	37.93	60.07	81.56	77.97	93.15	80.21	70.85	78.36	77.30	77.54	217%
19	9.79	18.41	163.06	257.53	438.12	716.28	851.41	991.32	1088.97	1043.66	773.52	7804%	49	24.43	37.87	59.98	81.08	78.16	92.91	79.00	70.16	78.59	76.58	77.02	215%
20	42.22	58.82	84.54	384.79	328.37	405.54	305.48	319.08	223.14	178.12	115.59	174%	50	65.59	85.87	355.94	908.99	1181.45	1266.85	1178.44	1205.17	1159.55	1123.66	545.99	732%
21	138.69	160.77	385.62	608.22	740.92	857.26	914.72	998.44	1047.04	1061.13	621.56	348%	51	84.84	74.95	67.44	52.69	37.33	49.87	52.73	80.27	181.44	196.99	313.24	269%
22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-	52	120.35	398.84	773.17	964.99	953.36	960.43	952.97	951.19	926.68	909.25	767.06	537%
23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-	53	39.52	21.26	75.68	141.73	113.09	158.74	118.91	118.98	137.14	141.74	143.48	263%
24	32.25	34.53	159.30	288.27	208.24	305.40	162.74	142.66	194.86	206.23	103.53	221%	54	112.09	182.02	413.84	349.92	356.23	455.26	541.25	585.04	617.14	525.43	470.01	319%
25	48.57	55.45	244.18	484.55	462.95	460.17	433.78	426.42	402.92	385.55	229.13	372%	55	15.22	17.50	252.12	643.79	855.05	900.97	1023.40	1130.56	1203.03	1263.05	499.90	3184%
26	137.67	127.11	362.12	542.71	564.70	663.03	642.08	660.27	600.54	591.16	463.24	236%	56	69.13	86.01	316.56	666.70	708.15	658.30	684.68	849.82	924.48	874.97	600.63	769%
27	70.57	71.46	169.96	182.62	177.82	396.52	719.76	1016.98	1219.36	1376.41	1159.44	1543%	57	29.61	60.72	156.89	180.67	166.50	170.77	154.59	179.99	170.73	166.13	184.77	524%
28	70.49	71.42	167.72	182.04	175.39	390.85	714.00	1014.72	1218.54	1370.28	1161.89	1548%	58	43.85	41.94	292.43	430.68	429.64	542.12	501.11	527.27	480.67	472.73	356.24	712%
29	70.78	94.95	137.40	298.80	268.00	226.01	116.02	166.34	107.86	183.12	115.74	64%	59	100.10	137.46	427.06	607.69	599.91	622.03	610.18	616.34	609.20	588.99	442.21	342%
30	19.68	20.40	158.95	724.05	825.91	893.45	347.36	464.66	310.57	419.35	112.85	473%													

APPENDIX 14: Scenario 4 Change of Number of Vehicles According to the Rate of Autonomous Vehicles Based on Links

Data Collecting Point	Number of Vehicles											Change (%)	Data Collecting Point	Number of Vehicles											Change (%)
	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%			0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	
1	743	85	52	42	37	100	17	36	29	31	750	0.94%	31	187	63	52	46	35	8	1	1	1	1	191	2.14%
2	396	69	39	28	22	22	20	27	26	38	400	0.98%	34	586	346	363	385	407	581	587	515	349	294	588	0.27%
3	557	557	557	557	557	557	557	557	557	557	557	0.00%	35	417	20	21	24	28	5	66	88	110	111	419	0.38%
4	397	69	39	28	22	22	20	26	26	38	400	0.88%	36	541	249	252	263	271	401	407	326	208	168	544	0.65%
5	1059	419	388	378	372	433	353	372	365	367	1066	0.65%	37	542	7	12	19	30	2	96	129	158	160	542	-0.02%
6	381	67	38	27	22	20	20	26	26	38	385	1.02%	38	1846	211	229	241	291	149	524	619	727	695	1846	0.01%
7	1133	84	98	110	119	92	93	157	139	126	1135	0.17%	39	3257	3256	3257	3257	3257	2369	3257	3257	3258	3258	3258	0.02%
8	1254	134	150	172	178	142	202	240	226	217	1262	0.65%	40	1296	205	213	238	267	238	475	435	413	373	1303	0.52%
9	1562	657	416	329	277	755	251	247	195	208	1610	3.10%	41	2362	1216	600	376	254	292	632	794	1032	1201	2393	1.31%
12	1177	593	616	623	627	558	636	653	658	663	1180	0.22%	42	559	305	296	269	230	222	151	155	128	95	568	1.72%
