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DIME
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Master of Science Thesis in

Safety Engineering for Transport, Logistics and Production

ITS for traffic management: a simulation model to evaluate traffic flows from suburban areas to the city of Genova

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Abstract

The necessity to fullfill the growing requirements for transportation has become a global problem. As a consequence of the greater need for transportation, cities are becoming heavily congested with vehicles, and travel times are increasing. Day by day, those problems are adversely affect people's daily lives and needed to be solved with the help of current technology and knowledge that we have. Managing traffic flow is an essential for controlling average travel time and effective traffic management. Intelligent Transportation Systems (ITS) are advance technologies that use information and communication technologies to provide new, long-term solutions for transportation and traffic management.

Those who commute from the suburban area to the city center for work are one of the groups most affected by the congestion and increased travel time. The objective of this thesis is to identify and develop a model of traffic flows from suburban areas to the city of Genoa. After deciding to the proper simulation model, alternative routes and average travel times were examined with it for the selected study area. Travel times varied in accordance with the traffic flow distributions in different conditions, according to the results of the cases analyzed using the created model. It is feasible to analyze other routes as an alternative and ensure that average travel time of users to Genoa is optimum based on the results.

Özet

Ulaşım için artan ihtiyaçların karşılanması gerekliliği küresel bir sorun haline gelmiştir. Ulaşıma olan ihtiyacın artmasının bir sonucu olarak, şehirler araçlarla sıkışık hale gelmekte ve seyahat süreleri artmaktadır. Gün geçtikçe insanların günlük hayatını olumsuz yönde etkileyen bu sorunların, günümüz teknolojisi ve sahip olunan bilgi birikimi ile çözülmeleri gerekmektedir.Trafik akışını yönetmek, ortalama seyahat süresini kontrol etmek ve etkili trafik yönetimini için çok önemlidir. Akıllı Ulaşım Sistemleri (AUS), ulaşım ve trafik yönetimine yeni, uzun vadeli çözümler sağlamak için bilgi ve iletişim teknolojilerini kullanan ileri teknoloji sistemlerdir.

Banliyö bölgesinden şehir merkezine iş için gidip gelenler, trafik sıkışıklığından ve artan seyahat süresinden en çok etkilenen grupların başında gelmektedir. Bu tezin amacı, banliyö bölgelerinden Cenova şehrine trafik akışı modelini oluşturmak ve geliştirmektir. Bu amaçla, uygun simülasyon modeline karar verildikten sonra seçilen çalışma alanı için alternatif güzergahlar ve ortalama seyahat süreleri incelenmiştir. Oluşturulan model kullanılarak elde edilen analiz sonuçlarına göre, seyahat süreleri farklı koşullardaki trafik akış dağılımlarına göre değişmiştir. Alternatif olarak diğer rotaları analiz etmek ve sonuçlara göre kullanıcıların Cenova'ya ortalama seyahat sürelerinin optimum olmasını sağlamak mümkündür.

ACKNOWLEDGMENTS

In the first place, I would like to express my appreciation to my supervisor Prof. Davide Giglio for all his patience, devotion, and help during these months. His guidance has been instrumental in accomplishments of this work.

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CONTENTS

TABLE OF FIGURES

LIST OF TABLES

1 INTRODUCTION

Significant improvements in transportation infrastructure have resulted from the growing need for mobility. As a result, European towns are becoming clogged with automobiles increasingly, resulting in unpleasant daily occurrences such as increasing traffic congestion and unanticipated emergencies and accidents. Inefficiencies result in massive time losses, a reduction in car and pedestrian safety, excessive pollution, a deterioration in the quality of life, and a massive waste of nonrenewable fossil fuels. These situations impact our lives, especially in urban regions, where individuals are increasingly required to move quickly between different locations.

One of the segments most affected by this situation is those who come from suburban areas to work every day to the city center.

These inefficiencies highlight the need for more efficient and safer mobility solutions to be developed. As a result of the previous, traffic evaluation and management has been identified as a vital service that Information and Communication Technologies should provide in transportation.

Intelligent Transportation Systems (ITS) are cutting-edge technologies that aim to provide innovative transportation and traffic management services. It allows different users to be better informed and use transportation networks safer, more coordinated, and 'smarter.' Compared to traditional transportation systems, the integration of artificial intelligence with transportation systems is the main distinguishing feature of ITS.

Advanced Traveler Management Systems (ATMS) and Advanced Traveler Information Systems (ATIS) are ITS components that offer users real-time information about the present and prospective traffic conditions. The radio broadcast, in-vehicle devices, and, of course, the Internet are all data transfer channels. The goal is to reduce traffic congestion and make better use of infrastructure.

1.1 Purpose and Scope

The objective of this thesis is to develop a model that describes traffic flows from suburban areas to Genoa and use the results to provide traffic flow information for ITS traffic management. The use of a discrete event model, the development of a traffic flow simulation model to evaluate system performance, and simulation to analyze model and case studies are the primary research phases.

1.2 Problem statement

Traffic congestion is considered a serious traffic problem in cities, especially as travel demand increases at peak hours. As flow approaches capacity, congestion on the roads increases. This thesis is about vehicle traffic modeling and simulation in order to produce vehicular traffic that is as relatively close to real traffic as feasible. The necessity of controlling road traffic is growing in tandem with the increase in vehicle manufacture and use. The traffic flow distribution is affected by the parameters of a vehicle, road, traveler, and management.

1.3 Thesis Outline

Table 1.1 is organized by chapters of the study. The goal of the thesis outline is to show the academic frameworks that have been used and generated from this study.

Table 1-1:Thesis Outline

Chapter 1	This section provides an overview of this study.
Chapter 2	This chapter provides fundamental information about ITS by focusing on the history and architecture of what is ITS.
Chapter 3	This chapter discusses the method of data collection for Intelligent Transportation Systems.
Chapter 4	This chapter provides information on the methodology for data communication.
Chapter 5	The chapter discusses the ITS data analysis and processing methods.
Chapter 6	This chapter provides the ITS applications.
Chapter 7	This chapter discusses the methodologies and ExtendSim characteristics and parameters for this thesis.
Chapter 8	This chapter has discussed the model and application to a case study and interpreted the results.

2 INTELLIGENT TRANSPORTATION SYSTEMS (ITS)

ITS can be defined as a set of solutions that use a combination of telecommunications and computer technologies to improve transportation management, maintenance, monitoring, control, and safety. ITS can be applied to any mode of transportation and takes into account all of the agents involved, including the vehicle, the infrastructure, and the user (driver or passenger). As a consequence, lives, time, money, energy, and the environment are saved.

ITS rely on research findings from a wide range of fields, including electronics, control, communications, sensing, robotics, signal processing, and information systems. This multidisciplinary structure adds complexity to the problem because it needs information transfer and coordination between several research fields. Because of this diversity, ITS includes different tools and services (Fig.2.1.).

Figure 2-1: Intelligent transportation systems illustration [1]

Drivers, companies, and public transportation passengers are among the users of ITS, who rely on it to make informed travel decisions based on factors such as traffic, infrastructure maintenance or construction activity, and weather conditions that might affect travel time and safety. Information from ITS is also used by policymakers and road or highway operators in the management and future development of road networks. The fundamental motivation for ITS is to address traffic congestion, which is on the rise globally as a result of population increase, urbanization, greater motorization, and changing population density. Congestion affects the efficiency of transportation infrastructure, increasing travel times, increasing fuel use, and polluting the air.

Accidents, traffic backups, severe weather conditions, road construction, and other issues may all be avoided thanks to the distributed sensor technology that makes up the ITS system. Real-time road conditions can be gathered, and alerts can be sent to drivers via dynamic messaging, highway advisory radio, in-car navigation systems, or Smartphone apps. Drivers consider the information of traffic while deciding whether to take a specific route, reschedule their trip route and time, or change modes of transportation. Commercial fleet operators utilize ITS data to manage their fleet and select when and how to deploy their vehicles. ITS also provides public transportation information such as bus and rail schedules, route planners, and tariffs.

Highway toll collection has also been considerably improved thanks to ITS technology. To identify vehicles and collect toll money without stopping or delaying traffic, automatic toll collection systems employ RFID transponders, license plate recognition systems, or barcode tags. This helps to eliminate or reduce bottlenecks along roads with toll booths. When vehicles enter congested city zones in cities that have designated cordon zones with congestion pricing, extra tolls are collected via an electronic toll collecting system. High occupancy vehicle (HOV) lanes are available on several high-traffic networks. Different in-car and exterior automatic vehicle occupancy counting systems are being developed for law enforcement applications [2].

Cars driving around city blocks searching for parking places are one of the primary contributors to congestion and pollution in city streets. Managing real-time information about city parking spots on public roadways and in parking garages is a critical component of the service that ITS is intended to provide. A network of distributed electronic sensors might monitor parking spot availability and deliver real-time information to drivers.

ITS technology is also important in the avoidance of accidents and the rapid reaction to emergencies. Collision avoidance systems, lane departure warning systems, and sleepy driver warning systems are examples of in-vehicle safety technology that is now available. ITS technology aids in the identification and rapid reaction to automotive accidents and other catastrophe situations in incident and emergency response. On-board accident notification systems use sensors to detect a collision and immediately notify the incident and vehicle position to an emergency contact center. Emergency vehicle preemption technology allows emergency vehicles to have the right-of-way at traffic signals in order to respond quickly to incidents. The transmission of real-time data between emergency responders, police, and traffic managers enables coordinated traffic management and emergency operations. Standardization initiatives are also ongoing to facilitate the development of cooperative systems and assure technology interoperability.[2]

2.1 ITS History

The goal of ITS is to leverage the latest technology to produce "smarter" roadways, cars, and users. Since the 1930s, ITS has been gradually infiltrating our daily lives. The main advances in ITS have occurred in Europe, the United States, and Japan, and it has gone through three phases: preparation (1930-1980), feasibility study (1980-1995), and product development (1995-present) [3].

- Preparation (1930-1980)

This is the early stage of ITS development, when the technologies were still in their infancy and building new roads was more appealing than creating ITS. The electric traffic lights, which were deployed in 1928, were the first ITS system that most people believed to be "the original" ITS. The ITS movement did not gain ground until the 1960s when the first computer-controlled traffic lights arrived in the United States. The ERGS (Electronic Route Guidance Systems) were developed in the United States from the late 1960s to 1970 and employed two-way road vehicle communications to offer route guidance. The CACS (Comprehensive Automobile Traffic Control System) [3] and the ALI (Autofahrer Leit und Information System) [4] were created in Japan and Germany, respectively, in the 1970s, and are dynamic route guidance systems based on real-time traffic conditions. This decade was especially significant for ITS since it saw the introduction of the microprocessor and the start of the development of GPS. Despite the fact that these technologies are now integral parts of many ITS systems, they were not previously identified with ITS.

- Feasibility study (1980-1992)

In Europe, Japan, and the United States, this age is marked by an explosion of development initiatives supported by businesses and the government. The PROMETHEUS (Program for European Traffic with Efficiency and Unprecedented Safety) project was formed in Europe by governments, industries, and institutions from 19 countries. Between 1987 and 1994, this program produced a number of ITS technologies. The test vehicle VITA I1 was created in the 1990s by a group led by Daimler-Benz. This vehicle used 10 cameras and 60 processors to keep the vehicle in the center of the lane, maintain a safe distance from the vehicle in front, change lanes, and overtake other vehicles without colliding. Other projects, such as the ARGO project, which intended to design, develop, and test new solutions for future spacecraft, were created as part of PROMETHEUS. DRIVE (Dedicated Road Infrastructure for Vehicle Safety in Europe) was established to design and test the communication system, as well as to provide drive assistance and traffic control. ERTICO (European Road Transport Telematics Implementation Coordination Organization), a public-private partnership, was formed to assist in the refinement and implementation of Europe's Transport Telematics Project. The Mobility 2000 research team in the United States created the framework in the late OS for the founding of the IVHS America (Intelligent Vehicle Highway Systems), a public-private platform for uniting national ITS interests and encouraging worldwide ITS collaboration. The name of the organization was changed from IVHS to ITS America (Intelligent Transportation Society of America) by the USDOT (United States Department of Transportation) in 1994. NAHSC (National Automated Highway System Consortium) was founded by the US Department of Transportation, General Motors, University of California, and other universities to perform AHS (Automated Highway System). Various completely autonomous test cars were exhibited on California roadways as part of this project. In Japan, programs such as RACS (Road Automobile Communication System) by the Ministry of Construction and AMTICS (Advanced Mobile Traffic Information and Communication System) by the National Police Agency were completed in the 1980s. It was able to unite those two programs into VICS in the 1990s by merging efforts with the Ministry of Posts and Telecommunications and working on standardizing projects (Vehicle Information and Communication System). A VICS terminal acts as a locator, displaying the vehicle's location on a map screen and allowing contact with ground stations to gather traffic data for route planning. The Advanced Cruise-Assist Highway System Research Association was founded in 1996 by the Ministry of Construction and twenty-one major corporations, including Toyota, Nissan, Honda, and Mitsubishi, to test different fully autonomous cars on a highway [3].

- Product development (1995-present)

In the mid-1990s, a single policy was established to deal with ITS consistently and harmoniously. This led to the current phase, which is concerned with the development of feasible products. Several projects have been established or are in the process of being developed. The Chauffeur project, led by Daimler-Benz and research institutions in Europe, has as its goal the autonomous following of another vehicle driven by a human driver. By the late 1990s, the major focus of ITS initiatives in the United States had switched to large-scale integration and deployment.

2.2 Architecture (Structure)

The combination of diverse technologies requires that all present and future ITS systems work in cooperation. The objective of system architecture development is to make it easier to build integrated systems, provide system scalability, and encourage national and worldwide standards. From the start of ITS implementation, the system architecture gives rules to follow. At all levels, national, provincial, and regional, system architecture is essential.

The multi-tier architecture of ITS consists of the following layers: Physical layer, Communication layer, Operation layer, and Service layer (Fig.2.2).

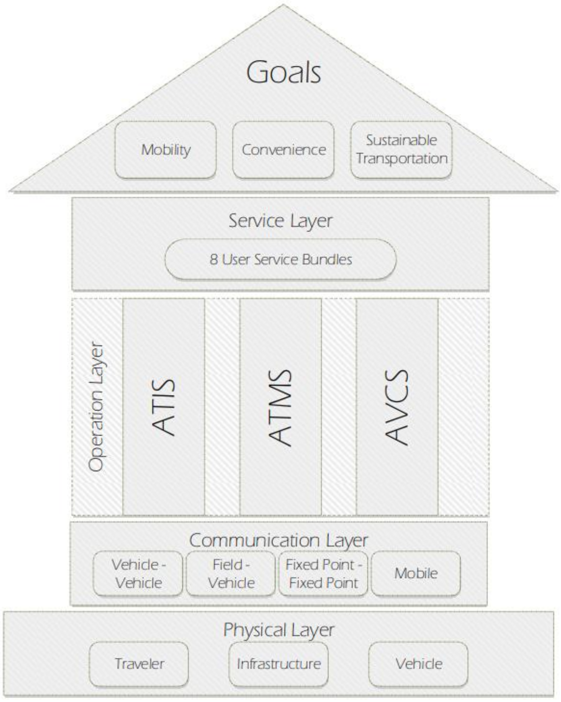


Figure 2-2: Architecture of ITS [5]

Interconnection, operation, and service are all ensured by this four-tier framework. All of those levels work together to achieve their objectives.

1. Physical layer: This layer includes all aspects of the transportation system, such as infrastructure, vehicles, and people. With the advancement of information technology, almost everything may be considered an agent capable of seeing their surroundings, controlling their actions, and interacting with other agents. This enables the collection of basic traffic data as well as the response to changes in the surrounding environment. It should be noted that generic sensors and platforms, such as roadside sensors, onboard sensors, and online social media platforms, gather data at the physical layer. From various angles, they may all represent the traffic situation.

2. Communication layer: The communication layer ensures that information is sent across ITS subsystems in a timely and precise manner. The communication layer, according to American national ITS Architectures, includes four basic types of communication options:
   - Field-vehicle communications. Vehicles and infrastructures can communicate with one another.
   - Fixed point- fixed-point communications. Stationary entities' communication.

- V2V (vehicle-to-vehicle) communication A vehicle-to-vehicle wireless communication connection.
- Wireless (mobile) communications across a wide area. A communications system that allows vehicles and travelers' mobile devices to communicate.

Data exchange inside the physical layer; data interchange between the physical layer and the operation layer are all supported by the combination of those possibilities.

3. Operation layer: The backbone of the ITS design is the operation layer, which gathers and transforms data into information and knowledge. The data collected from all aspects of the transportation system will be disposed of or dispersed. Data disposal results will be sent back to the physical layer in the form of services in the service layer.
   The following are the three basic components of the operation layer:
   - Advance transportation management systems (ATMS)
   - Advance traveler information systems (ATIS)
   - Advance vehicle control systems (AVCS)

   Overall management is represented by ATMS. The purpose of ATIS is to provide information to passengers. AVCS is a new level of vehicle and infrastructure control technology. They all constitute the minimum operational function, or, to put it another way, they represent the center of transportation operations, as stressed by ITS.

4. Service layer: The deployment and execution of services take place at the service layer. In order to provide better transportation services, the results of the operation layer will be integrated. Its user might be the general public or a system operator. [5]

The Traffic Management Center (TMC) is an essential component of ITS. A Traffic Management Centre (TMC) is the transportation administration's main center, where data is collected, analyzed, and merged with other operational and control ideas to operate the complicated transport network in real-time [6].

The performance of the TMC and its effective operations are significantly dependent on the following factors:

- Automated data collection with precise location information
- Fast data transmission to traffic management centers
- Precise data analysis at TMC to create accurate information
- Reliable/correct information back to travelers/public

3 DATA COLLECTION

Data collection planning necessarily requires precise, wide-ranging, and appropriate data collection as well as real-time monitoring. The collecting of timely and reliable information on traffic and road conditions is a need for many ITS services. Automatic Vehicle Identifiers, GPS-based automatic vehicle locators, sensors, and cameras are examples of such devices. Firstly, the hardware devices save information such as traffic counts, surveillance, travel speed and duration, location, vehicle weight, and delays, among other things. These hardware devices are linked to servers. Servers are located at data collection centers and store massive volumes of data to analyze.

3.1 Sensors

Sensors and detectors placed along the roadside with technological applications and techniques have been implemented for collecting traffic data such as highway traffic counts, surveillance, control, etc.

First sensors on the road surface are categorized with different characteristics, for instance, optical, acoustic, magnetic, and pressure/vibration (seismic/piezoelectric sensors) induced by vehicle weight. These sensors' measurements are used to calculate the traffic parameters.

Besides the traditional sensors used in the past, new sensors are available with innovative technologies, multifunctional, cost-effective, and adaptable. Ultrasonic and acoustic systems, magnetic detectors, infrared systems, LIDAR light detection, inductive loop detectors, seismic and inertia-switch detectors, and video image processing detectors are an example of such sensors. Many of these detectors are in the category of the intrusive method. In principle, they are placed in or on the road surface and ensured traffic information at that location. The most important ones are shortly explained hereinafter.

3.1.1 Pneumatic road tubes

Pneumatic road tube (Fig. 3.1.) is placed across the roadway for utilizing to identify vehicles by measuring the difference in air pressure caused by vehicle tire passing over tube [7]. A counter on the side of the road records and processes the pulse of air that is generated [8]. Based on how the road tube layout is designed, counts can be transformed to count, speed, and/or categorization [7]. Weather, temperature, and traffic conditions all affect the performance of pneumatic road tubes. In the snow, they are ineffective. Air temperature is also a factor in the air changing on-road tubes. In low-speed flows, road tubes may have trouble identifying vehicles. The counting of bicycles is a specific use of road tubes [7].

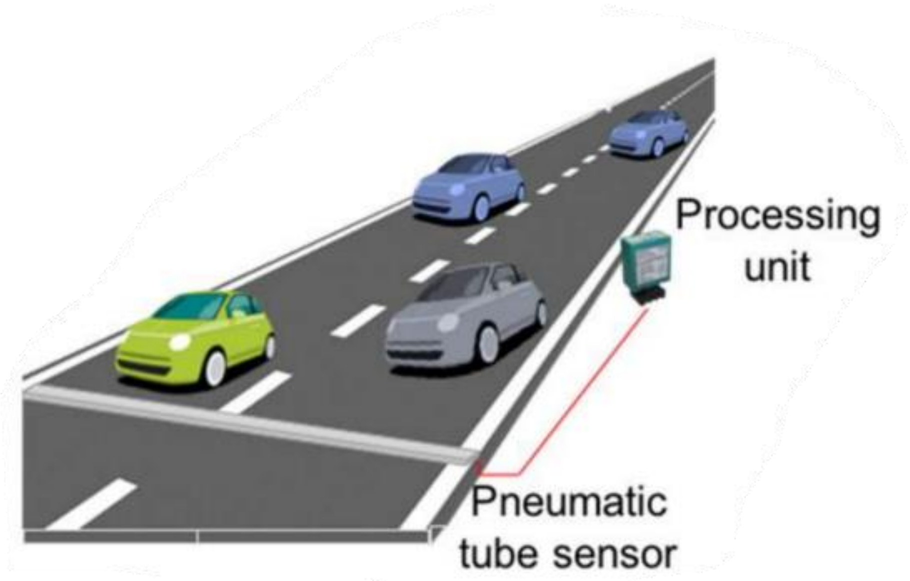


Figure 3-1: Pneumatic Road tubes [9]

3.1.2 Inductive loop detectors

The most frequent sensor used in traffic control applications is the inductive loop detector (ILD). An inductive loop (Fig.3.2.) is a wire that is implanted on (for temporary use) or in the roadway in varied sizes and forms. The wire loop is activated with signals ranging in varying frequencies and acts as an inductive element in combination with the electronics unit. In the instance of traffic monitoring, a massive metal car serves as the magnetic field, while an inductive loop serves as the electrical conductor. The signals generated are recorded by the counter unit at the roadside. Vehicle passing, existence, count, and occupancy are all data provided by standard inductive loop detectors. Inductive loop sensors have a reduced equipment cost and are unaffected by bad weather conditions as compared to other sensor methods.