13	1156	419	382	351	312	74	190	212	216	211	1184	2.39%	43	1315	787	472	330	231	350	367	451	532	596	1594	21.23%
14	389	68	38	28	21	20	20	26	25	37	393	0.98%	44	786	476	533	493	419	425	189	216	184	159	811	3.22%
15	196	68	63	59	52	12	28	34	35	34	200	1.99%	45	1284	789	881	896	818	718	505	457	397	349	1290	0.43%
16	283	68	37	25	18	20	15	19	17	27	287	1.27%	46	857	367	328	291	253	134	190	217	232	236	876	2.22%
17	340	176	132	109	93	134	58	64	61	57	344	1.09%	47	674	229	256	267	282	150	287	300	293	290	678	0.62%
18	689	13	19	24	28	17	41	59	64	71	697	1.13%	48	192	14	22	29	37	10	50	62	66	71	193	0.42%
19	727	517	301	221	165	620	109	99	84	77	728	0.01%	49	192	14	22	28	36	10	50	62	66	71	193	0.63%
20	533	51	51	53	46	52	42	38	23	14	537	0.79%	50	952	168	168	185	200	104	256	238	240	241	962	1.06%
21	823	260	220	208	199	235	244	235	198	199	876	6.35%	51	409	248	275	264	229	225	106	116	96	81	420	2.89%
22	33	33	33	33	33	33	33	33	33	33	33	0.00%	52	508	134	126	111	102	104	78	78	65	57	540	6.26%
23	33	33	33	33	33	33	33	33	33	33	33	0.00%	53	558	269	132	85	59	80	156	189	218	256	567	1.65%
24	32	10	11	12	14	17	19	18	14	14	32	2.54%	54	349	91	73	64	55	72	38	38	32	30	373	6.85%
25	484	56	56	59	52	57	48	43	27	17	538	11.22%	55	505	13	19	28	40	16	122	108	90	80	507	0.42%
26	842	274	231	221	211	248	250	242	201	202	894	6.21%	56	659	117	138	148	154	89	178	166	166	165	669	1.58%
27	307	105	84	75	58	14	4	3	3	3	313	1.89%	57	365	79	84	96	100	73	98	105	92	84	369	1.01%
28	306	105	84	75	58	14	4	3	3	3	312	1.89%	58	1288	323	203	171	156	134	217	222	202	251	1280	-0.67%
29	324	125	130	138	147	190	221	209	168	154	347	7.22%	59	809	230	190	167	145	189	108	108	88	76	869	7.37%
30	342	103	109	118	128	175	207	194	150	135	348	1.87%													

APPENDIX 15: Scenario 4 Change of Speeds According to the Rate of Autonomous Vehicles Based on Links

Data Collecting Point	Speeds (km/h)											Change (%)	Data Collecting Point	Speeds (km/h)											Data Collecting Point
	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%			0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	
1	49.75	52.58	52.43	52.45	52.72	52.90	51.28	51.43	50.30	42.65	52.02	4.57%	31	52.11	52.65	52.67	52.45	51.38	38.88	14.92	14.42	7.76	4.00	52.15	0.09%
2	48.95	51.82	52.49	50.99	52.81	52.82	47.61	52.99	52.65	52.36	49.42	0.98%	34	31.40	21.11	16.05	23.94	25.04	30.90	34.37	32.15	24.72	20.65	34.78	10.77%
3	52.95	52.90	52.69	52.83	52.80	52.95	52.77	52.76	52.77	52.79	52.80	-0.28%	35	51.98	52.93	52.92	53.16	53.10	36.78	52.78	50.12	44.92	34.13	52.37	0.76%
4	50.80	52.16	52.89	51.37	53.06	53.06	47.78	53.17	52.72	52.39	51.93	2.23%	36	51.22	28.87	22.09	30.90	33.99	48.67	51.63	44.76	30.34	25.79	52.45	2.41%
5	51.90	52.66	52.46	52.71	52.79	52.69	52.83	52.80	52.86	52.90	52.07	0.32%	37	52.07	37.15	42.85	48.46	46.07	13.44	52.63	49.99	44.75	32.75	52.45	0.73%
6	50.99	52.12	52.64	51.19	52.83	52.76	46.43	53.05	52.75	52.48	52.01	2.00%	38	52.09	11.15	4.49	9.98	10.90	17.02	37.98	38.39	29.82	25.72	52.76	1.28%
7	33.25	10.32	6.66	11.11	11.93	10.01	10.80	14.70	14.05	13.41	35.18	5.79%	39	50.90	50.48	50.76	51.21	51.38	40.43	51.24	51.44	51.55	51.53	51.28	0.74%
8	45.70	11.07	5.63	13.92	15.17	13.33	14.84	15.07	11.53	11.04	51.42	12.51%	40	49.90	52.06	49.29	50.48	51.46	20.14	36.61	39.99	42.64	39.39	51.18	2.56%
9	46.27	49.29	46.30	49.06	49.00	47.79	50.62	51.60	52.51	52.34	49.39	6.75%	41	46.18	39.87	12.38	39.02	37.86	18.41	37.53	40.73	37.01	28.98	52.15	12.94%
12	51.82	49.98	51.03	52.07	52.06	45.50	51.95	51.75	51.70	51.42	50.74	-2.09%	42	48.39	50.33	49.42	49.72	49.70	19.46	45.46	48.60	49.48	49.16	48.58	0.40%
13	50.40	51.46	49.70	51.29	47.80	50.51	25.60	15.43	11.75	10.24	51.16	1.51%	43	43.96	45.83	46.08	50.46	51.19	48.84	48.93	47.00	44.64	42.65	39.59	-9.94%
14	45.36	49.99	51.50	49.57	51.67	49.95	45.60	51.82	52.27	52.19	51.58	13.71%	44	49.96	51.14	41.27	41.55	37.46	45.30	23.00	26.20	23.13	19.66	50.81	1.70%
15	47.33	50.40	50.44	50.19	48.79	40.50	43.03	48.04	48.72	48.29	46.95	-0.81%	45	50.81	27.51	20.57	33.70	40.13	26.33	24.84	28.90	25.36	22.40	52.87	4.04%
16	52.66	52.71	50.14	49.87	53.10	51.24	42.52	42.29	35.68	52.94	52.65	-0.02%	46	52.44	52.60	52.53	52.73	52.65	39.08	52.82	52.49	49.42	46.85	52.56	0.23%
17	51.84	52.51	52.37	52.25	51.19	51.14	47.53	52.94	52.93	52.82	52.77	1.78%	47	52.13	52.11	51.72	51.84	51.73	21.77	50.28	50.92	52.33	52.36	52.24	0.20%
18	51.53	43.07	45.33	49.80	48.26	45.44	51.26	52.23	52.17	52.39	51.46	-0.12%	48	52.43	45.41	52.67	52.79	53.05	47.29	52.91	52.86	52.72	52.69	52.62	0.36%
19	51.63	34.54	13.85	22.97	20.01	37.28	13.09	12.77	11.01	10.85	52.30	1.30%	49	52.37	45.39	52.54	52.75	53.02	47.19	52.93	52.79	52.68	52.66	52.50	0.24%
20	51.76	52.44	52.55	52.58	52.49	52.51	52.78	52.37	50.18	44.37	52.73	1.88%	50	51.16	52.05	52.11	51.98	52.14	52.97	51.99	51.75	52.15	50.60	53.76	5.08%
21	48.85	51.46	51.53	51.80	52.05	50.79	51.81	51.90	51.92	51.97	44.84	-8.22%	51	52.21	52.16	52.13	52.39	52.35	52.17	52.80	53.03	52.98	53.15	52.77	1.08%
22	52.29	52.34	52.25	52.44	52.48	52.29	52.57	52.62	52.70	52.75	52.79	0.95%	52	36.62	45.63	39.79	44.91	45.28	42.85	43.89	44.02	43.59	46.44	30.52	-16.65%
23	52.77	52.76	52.54	52.72	52.74	52.74	52.73	52.73	52.75	52.74	52.76	-0.02%	53	51.87	50.45	45.44	47.61	46.81	48.56	49.07	47.66	41.03	36.80	52.20	0.64%
24	53.08	45.07	45.55	45.15	46.41	53.50	53.04	51.19	39.77	31.65	53.02	-0.11%	54	48.54	51.82	51.90	51.53	52.09	51.64	51.10	52.14	46.92	50.25	46.33	-4.56%
25	40.81	47.62	44.25	47.28	46.97	47.26	46.44	46.05	44.85	41.83	33.89	-16.96%	55	52.09	43.68	43.76	48.70	44.93	49.95	43.24	23.26	14.69	13.30	52.58	0.94%
26	49.73	50.90	49.44	50.82	50.69	50.42	52.39	52.92	53.39	53.23	52.75	6.06%	56	48.44	24.25	52.42	52.31	52.32	52.86	52.45	52.00	52.46	52.43	51.35	6.01%
27	52.52	52.67	52.64	52.73	51.53	46.88	28.14	21.03	13.16	11.94	52.57	0.10%	57	52.05	49.35	50.03	51.27	52.09	48.50	52.88	52.63	52.66	52.62	52.12	0.13%
28	51.88	52.46	52.60	52.59	51.33	46.82	29.17	20.89	13.05	12.05	51.93	0.09%	58	45.91	49.60	46.03	47.33	45.57	33.15	16.76	14.74	11.64	12.17	48.79	6.26%
29	33.76	52.21	52.03	51.99	52.16	51.78	52.20	52.20	52.24	52.08	50.69	50.15%	59	47.20	48.90	47.19	48.88	48.30	48.02	47.30	47.16	48.82	50.29	45.20	-4.24%
30	50.46	52.66	51.13	49.82	51.29	52.48	52.54	51.27	47.43	35.26	52.53	4.10%													

APPENDIX 16: Scenario 4 Change of Queue Delays According to the Rate of Autonomous Vehicles Based on Links

Data Collecting Point	Queue Delays (sec)											Change (%)	Data Collecting Point	Queue Delays (sec)											Change (%)
	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%			0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	