The use of inductive loop sensors has several disadvantages, problems related to installations on poor road surfaces and the use of inadequate installation processes and performance of inductive loops are significantly affected by traffic load and very high temperature [7][10].

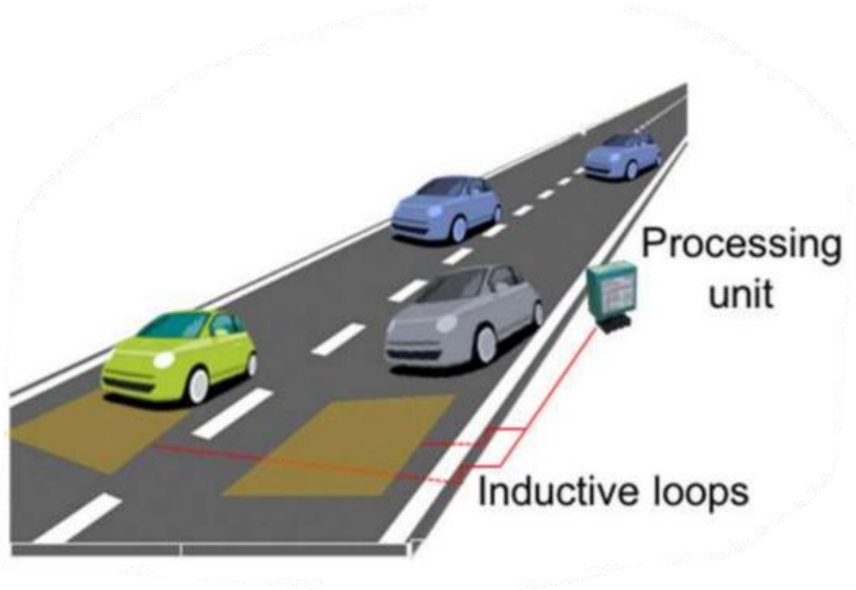


Figure 3-2:Inductive loop detectors [9]

3.1.3 Piezoelectric Sensors

Piezo-electric sensors are often installed in a traffic lane groove carved into the surface, shown in Fig.3.3. Data is collected by the sensors with the conversion of mechanical energy into electrical energy. When the piezoelectric material is mechanically deformed, the surface charge density of the material changes, resulting in a voltage difference between the electrodes. The degree of deformation has a direct relationship with the signal's amplitude and frequency. When the vehicle axle force is released, the output voltage reverses polarity. An alternating output voltage comes from the polarity change. Weight-in-motion, vehicle count and categorization, and speed data can all be detected and recorded using this voltage change. They are slightly more expensive to install than an inductive loop, but they give substantially extra information of enhanced speed data and the capacity to identify different measurements [7].

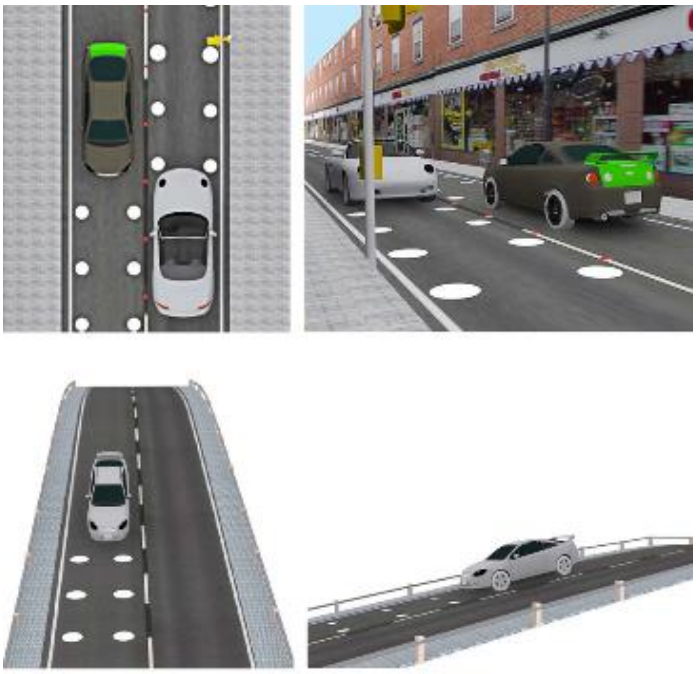


Figure 3-3:Piezoelectric sensors [11]

3.1.4 Magnetic Sensors

Magnetic devices (or magnetometers) are the most common method of gathering traffic data. Disturbance in the earth's natural magnetic field which is created by a vehicle passing within the sensor zone is detected by magnetic devices, seen in Fig.3.4. They detect a disturbance in the earth's natural magnetic field created by a vehicle passing within the sensor zone. The equipment must be near to the vehicles, generally right underneath, in order to detect. Counting, speeding, and simple categorization data may all be collected with magnetic sensors. Magnetic detectors have the benefit of not being influenced by bad weather [7][8].

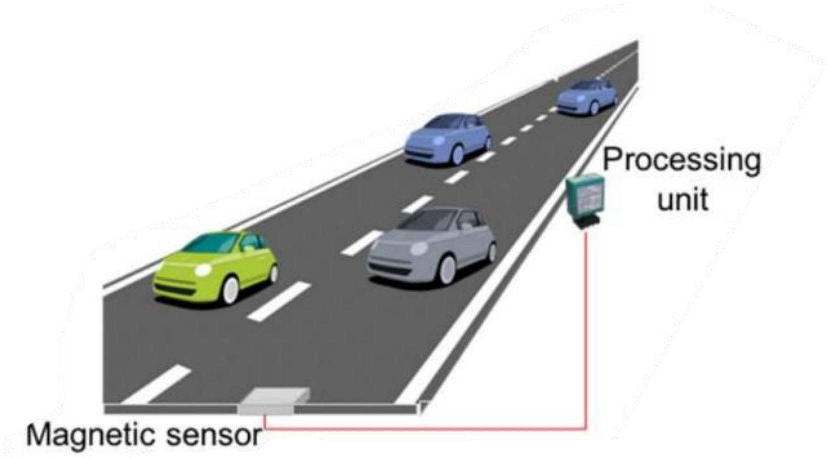


Figure 3-4:Magnetic sensors [9]

Aboveground sensors can be installed on the road in two different ways; they can be placed above the traffic lane that they are monitoring or on the roadside to see multi-lane with different angles to the flow direction. The aboveground sensors are categorized under non-intrusive sensors. Video image processing, microwave radar, passive infrared, ultrasonic, passive acoustic array, and combinations of sensor technologies are an example of aboveground sensors that are currently used. The most important ones are briefly discussed below.

3.1.5 Video Image Processing Detectors

One of the most recent technologies to be applied to traffic detection is video image detectors (VID) that use image processing. Video image processing is used in current traffic management tools to automatically examine the scene of interest and obtain information for traffic monitoring and control. The video image detection devices consist of one or more cameras, a microprocessor-based computer to analyze the pictures, and software to clarify the images and translate them into traffic flow data. To collect traffic data, two methods are used: trip line and tracking. To identify the presence of a vehicle, trip line approaches monitor defined zones on the road, which can be seen from Fig.3.5. Algorithms are used in video tracking approaches to recognize and track vehicles as they move across the field of vision. Count, speed, and categorization data can be recorded by video detection systems. Wind, temperature, and light conditions all have an impact on this technology [7][10].

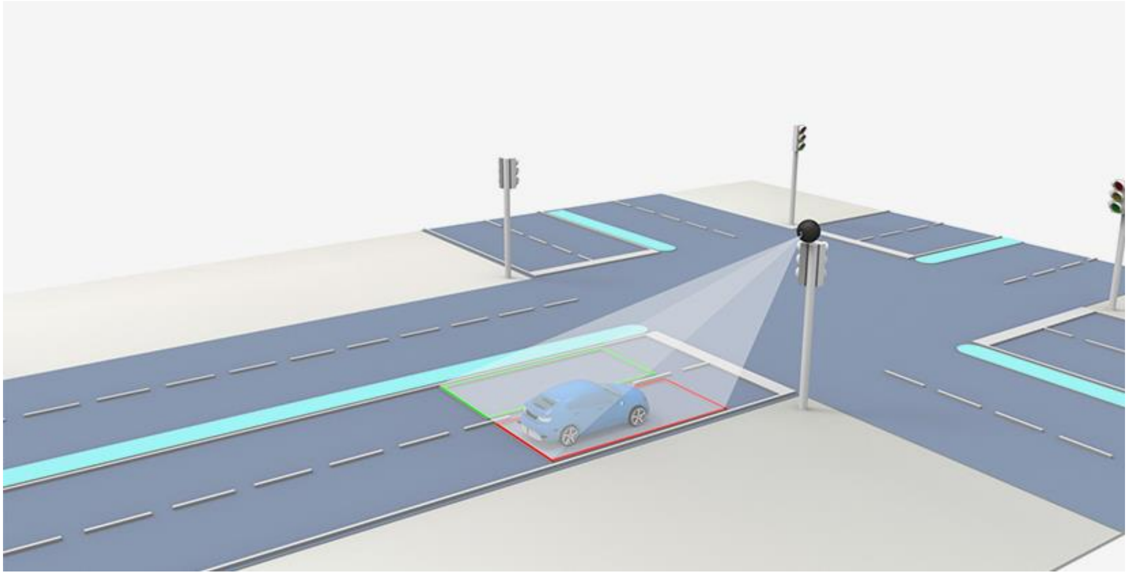


Figure 3-5:Video image detectors [12]

3.1.6 Infrared sensors

For traffic applications, active and passive infrared sensors are available. The sensors are located overhead to provide a view of incoming or leaving vehicles, as well as traffic in a side-looking arrangement. Signal control, volume, speed, and class measurement, as well as identifying people at crosswalks, are all done by infrared sensors. The received data are analyzed for the presence of a vehicle using real-time signal processing.

Active infrared devices generate a laser beam, which is shown in Fig.3.6., at the road surface and measure the return of the reflected signal time. The time it takes for the signal to return is shortened when a vehicle drives within the path of the laser beam. A vehicle's presence is indicated by a decrease in time. Inclement weather has an impact on active infrared detectors since the short wavelength cannot penetrate snow and rain.

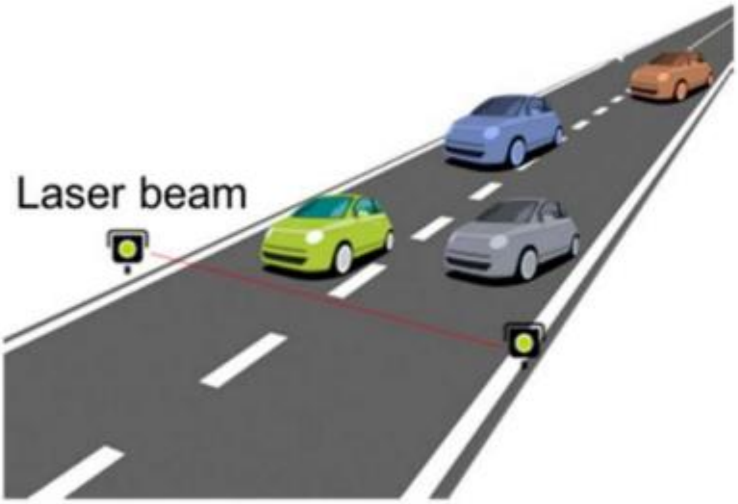


Figure 3-6:Laser beam [9]

Passive infrared detectors identify the presence of vehicles by calculating the quantity of infrared energy emitted by the detecting zone (Fig.3.7.). A vehicle's temperature will always be different from the surrounding environment. The energy radiated when a vehicle is present is compared to the infrared radiation normally emitted by the road surface. The difference in heat energy is measured because the roadway may create more or less radiation than a vehicle. Since the technology is fully passive, the risk of interfering with other devices is minimal. Inclement weather has no impact on passive infrared detectors [7][8].

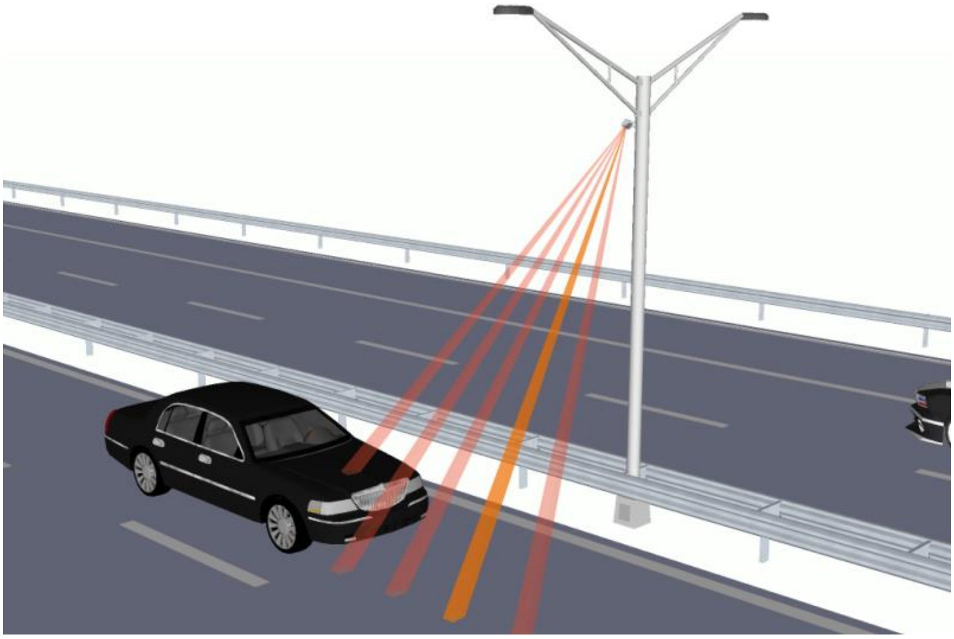


Figure 3-7:Passive infrared detectors [13]

3.1.7 Microwave Radar

Microwave Radar is able to identify distant objects and specify their speed and position. An overhead antenna which can be seen from Fig.3.8., transmits energy toward a section of the roadway from a roadside-mounted microwave radar. The size and distribution of energy over the aperture of the antenna are used to manage the beamwidth or region in which the radar energy is transmitted. A part of the transmitted energy is reflected to the antenna when a vehicle passes across the antenna beam. The energy is then sent to a receiver, which makes the detection and calculates vehicle data including volume, speed, occupancy, and length. The presence of stationary cars can be detected using radar sensors. They are weather-insensitive and may operate at any time of day or night. When the radar equipment is located near other high-power radars, electromagnetic interference may develop [7][10].

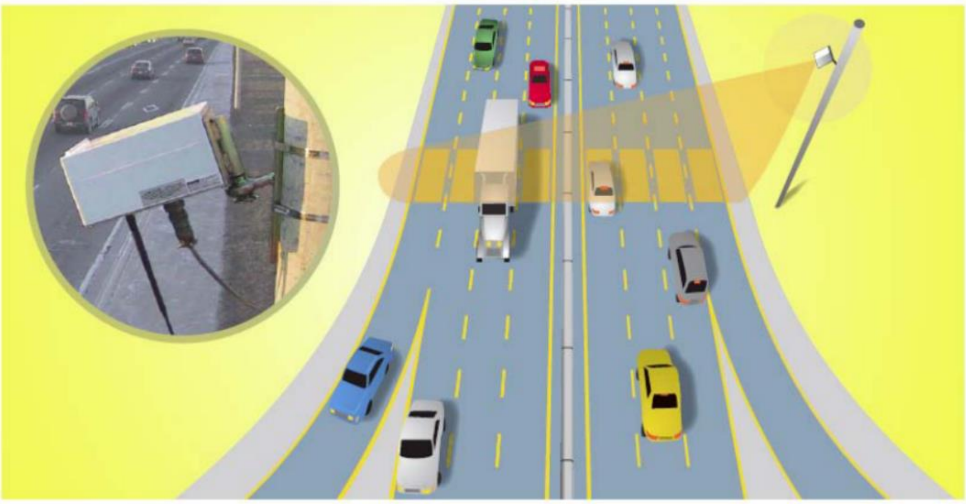


Figure 3-8:Microwave radar [14]

3.1.8 Ultrasonic and Passive Acoustic

The majority of ultrasonic sensors use pulse waveforms to give vehicle count, presence, and occupancy data. Pulse waveforms detect the part of the energy transmitted by reflecting to the sensor from an area determined by the transmitter's beamwidth, allowing distances to the road surface and vehicle surface to be measured. The presence of a vehicle is indicated if a different distance from the normal road surface background is measured. The ultrasonic energy that is received is transformed into electrical energy, which is then analyzed by signal processing electronics. Ultrasonic sensors are often installed above the monitored traffic lane. Illustration of overhead and side top-mounted sensors are shown in Fig.3.9.

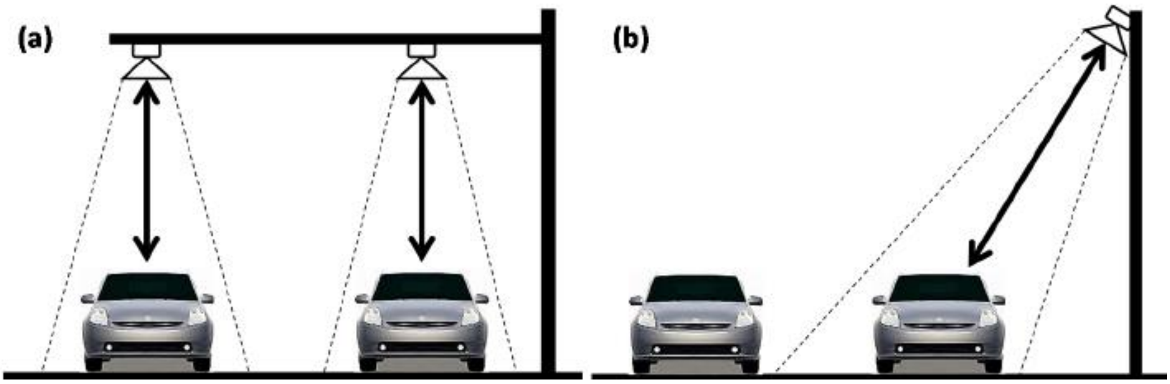


Figure 3-9:Ultrasonic sensors (a) Overhead mount and (b) side top mount [15]

Passive Acoustic sensors detect acoustic energy or audible noises produced by vehicular traffic from a number of sources within each vehicle, as well as from the interaction of a vehicle's tires with the road, to evaluate vehicle passing, presence, and speed. The sensor detects a sound from a vehicle moving within the detection zone, the signal processing algorithm recognizes an increase in sound energy, and a vehicle presence signal is created. The sound is then compared to a collection of sound characteristics that have been preprogrammed to recognize different types of vehicles. The sound energy level falls below the threshold when the vehicle exits the monitoring zone, and the vehicle presence signal is turned off. The disadvantage of the passive acoustic sensors is that they are sensitive to snow and cold temperatures [7][10].

3.1.9 Wireless Sensor Networks

At present, wired sensors are used to collect traffic data for traffic planning and management. The considerable cost of equipment and maintenance, as well as the time it takes to install these existent sensor systems, prevents the widespread deployment of real-time traffic monitoring and management.

Wireless sensors with integrated sensing, computation, and wireless communication abilities provide significant cost and installation benefits. Wireless sensor networks (WSNs) have the capability to increase the efficiency of the current transportation systems dramatically. The goal of the network in several WSN applications is to deliver sensor data to a gateway device for gathering. The wireless sensor network is presented in Fig.3.10.

A WSN is generally made up of two parts: the first part is a collection of resource-constrained nodes that are deployed over the spatial region to be watched and capable of completing user-defined data-gathering activities, and the second part is one (or many) sink node where the WSN's data may be retrieved by the end-user [16]. WSNs are frequently installed in distant and/or hazardous environments, and the sink is the only node through which the WSN is queried and accessible for data collection activities. As a result, the sink is anticipated to be linked to the backend through a long-distance connection (i.e., satellite communication, Wi-Fi, Wi-Max, etc.).

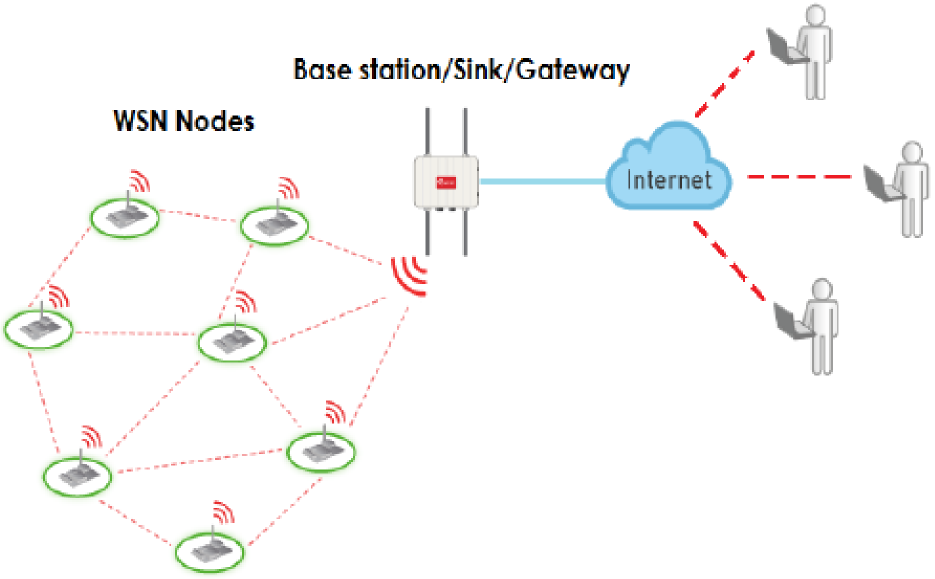


Figure 3-10:Wireless sensor network [17]

WSNs are developed with distinct performance concerns than more traditional data networks due to their unique properties. In WSN medium-access control (MAC) protocol design, performance parameters such as average power consumption, message latency, and fairness, as well as low channel occupancy, self-organizing and self-maintenance, and scalability, are significant. Even though WSNs provide a more cost-effective means of monitoring traffic, deploying WSNs on every road in a large city is still prohibitively expensive [16][18].