1	38.39	409.51	680.88	776.71	587.43	298.53	524.31	279.31	366.04	442.84	22.37	-41.75%	31	81.01	422.52	414.40	525.91	637.91	412.99	282.48	256.09	113.15	45.15	53.68	-33.73%
2	68.00	337.43	440.92	487.40	539.58	779.72	965.90	1103.52	1073.55	1159.77	54.78	-19.44%	34	7.28	292.93	237.82	197.23	146.06	10.50	1.70	16.99	190.40	57.89	0.87	-88.06%
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-	35	11.87	679.68	696.62	870.82	905.59	230.35	20.39	71.92	322.75	255.20	8.29	-30.21%
4	67.74	338.17	440.92	487.55	540.51	778.55	974.02	1103.98	1080.17	1161.58	54.72	-19.22%	36	36.89	532.62	456.25	416.62	376.65	37.92	13.83	81.79	329.51	108.89	21.61	-41.41%
5	26.24	79.53	85.90	87.50	69.24	67.79	29.98	23.27	17.56	15.88	15.42	-41.22%	37	0.19	929.30	987.45	1172.24	934.36	13.77	12.57	93.56	315.82	213.38	0.17	-7.63%
6	68.97	337.46	456.80	477.38	538.89	856.51	935.60	1102.56	1096.25	1165.66	56.30	-18.37%	38	0.00	899.05	919.43	866.22	751.73	703.97	197.89	196.32	298.82	261.32	0.00	
7	10.07	404.15	343.63	323.86	318.31	348.77	341.87	305.43	415.57	505.51	4.48	-55.49%	39	0.00	0.00	0.00	0.00	0.00	37.08	0.00	0.00	0.00	0.00	0.00	-100.00%
8	19.68	817.81	696.27	640.91	643.90	714.24	604.26	601.16	695.78	760.57	13.82	-29.79%	40	21.23	1308.56	1179.79	1171.47	1081.23	697.66	317.04	472.16	671.66	419.01	14.31	-32.60%
9	115.04	414.11	629.65	726.12	633.73	332.84	336.66	370.25	508.69	706.04	66.27	-42.39%	41	26.22	161.55	375.35	469.59	568.08	398.57	187.15	213.14	229.23	226.53	20.93	-20.16%
12	20.44	47.19	31.97	34.94	39.38	81.50	46.70	66.40	78.85	94.33	16.19	-20.76%	42	68.50	501.63	454.60	527.32	624.65	493.95	765.55	607.55	769.91	772.27	41.69	-39.14%
13	69.12	436.25	419.69	573.51	656.21	371.28	500.79	775.57	1098.31	1174.30	43.32	-37.32%	43	53.13	195.63	177.55	262.95	294.35	414.74	406.43	298.92	344.85	384.10	28.60	-46.16%
14	69.27	349.69	462.52	475.02	547.22	854.80	943.61	1109.42	1109.20	1191.00	56.43	-18.54%	44	84.78	223.60	201.79	365.32	540.32	197.17	1263.52	952.36	1109.67	1299.91	23.96	-71.73%
15	72.65	417.40	447.07	600.96	734.56	400.82	591.93	961.38	1220.30	1316.76	45.35	-37.58%	45	17.10	82.10	74.03	95.96	127.88	37.03	202.56	183.93	229.45	276.31	8.95	-47.62%
16	51.26	317.28	387.63	437.48	505.90	837.14	990.44	944.35	896.10	1243.89	39.26	-23.41%	46	69.76	338.41	329.58	486.14	593.04	384.02	443.67	548.38	670.79	732.11	39.01	-44.07%
17	59.71	222.81	349.74	515.38	653.58	118.27	600.05	908.89	1112.36	1169.44	43.12	-27.78%	47	24.53	330.82	240.20	168.65	123.96	673.26	82.99	89.86	95.39	90.78	17.35	-29.28%
18	29.73	1159.14	1045.96	990.17	918.80	1075.81	935.01	904.98	997.39	1085.09	20.97	-29.45%	48	24.42	123.04	110.25	83.64	50.75	111.04	46.65	57.58	53.77	66.65	16.45	-32.67%
19	9.79	254.25	642.87	920.57	938.50	244.87	1306.36	1185.51	1421.54	1496.80	7.69	-21.38%	49	24.43	123.44	110.25	80.05	50.01	111.04	46.57	57.98	53.01	67.62	16.46	-32.63%
20	42.22	1191.66	1105.85	1052.85	1066.38	1095.54	1070.02	1027.33	1089.51	992.22	32.54	-22.91%	50	65.59	1151.14	1059.41	1120.07	1009.72	534.61	199.35	383.60	706.94	780.26	54.20	-17.37%
21	138.69	310.02	287.92	324.83	319.52	170.54	140.93	213.42	409.00	586.74	56.30	-59.41%	51	84.84	215.28	200.45	287.99	461.61	184.90	1129.39	843.63	957.14	1125.22	24.96	-70.58%
22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		52	120.35	556.22	673.99	795.17	846.91	532.44	818.71	908.48	1065.24	1088.87	101.20	-15.91%