3.2 Automatic Vehicle Identifications (AVI)

The main purpose of an automatic vehicle identification (AVI) system is to identify a vehicle fully automatically, uniquely, and accurately at specified interrogation checkpoints. An AVI system is composed of two parts: a transponder that is mounted on the vehicle to be recognized and has no influence on its operation, and an interrogator that is placed on or near the road and gets the information from the transponder. The AVI transponder is typically passive, sealed, and installed on the vehicle with no electrical connection. The AVI interrogator is a low-power gadget with a restricted range of only a few feet.

The location of the vehicle at a given moment can be determined via a coded radio signal emitted by the vehicle passing by the AVI terminal (or beacon) mounted at a specified point. The real travel time through a road network to the traffic center can be determined by detecting the same vehicle at another AVI terminal. A different technique for vehicle identification is to utilize license plate readers, in which particular technologies are used to read the plate number from images collected by the infrastructure cameras.

The following are some of the AVI applications:

- **Fleet Control:** Vehicle fleet operators need to know where the fleet's components are located in order to use their resources efficiently, for this purpose the AVI system is used for fleet control.
- **Revenue Collection:** The use of AVI might help to speed up processes at toll gates, parking lots, park gates, and other locations where a vehicle must stop to provide payment. AVI might allow for continuous vehicle passing as well as automatic recording and payment via computers linked online to the AVI interrogators. Tollgate configuration example is shown in Fig.3.11.
- **Traffic Operations:** AVI has the potential to improve traffic management, especially in areas where priority access systems are proposed or used. By allowing users to identify vehicles by type in a unique and accurate way. Surveillance and control systems may benefit as well because AVI data allows for the more exact specification of traffic composition.
- **Traffic Planning:** The transportation planning process requires the estimation of the quantity and distribution of interzonal trips by time, route, and mode. The placement of AVI interrogators at strategic sites might generate automated and instructive data in a way that traffic managers can use effectively.

The advantages of an AVI system may be found in a variety of areas, including driver safety, cost, comfort, and convenience, cost reduction, and enhanced implementation, planning, and design efficiency.

Figure 3-11: Tollgate example

3.3 Automatic Vehicle Location (AVL)

Automatic vehicle location (AVL) is a technology that was developed for fleet management and vehicle tracking. The overall goal of an Automatic Vehicle Location (AVL) system in a transportation context is to enhance customer service and increase efficiency. The following are just a few examples of the many advantages of an AVL system; adherence to schedules, safety and security, performance monitoring, public information, fleet management, and management system improvements. The AVL (Fig.3.12) communications software system was created in a geographic information system (GIS) context, however, SMS technology is used in these sorts of systems [20][21]. The majority of AVL systems offer location data in the form of coordinates. These coordinates must match coordinates on a map in order for the vehicle's location to be easily identified. The coordinate systems of the map and the AVL system must be consistent, compatible, and sufficiently precise for the matching procedure to be effective. The AVL location must match a single, unequivocal point on the map in order to meet the accuracy criteria. This matching procedure may be done with relatively modest AVL and digital map system accuracies in many AVL situations when the vehicle's numerous stops or destinations are spread out across a vast region.

Figure 3-12: Automatic vehicle location system [22]

3.4 Floating Vehicle (Car) Data (FVD)

Floating vehicle data (FVD) is a traffic data collection technology that uses a group of individual vehicles that are floating in the existing traffic and can be seen as a distributed moving sensors network. Each vehicle has a positioning (GPS) and communication (GSM, GPRS, UMTS, etc.) system that sends the location, speed, and direction information to a control system that combines the data from all the vehicles. FCD systems are rapidly being employed in a wide range of critical applications because they surpass the constraints of fixed traffic monitoring technology. The public sector can utilize FCD to collect road traffic information and to provide real-time traffic control. Drivers can get information from FCD systems, including dynamic rerouting information, in a variety of methods such as satellite navigation systems, cell phones, or dynamic message signs. Drivers who receive traffic information with these methods can make better decisions and spend less time in traffic [23][24].

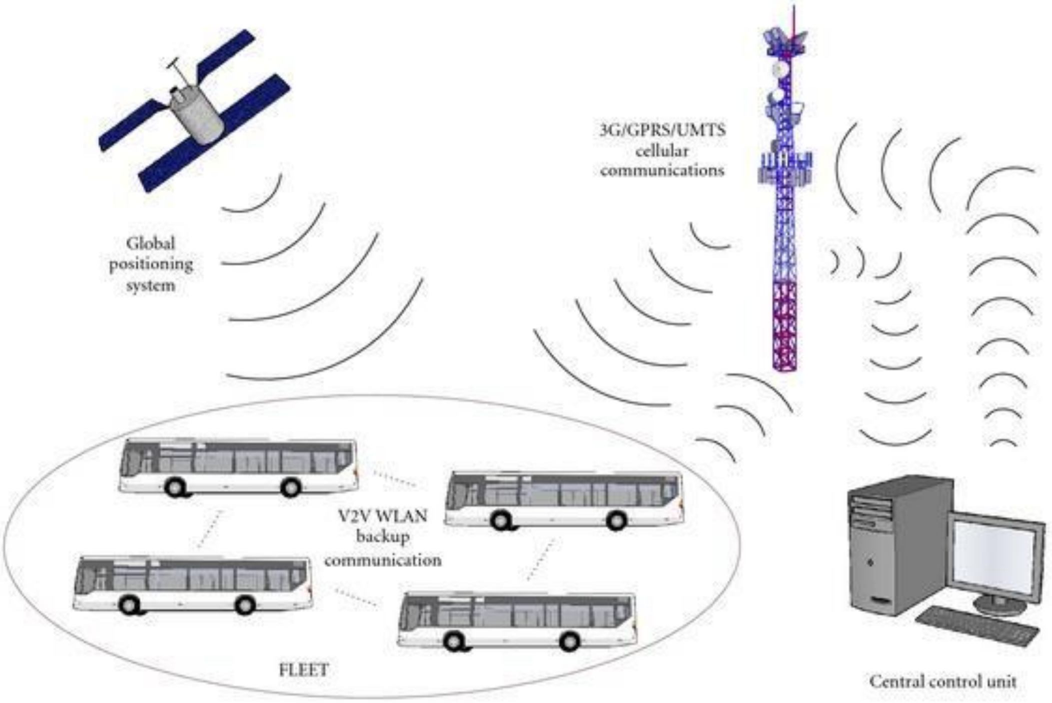


Figure 3-13:Floating car data [25]

3.5 V2V-V2I-V2X Technologies

In terms of transportation, road traffic is rapidly increasing, and vehicle traffic congestion is becoming a serious issue, particularly in urban areas across the world. Traffic congestion affects the efficiency of transportation infrastructure, increases travel time, fuel consumption, and pollution, and increases user dissatisfaction and tiredness. Vehicle density has always been one of the most important indicators for analyzing road traffic situations. A high vehicular density typically means congested traffic; nevertheless, vehicle density in a city varies greatly depending on the location and time of day. Assessing the density of a vehicle environment is crucial because it permits traffic congestion solutions aimed at improving traffic flow, decreasing pollution, and enhancing driver comfort to be implemented.

Vehicular networks (VNs) provide all of the necessary communications to allow coordinated driving among vehicles and infrastructure nodes, as shown in Fig.3.14 [26]. Vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications are two types of VNs.

VNs, for example, offers a variety of applications for regulating traffic flow, network security, health issues, environmental protection, mobile infotainment, and so on, while the primary goal for deploying this type of network has been to improve driver safety.

Most vehicle density estimating methods now in use are intended to work with extremely particular infrastructure-based traffic information systems, which need the usage of vehicle detection equipment such as inductive loop detectors or traffic surveillance cameras. These techniques, however, are constrained since they can only know about traffic density in previously specified locations (i.e., the streets and intersections where these devices are already deployed), making it impossible to estimate vehicular density over a whole city.

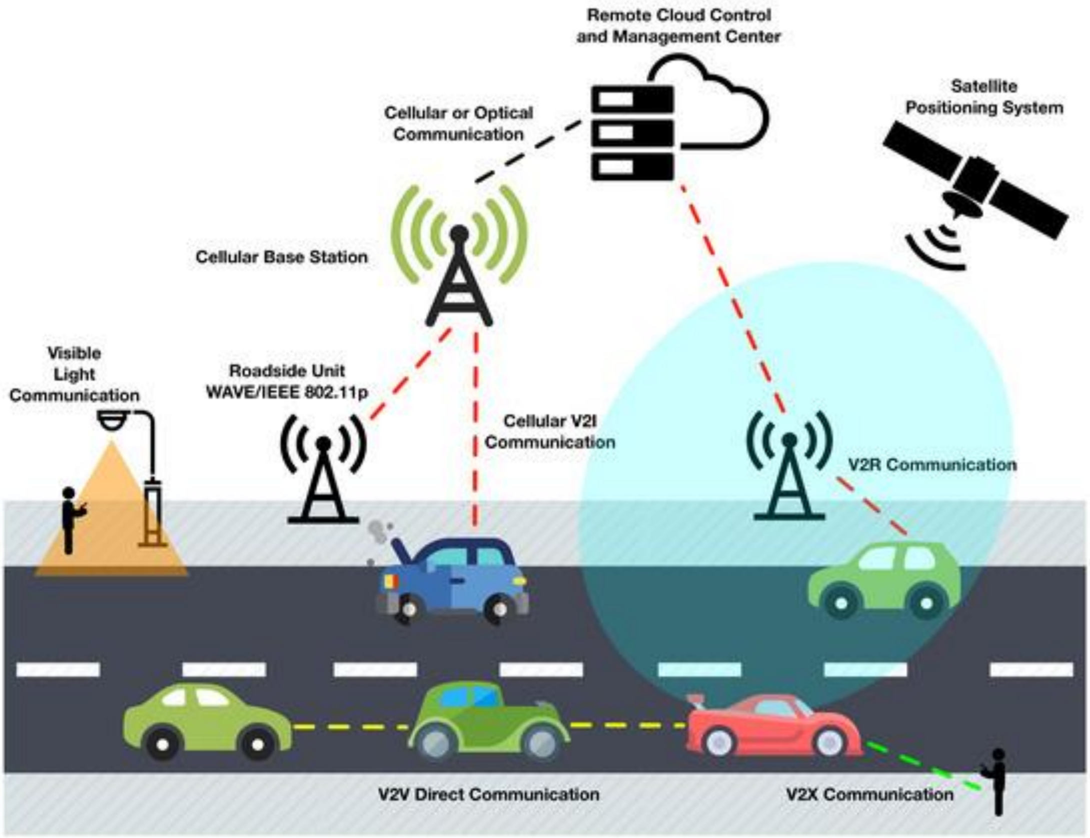


Figure 3-14:V2V-V2I-V2X systems [27]

Intelligent Transport Systems have taken the place of traditional modes of transportation (ITSs). These new technologies are contributing to the resolution of transportation engineering's most important concerns, such as traffic congestion and accidents. Nonetheless, this system has to be able to work together, for example, permitting communication with and among vehicles. The information sharing between the many associated parties necessitates the use of appropriate communication protocols, such as the IEEE 802.11p and LTE-V2V standards, which are designed to facilitate vehicle transmissions. In further detail, the IEEE 802.11p standard for Wireless Access in Vehicular Environments has been introduced (WAVE) [27]. Its purpose is to make V2V and V2I communication faster and more efficient. Its unique architecture makes coordination and collaboration between vehicles and infrastructures much easier.

3.5.1 Vehicle-To-Vehicle

Wireless data communications between vehicles are the basis of V2V technology. The major goal of this communication is to reduce accidents by allowing cars in motion to share information about their location and speed over an ad-hoc mesh network.

The latter employs a decentralized connection technique that can produce a completely linked or partially connected mesh topology. Each node in the first circumstance is directly connected to the rest of the network. In the second case, certain nodes can be linked to all others, but the others are only connected to the nodes with whom they often share the majority of their data. The nodes of a mesh network can interchange messages and information with surrounding nodes with whom they are directly linked or take one of the several pathways available to reach the target by utilizing this network structure.

When mesh networks were exclusively wired, this architecture was prohibitively expensive and difficult to implement since each node needed to be physically linked to the others. These constraints have since been solved by utilizing the benefits of wireless communications and the development of Wireless Personal Area Networks (WPANs).

3.5.2 Vehicle-To-Infrastructure

The V2I allows transit vehicles to communicate with the road system. RFID readers, traffic signals, cameras, lane markings, street lighting, signage, and parking meters are among the components. V2I communications are often wireless, bidirectional, and, like V2V, use Dedicated Short-Range Communication (DSRC) [27] frequencies to transfer data. An ad-hoc network transmits data from infrastructure components to vehicles and vice versa. V2I sensors in the ITS may collect data on infrastructure and give real-time advice to passengers, such as road conditions, traffic congestion, any accidents on the road, the existence of work sites, and the available parking spots. Similarly, traffic surveillance and management systems may use data from infrastructure and vehicles to create variable speed restrictions and change Signal Phase and Timing (SPaT) to save fuel and improve traffic flow.

3.5.3 Vehicle-To-Everything

The above-mentioned V2V and V2I communication models are completed in the V2X, which is a generalization. Vehicle-to-Pedestrian (V2P), Vehicle-to-Roadside (V2R), Vehicle-to-Device (V2D), and Vehicle-to-Grid (V2G) are examples of more specialized forms of communication that include data flow from a vehicle to any entity that might impact it, or vice versa [27]. One of the major goals of V2X technology is to facilitate viable and effective communication systems between vehicles and pedestrians in order to reduce potentially catastrophic accidents.

4 DATA COMMUNICATION

The collection and analysis of traffic-related data are not the only factors to evaluate the effectiveness of the ITS system. The importance of the communication system has long been recognized since ITS necessitates linking road infrastructure, centers, and vehicles via wired or wireless communication infrastructure. Communication links link different components of traffic management systems jointly, allowing orders and data to be sent between field equipment and control centers, as well as information to be transmitted to travelers [28].

To "pass on the message," a variety of communication technology is available. This can be wired or wireless, with varying levels of technology. All present and future telecommunication infrastructure, whether fixed or mobile, may and should be exploited to reduce costs and capitalize on the telecoms industry's continual technical advancement.

In terms of frequency range or bits per second, data transmission expenses often increase as bandwidth needs rise. Due to the small number of bits per unit time, traffic parameters received from traffic sensors are transferred through low-bandwidth wireline or low-bandwidth wireless communications. Live video pictures, on the other hand, contain a large number of bits of information per unit of time, necessitating a wide bandwidth of communication means for transmission.

Fiber optics is a type of transmission media that allows data to be sent from one location to another [29]. The cost of fiber optics which is one of the settings for transmission and uses to transmit data from one to another location is so cheap. The only significant cost is installation because of this a number of traffic authorities make an agreement with the telecommunications sector and fiber optics placed along the highway during road construction.

Continuous Air interface Long and Medium range (CALM) 's goal is to enable a variety of communications to support ITS applications that perform equally well on different network platforms, such as Second Generation (2G) mobile (e.g., GSM/GPRS), 3G,4G, satellite, microwave, millimeter-wave, infrared, WiMAX, and short-range technologies such as Wi-Fi [30].

A logical decision is taken about platforms that use in a certain area or specific application based on criteria for efficient resources usage. Examples of the criteria are what platform is cheapest, offers the highest performance, has the greatest level of coverage, what communication equipment is available in the vehicle, etc.

In the development of new ITS applications, four types of communication capabilities are viewed as critical [31]:

- Wireline communication broadcast systems enable exchanges of data between fixed sites, often via telephone or fiber optic lines, such as transportation hubs, roadside equipment, traveler information kiosks, and personal computers at fixed locations, and also fixed systems and wide-area wireless.
- Wide-area communication via broadcast or interactive two-way communication enables wireless data interchange between mobile receivers installed or carried by individuals on infrastructure-based devices and vehicles.
- Close-range wireless data interchange between fixed roadside equipment and emitters-receivers in moving vehicles is enabled through dedicated short-range communication.
- Vehicle-to-vehicle communications, allow moving vehicles to exchange data.

4.1 Wireless Communications

The four subsystems of ITS are the center, vehicle, road, and travelers. For linking ITS subsystems, a variety of wireless and wired communication options exist. For many years, the automotive and transportation sectors have investigated the use of wireless technology to improve services to drivers. This interest is heightened by the fact that wireless communications are now regarded as the most efficient way of transmitting and collecting data from moving vehicles. The two primary wireless-based applications now employed in automobiles are listed below:

- Wireless phones—wireless phones enabled drivers in transit to receive and distribute information to any person or system that was phone-connected. In general, this technology removed motorists' solitude while driving.

- Vehicle–roadside wireless services—in the late 1980s, electronic toll collection was introduced, allowing cars equipped with an onboard transponder to pay tolls without stopping. For a variety of applications requiring the identification of passing vehicles, radio-frequency, microwave, infrared, and optical technologies are being utilized [28].

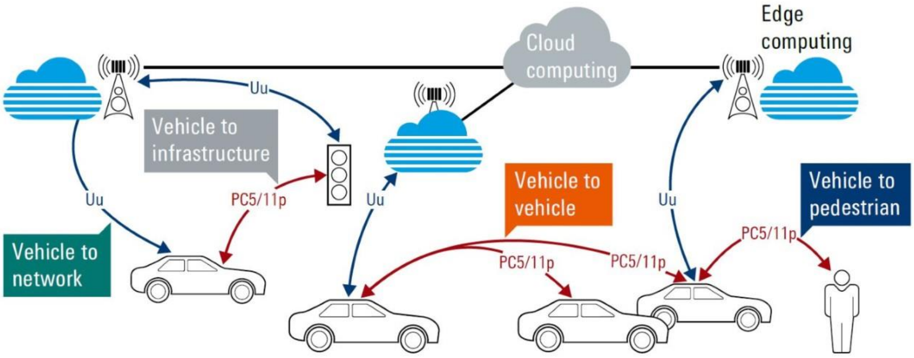


Figure 4-1:Wireless communication for vehicle [32]

There are now significant efforts being made to establish information systems that allow data interchange with mobile vehicles. Several protocols for wireless communication between moving objects have been created to meet this demand. There is presently five wireless local area network (WLAN) standards. These are the 802.11a, 802.11b, and 802.11g sub-standards of the 802.15 (Bluetooth), 802.15.4 (ZigBee), and universal wireless compatibility (Wi-Fi) families of standards.[31]

Today's wireless communication alternatives include Worldwide Interoperability for Microwave Access (WiMAX), Wireless Fidelity (Wi-Fi), and Dedicated Short-Range Communications (DSRC) for interacting between vehicle and road subsystems. WiMAX is a wireless broadband standard based on the IEEE 802.16 family of standards that are meant to give high-speed wireless broadband connectivity to a variety of customers. The WiMAX connection rate may theoretically reach 70 Mbps, with a coverage range of up to 10 miles. The large range of possible profiles with varying channel bandwidths ranging from 1.75 MHz to 20 MHz, which may suit diverse ITS application needs with effective bandwidth consumption, is a key feature of WiMAX technology. WiMAX may work in both licensed and unlicensed bands [28].

Wi-Fi refers to the IEEE 802.11 standard family, which currently enables wireless connectivity in hotspot-type short-range low-cost, high-bandwidth, and low-latency coverage. Although the Wi-Fi link rate may theoretically reach up to 54 Mbps, the coverage range is less than 0.4 miles. Early Wi-Fi had a limited channel bandwidth of 20 MHz, while the recently released IEEE 802.11n currently enables 600 Mbps with a channel bandwidth of 40 MHz. Wi-Fi is only available in unlicensed frequency channels [28].

Wi-Fi and WiMAX may be used to connect ITS equipment in the field in a variety of network topologies, including mesh networks and point-to-point networks. Mesh networking is a new technology that consists of mesh routers and mesh clients, with each node acting as both a host and a router, passing data packets to target nodes within its transmission range. Mesh networking has several advantages, including redundant, reconfigurable pathways between nodes and the ability to redirect data to ensure network reliability if any nodes fail. Mesh networks can be used to offer coverage across a broader region than point-to-multipoint design generally allows. [28]

The Dedicated Short-Range Communications (DSRC) standards have been utilized to provide communication capabilities between roadside devices and automobiles. The 915-MHz frequency was chosen as the starting point for the development of electronic toll collecting systems and commercial vehicle clearance systems. While adequate for the intended use, it lacked the high data rates and communication ranges required for new ITS applications. In response to this demand, the focus has lately switched to a new 5.9-GHz standard built exclusively for transportation applications, which enables communication speeds of up to 27 Mbps, a communication range of up to 1000 m, and a substantially lower risk for interferences [31].

The Bluetooth standard gives a maximum data throughput of 1 million bits per second (Mbps) over a communication range of 10 meters in terms of communication characteristics. The ZigBee standard, which uses the 802.15.4 protocol, has a little longer range (30 meters) but a lower data transfer rate (0.25 Mbps). It also allows for substantially more communication nodes within a network (216 vs. 8) than Bluetooth, making it more suitable for applications that need communications between large numbers of cars in geographically constrained areas, such as parking lots. Because both standards have a narrow communication range, they are less likely to cause interference from other applications [31].

ITS network design necessitates careful consideration of the wireless technology to employ and where the devices will be deployed. This procedure begins with determining the needs of the different sensors, cameras, and other ITS components. Wi-Fi, WiMAX, and DSRC can all provide adequate throughput to meet the majority of an ITS network's present demands, but each has its own set of advantages and disadvantages [28].

4.2 Internet of Things (IoT)

The Internet of Things (IoT) is a cutting-edge technology that takes a wide approach to solve technical difficulties. The Internet of Things (IoT) is a combination of information and communication technologies that are tied to a specific application (Fig.4.2.) [33].

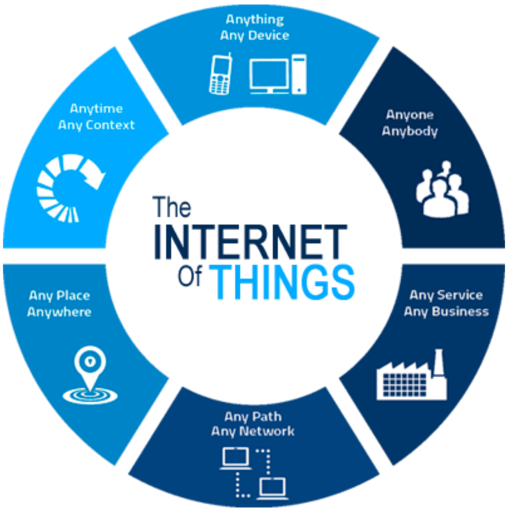


Figure 4-2:Internet of Things

The Internet of Things (IoT) is a network that links various gadgets, Fig.4.2. The Internet of Things, according to the International Telecommunication Union, is a network that can connect message instruction and sensor equipment such as RFID, IR sensor, GPS, laser scanner, and so on to implement information exchange and sharing, resulting in a simultaneous and intelligent management network [34].