23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		53	39.52	181.81	100.25	221.95	200.17	564.81	318.75	329.91	343.37	489.54	28.96	-26.74%
24	32.25	261.78	232.04	215.27	217.74	24.74	12.00	33.55	118.98	76.15	7.24	-77.54%	54	112.09	452.92	579.57	658.31	785.11	399.37	849.23	1008.88	997.50	1141.98	90.73	-19.06%
25	48.57	1234.37	1143.49	1080.43	1086.16	1115.38	1099.24	1079.49	1193.40	1159.42	38.79	-20.14%	55	15.22	1263.76	1099.62	1145.82	904.97	181.35	89.49	471.67	837.04	383.29	8.81	-42.14%
26	137.67	303.56	276.00	314.77	304.44	178.58	160.91	243.96	438.38	629.16	53.35	-61.25%	56	69.13	1063.21	848.61	900.20	873.17	454.48	225.80	400.07	695.44	803.15	53.88	-22.06%
27	70.57	434.87	395.20	511.04	615.50	478.28	510.16	343.43	179.10	191.07	44.59	-36.82%	57	29.61	15.82	8.98	10.29	6.11	8.11	4.17	21.56	19.84	21.05	18.46	-37.67%
28	70.49	430.94	395.80	509.46	620.45	478.28	512.71	343.43	179.10	191.07	44.56	-36.79%	58	43.85	387.34	451.55	637.07	635.55	557.98	816.39	1121.09	1261.19	1178.33	32.90	-24.97%
29	70.78	180.49	161.90	150.71	145.53	20.46	10.87	27.02	120.03	51.03	5.87	-91.70%	59	100.10	506.77	628.97	740.88	826.72	479.85	930.89	962.48	1122.01	1198.12	81.63	-18.46%
30	19.68	393.21	311.93	262.06	275.95	24.68	12.68	38.46	260.11	127.99	6.48	-67.08%													

APPENDIX 17: Scenario 5 Change of Number of Vehicles According to the Rate of Autonomous Vehicles Based on Links

Data Collecting Point	Number of Vehicle											Change (%)	Data Collecting Point	Number of Vehicle											Change (%)
	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%			0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	
1	694	678	658	635	632	643	656	693	726	742	751	8%	31	78	78	94	97	119	122	138	138	152	165	191	144%
2	273	282	311	309	346	346	364	374	388	394	401	47%	34	455	451	512	508	575	566	586	587	587	588	588	29%
3	557	557	557	557	557	557	557	557	557	557	557	0%	35	219	227	265	276	338	346	386	392	405	411	419	91%
4	274	282	311	309	346	347	364	374	389	395	402	47%	36	334	331	386	387	462	466	497	505	518	526	544	63%
5	1012	996	978	955	952	961	974	1012	1044	1055	1066	5%	37	293	303	353	371	450	464	511	522	537	541	542	85%
6	259	267	298	296	332	333	351	360	374	380	385	49%	38	1037	1066	1243	1295	1562	1615	1758	1790	1837	1846	1846	78%
7	1102	1068	1004	970	947	967	968	1056	1111	1131	1135	3%	39	2480	2794	2852	2875	3156	3256	3257	3257	3257	3258	3258	31%
8	1175	1160	1139	1128	1126	1136	1147	1183	1231	1256	1263	8%	40	585	590	716	737	934	985	1104	1133	1238	1289	1303	123%
9	1248	1274	1354	1367	1461	1461	1516	1536	1565	1582	1609	29%	41	1890	2081	2172	2183	2230	2259	2288	2315	2356	2373	2392	27%
12	1133	1129	1117	1104	1103	1109	1114	1129	1155	1171	1184	4%	42	149	143	199	209	281	300	354	360	424	481	572	284%
13	471	477	572	582	708	734	828	833	927	1011	1182	151%	43	857	949	1012	1039	1086	1140	1200	1235	1323	1412	1594	86%
14	258	266	297	298	335	338	356	365	380	389	394	53%	44	184	180	232	236	306	331	385	384	476	543	811	340%
15	79	79	94	94	117	123	141	140	156	170	200	154%	45	413	407	489	498	610	639	731	733	852	902	1290	213%
16	157	166	199	201	240	242	259	266	277	282	286	82%	46	332	340	404	411	487	504	568	565	635	709	875	164%
17	203	204	233	236	261	266	286	284	299	314	344	69%	47	638	634	625	615	614	620	619	641	659	673	680	7%
18	645	631	619	606	606	611	618	637	667	690	699	8%	48	180	180	177	175	174	176	175	182	188	191	193	7%