The Internet of Things (IoT) is a network processing system in which things that may store information about items, such as RFID, are installed, and readers receive the information and communicate it wirelessly to a background information processing system [34]. To fulfill the purpose of intelligent management, such as tracking and tracing of things, main information systems can be combined to build a wide network.

4.2.1 IoT Architecture for Transportation System

There are five levels to the IoT architecture for transportation systems. These layers are the application layer, sensor layer, communication layer, service layer, and infrastructure [33]. Transportation is mostly used to move a thing or a live being from one location to another. Transportation is engaged in many activities in everyday life, such as moving products and people, whether by road, river, or air. The study of the transportation system encompasses a wide range of aspects. All these aspects should be detected and sent to the service layer over a reliable communication channel. Appropriate decisions were made at the service layer to control the system in accordance with the requirements. The infrastructure layer stores all necessary and detected data.

- Application layer: Different tasks should be monitored according to the client's needs at the application layer. Application layers in transportation include duties involving people, vehicles, roads, commodities and other services, traffic, and so on.
- Sensing layer: The sensing layer is responsible for interacting between the application layers and the vehicle captains via an electrical device known as a sensors

network. These sensors and other equipment were built inside the vehicle or installed at the application location.

- Communication layer: One of the most critical levels of IoT systems is the communication layer. Between the sensor layers and the service layers, this layer serves as an information bridge. This layer aids data transfer from the sensor layer to the service layer through 3G/4G/5G networks, Wi-Fi, wired networks, optical fiber, public and private networks, and so on. Security concerns are the most critical aspects to consider when creating this layer. Apart from this, there are issues such as data transmission speeds, data transfer transparency, and data transfer dependability to consider. The improved service is provided through a more stable and powerful communication network.
- Service layer: The service layer is responsible for carrying out the tasks specified by the application layer or by the client. Through the communication layers, the service layer receives comprehensive information from the sensor layer. The data was processed in a variety of ways, and numerous analyses were carried out using a variety of computer tools.
- Infrastructure layer: The infrastructure layer is responsible for developing the technologies necessary to provide various services. GIS mapping service, cloud computing platform, cloud storage, big data analytics tools, and so on are among them. This layer primarily provides for the enhancements needed to provide dependable services.

Many advantages are achievable when IoT technology is linked with transportation systems. Among the advantages are:

- The vehicle's trip distance is optimized, resulting in lower fuel consumption and more profitability.
- During lethal and dangerous situations, it is possible to optimize or redirect the routes.
- A service can be operated based on demand through a centralized control network.
- Traffic control based on vehicle count can help to ensure public safety.
- Exports and imports of goods and materials, as well as purchases and other shipping data, may all be kept up to date.
- Increases revenue for owners of transportation and logistics companies.

4.3 5G for Intelligent Transportation Systems

The 5G era will herald in new network and service capabilities. Technological developments will assist the 5G network, which will revolutionize the foundation of mobile communication networks. By delivering an entirely new network architecture, 5G will empower a wide range of application possibilities. It will enable network ubiquity, greater data rates, reduced latency, enormous simultaneous connections, and network continuity across the world, even in difficult settings for existing 4G, such as high mobility and in crowded or sparsely populated regions. Furthermore, 5G will be a critical facilitator for IoT, offering a platform for connecting many sensors and actuators while maintaining strict energy efficiency and transmission limits.

A device with 5G will be capable of maintaining network connectivity at all times and in all places, allowing all devices in the network to be connected. To that purpose, the basic 5G system architecture is projected to handle up to a million simultaneous connections per square kilometer, allowing the adoption of a wide range of new IoT ideas [35].

In comparison to 4G, 5G will handle 10 to 100 times more data speeds and linked devices. Furthermore, 5G will deliver near-complete availability and geographic coverage, as well as enhanced security and privacy. In addition, 5G will use ten times less energy while improving device battery life by ten times. New radio access, huge Multiple Input Multiple Output (MIMO), heterogeneous ultra-densification, channel coding, decoding, and Millimeter Wave (mmWave) are among the important technologies that will be implemented in 5G [36].

5G will meet the needs of a wide range of vertical industries, including energy, health care, manufacturing, automotive, and public transportation, to mention a few of them. To fulfill the diverse service requirements of vertical industries, it is separated into categories that support the communication service requirements of certain usage. Categories are classified into many types based on the separation of the aspects of the services they support. The Third Generation Partnership Project (3GPP) has established four network classifications [36]:

- Enhanced Mobile Broadband (eMBB): This network type is a natural progression from existing 4G networks, bringing higher data speeds and improved coverage and user experiences to densely populated urban areas.

- Massive Internet of Things (mIoT): This type often contains a huge number of devices congregated in a compact space. Low-cost and low-energy devices that transfer small data packets. This network type allows for mass sensing, monitoring, and metering, all of which need minimal data quantities but is constrained by cost and energy.

- Ultra-Reliable and Low Latency Communication (uRLLC): This is sometimes referred to as crucial communications. In general, this supports devices with strict latency and reliability requirements. The most creative 5G feature is undoubtedly uRLLC. It has the potential to enable a wide range of applications, including ones that are currently unknown.

- Vehicle-to-Everything (V2X) communication: This communication is a vital technology for connecting vehicles, roadside devices, and pedestrians in an intelligent transportation system.

As they establish performance objectives, these network types face a wide variety of technological issues, including power efficiency, high reliability, spectrum efficiency, channel robustness, low latency, reduced cost, high energy performance, cooperative networking, co-existence, and so on.

5G has the potential to radically transform the ITS environment. 5G and its variants, such as eMBB, mIoT, uRLLC, and V2X, can increase and improve ITS operation and performance in a variety of ways. The enabling technologies as well as the evolution of vehicles have to be analyzed in order to completely implement the notion of ITS.

4.3.1 Vehicular Communication

The modern vehicle has evolved into a sensor platform that collects and transmits data from its environment. An on-board computer processes the data, which is subsequently utilized for navigation, pollution control, and traffic management, among other things. Advanced safety applications that minimize traffic accidents, boost traffic efficiency, and improve access to emergency vehicles can all benefit from this data. These applications, on the other hand, necessitate a coordinated architecture that includes aspects such as ultra-low latency for warning signals, increased data rates for transferring sensory data between vehicles and infrastructure, high mobility, high reliability, and scalability [36]. However, fast data processing necessitates the use of a very powerful onboard computer. To eliminate the usage of expensive equipment, it should be feasible to send data to the cloud through the Internet to execute large processing tasks. As a result, IoT can help collect more data for traffic control centers, including the data presently captured by vehicles [35].

Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), Vehicle-to-Pedestrian (V2P), and Vehicle-to-Network (V2N) are the four types of vehicular communication use cases defined by the 3GPP. V2V and V2P communications are primarily between vehicles or between vehicles and vulnerable road users (for example, pedestrians and bicycles) to transmit position, speed, and direction information in order to avert accidents. Direct connection between vehicles and roadside infrastructure, such as Roadside Units (RSU), is part of V2I [36]. The RSU acts as a forwarding node to broaden the range of communications received from a vehicle. V2N transmission occurs between a vehicle and a V2X application server to enable services such as entertainment streaming video and connection for dynamic route management.

4.3.2 5G-V2X Use Cases

5G can help to actualize the goal of AV by enabling the real-time interchange of sensor data with the huge number of connections required to interact with thousands of automobiles, roadside sensors, and other adjacent devices. 5G is also projected to deliver high-performance, dependable, and robust communications, as well as improved coverage to aid in accident avoidance in urban and rural locations.

3GPP sets the performance requirements for expanded V2X scenarios based on various levels of vehicle automation. Vehicle platooning, remote driving, advanced driving, and extended sensors are examples of advanced applications. Furthermore, each of the 3GPP improved V2X application cases is briefly explained in the following sections:

- Vehicle Platooning: Platooning allows vehicles to move in a tightly coordinated group with greatly decreased inter-vehicle distance, boosting road capacity, fuel economy, accident rates, and productivity by freeing drivers to undertake other activities. All platoon vehicles exchange information with the leading vehicle on a regular basis and carry out platoon operations. All vehicles in a platoon can operate autonomously.
- Remote Driving: Remote driving allows a human operator or remote driver to manage a vehicle from afar utilizing a cloud-based program and V2N connection.
- Extended sensors: The capacity of a vehicle to transmit raw or processed information about things in its proximity outside the view of its onboard sensors is referred to as extended sensors. Vehicle, RSU, pedestrian, and V2X application servers can all share information. A vehicle's sensor data can range from a snapshot of a seen item to a real-time video feed. For both automobiles and pedestrians, sensor data from a variety of sources increases situational awareness and road safety. New features and capabilities, such as cooperative driving and the exact positioning required for autonomous driving, are enabled by extended sensors.
- Advanced Driving: Advanced driving allows for semi- or completely autonomous driving. In this case, longer intervehicle distances are permitted. Each vehicle, or RSU, communicates data from local sensors with other cars, allowing them to plan their routes together. Advanced driving has several advantages, including safer travel, fewer collisions, and greater traffic efficiency. [2]

  Before completely autonomous vehicles, there are various intermediary phases that include how people interact with them. The Society of Automotive Engineers (SAE) has recognized six stages of driving automation, ranging from no automation to complete automation [35]. Briefly,

  - No automation (Level 0): The driver maintains control at all times.
  - Driver Assistance (Level 1): The system performs minor driving tasks.
  - Partial Automation (Level 2): The driver must keep an eye on the road while performing dynamic driving responsibilities.

    - Conditional Automation (Level 3): The driver does not need to oversee driving activities, but he or she must be able to regain control if necessary.
    - High Automation (Level 4): During the indicated use case, no driver is required.
    - Full Automation (Level 5): This is the highest level, which refers to a system that is completely self-contained and does not require a driver.

For levels 1 and 2, when a human driver observes the driving environment, autonomous driving is theoretically conceivable without V2X communication [35].

5 DATA ANALYSIS AND PROCESSING

Data analysis contains multiple steps for the procedure of collected data at TMC. Error correction, data cleaning, data fusion, and analysis. Data inconsistencies are classified and sorted out with software. For further analysis, the data is adjusted and aggregated in preparation for analysis. To estimate and forecast traffic conditions, the cleaned and integrated traffic data will be analyzed. These approaches for estimating traffic conditions will be utilized to deliver appropriate information to users.

The traffic data collected at the traffic management center must be analyzed, checked, reconciled, and integrated into a format that the operator can benefit from. Data processing provides technologies in different fields for efficient use.

5.1 Traffic and travel information

One of the most essential data processing applications is providing real-time traffic information and/or predicted travel time to users (PTT).

Travel Advisory Systems (TAS) is one of the data processing applications which are used to provide real-time traffic information, updates such as delay, accidents, change in route, etc., and/or predicted travel times (PTT) to users. Data fusion for predictive information would also include changes over time-based on departure times, road works, weather, events, incident reports, and more. PTT may also take into consideration vehicle type, driver characteristics, and certain time constraints as additional parameters.

A large variety of electronic devices are used to serve this information such as Dynamic Message Signs (DMS), the media, In-Vehicle Units (IVU), and mobile devices, highway advisory radio, internet, SMS, etc. [37]. Travelers’ can access information to help them choose the mode of transportation and/or departure time for the trips to be planned.

5.2 Automatic incident detection (AID)

Another essential data processing technique, on the infrastructure side, is automatic incident detection (AID) [38]. Automatic incident detection (AID) has been shown to be beneficial in accelerating rescue operations and traffic diversion near incident areas, as well as in decreasing incident detection time. AID can also be used for other purposes. AID has been used, for example, to assess traffic conditions or the degree of congestion. Estimation of travel time has been calculated by using AID cameras with the assumption that AID can calculate the mean speed of each segment along with enclosed space. This is performed thanks to computer processing, which is composed of complex algorithms applied to acquired data. The detection system's input data is analyzed against an algorithm to determine if an event has happened. Mostly, AID technology is not intended to replace traffic center operators, but rather to warn them of traffic patterns similar to those seen in an incident.

5.3 Vehicle location and navigation

Vehicle location requires additional systems that continue to function even when the vehicle is in an extraordinary situation, by reason all satellite navigation systems require the observation of at least four satellites to operate. These coverage gaps may be filled by map matching, a popular in-vehicle navigation system's fundamental component. Map matching determines the location of the vehicle on the map by using an extremely accurate digital map of the vehicle and heuristic algorithms[37].

Another method of navigation is dead reckoning, which employs a gyroscope or other inertial guiding principles to determine the location of a vehicle in relation to a given starting point. Nevertheless, dead reckoning cannot work by itself, due to the cumulative error must be adjusted on a regular basis, ideally automatic.

Multiple advance traveler information and route assistance systems require digital maps. Raw road network data is acquired from digitized and paper maps, aerial images, and other information sources to build digital maps. Before being digitized using specialized computer software the data is merged with navigation features.

5.4 Location-based Services

One of the initial ITS offers on the market was the satisfaction of rescue services because safety and security are top priorities of many customers in between a wide variety of developing and existing location-based services.

Distress signals can be sent manually or automatically to the rescue center, for example, when an airbag deploys, and the position of the vehicle in distress is sent automatically and accurately using GNSS. These types of rescue services are frequently combined with other ITS services like stolen vehicle tracking and driving instructions.

6 ITS APPLICATIONS

Intelligent transportation systems embrace a diverse set of technology and applications that are constantly evolving. The main reasons for using ITS applications are transportation safety, effectiveness, and services for users. Data collection, analysis, and application of analytical results in operations, control, and research concepts for traffic management, where location is a key factor, constitute the foundation of ITS applications. The application relies heavily on sensors, information processors, communication systems, roadside messaging, GPS updates, and automated traffic priority signals [39][40].

Intelligent Transportation has a wide range of applications, few of them are discussed thereinafter.

6.1 Advance Traffic Management System (ATMS):

Advance traffic management systems (ATMS) are an essential element of intelligent transportation systems that have been utilized to enhance traffic service quality and try to minimize delays. Advance traffic management systems focus on traffic control tools and combine many sub-systems, such as traffic signals, vehicle detection, ramp metering, and the dynamic or variable message systems into an interface that offers drivers real-time traffic data, highway status information, and predicts traffic to plan and operate more effectively. Traffic operations centers (TOCs) are centralized traffic management centers that depend on information technologies to develop a joint perspective of traffic flow and detect accidents, hazardous weather conditions, and other road hazards [39][41].

There are three primary ATMS components. The data collection group check on the traffic situation. Cameras, sensors, semaphores, and electronic displays are examples of support systems that assist system operators in managing and controlling real-time traffic. Real-time traffic control systems may modify semaphores, transmit messages to electronic displays, and regulate highway access using the information supplied by the two preceding sections. Adaptive traffic signal control refers to intelligent traffic signal timing that is dynamically managed. Giving traffic signals the capacity to identify the existence of waiting vehicles or allowing vehicles to transmit that information to a traffic signal, might enhance traffic signal timing, resulting in improved traffic flow and reduced congestion.

Ramp metering is also an advanced transportation management method that can provide considerable traffic control advantages. Ramp meters are traffic lights installed on highway entry ramps that split up concentrations of vehicles entering the highway, reducing highway flow disturbances, and making merging safer. Ramp meters are red-green stoplights that can be programmed to turn on and off at specific times of the day, or they can be controlled by a detector installed upstream on the roadway. This sort of management controls the input flow at select roadways by metering one vehicle at a time, preventing highway congestion, and preserving smooth traffic conditions [39][41].

6.2 Advanced Traveler Information Systems:

Advance Traveler Information Systems (ATIS) supply real-time travel-related information to users of transportation systems, such as routes, navigation guidance, and delay information by the reason of congestion, accidents, weather, or road repairs, to help with route choice, optimize traffic flow, and reduce pollution [39][41].

A effective traveler information systems are capable of briefing drivers about their exact location in real-time, giving information of current traffic or road circumstances on present and nearby roadways, and supporting users with route selection and navigation guidance that are best, in principle this information should be accessible on diverse and various platforms, both in and out of the vehicle.

Collection, processing, and distribution are the three main aspects of providing real-time traffic information, each of them requiring a different combination of technology devices, platforms, and players.

Some of the several technologies used to provide different information are:

- GPS-enabled navigation systems in vehicles
- A website with a color-coded map representing highway congestion levels
- Dynamic road message signs enabling real-time transmission of information about congested traffic, bottlenecks, accidents, and routes during road works and repairs.

Another advanced traveler information systems make parking easier by utilizing systems that alert vehicles to available parking spots across the city and even allow drivers to book spaces ahead of time.

6.3 ITS-Enabled Transportation Pricing Systems:

Electronic toll collection (ETC), congestion pricing, fee-based express (HOT) lanes, and usage-based charge systems for vehicle miles traveled (VMT) are examples of ITS-enabled transportation pricing systems. ITS has a critical role in the finance of a country's transport systems. Electronic toll collection (ETC), sometimes known as "road user charging", is the most prevalent use, in which drivers can pay tolls automatically using a DSRC-enabled onboard gadget or a tag put on the windshield [41].

Another ITS-enabled technique to reduce traffic congestion is High-Occupancy Toll (HOT) lanes, which are designated for buses and other high-occupancy vehicles but may be allowed access to only one vehicle for a fee [41]. The number of cars utilizing the designated lanes can be managed using dynamic pricing to always ensure free-flowing traffic, including during peak hours, improving total traffic flow on a specific section of road.

A vehicle mile traveled (VMT) tax system, which charges motorists for each mile driven, is another ITS-enabled option that states are investigating for funding their transport systems [41]. VMT fee system can be considered an alternative to the existing fuel taxes and other charges used to fund many countries' transportation systems.

6.4 Advanced Public Transportation Systems:

Advanced Public Transportation Systems (APTS) are applications that adopt electronic technology to develop the operation and efficiency of high-occupancy vehicles like buses and trains. APTS utilize ATMS and ATIS technology to enhance public transportation by providing route information, time schedules, and expenses, as well as real-time information regarding changes in transportation systems. By providing passengers with improved access into the arrival and departure state (as well as overall punctuality) of buses and trains, APTS helps to make public transportation a more appealing alternative.

Through APTS, a fleet's services may be monitored, scheduled, and developed, and a more adaptable service with safety and efficiency can be predicted, ensuring the satisfaction of customers and cost control [39][41].

Electronic fee payment solutions for public transportation systems are also considered. Automatic payment systems using multi-use smart cards or mobile phones with near-field communication technologies for contactless payment are also included in APTS [39][41].

6.5 Advanced Vehicle Control Systems (AVCS):

AVCS consists of sensors, computers, and control systems that aim to assist and warn drivers for increasing their control over vehicles as well as make travel safer and more efficient. The major goals of these systems are to elevate the safety, reduce traffic congestion on roadways, and improve the efficiency of transport systems. The driver can get visual and audible information on traffic, risks, and all vehicle conditions via in-vehicle sensors. For instance, vehicle collision warning systems notify the driver of a looming accident. Based on data from sensors on the vehicle, the vehicle might autonomously stop or keep away from a collision in more advanced AVCS applications. Both systems are self-contained within the vehicle and potentially bring significant benefits in terms of increasing safety and minimizing traffic congestion caused by accidents. Automatic control provides for a faster and more efficient response in dangerous circumstances, which is especially beneficial for older or inexperienced drivers.

The insertion of high-tech devices and processors in vehicles allows for the use of software applications and artificial intelligence systems to regulate internal operations, as well as ubiquitous computing and other programs that are meant to be merged into a larger transport system [39].

6.6 Advanced Commercial vehicle operations (CVO):

Commercial vehicle operations (CVO) systems implement a variety of ITS technologies to allow for uninterrupted central office monitoring of truck operations and to maximize the safety and efficiency of commercial vehicles such as trucks, vans, taxis, and fleets [39]. CVO systems have been beneficial for large and medium businesses with commercial fleets since they help enable the administration of all vehicles, as well as the control of speed and stopping periods, while also ensuring that the destination is fulfilled. Furthermore, ITS technologies improve the speed at which goods are delivered, patient transportation, and operating expenses are reduced.

These systems comprise technology for information for travelers, traffic management, vehicle control, and management such as [39]:

- Automatic weighing systems
- Automatic Vehicles Location
- Automatic Vehicles Classification
- Automatic Vehicles Identification
- Pedestrian Movement Detection
- Board Computers
- Real-Time Traffic Transmissions

6.7 Advanced Rural Transportation Systems (ARTS):

Advanced Rural Transportation Systems (ARTS) inform about rural roads and other transport systems. ARTS are intended to address issues that arise in rural settings. Steep gradients, blind corners, curves, limited navigation markers, a mix of users, and a few alternate routes are all characteristics of rural roads. Provided information examples include automatic reporting of traffic and weather conditions, as well as directional information. Motorists driving to distant or rural regions will benefit from this sort of information. Autonomous Navigation Systems, Enhanced Vision, Mayday Signaling, and Traveler Safety and Security are all subcategories of ARTS [39].

7 SIMULATION

7.1 Simulation Models

The goal of traffic modeling is to properly simulate traffic as seen and measured on the road. Without replicating, traffic modeling assumed the form of a traffic system. It was created based on the expertise of modelers in integrating mathematical models into traffic systems.

To manage traffic problems, simulation models primarily concentrate on three output values. The first one is the flow of traffic. Alternative routes can be found in traffic flows relying on the number of vehicles. Modelers can develop ways to decrease the degree of congestion on particular roadways by utilizing the simulation model. The network element is the second output.

In traffic simulation, network elements include a link, merge, link cross, and other road features which are connected to the road's geometric layout. The road geometric design may be altered using proper simulation tools to examine how it affects the existing traffic condition. The skim category is the third output. The use of a simulation model can aid in the estimation of travel time and cost. This is particularly useful when a traffic improvement analysis must be made. The transportation planner may readily compare performance without incurring any additional costs in terms of money or time.

The simulation models were divided into categories based on their intended use. The following sections discuss the types of traffic simulation models.

7.1.1 Microscopic Modelling

A microscopic model explains in considerable detail both the system elements and their interactions. The movement of individual vehicles and their related time and space is the basis for microscopic modeling [43]. Microscopic modeling is based on the features of different vehicle movements in the traffic flow, such as automobiles, buses, motorbikes, and so on.

Microscopic modeling was used to gather data on flow, density, speed, travel and delay times, lengthy queues, stops, pollutants, fuel consumption, and shock waves. Car-following models, lane-changing models, and individual driver gaps were used to define the properties of microscopic modeling methodologies.

7.1.1.1 Car Following Models

These algorithms established the idea of a driver recognizing and following a leading vehicle at a reduced pace [43]. This is a circumstance similar to being in a vehicle platoon and not being able to change lanes. The connection with the lead vehicle was usually defined using the following car algorithm which was the function of speed, spacing, and acceleration.

7.1.1.2 Lane Changing Models

The lane-changing model is a decision-making method that predicts a driver's behavior while performing a lane change in a certain period of time [44]. During lane-changing movements, driver behavior has a significant impact on traffic flow phenomena. Lane-changing maneuvers are made up of three key driving behaviors:

- Lower-level control including steering and acceleration,
- Monitoring denotes a state of awareness in order to sustain a condition.
- Lane changing decision

When a vehicle switches from the present lane to the target lane, it acts as a moving obstacle, reducing the freeway's capacity and safety.

7.1.1.3 Gap Acceptance Models

The number of vehicles that can pass through a conflict point is calculated by gap acceptance. The gap is the time difference between vehicles in the target lane that are leading and lagging [43]. The dimension of the gap that will be accepted or refused by a car attempting to merge or cross the intersection was determined using gap acceptance models. The acceleration rate desired speed, and speed acceptance is the parameters of the gap acceptance model.

7.1.2 Macroscopic Modelling

At a low degree of detail, a macroscopic model defines entities, their activities, and interactions. The traffic stream is represented in a macroscopic model as an aggregation of properties such as speed, flow, and density. The three main features of traffic are flow, speed, and density [43]. Speed-flow-density relations have been examined by researchers and mathematical explanations have tried to be developed.

One of the developed models is the Greenshields Model which is used to create a continuous traffic flow model. According to the Greenshields model, the relationship between speed and density is linear as shown in Figure 1. When traffic density rises, flow declines until it reaches an optimum when there are more vehicles on the roads. Because of the interaction of vehicles, the speed also reduces.

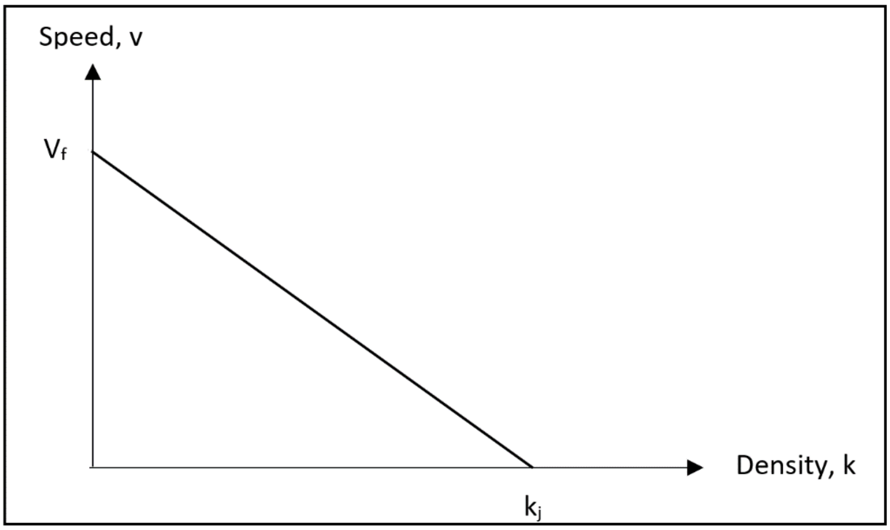


Figure 7-1:Speed versus density

$$v = v_f - \frac{v_f}{k_j} k \qquad (7.1)$$

Where,

v = speed (km/h)

k=density (veh/km)

v_f = free mean speed (veh/km)

k_j = jam density (veh/km)

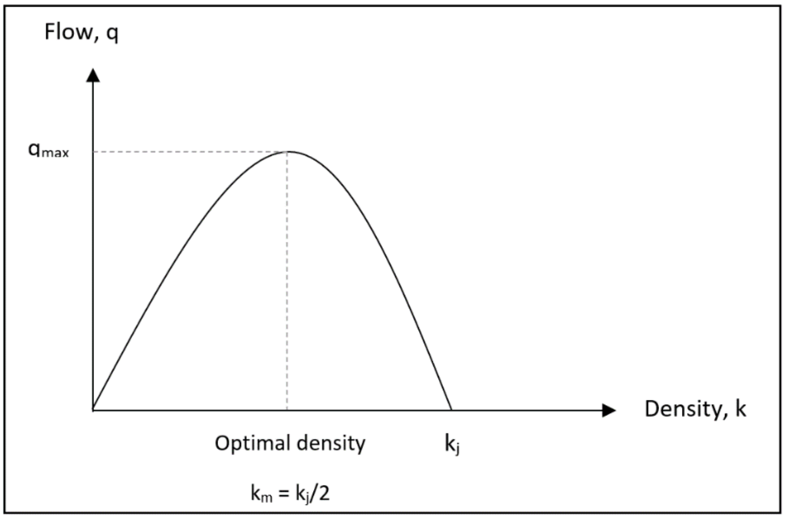


Figure 7-2:Flow versus density

The relationship between flow and density based on Greenshields is a parabolic curves seen in Fig.7.2.

$$q = \left(v_f - \frac{v_f}{k_j} k\right) k \tag{7.2}$$

Where

q= flow

When the flow rate is low, the speed is increased. The drivers can go at their preferred speed. The speed steadily reduces as when the flow rises. The maximum flow indicates that the situation has changed from non-congested to congested.

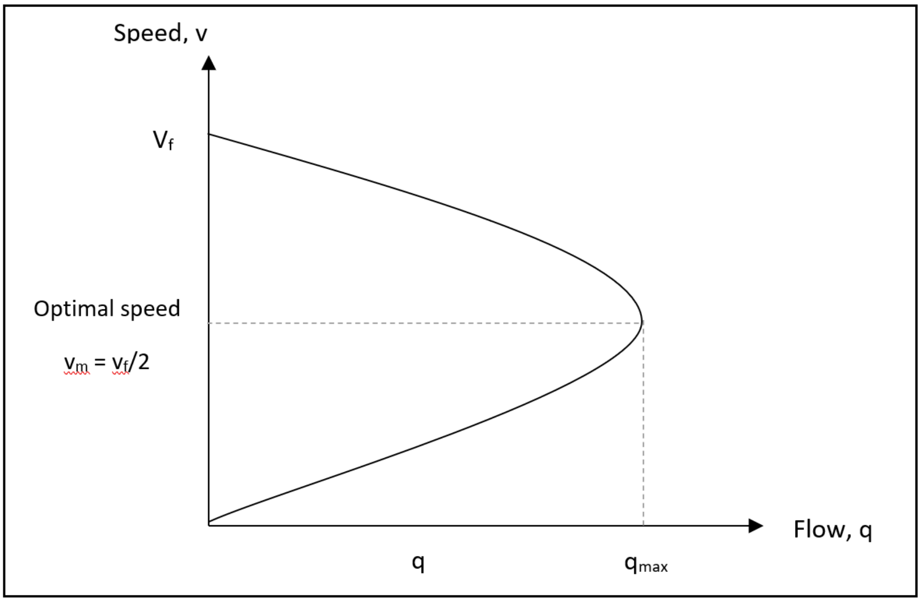


Figure 7-3:Relation between speed and flow

The relation between speed and flow is depicted in Greenshields model as shown in Fig.7.3.

$$q_m = v_m k_m \;\; or \;\; q_m = \frac{v_f k_f}{4} \qquad (7.3)$$

Where,

q_{max}= maximum flow

v_m= optimal speed

k_m = optimal density

When the capacity (q_{max}) is at its maximum, the density rises and the speed falls owing to the maximum number of vehicles passing at a specific spot. High density and low speed are two features of a congested unstable flow. Vehicles cannot enter since there is no space. When there are spaces for merging lanes, the features of uncongested steady flow include slow density and high speed.

7.1.2.1 Davidson Travel Time Function

Travel time functions are an essential element to traffic assignment algorithms, especially when analyzing congested traffic circumstances. The function that follows is Davidson's function, which estimates travel time as a function of traffic volume [45].

$$T = t_0\left(1 + \frac{JV}{C-V}\right) \qquad (7.4)$$

Where,

t_0 = free-flow travel time

J = curvature parameter

C = capacity

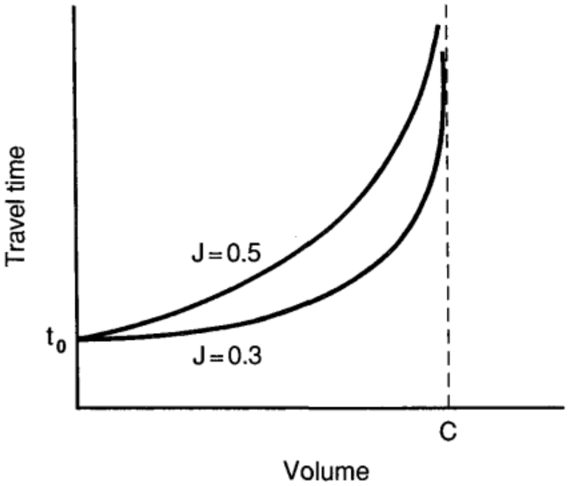


Figure 7-4:Davidson's travel time function

The curvature parameter for constant capacity and free flow travel time defines a family of travel time functions as shown in Fig.7.4.

7.1.3 Mesoscopic Modelling

Mesoscopic modeling is a type of modeling that explains the examined transportation components in small groupings. Microscopic and macroscopic modeling are combined in mesoscopic models. Platoon dispersion is modeled in the mesoscopic simulation [43]. There are two types of mesoscopic modeling: platoon dispersion and vehicle platoon behavior.

Platoon dispersion is the first approach. The distance between vehicles increases as a platoon proceeds downstream from an upstream intersection, which may be due to changes in vehicle speeds, vehicle interactions, or other factors. The second approach is vehicle platoon behavior, which involves a group of vehicles traveling at the same speed and within a short distance. Vehicle platoon behavior is the ability to forecast the arrival time of a vehicle platoon over time.

7.1.4 Discrete-Event Modelling

Discrete simulation models describe that the states of real-world systems (whether continuous or discrete) change rapidly at points in time. Discrete-time and discrete-event are the two categories of discrete models.

A system is described in discrete-event simulation in terms of its state at each point in time, as well as the entities that flow through it and the entities that represent system resources, as well as the actions and events that cause the system state to change [46]. Discrete-event models are suitable for systems where changes in system state occur at discrete intervals in time.

The following are some of the most important concepts:

- System: A system is a group of entities (for example, humans and computers) that interact over time to achieve one or more goals.
- Model: A system's abstract representation, typically incorporating structural, logical, or mathematical linkages that define a system in terms of states, entities and attributes, sets, processes, events, and delays.
- System state: A set of variables that contains all of the data needed to describe the system at any given time.
- Entity: Any system item or component that has to be explicitly represented in the model.
- Attributes: The characteristics of a certain entity. List a group of related elements that are arranged in a logical order.
- Event: An event that occurs in an instant and causes a system's state to change.
- Event list: A collection of future event alerts, organized by time of occurrence.
- Activity: A period of time of a specific length that is known when it begins.
- Delay: A period of undefined unlimited length that is unknown until it expires.
- Clock: A variable that represents the simulated time.

In a discrete-event model, the state variables change only at a discrete set of points in time at which events occur. Activity times and delays cause events to occur. Entities may compete for system resources, sometimes entering queues as they wait for a resource to become available. Activity and delay times have the potential to "hold" things for certain periods of time. A discrete-event simulation model is executed over time ("run") using a process that advances simulated time [46]. The system status is updated at each event, as well as the capture and release of resources that may occur at that moment.

An activity often reflects a service time, an interarrival time, or any other processing time that the modeler has characterized and specified. The length of an activity can be described in several ways; deterministic, statistical, or a function that is determined by system variables and/or entity properties.

Different simulation programs use different languages to describe the same or related ideas; for example, lists are sometimes referred to as sets, queues, or chains. Sets or lists are used to store entities as well as event announcements. A list's entities are always sorted according to some rule, such as first-in-first-out or last-in-first-out, or rated according to some entity feature, such as priority or due date [46]. The event time noted in the event notification is always rated first in the future event list.

7.2 ExtendSim Simulation

ExtendSim (or Extend as it was originally named) provides the simulation analyst with the broadest variety of technologies accessible in a single family of simulation tools. It was the first graphical simulation tool to embrace the concept of modeling components as objects, as well as the first "drag and drop" simulation software. This simulation program includes continuous, discrete event, discrete rate, and agent-based simulations. ExtendSim involves libraries which are storage locations for the blocks, each with its own set of behaviors, message answers, user interface, and data.

ExtendSim comes with numerous libraries, each of which contains blocks for simulating certain situations or types of systems, and several examples of libraries are listed in Tab.7.1. Users may also create their libraries of custom blocks or libraries to maintain and arrange the model to best suit their modeling needs.

Table 7-1:ExtendSim Libraries

Library	Description
Item	Blocks for item processing
Value	Blocks for value processing
Plotter	Plots and charts
Animation	2D or 3D animation of the model
Rate	Processes that are high-speed, high-volume, or rate-based

Items are generated according to a probability distribution, timeline, or spontaneously and move from one block to the next one while the simulation is running; each item can have certain properties to obtain a model as desired. ExtendSim models are developed by dragging and dropping blocks into a model worksheet, linking them, and then entering simulation data. Each sort of block has its own set of features, including functionality, help, icons, and connections. A block's data is unique to each occurrence.

A variety of functions are executed by blocks in a simulation model, including:

- Simulating the phases in a process (Queue, Activity)
- Making a calculation (Math, Random Number)
- Interfacing with other applications or data storage (Read, Write)
- Supplying a utility model (Find and Replace, Count Blocks)
- Plotting the model output (Plotter, Histogram)
- Tools for producing interfaces (Popup, Buttons)

The main blocks used in the model are briefly explained below:

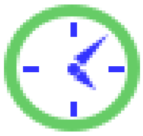


Figure 7-5:Executive block

- Executive block: In the discrete event and discrete rate models, this block must be located on the left of all other blocks. It allows for simulation control, item allocation, attribute management, and other discrete event and discrete rate model parameters, as well as event schedules.

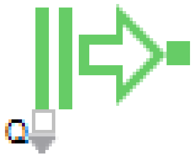


Figure 7-6:Create block

- Create Block: The Create block is typically used to generate items for a model. While the Create block may also generate values, it can also create items infinitely, randomly, and according to a schedule. The Create block always sends objects to the downstream block when it creates them. As a result, this block is usually preceded by a block with the capacity to retain items, such as the Queue.

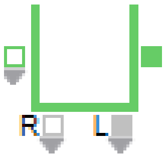


Figure 7-7:Queue Block

- Queue Block: Items are queued and released according to the queuing behavior chosen by the user. The type of queuing behavior, the maximum queue length, whether or not the queue is a reneging queue, and many other options can be defined using different tab sections in the block, and what items presently occupy in the block or what items have historically moved through the block can be recorded and viewed.

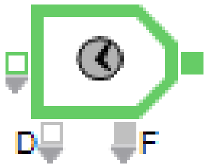


Figure 7-8:Activity Block

- Activity Block: The activity block keeps one or more items and distributes them based on the process and arrival times for each item. The process tab allows the users to specify how many items in the block can be processed at once, and how long each item will take to process. Specify processing time (delay) is used to specify the processing time. Delay can be specified whether be a constant, a value from the D connection, an attribute value supplied by distribution, or a lookup table.

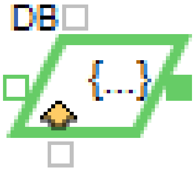


Figure 7-9:Set block

- Set Block: The properties of items passing through the block are set using this block. The value input connector or the dialog may be used to set multiple properties such as attributes, the priority value on an item, and the quantity of the item.

Figure 7-10:Select item in block

- Select Item In: Depending on a decision, one input is chosen to be output. The item present at the specified input is transferred to the output. Choosing an input according to item priority, randomly, sequentially, merging, or selecting based on the chosen connector are all possibilities available in the dialog.

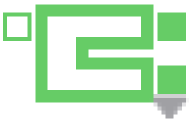


Figure 7-11:Select item out block

- Select Item Out: Depending on a decision, chooses which output the input should utilize. Based on a selection, one output connector is chosen to output an item from one of several input connectors. The dialog allows users to pick an output based on the property, connection priority, randomly, sequentially, or by selecting a connector.

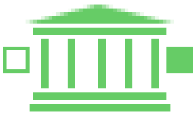


Figure 7-12:History block

- The history block shows and records information about the items that pass through it. The time the item arrived in the block is shown in the first column of the table in the dialog. The remaining columns represent the item's property values.

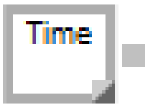


Figure 7-13:Simulation variable block

- Simulation variable: The value of a simulation variable is provided in this block. It is typically used in combination with a decision-type block, such as to terminate a process when the current time reaches a specified value. The commonly utilized variables are current time and current run number.

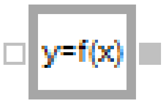


Figure 7-14:Equation block

- Equation Block: This block updates the set of output variables using the set of input variables and the user-defined equation. Many different types of input and output variables, ExtendSim's built-in operators, ModL programming language, and more than 1000 ModL functions are accessible to support the equation needs. ExtendSim's blocks are programmed in ModL, which is a compiled language.

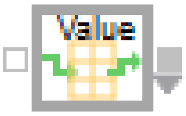


Figure 7-15:Lookup table

- Lookup Table: The block calculates the output value for a given input or time period. It has a table of values (x in and y out) that is used to determine the output value for a given input. The output is calculated based on where the input appears on the curve, as defined by the table of values. The table can be written into the dialog, imported from a file, pasted from the Clipboard using the Edit menu commands, or dynamically linked to from other parts of the model.

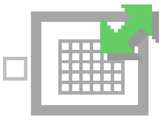


Figure 7-16:Data import export block

- Data Import Export Block: Data from external data sources is imported and exported into ExtendSim global arrays and database tables. The Data Import Export block allows users to import and export data from and to Microsoft Excel. Choose the workbook, then the worksheet inside it. A range can be provided to import or export only a section of the global array or database table.

Figure 7-17:Hierarchical block

- Hierarchical Block: Models with thousands of blocks are not uncommon, making it difficult to understand what is going on in the model. Hierarchy assists in resolving this issue by combining several blocks into a single hierarchical block that reflects a component of the process being modeled. Submodels, text, pictures, and clones of dialog items and tables can all be found in a hierarchical block. There are several layers of hierarchy since hierarchical blocks can include other hierarchical blocks.

Figure 7-18:Exit block

- Exit Block: Items are passed out of the simulation. This block's total number of items received is displayed in its dialog and on the value output connectors. When the process is completed with an item, it's critical to leave it from the model.

8 MODEL

8.1 Study Area

Genoa is the capital of the Liguria region and the sixth-largest city in the country. Genoa played a strong economic role as a major port and steel and shipbuilding center

The University of Genoa is part of the city of Genoa. The University of Genoa is composed of various campuses spread around the city. The population of the university, together with students and university staff, reaches approximately 40,000 people.

There are numerous companies and industries due to the development of economic structure, and for the university with a high educational capacity, there is a daily flow from the surrounding cities, particularly from the suburban areas to Genoa.

The access routes to Genoa are becoming increasingly congested as a consequence of this high volume of movement. The study on the simulation transport model of this traffic flow from suburban areas to Genoa will be presented in the following sections.

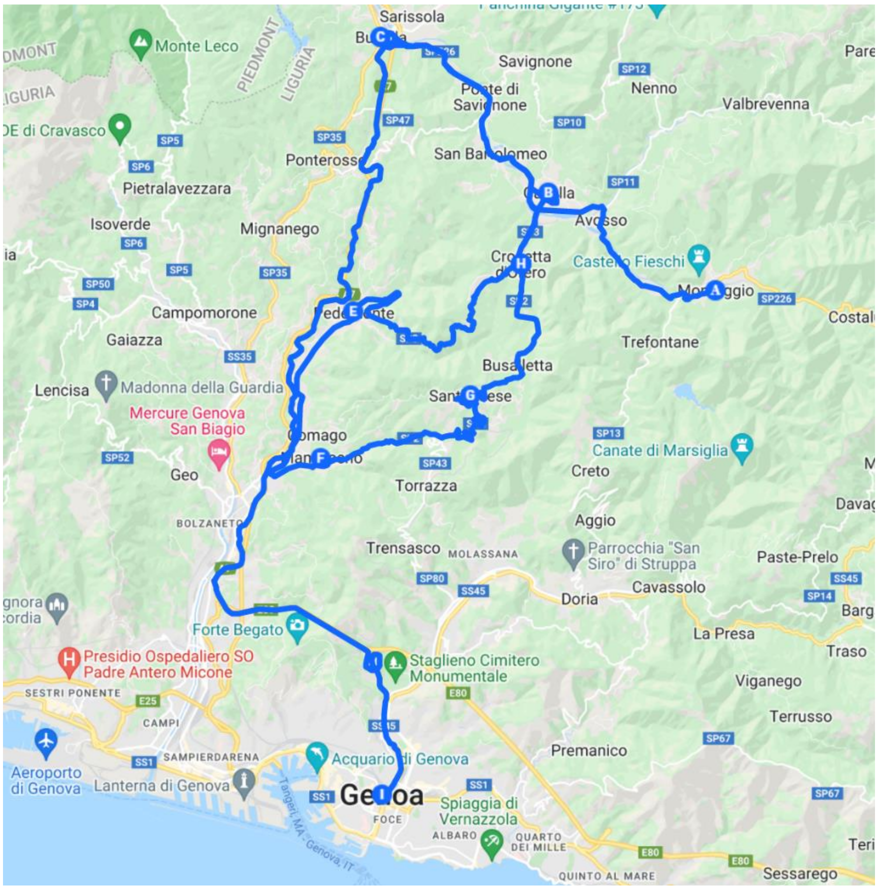


Figure 8-1:Study area

The studied area includes a one-way entrance traffic flow to Genoa as marked on the map in Fig.8.1. This area mainly covers the SP226, SP2, SP3, and A7 roadways. Later, SP2 and SP3 are examined in particular from these roadways. While modeling this roadmap, traffic with the final destination Genoa is prioritized, although drivers' travel to places included in the model outside of Genoa is also considered. The directions of the modeled roadways are different, as can be seen in the simplified representation of the region in Fig.8.2. There is two-way traffic for Sp226 between Busalla, Savignone, and Casella, but only one-way traffic between Montoggio and Casella.