19	720	727	727	727	727	727	727	727	727	727	727	1%	49	180	180	176	175	174	176	175	182	187	191	193	7%
20	485	468	473	472	475	478	481	496	517	531	538	11%	50	404	402	499	512	656	690	768	797	887	942	960	138%
21	529	547	626	641	732	735	793	808	837	853	875	65%	51	103	101	125	132	168	177	210	210	255	279	420	308%
22	33	33	33	33	33	33	33	33	33	33	33	0%	52	219	210	269	274	336	341	369	393	451	504	537	145%
23	33	33	33	33	33	33	33	33	33	33	33	0%	53	435	489	519	521	531	538	545	549	557	563	566	30%
24	21	21	24	24	30	29	32	32	32	32	32	55%	54	160	162	198	197	253	270	282	307	338	356	373	133%
25	349	353	402	409	440	449	440	476	509	527	539	55%	55	260	263	313	324	398	410	450	465	492	501	507	95%
26	535	554	636	651	747	750	810	824	852	870	893	67%	56	277	275	342	350	446	471	524	544	606	642	668	141%
27	128	128	155	159	194	198	225	225	249	269	313	145%	57	336	335	328	321	318	324	322	347	357	364	370	10%
28	128	128	155	159	193	198	224	225	248	268	312	145%	58	727	784	925	941	1089	1103	1184	1197	1251	1269	1285	77%
29	238	239	266	277	311	310	331	339	344	347	347	46%	59	461	455	554	556	653	656	682	720	790	826	870	89%
30	228	229	264	271	316	316	336	342	347	348	348	53%													

APPENDIX 18: Scenario 5 Change of Speeds According to the Rate of Autonomous Vehicles Based on Links

Data Collecting Point	Speeds (km/h)											Change (%)	Data Collecting Point	Speeds (km/h)											Change (%)
	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%														
1	49.81	50.19	49.72	50.60	50.79	50.79	50.11	51.34	51.51	51.75	52.09	5%	31	52.23	52.49	52.35	52.05	51.97	52.22	52.22	52.17	52.36	52.28	52.35	0%
2	50.22	50.36	47.59	49.13	47.72	48.26	48.55	47.76	49.60	49.47	49.16	-2%	34	27.10	28.03	23.16	31.91	33.12	33.41	34.33	34.52	34.73	34.80	34.80	28%
3	52.95	52.90	52.69	52.83	52.80	52.78	52.77	52.76	52.77	52.79	52.80	0%	35	45.66	45.69	48.24	49.61	52.26	52.18	52.16	52.25	52.41	52.43	52.35	15%
4	51.42	51.42	51.24	51.24	51.16	51.20	51.32	50.86	51.57	51.64	51.75	1%	36	42.07	39.38	40.65	45.89	50.83	49.18	51.54	51.75	51.77	52.22	52.51	25%
5	50.84	51.07	51.09	51.37	51.50	51.60	51.44	51.71	51.83	51.88	52.01	2%	37	40.39	40.27	46.71	44.20	52.12	50.79	52.19	52.29	52.36	52.39	52.44	30%
6	51.51	51.48	51.24	51.41	51.34	51.53	51.38	51.54	51.59	51.75	51.84	1%	38	29.26	32.09	30.15	37.84	47.16	47.77	51.12	51.92	51.88	52.58	52.75	80%
7	32.13	30.22	17.74	26.41	25.27	25.11	29.17	24.04	26.63	29.87	34.81	8%	39	49.88	49.54	49.62	49.95	49.78	49.75	50.11	50.46	50.72	50.99	51.28	3%
8	40.03	38.23	26.30	31.73	35.32	33.70	32.06	33.88	38.59	46.68	51.49	29%	40	25.19	24.95	18.75	28.74	31.54	34.70	37.44	42.66	45.83	49.61	51.04	103%
9	43.04	43.35	31.91	43.64	43.41	43.92	44.20	44.52	45.62	47.14	49.72	16%	41	40.72	40.02	29.14	40.63	40.66	42.62	43.72	46.77	49.42	51.25	52.28	28%
12	50.15	50.06	50.04	50.48	50.52	50.44	50.64	50.77	50.67	50.73	50.74	1%	42	15.30	15.86	10.02	19.28	21.96	23.26	24.19	27.08	27.63	37.19	48.57	217%
13	49.67	49.96	48.50	50.11	50.28	50.11	50.16	50.21	50.45	50.83	51.28	3%	43	40.19	40.71	28.63	40.11	39.26	39.54	39.04	39.46	39.46	39.99	39.74	-1%
14	51.03	50.80	49.54	49.66	49.81	49.77	49.80	50.42	50.56	50.92	51.34	1%	44	20.58	22.41	18.95	25.29	28.55	30.43	34.04	36.48	39.59	49.63	50.69	146%
15	48.58	49.03	47.75	49.08	48.22	48.15	47.65	47.92	47.60	47.80	46.95	-3%	45	17.15	16.39	10.88	17.74	19.27	18.50	18.80	18.44	18.26	18.48	52.86	208%