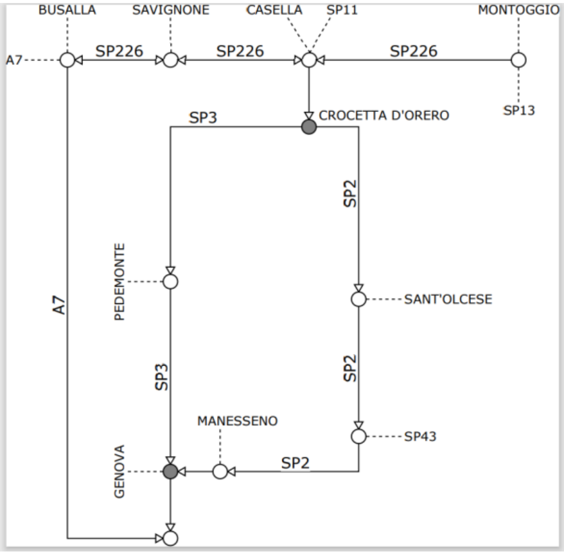


Figure 8-2:Simplified representation of the area

Due to the different direction flows, the Crocetta D'orero and A7 roads are alternatives for drivers to travel to Genoa. While there is direct access to Genoa from the A7 highway, on the contrary, Sp2 and Sp3 roads are options at the Crocetta D’orero junction (Fig.8.3). After the simulation model was created, the focus was on the flow distribution between SP2 and SP3, and how drivers could have less average travel time to Genoa.

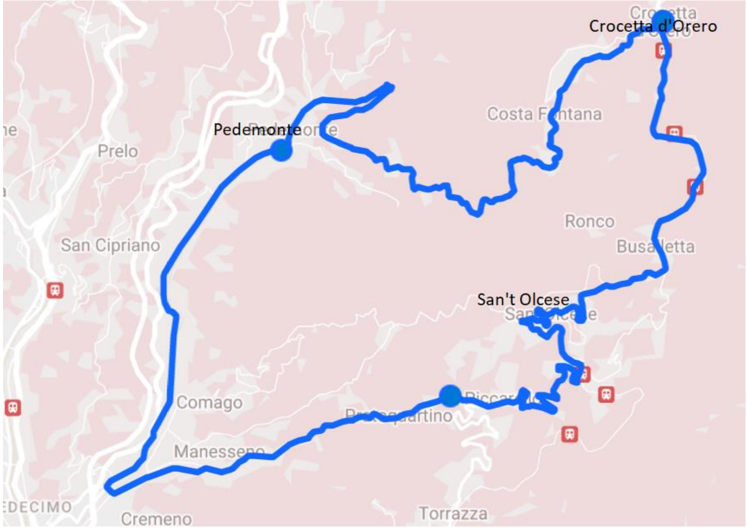


Figure 8-3:SP2 and SP3 roads representation

8.2 Model

The ExtendSim software tool was used to model and simulate the area of interest. The general model seen in Fig.8.4 will be explained in detail in this section. The model is separated into parts, with each part explaining which blocks are utilized and how they contribute to the overall framework.

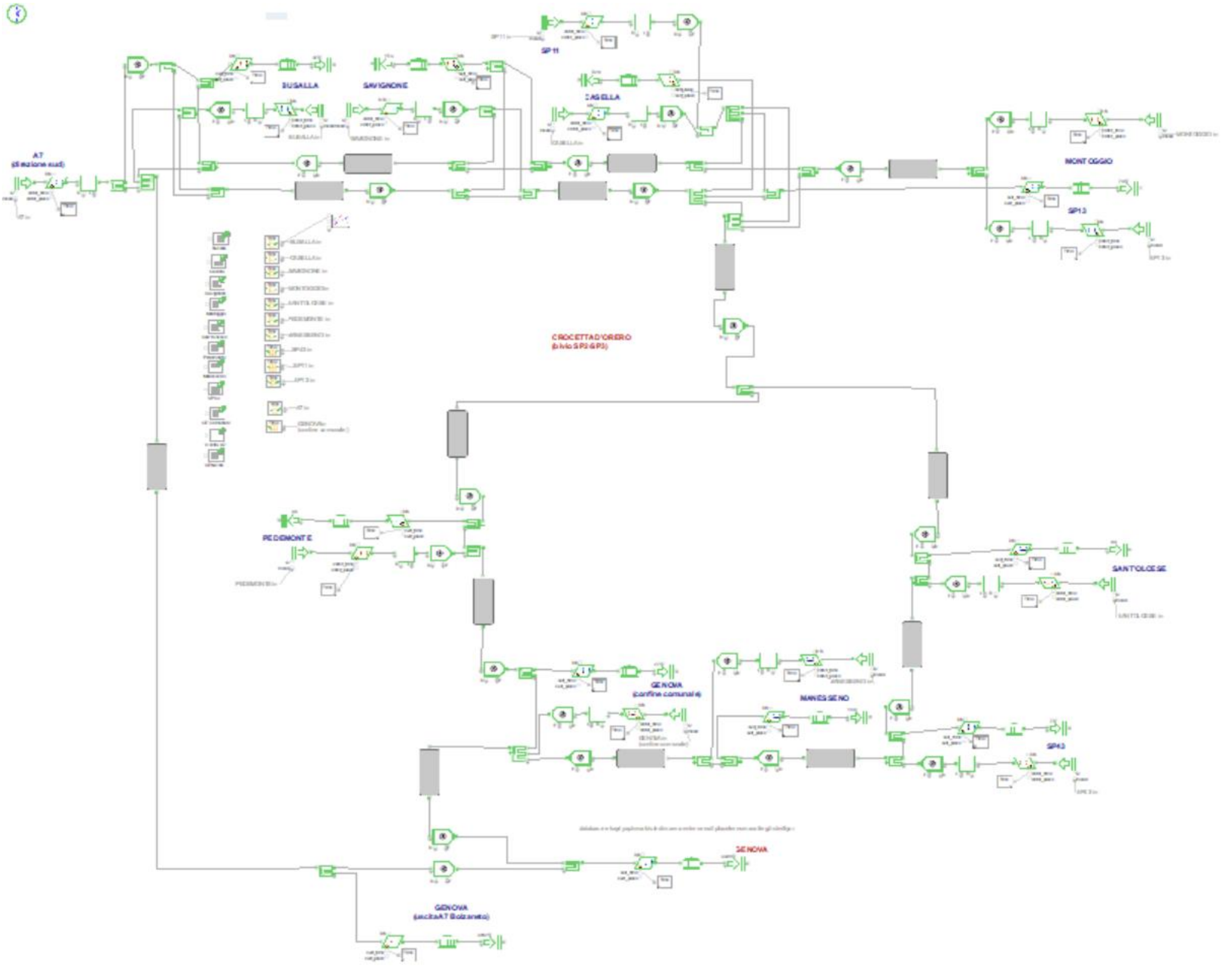


Figure 8-4:ExtendSim model

The starting part of the model (Fig.8.5) can be considered as the incoming flow from the A7 highway. The create block is used to generate the vehicle flows as a first block.

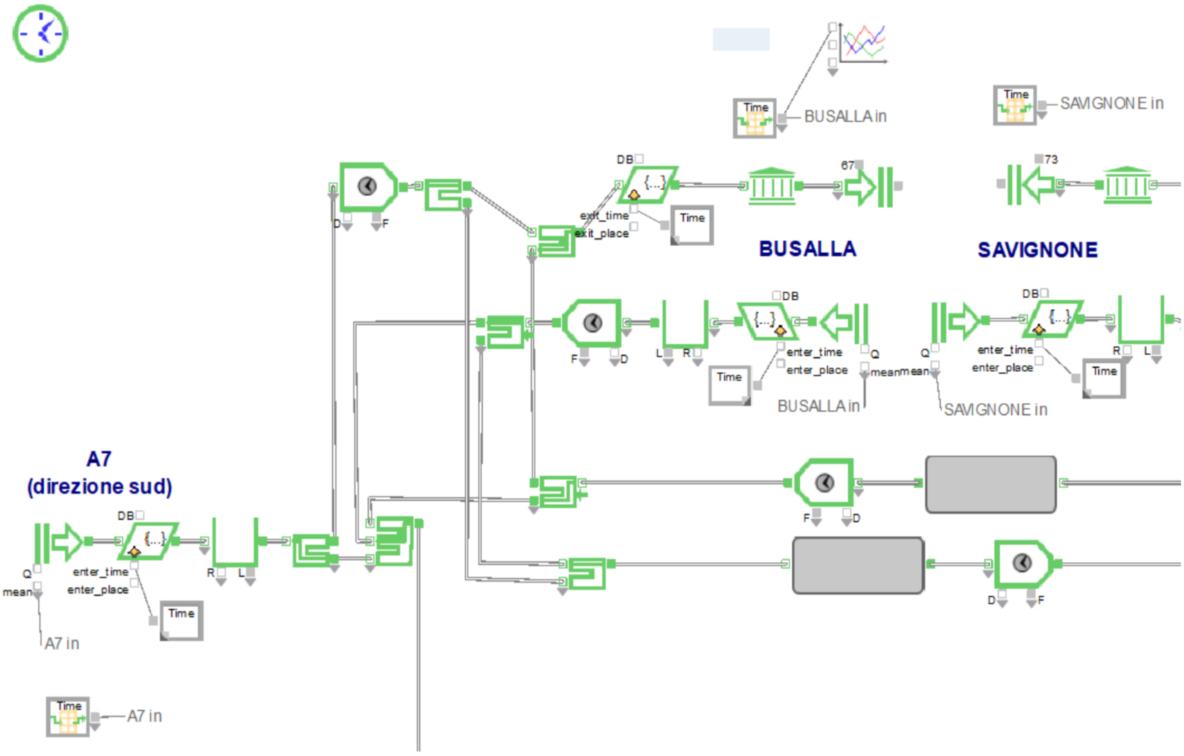
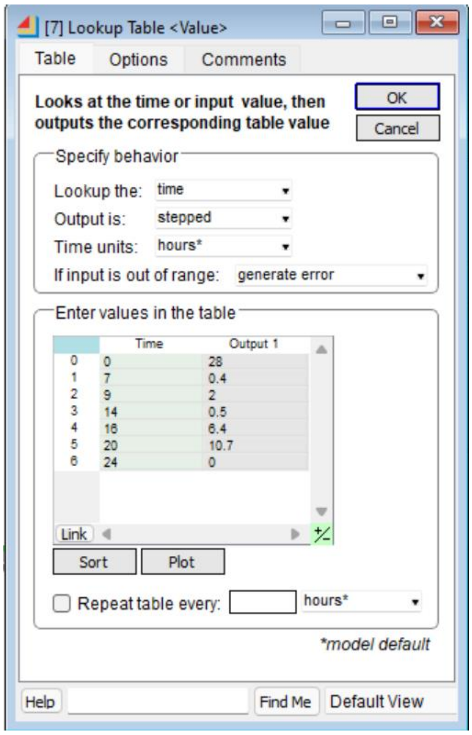


Figure 8-5:Initial part of the ExtendSim model

The total number of vehicles produced changes according to the distribution selected in the create block. The exponential distribution was used as the distribution in this model. The mean value of the distribution selected in the create block was calculated using the lookup table block. Since the simulation run time is considered to be 24 hours, the time input data in the lookup table is entered according to a total of 24 hours. As can be seen from the lookup table value in Fig.8.6, this time is divided according to the time intervals that are considered to be congested traffic. The hours between 7.00 and 9.00 a.m. and 2.00 and 4.00 p.m. are accepted as peak hours of traffic. When the general start times of jobs and lectures are considered, the morning traffic density to Genoa is expected to be the highest.



Looks at the time or input value, then outputs the corresponding table value

Specify behavior

Lookup the: time

Output is: stepped

Time units: hours*

If input is out of range: generate error

Enter values in the table

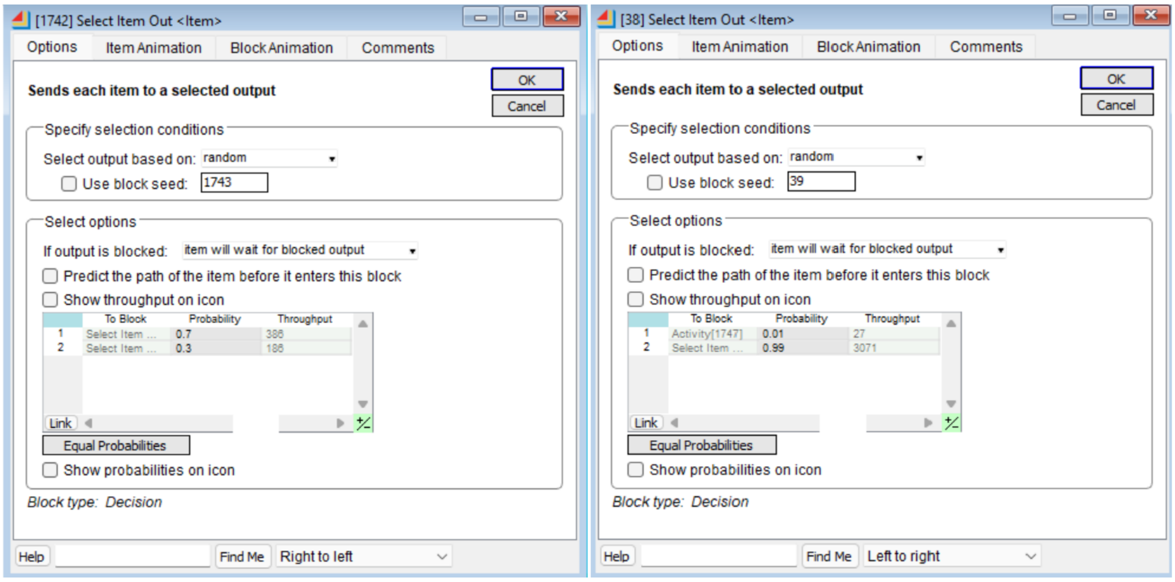
	Time	Output 1
0	0	28
1	7	0.4
2	9	2
3	14	0.5
4	16	6.4
5	20	10.7
6	24	0

☐ Repeat table every: hours*

*model default

Figure 8-6:Lookup table of A7

Select item in and out blocks have an essential role in the simulation of the model. These blocks provide the management of possible route selections. While the select item out block distributes the traffic flow based on the probability values, the select item in block merges the incoming traffic flows from diverse routes and transmits them as a single flow. In the model, the probability distributions of the select item out blocks are processed distinctively according to the route differences and the target destinations to be reached.



[1742] Select Item Out <Item>

Sends each item to a selected output

Specify selection conditions

Select output based on: random

☐ Use block seed: 1743

Select options

If output is blocked: item will wait for blocked output

☐ Predict the path of the item before it enters this block

☐ Show throughput on icon

	To Block	Probability	Throughput
1	Select Item ...	0.7	388
2	Select Item ...	0.3	186

☐ Show probabilities on icon

Block type: Decision

Right to left

[38] Select Item Out <Item>

Sends each item to a selected output

Specify selection conditions

Select output based on: random

☐ Use block seed: 39

Select options

If output is blocked: item will wait for blocked output

☐ Predict the path of the item before it enters this block

☐ Show throughput on icon

	To Block	Probability	Throughput
1	Activity[1747]	0.01	27
2	Select Item ...	0.99	3071

☐ Show probabilities on icon

Block type: Decision

Left to right

Figure 8-7:Select Item Out Block of Busalla (right) and A7 (left)

For example, as shown in Fig.8.7, a distribution of probability was made by predicting that traffic flows that originate from Busalla would travel along with the A7 highway at a rate of 70% and continue the SP226 road at a rate of 30%. On the other side, the probability that 99% of the traffic flow coming from highway A7 keeps remaining on the highway and reaches the city of Genoa. The residuary 1% is considered to go on the way to Busalla or SP226.

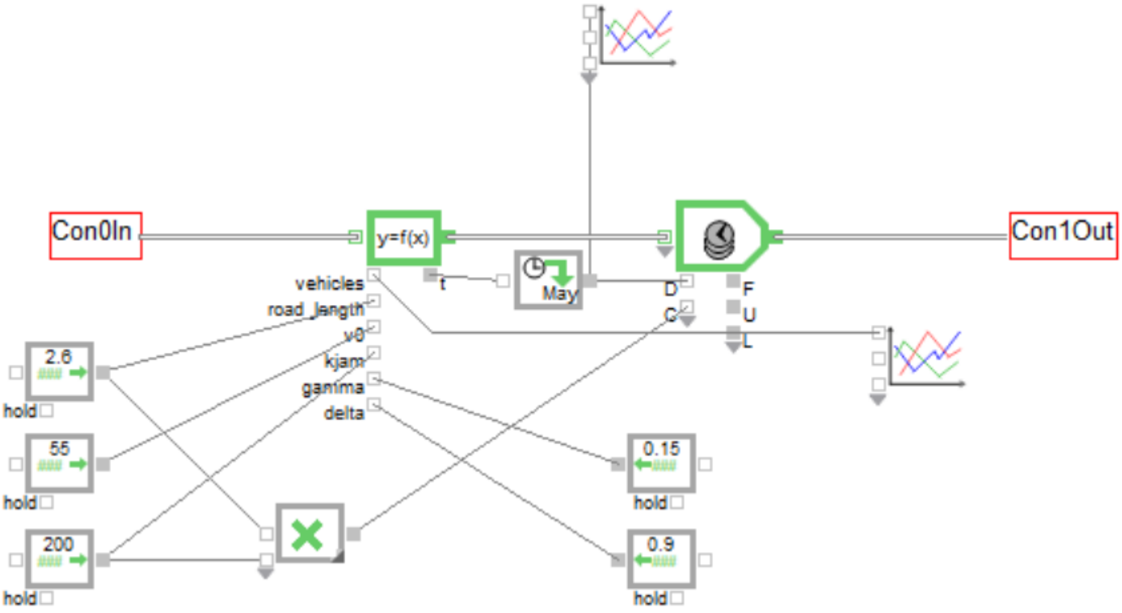


Figure 8-8:Part of travel time calculation

The equation block was used to compute the travel time, and the constant block was used to define the constants in the equations (Fig.8.8). Travel time varies depending on traffic flow density. Davidson's travel time function and Greenshields relationships were combined and implemented the Equation block to calculate the travel time. Greenshields flow-density relationship is replacement the flow function in the Davidson travel time function. Thus, the calculation of congested travel time has been simplified and can be calculated with known values. The equations utilized are listed below.

Where;

k = density (veh/km)
Q = capacity
ks = congestion density
f = flow
t_{ks}= congestion travel time
gamma = 0.15
delta = 0.9
t= travel time

$$k = \frac{vehicles}{road\ length} \tag{8.1}$$

$$Q = v_0 * \left(\frac{kjam}{4}\right) \tag{8.2}$$

Traffic flow density is calculated by vehicles number and road length and notated in Eqn 8.1. Free flow speed and the maximum density of the road is needed to calculate the road capacity (Eqn. 8.2.). These two equations are the auxiliary equations in the calculation of the travel time.

$$k_s = \left(\frac{kjam}{2}\right) * \left(1 - \sqrt{1 - \frac{(4*delta*Q)}{(v_0*kjam)}}\right) \tag{8.3}$$

$$k \leq ks \begin{cases} f = v_0 * \left(k - \left(\frac{k^2}{kjam}\right)\right) \\ t = \left(\frac{road\ length}{v_0}\right) * \left(1 + \frac{(gamma*f)}{(Q-f)}\right) \end{cases} \tag{8.4}$$

Travel time equation contains flow of the road at the specific density. For determining this flow free speed flow, maximum density and the density of road is needed. After calculation of traffic flow, with known values, road length, free speed flow, capacity of the road, and parameter of gamma, travel time of the density k, which is less or equal to the congested density, can be determined. And this set of equations is presented in Eqn. 8.4.

$$k > ks \begin{cases} m = \dfrac{\left(road\ length * gamma * Q * \left(1 - \frac{2 * ks}{kjam}\right)\right)}{\left(Q - v_0 * \left(ks - \frac{ks^2}{kjam}\right)\right)} \\ t_{ks} = \left(\dfrac{road\ length}{v_0}\right) * \left(1 + \dfrac{\left(gamma * v_0 * \left(ks - \frac{ks^2}{kjam}\right)\right)}{\left(Q - v_0 * \left(ks - \frac{ks^2}{kjam}\right)\right)}\right) \\ t = t_{ks} + m * (k - ks) \end{cases} \tag{8.5}$$

In another case, for the density to be greater than the congested density (Eqn 8.3.), the equations required to calculate the travel time are presented in Eqn 8.5. Unlike the first case, first travel time of the congested flow density is calculated, and then travel time is calculated by summing up travel time of congested traffic flow density and the time after the congestion flow which is the time calculated from the density difference.

As a result of the travel time calculation part, the application of different equations is decided according to the value of the density in this calculation part. If the density (k) is lower than the congestion density (ks), traffic flow and travel time is calculated by Eqn.8.4 and if the flow density is higher than the congestion density set of the equations that are given in the Eqn. 8.5 are used. This logic is implemented with the variables and constants blocks are connected the equation block. In this manner, the required delay time for the activity block operation was determined by taking into account the maximum capacity, the speed limit on the road, and the length of the road. The number of maximum items in the activity is also evaluated in this part using road length and maximum density.