16	43.27	44.45	52.34	49.88	52.42	52.32	52.46	52.56	52.63	52.54	52.63	22%	46	52.31	52.31	52.14	52.36	52.39	52.42	52.38	52.45	52.52	52.59	52.58	1%
17	49.03	50.56	51.32	52.07	52.34	52.20	52.37	52.50	52.54	52.60	52.66	7%	47	50.83	50.94	51.01	51.50	51.62	51.76	51.56	51.83	51.94	52.10	52.17	3%
18	50.16	50.26	50.30	50.85	51.02	51.13	51.00	51.21	51.13	51.27	51.33	2%	48	52.45	52.40	52.31	52.48	52.42	52.55	52.43	52.60	52.48	52.47	52.50	0%
19	46.73	47.29	45.80	48.83	49.55	49.86	50.37	50.85	51.26	51.86	52.34	12%	49	52.20	52.20	52.24	52.35	52.27	52.53	52.36	52.47	52.38	52.40	52.41	0%
20	49.45	50.72	50.65	51.27	51.40	51.56	51.26	51.85	52.11	52.26	52.92	7%	50	40.61	36.80	44.39	43.33	50.18	48.73	49.13	50.79	52.65	53.10	53.84	33%
21	44.80	45.17	38.58	45.29	45.70	45.90	45.81	45.50	45.91	45.52	44.60	0%	51	37.90	36.68	44.63	40.63	47.33	47.31	49.98	49.78	52.55	52.57	52.61	39%
22	52.29	52.34	52.25	52.44	52.48	52.51	52.57	52.62	52.70	52.75	52.79	1%	52	23.89	21.79	16.99	25.61	27.43	26.62	27.45	27.35	28.19	28.38	29.21	22%
23	52.75	52.73	52.53	52.66	52.73	52.66	52.75	52.73	52.75	52.73	52.76	0%	53	49.93	50.71	49.19	50.74	50.88	51.08	51.09	51.33	51.63	51.82	52.19	5%
24	46.24	43.62	50.05	51.01	52.84	53.12	53.03	53.12	52.96	52.98	53.09	15%	54	27.94	26.43	23.06	30.84	38.69	41.35	43.77	44.93	44.65	45.70	46.73	67%
25	34.70	38.49	33.17	43.24	42.74	41.92	42.88	39.80	37.70	35.69	34.44	-1%	55	40.49	37.76	45.56	44.36	49.62	50.81	49.64	52.30	52.32	52.48	52.62	30%
26	46.77	46.92	42.82	47.38	47.84	48.38	48.91	49.57	50.73	51.66	52.93	13%	56	40.05	36.23	41.75	42.81	49.39	48.10	48.08	49.17	51.02	51.23	51.09	28%
27	52.69	52.77	52.57	52.51	52.55	52.60	52.64	52.58	52.57	52.48	52.75	0%	57	51.54	51.64	51.56	51.86	51.85	51.97	51.79	51.97	52.02	52.03	52.04	1%
28	52.07	52.30	52.06	52.16	52.07	52.16	52.25	52.14	52.04	51.98	52.13	0%	58	38.56	41.00	34.57	43.39	43.91	43.72	44.20	45.44	46.26	47.16	48.41	26%
29	36.78	34.01	25.07	34.41	32.36	33.51	40.76	44.51	47.53	50.27	50.55	37%	59	30.00	30.97	30.48	36.77	42.30	42.14	40.77	43.82	43.08	44.14	44.60	49%
30	45.00	47.06	44.56	47.25	51.23	51.19	52.25	52.44	52.44	52.47	52.52	17%													

APPENDIX 19: Scenario 5 Change of Queue Delays According to the Rate of Autonomous Vehicles Based on Links

Data Collecting Point	Queue Delays (sec)											Change (%)	Data Collecting Point	Queue Delays (sec)											Change (%)
	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%			0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	
1	43.94	46.63	56.60	57.55	64.78	61.11	48.27	54.17	42.79	31.53	21.45	-51%	31	201.24	159.67	243.28	209.71	241.50	221.39	223.77	185.49	200.49	129.55	55.69	-72%
2	88.63	95.44	109.58	115.99	113.84	110.48	98.79	94.35	80.15	67.53	55.70	-37%	34	23.01	6.31	9.35	4.75	2.91	6.94	1.70	1.41	1.19	0.95	0.87	-96%
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	35	57.77	52.63	88.80	73.25	47.18	68.38	26.68	20.68	24.27	15.19	8.16	-86%
4	88.28	94.76	109.26	114.14	111.04	106.51	98.15	90.77	80.31	67.54	55.64	-37%	36	67.14	36.45	77.61	54.07	56.97	68.14	53.86	44.77	51.03	37.38	22.40	-67%
5	29.56	30.87	36.93	37.03	41.56	39.27	31.01	36.08	29.01	21.48	14.66	-50%	37	41.76	43.17	84.56	56.77	26.44	42.85	2.59	1.04	2.12	0.27	0.17	-100%
6	90.52	96.24	111.63	117.21	113.14	108.67	100.68	90.44	82.14	69.30	57.10	-37%	38	28.21	29.67	63.94	40.65	16.76	32.65	0.86	0.07	0.82	0.00	0.00	-100%