The number of vehicles can be displayed graphically over time utilizing the line graph block. The results of the graph can help to verify whether the time intervals with a high number of vehicles are parallel with the time intervals regarded to be heavy traffic. Traffic congested time intervals are compatible, as seen in the example of line graph Fig.8.9. This demonstrates that the calculations made provide the assumptions.

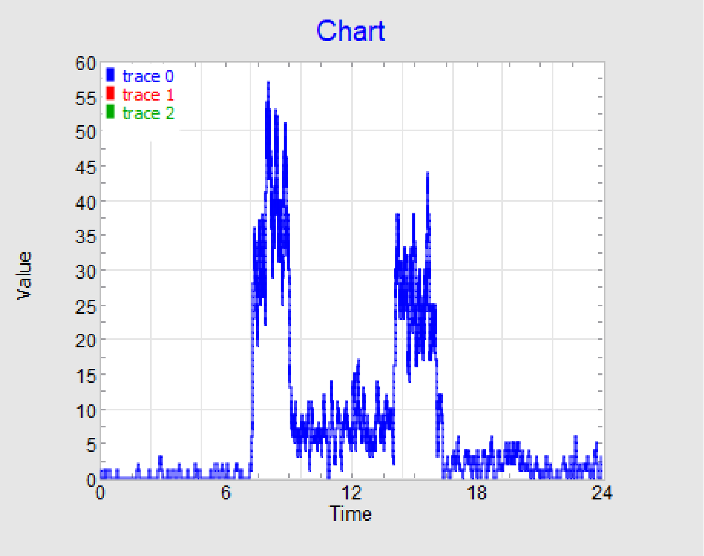


Figure 8-9:Line chart of vehicles numbers vs time

This series of blocks, which calculate capacity and travel time, has been transformed into a hierarchical block, as shown in Fig.8.10, and is utilized as such in the model. This hierarchical block, which should contain different parameters for each road, prevents confusion in the model and make it easier to process them separately.

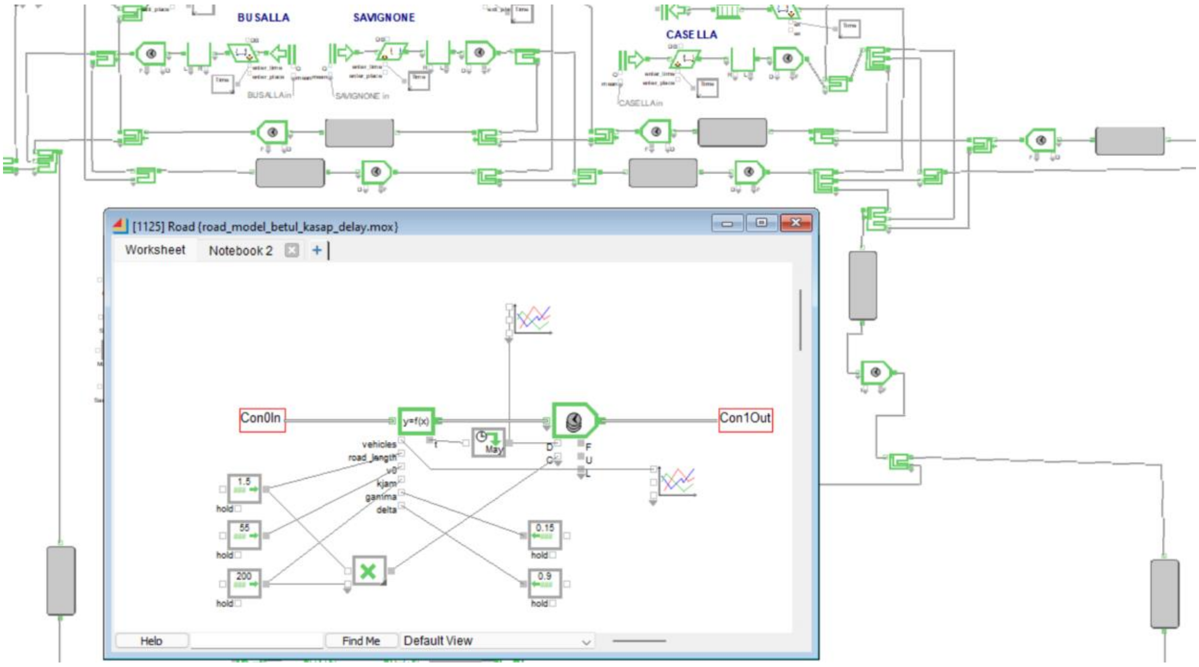


Figure 8-10:Hierarchical blocks and inside of blocks

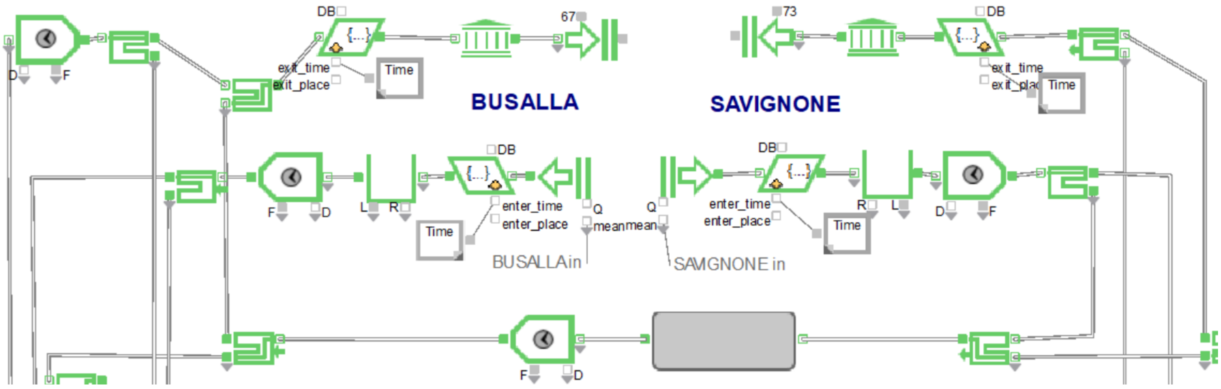
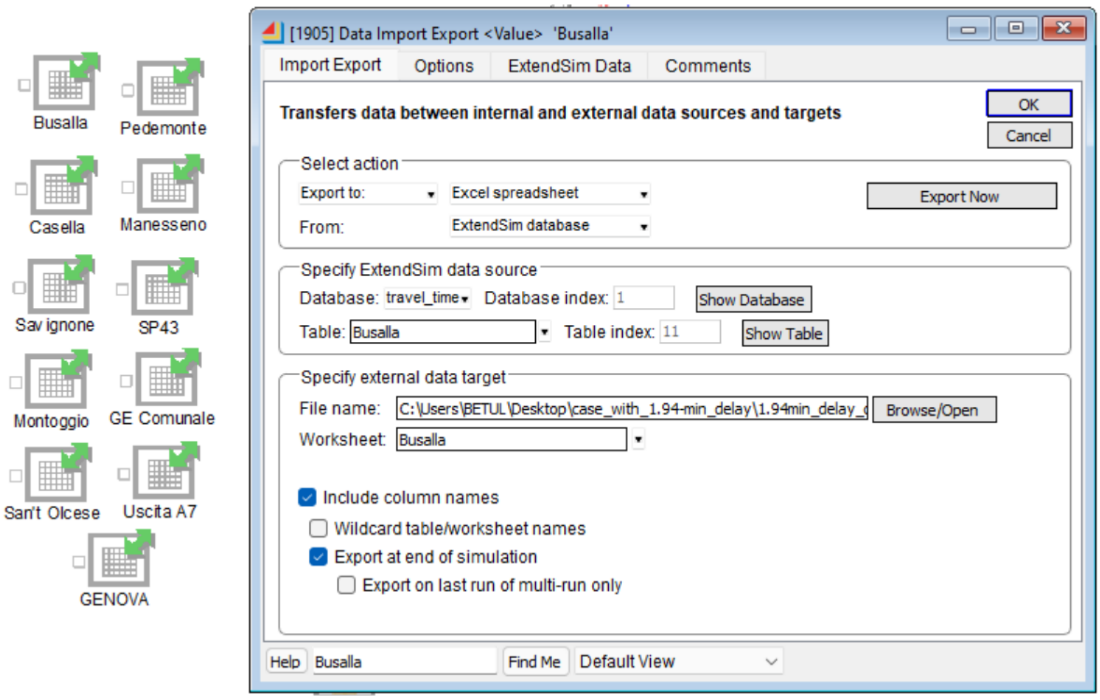


Figure 8-11:Set and History Blocks position in model

Set block and simulation variable block is needed to record the input and output times in input and output. The set block is placed after the create block in order to define the attributes such as entry location and entry time for the items passed over the block, and the layout of them in the model is shown in Fig.8.11. As well, the exit location and exit time attributes are defined by using the set blocks before the exit block. The simulation variable block is required in order to assign time attributes in a consistent manner with the simulation time.



Transfers data between internal and external data sources and targets

Select action
Export to: Excel spreadsheet
From: ExtendSim database

Specify ExtendSim data source
Database: travel_time Database index: 1
Table: Busalla Table index: 11

Specify external data target
File name: C:\Users\BETUL\Desktop\case_with_1.94-min_delay\1.94min_delay_
Worksheet: Busalla

☑ Include column names
☐ Wildcard table/worksheet names
☑ Export at end of simulation
☐ Export on last run of multi-run only

Busalla
Default View

Figure 8-12:Data Import and Export Blocks

These defined attributes are recorded using the history block. In addition, with the option to store in the database at the end of the simulation run, which is the option of the history block, all attributes, namely enter time, enter the place, exit time, exit place, are saved in the created database. These recorded values are stored separately for each case and city as an excel file output via the data import-export block (Fig.8.12) to be converted into usable data.

8.3 Input Data

Different calculations and assumptions were made based on the towns for the traffic flow data required for the simulation model. Firstly, the populations of the area (Tab.8.1) where the traffic flow was modeled were researched.

Table 8-1:Population of cities [47]

City	**Population**	**20-24 year**		**25-49 year**		**50-54 year**		**55-64 year**	
BUSALLA	5257	237	4.5%	1448	27.6%	442	8.41%	897	17.06%
CASELLA	3109	123	4.0%	877	28.3%	276	8.88%	503	16.18%
SAVIGNONE	3064	148	4.8%	862	28.1%	276	9.01%	525	17.13%
MONTOGGIO	2017	88	4.4%	545	27.1%	208	10.31%	354	17.55%
SAN'T OLCESE	2263.2	85.6	3.8%	629.6	27.8%	182	8.04%	330.8	14.62%
PEDEMONTE	6096.8	260.8	4.3%	1688	27.7%	551.2	9.04%	904	14.83%
MANESSENO	3394.8	128.4	3.8%	944.4	27.8%	273	8.04%	496.2	14.62%
SP43	2263.2	85.6	3.8%	629.6	27.8%	182	8.04%	330.8	14.62%
SP11	1554.5	61.5	4.0%	438.5	28.2%	138	8.88%	251.5	16.18%
SP13	1008.5	44	4.4%	272.5	27.0%	104	10.31%	177	17.55%

It was necessary to make assumptions for places that do not have population information but are included in the traffic flow in the model. When SP43, SP11, and SP13 are specifically considered, there is a population that cannot be neglected in the absence of direct demographic information but provides traffic flow to Genoa through these routes. The assumptions made to obtain the population of these flows, and also A7 highway flow are as follows:

- The population anticipated creating traffic flow from the SP43 route is assumed to be the same as the population of San't Olcese.
- The entire population of people who might utilize the Sp11 is projected to be half the population of Casella.

- The impact of surrounding towns, which is considered also for other assumptions, is taken into account for SP13, and the accepted population of Sp13 is equal to half the population of Montoggio is assumed.
- The incoming flow of the A7 highway, which has a high flow, is assessed as at least 1 vehicle per second, without taking into account the effect of the population of the town.

The age distribution of the population was taken into consideration. The population of each town is divided into four age groups: 20-24, 25-49, 50-54, and 55-64. The goal of selecting these age groups is to identify those who utilize vehicles actively the most. Active drivers between the ages of 25 and 49 are quite likely to go to Genoa every day for work.

Table 8-2:Percentage of the population to travel Genoa

City	**Population**	**25-49 year**		**Percentage of the population to travel Genoa**	
BUSALLA	5257	1448	27.6%	50.0%	724
CASELLA	3109	877	28.3%	30.0%	263
SAVIGNONE	3064	862	28.1%	25.0%	216
MONTOGGIO	2017	545	27.1%	25.0%	136
SAN'T OLCESE	2263	630	27.8%	55.0%	346
PEDEMONTE	6097	1688	27.7%	60.0%	1013
MANESSENO	3395	944	27.8%	65.0%	614
SP43	2263	630	27.8%	40.0%	252
SP11	1555	439	28.2%	55.0%	241
SP13	1009	273	27.0%	50.0%	136

The calculations of the towns were made separately for each age group and the 25-49 range is presented in Tab.8.2 as an example. After examining the percentages of different age ranges in the total population, assumptions were made about what percentage of this population comes to Genoa every day for work or any other reason. A certain number of people have been reached as a result of the percentage assumption. Different percentages were accepted according to the populations of the towns. For example, as seen in Table 2, the population of Busalla is higher than Casella. Therefore, it is expected that the number of people traveling from Busalla to Genoa will be higher.

Aside from town differences, the percentages vary according to age range. It is natural to expect that the 55-64 age group of the senior population will travel to Genoa less frequently. Therefore, it is predicted that the percentage of travelers in this demographic group will be low.

Other assumptions are required to generate the traffic flow data. The average number of vehicles was calculated by the second assumption, and it is focused on what percentage of people was assumed to travel to Genoa every day for any purpose with their vehicles. The number of vehicles utilized by passengers (shown in Tab.8.3) in various cities and age groups was calculated using the first two assumptions.

Table 8-3:Vehicle numbers of 25-49 age range

City	**Population**	**25-49 year**		**% of people to travel Genoa**		**Estimated % of vehicle number**	**Number of vehicles**
BUSALLA	5257	1448	27.6%	50.0%	724	65.0%	471
CASELLA	3109	877	28.3%	30.0%	263	70.0%	184
SAVIGNONE	3064	862	28.1%	25.0%	216	70.0%	151
MONTOGGIO	2017	545	27.1%	25.0%	136	85.0%	116
SAN'T OLCESE	2263	630	27.8%	55.0%	346	75.0%	260
PEDEMONTE	6097	1688	27.7%	60.0%	1013	70.0%	709
MANESSENO	3395	944	27.8%	65.0%	614	60.0%	368
SP43	2263	630	27.8%	40.0%	252	65.0%	164
SP11	1555	439	28.2%	55.0%	241	65.0%	157
SP13	1009	273	27.0%	50.0%	136	70.0%	95

To utilize the obtained vehicle numbers in the model and process the lookup table, different computations are required. The first of these calculations is the application of the density percentages presented in Fig.8.13 density-time graph to the number of vehicles.

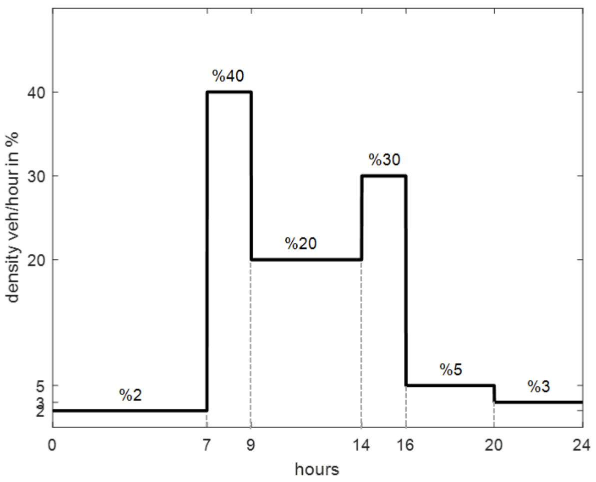


Figure 8-13:Density-time graph

As seen in the graph, the hours between 7 and 9 a.m. are projected to be peak hours with the highest vehicle density. The second peak period of the simulated 24 hours was predicted to be between 2-4 pm. The traffic flow to Genoa is expected to be light throughout the rest of the 24 hours, and vehicle/hour density is distributed over this time.

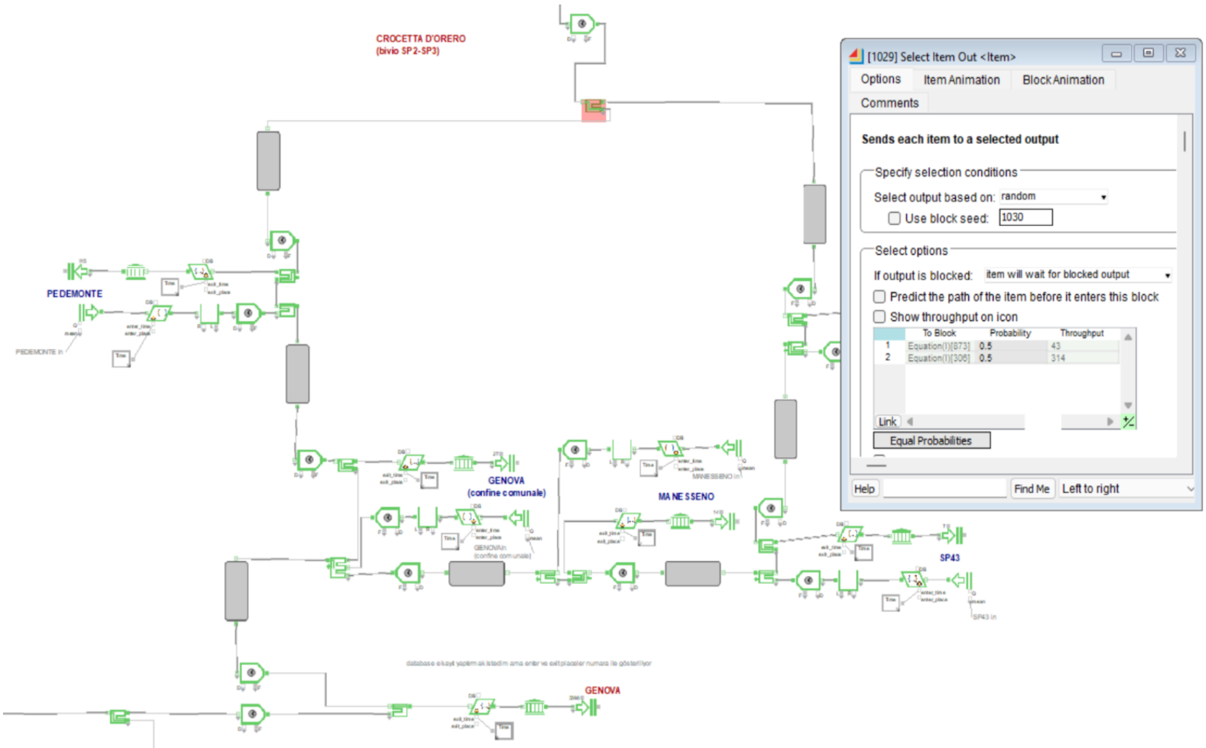
Table 8-4:Calculation example table of Busalla

BUSALLA								
hour	% for hour	25-49 year	20-24 year	50-54 year	55-64 year	total number of veh/hour	veh/min	exp 1/(Veh/min)
0-7 am	0.02	9.41	1.23	1.44	2.92	2.14	0.04	28.01
7-9 am	0.4	188.24	24.65	28.73	58.31	149.96	2.50	0.40
9-2 pm	0.2	94.12	12.32	14.37	29.15	29.99	0.50	2.00
2-4 pm	0.3	141.18	18.49	21.55	43.73	112.47	1.87	0.53
4-8 pm	0.05	23.53	3.08	3.59	7.29	9.37	0.16	6.40
8-12 pm	0.03	14.12	1.85	2.15	4.37	5.62	0.09	10.67

Calculations were made separately for each city, as shown in Tab.8.4 as an example. The total number of vehicles obtained in each age range was calculated according to the density in that time. Vehicle densities are calculated according to hour intervals in age categories as a result of these calculations. Finally, for each hour interval, the overall vehicle density was computed. Since the minute is used as a time unit in the simulation lookup table block, this value has been converted to the number of vehicles per minute. The obtained values represent the final data to insert in the lookup table, and the items will be generated by exponential distribution in simulation with create a block which provides data from the lookup table. For this reason, the last computed value has been converted to the exponential form to be compatible with the distribution.

8.4 Simulation Run

There are scenarios to be examined in order to understand the model performance while running the simulation. Probability distributions of the select item out the block in Crocetta d'Orero (shown in Fig.8.14) are made at different rates to understand the traffic flow in SP2 and SP3 roads and the effect of vehicles on average travel times to Genoa. Due to these ratio distributions, 9 different scenarios are formed to be calculated. There are some points to be considered while comparing the scenarios. The first is that only the factor affecting the scenarios to be compared should be changed, while all other factors should remain unchanged. Given that every variable except the probability distribution variable must be the same in all scenarios, the number of simulation seeds from the simulation setup option should be maintained constant while the simulation is running. the number of seeds approved in this study is 7 for the simulated runs to be used in the comparison.



Sends each item to a selected output

Specify selection conditions

Select output based on: random

☐ Use block seed: 1030

Select options

If output is blocked: item will wait for blocked output

☐ Predict the path of the item before it enters this block

☐ Show throughput on icon

	To Block	Probability	Throughput
1	Equation(I)[873]	0.5	43
2	Equation(I)[306]	0.5	314

Figure 8-14:SP2 and SP3 routes and select item out block

The probability distribution information of nine scenarios developed to simulate traffic flow between SP2 and SP3 is shown in the following Tab.8.5.

Table 8-5:Probability distribution of scenarios

	Probability Distribution Rates	
Scenarios	**SP2**	**SP3**
1	90%	10%
2	80%	20%
3	70%	30%
4	60%	40%
5	50%	50%
6	40%	60%
7	30%	70%
8	20%	80%
9	10%	90%

As a result of the simulation run of these 9 scenarios, the travel times of each vehicle are obtained separately. The obtained results are initially classified according to the starting towns of the traveling after being exported to an excel sheet. Data categorized by the town has been used to calculate average travel times to Genoa. These 9 scenarios are analyzed separately in three different cases. The model that is created is the first of these cases. The others are two different cases obtained by inserting delay time SP3 road after the town of Pedemonte in the hierarchical block.