7	15.41	17.97	22.72	25.42	30.96	31.28	22.07	31.43	19.86	12.07	3.79	-75%	39	1.18	0.72	0.68	0.77	0.25	0.01	0.00	0.00	0.00	0.00	0.00	-100%
8	25.89	34.01	47.19	60.39	63.74	62.48	63.51	61.41	38.19	21.98	13.83	-47%	40	136.35	110.75	193.62	144.63	118.69	108.08	60.21	36.55	37.11	19.20	14.29	-90%
9	135.64	135.11	145.57	136.07	135.45	124.45	115.28	101.71	92.45	78.23	66.48	-51%	41	24.34	24.44	30.44	30.26	33.08	33.36	32.40	28.71	29.59	24.71	20.66	-15%
12	31.56	36.98	43.32	55.08	54.18	54.02	57.33	52.59	40.77	26.66	15.94	-49%	42	383.28	277.84	507.67	415.74	395.17	383.25	347.00	299.45	293.77	142.10	43.21	-89%
13	162.92	141.05	219.77	202.44	218.77	218.37	215.39	173.47	193.18	121.04	43.96	-73%	43	58.49	52.79	74.03	70.16	82.38	78.66	83.02	68.79	75.12	63.37	28.41	-51%
14	90.87	97.16	111.96	118.82	113.03	110.81	102.72	91.23	83.44	69.76	57.38	-37%	44	263.67	232.62	403.42	366.41	383.54	352.79	326.24	294.82	278.61	211.79	24.64	-91%
15	169.54	157.77	230.78	208.51	214.43	214.36	212.39	171.71	189.82	126.23	45.08	-73%	45	104.78	73.15	135.78	108.01	118.59	135.48	120.80	111.47	117.74	83.32	9.15	-91%
16	77.22	77.27	92.98	85.52	82.48	81.70	66.76	56.73	58.09	48.74	41.39	-46%	46	173.72	141.00	230.56	215.03	248.94	246.67	260.87	211.75	243.11	149.34	39.32	-77%
17	74.94	68.68	104.23	93.03	110.74	111.30	124.27	97.90	113.55	85.66	43.32	-42%	47	33.22	37.11	43.28	51.92	51.91	50.70	50.11	48.53	38.33	26.46	17.08	-49%
18	44.66	58.93	76.19	103.93	102.63	103.82	108.12	98.88	69.94	41.05	19.98	-55%	48	32.29	33.38	41.32	48.81	51.62	50.87	48.95	46.36	34.93	26.88	16.54	-49%
19	13.53	13.37	12.81	12.56	11.98	11.52	11.02	10.37	9.63	8.69	7.63	-44%	49	32.24	33.35	41.25	48.64	51.64	50.82	48.26	46.17	34.82	26.78	16.48	-49%
20	56.67	71.63	90.47	116.76	114.00	116.65	116.61	110.54	83.29	54.14	33.02	-42%	50	208.01	161.85	251.41	208.08	202.71	181.85	129.14	102.66	96.96	68.78	55.90	-73%
21	174.93	173.18	206.05	177.63	168.10	149.13	122.39	99.01	91.65	71.83	57.18	-67%	51	266.63	211.41	353.38	291.22	309.62	271.30	285.78	248.65	257.98	211.52	24.58	-91%
22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	52	219.16	198.51	250.52	243.66	264.40	263.16	257.76	214.57	212.35	165.19	112.29	-49%
23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	53	32.49	35.25	41.81	42.92	47.39	43.34	42.62	37.34	35.15	30.31	27.75	-15%
24	48.85	33.24	65.39	52.45	24.80	35.88	10.62	8.29	8.15	7.27	7.12	-85%	54	175.43	166.13	211.65	199.25	183.49	195.94	186.51	168.87	154.44	120.00	90.50	-48%
25	62.19	81.66	93.12	118.76	115.92	117.49	118.90	111.26	86.05	58.37	39.54	-36%	55	102.24	65.99	137.77	99.40	67.39	76.66	34.34	19.91	25.79	15.42	9.91	-90%
26	167.23	163.67	200.35	172.39	162.86	145.63	118.44	95.25	88.49	68.57	54.18	-68%	56	210.82	159.35	249.31	202.80	199.84	177.42	133.49	105.27	102.21	75.65	55.61	-74%
27	179.93	148.79	235.94	198.16	230.21	215.44	217.82	180.20	196.62	121.27	45.68	-75%	57	34.53	36.49	43.20	43.02	47.99	46.46	37.16	41.91	32.68	24.40	17.87	-48%
28	181.24	149.35	235.29	198.89	229.43	214.49	218.19	180.01	196.64	121.33	45.64	-75%	58	69.55	66.27	86.98	77.17	75.00	68.36	61.15	49.62	49.95	39.74	33.23	-52%
29	95.86	85.43	129.11	99.21	81.88	72.32	29.56	17.72	10.67	6.21	5.90	-94%	59	113.01	123.52	141.74	155.70	165.50	165.01	168.18	153.02	138.87	111.19	82.33	-27%
30	31.00	23.13	46.83	30.35	17.13	23.00	8.75	7.87	7.86	6.77	6.48	-79%													