8.4.1 Case 1: Model without delay

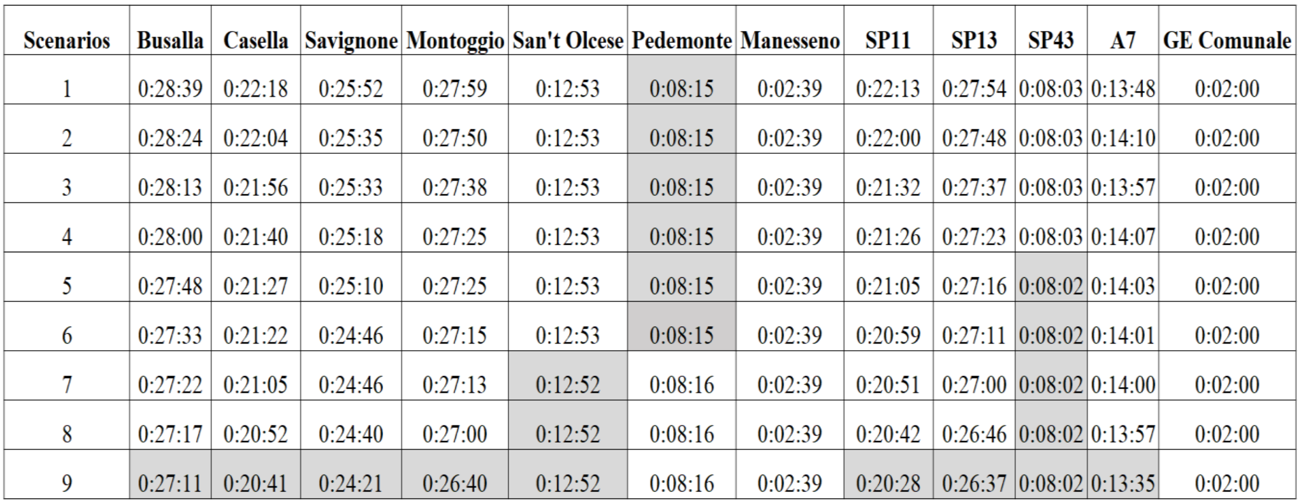
The first case consists of analyzing only nine scenarios on the model that is created. The effects and results of the probability distribution of traffic flow, which is regulated by the select item out block, on the average travel time to reach Genoa are obtained with the help of this analysis. The average travel times of the towns to Genoa computed for each scenario with the data obtained as a result of the simulation of the first case are presented in Tab.8.6.

Table 8-6:Average travel time of towns for scenarios

	Average Travel Time of Scenarios								
Enter Place	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Busalla	0:28:39	0:28:24	0:28:13	0:28:00	0:27:48	0:27:33	0:27:22	0:27:17	0:27:11
Casella	0:22:18	0:22:04	0:21:56	0:21:40	0:21:27	0:21:22	0:21:05	0:20:52	0:20:41
Savignone	0:25:52	0:25:35	0:25:33	0:25:18	0:25:10	0:24:46	0:24:46	0:24:40	0:24:21
Montoggio	0:27:59	0:27:50	0:27:38	0:27:25	0:27:25	0:27:15	0:27:13	0:27:00	0:26:40
San’t Olcese	0:12:53	0:12:53	0:12:53	0:12:53	0:12:53	0:12:53	0:12:52	0:12:52	0:12:52
Pedemonte	0:08:15	0:08:15	0:08:15	0:08:15	0:08:15	0:08:15	0:08:16	0:08:16	0:08:16
Manesseno	0:02:39	0:02:39	0:02:39	0:02:39	0:02:39	0:02:39	0:02:39	0:02:39	0:02:39
SP11	0:22:13	0:22:00	0:21:32	0:21:26	0:21:05	0:20:59	0:20:51	0:20:42	0:20:28
SP13	0:27:54	0:27:48	0:27:37	0:27:23	0:27:16	0:27:11	0:27:00	0:26:46	0:26:37
SP43	0:08:03	0:08:03	0:08:03	0:08:03	0:08:02	0:08:02	0:08:02	0:08:02	0:08:02
A7	0:13:48	0:14:10	0:13:57	0:14:07	0:14:03	0:14:01	0:14:00	0:13:57	0:13:35
GE Comunale	0:02:00	0:02:00	0:02:00	0:02:00	0:02:00	0:02:00	0:02:00	0:02:00	0:02:00

The average travel time for each entry place in different scenarios is computed distinctively, Tab.8.7 is shown the results of the comparison of these 9 scenarios. The scenarios where average travel times are optimal diverge for each enter place and are highlighted in the table.

Table 8-7:Comparison of results of case 1



Scenarios	Busalla	Casella	Savignone	Montoggio	San't Olcese	Pedemonte	Manesseno	SP11	SP13	SP43	A7	GE Comunale
1	0:28:39	0:22:18	0:25:52	0:27:59	0:12:53	0:08:15	0:02:39	0:22:13	0:27:54	0:08:03	0:13:48	0:02:00
2	0:28:24	0:22:04	0:25:35	0:27:50	0:12:53	0:08:15	0:02:39	0:22:00	0:27:48	0:08:03	0:14:10	0:02:00
3	0:28:13	0:21:56	0:25:33	0:27:38	0:12:53	0:08:15	0:02:39	0:21:32	0:27:37	0:08:03	0:13:57	0:02:00
4	0:28:00	0:21:40	0:25:18	0:27:25	0:12:53	0:08:15	0:02:39	0:21:26	0:27:23	0:08:03	0:14:07	0:02:00
5	0:27:48	0:21:27	0:25:10	0:27:25	0:12:53	0:08:15	0:02:39	0:21:05	0:27:16	0:08:02	0:14:03	0:02:00
6	0:27:33	0:21:22	0:24:46	0:27:15	0:12:53	0:08:15	0:02:39	0:20:59	0:27:11	0:08:02	0:14:01	0:02:00
7	0:27:22	0:21:05	0:24:46	0:27:13	0:12:52	0:08:16	0:02:39	0:20:51	0:27:00	0:08:02	0:14:00	0:02:00
8	0:27:17	0:20:52	0:24:40	0:27:00	0:12:52	0:08:16	0:02:39	0:20:42	0:26:46	0:08:02	0:13:57	0:02:00
9	0:27:11	0:20:41	0:24:21	0:26:40	0:12:52	0:08:16	0:02:39	0:20:28	0:26:37	0:08:02	0:13:35	0:02:00

When the starting places are examined separately, the lowest and optimum average travel time to Genoa for Busalla, Casella, Savignone, Montoggio, SP11, SP13, and A7 is achieved with scenario 9. In other words, if 90% of the vehicles arrive in Genoa via the SP3 route, they will travel with the optimum average travel time. Along with scenario 9, multiple scenarios offer optimum time for San't Olcese and SP43. Scenarios 9,8, and 7 have the shortest average travel time for San't Olcese. Furthermore, scenarios 9,8,7,6, and 5 provide the optimum times for SP43. In addition, scenarios 1,2,3,4,5, and 6 provide equal shortest for the travel from Pedemonte to Genoa. Conversely, the average travel time is the same in all scenarios for Manesseno and GE Comunale.

8.4.2 Case 2: Model with 10 minutes delay

This is the case where the 10-minute delay on the road to Genoa is analyzed after the city of Pedemonte, which will affect the SP2 and SP3 roads traffic density. It is essential to modify the present model in order to obtain the result of this case. A 10-minute constant block with a delay time has been added to the hierarchical block providing the computation of the travel time on SP3 after the Pedemonte. The changes made in the model are shown in Fig.8.15. The travel time calculated in the equation block is directly connected to the activity block from the delay connector in the non-delay model. When a delay occurs, the delay time is added to the calculated travel time and linked to the activity block delay connector.

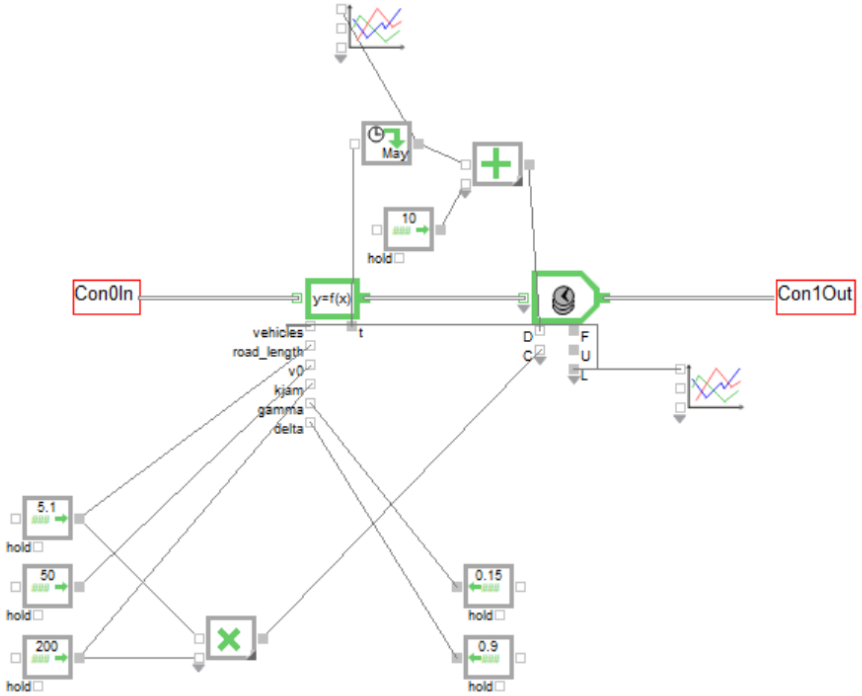


Figure 8-15:Hierarchical block for delay

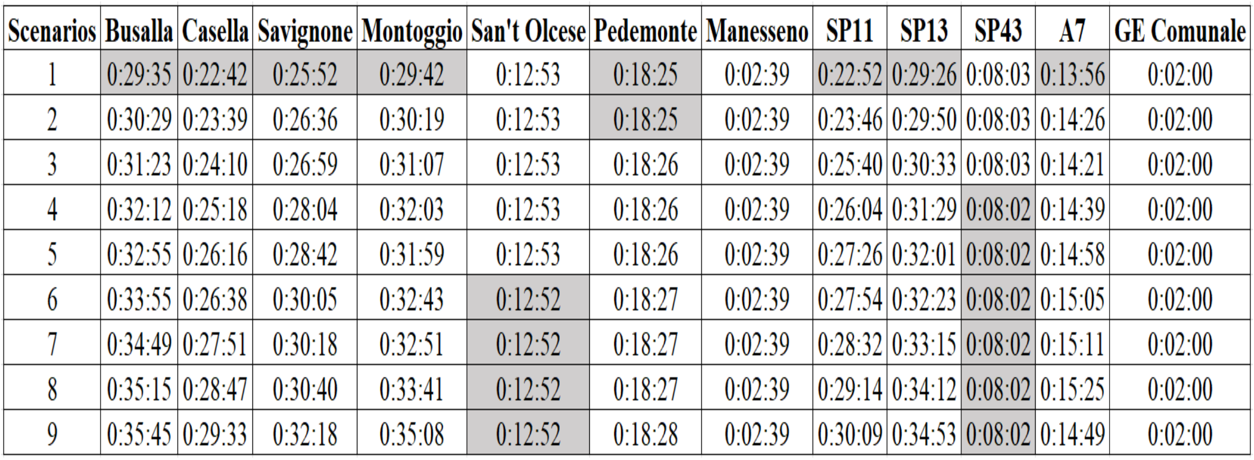
Nine scenarios are simulated using the new model with a 10-minute delay, and the average travel time is determined individually for each enter place, as in the no-delay model. Enter places that are affected by the traffic flow probability distribution for SP2 and SP3 and located before the Pedemonte are affected by this delay. Tab.8.8 indicates the calculated average travel times of the places based on the simulation results of the second case.

Table 8-8: Results of case 2

	Average Travel Time of Scenarios								
Enter Place	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Busalla	0:29:35	0:30:29	0:31:23	0:32:12	0:32:55	0:33:55	0:34:49	0:35:15	0:35:45
Casella	0:22:42	0:23:39	0:24:10	0:25:18	0:26:16	0:26:38	0:27:51	0:28:47	0:29:33
Savignone	0:25:52	0:26:36	0:26:59	0:28:04	0:28:42	0:30:05	0:30:18	0:30:40	0:32:18
Montoggio	0:29:42	0:30:19	0:31:07	0:32:03	0:31:59	0:32:43	0:32:51	0:33:41	0:35:08
San’t Olcese	0:12:53	0:12:53	0:12:53	0:12:53	0:12:53	0:12:52	0:12:52	0:12:52	0:12:52
Pedemonte	0:18:25	0:18:25	0:18:26	0:18:26	0:18:26	0:18:27	0:18:27	0:18:27	0:18:28
Manesseno	0:02:39	0:02:39	0:02:39	0:02:39	0:02:39	0:02:39	0:02:39	0:02:39	0:02:39
SP11	0:22:52	0:23:46	0:25:40	0:26:04	0:27:26	0:27:54	0:28:32	0:29:14	0:30:09
SP13	0:29:26	0:29:50	0:30:33	0:31:29	0:32:01	0:32:23	0:33:15	0:34:12	0:34:53
SP43	0:08:03	0:08:03	0:08:03	0:08:02	0:08:02	0:08:02	0:08:02	0:08:02	0:08:02
A7	0:13:56	0:14:26	0:14:21	0:14:39	0:14:58	0:15:05	0:15:11	0:15:25	0:14:49
GE Comunale	0:02:00	0:02:00	0:02:00	0:02:00	0:02:00	0:02:00	0:02:00	0:02:00	0:02:00

The travel time to Genoa will increase after a 10-minute delay on the SP3 route. Since the drivers do not want the travel time to be longer due to this delay, the travel time will be relatively less in scenarios with a high probability of SP2 route selection. However, the average time of the vehicles engaging in the traffic flow on the SP2 road will be the inverse, therefore in scenarios where the SP3 ratio is high, average travel times are predicted to be lower for those vehicles.

Table 8-9:Comparison of case 2 results



Scenarios	Busalla	Casella	Savignone	Montoggio	San't Olcese	Pedemonte	Manesseno	SP11	SP13	SP43	A7	GE Comunale
1	0:29:35	0:22:42	0:25:52	0:29:42	0:12:53	0:18:25	0:02:39	0:22:52	0:29:26	0:08:03	0:13:56	0:02:00
2	0:30:29	0:23:39	0:26:36	0:30:19	0:12:53	0:18:25	0:02:39	0:23:46	0:29:50	0:08:03	0:14:26	0:02:00
3	0:31:23	0:24:10	0:26:59	0:31:07	0:12:53	0:18:26	0:02:39	0:25:40	0:30:33	0:08:03	0:14:21	0:02:00
4	0:32:12	0:25:18	0:28:04	0:32:03	0:12:53	0:18:26	0:02:39	0:26:04	0:31:29	0:08:02	0:14:39	0:02:00
5	0:32:55	0:26:16	0:28:42	0:31:59	0:12:53	0:18:26	0:02:39	0:27:26	0:32:01	0:08:02	0:14:58	0:02:00
6	0:33:55	0:26:38	0:30:05	0:32:43	0:12:52	0:18:27	0:02:39	0:27:54	0:32:23	0:08:02	0:15:05	0:02:00
7	0:34:49	0:27:51	0:30:18	0:32:51	0:12:52	0:18:27	0:02:39	0:28:32	0:33:15	0:08:02	0:15:11	0:02:00
8	0:35:15	0:28:47	0:30:40	0:33:41	0:12:52	0:18:27	0:02:39	0:29:14	0:34:12	0:08:02	0:15:25	0:02:00
9	0:35:45	0:29:33	0:32:18	0:35:08	0:12:52	0:18:28	0:02:39	0:30:09	0:34:53	0:08:02	0:14:49	0:02:00

Tab.8.9 shows the results of comparing the scenarios based on entering places. When the places are evaluated independently, scenario 1 (90% of traffic flow is traveled on SP2) achieves the optimum average travel time to Genoa for Busalla, Casella, Savignone, Montoggio, Pedemonte, SP11, SP13, and A7. As a brief description, if 90% of the vehicles arrive in Genoa through the SP2 route, the average travel time will be optimal. Several scenarios with a higher probability of SP3 provide shorter travel time for San't Olcese and SP43. The sixth, seventh, eighth, and ninth scenarios for San't Olcese and SP43 are the scenarios with the shortest average travel time. The fourth and fifth scenarios also provide the same travel time for SP43. In contrast, the average travel time for Manesseno and GE Comunale is identical in all scenarios.

8.4.3 Case 3: Model with 1.93 minutes delay

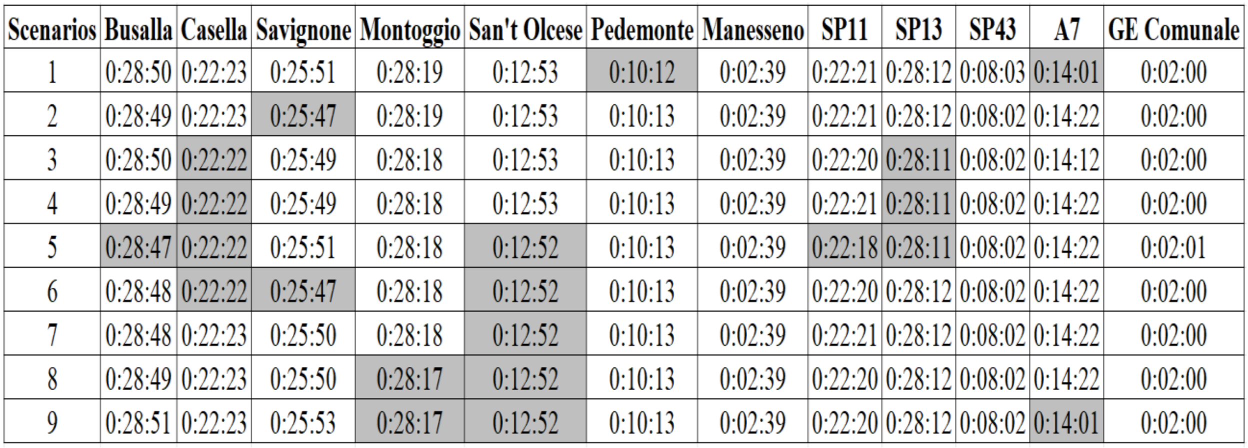
In the third case, the objective is to determine and analyze the scenario in which the travel time with delay from the majority of entrances to Genoa is the optimum, with a probability distribution of 50%-50% between SP2 and SP3. Simulation runs are performed with various delay times in order to reach scenario 5 with the optimal delay time, such as 5,2,1.75,1.9 minutes delay. The delay time of the many of the entering places of Busalla, Casella, SP11, San’t Olcese, and SP13, where the average travel time is shortest in scenario 5 (50%-50%), is determined to be 1.93 minutes based on the calculations based on the results of these various delay time runs. When there are delays of less than 1.93 minutes, the optimum is scenario nine, i.e., 90 percent likelihood of traffic flowing from SP3, whereas when this value is exceeded, scenario one is attained when SP2 probability is 90 percent. Average travel times calculated as a result of simulation of 1.93 minutes delay are presented in Tab.8.10.

Table 8-10:Results of case 3

	Average Travel Time of Scenarios								
Enter Place	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Busalla	0:28:50	0:28:49	0:28:50	0:28:49	0:28:47	0:28:48	0:28:48	0:28:49	0:28:51
Casella	0:22:23	0:22:23	0:22:22	0:22:22	0:22:22	0:22:22	0:22:23	0:22:23	0:22:23
Savignone	0:25:51	0:25:47	0:25:49	0:25:49	0:25:51	0:25:47	0:25:50	0:25:50	0:25:53
Montoggio	0:28:19	0:28:19	0:28:18	0:28:18	0:28:18	0:28:18	0:28:18	0:28:17	0:28:17
San’t Olcese	0:12:53	0:12:53	0:12:53	0:12:53	0:12:52	0:12:52	0:12:52	0:12:52	0:12:52
Pedemonte	0:10:12	0:10:13	0:10:13	0:10:13	0:10:13	0:10:13	0:10:13	0:10:13	0:10:13
Manesseno	0:02:39	0:02:39	0:02:39	0:02:39	0:02:39	0:02:39	0:02:39	0:02:39	0:02:39
SP11	0:22:21	0:22:21	0:22:20	0:22:21	0:22:18	0:22:20	0:22:21	0:22:20	0:22:20
SP13	0:28:12	0:28:12	0:28:11	0:28:11	0:28:11	0:28:12	0:28:12	0:28:12	0:28:12
SP43	0:08:03	0:08:02	0:08:02	0:08:02	0:08:02	0:08:02	0:08:02	0:08:02	0:08:02
A7	0:14:01	0:14:22	0:14:12	0:14:22	0:14:22	0:14:22	0:14:22	0:14:22	0:14:01
GE Comunale	0:02:00	0:02:00	0:02:00	0:02:00	0:02:01	0:02:00	0:02:00	0:02:00	0:02:00

As seen in the comparison table Tab.8.11, more than one place has achieved the optimal average travel time with more than one scenario when compared to other case. Almost all scenarios for Manesseno, SP43, and GE Comunale provide the shortest travel time to Genoa with 1.93 minutes delay. For the town of San't Olcese, which is located on SP2, scenarios 6,7,8, and 9 where SP3 is more likely are clearly situations with a shorter travel time.

Table 8-11:Comparison of case 3 results



Scenarios	Busalla	Casella	Savignone	Montoggio	San't Olcese	Pedemonte	Manesseno	SP11	SP13	SP43	A7	GE Comunale
1	0:28:50	0:22:23	0:25:51	0:28:19	0:12:53	0:10:12	0:02:39	0:22:21	0:28:12	0:08:03	0:14:01	0:02:00
2	0:28:49	0:22:23	0:25:47	0:28:19	0:12:53	0:10:13	0:02:39	0:22:21	0:28:12	0:08:02	0:14:22	0:02:00
3	0:28:50	0:22:22	0:25:49	0:28:18	0:12:53	0:10:13	0:02:39	0:22:20	0:28:11	0:08:02	0:14:12	0:02:00
4	0:28:49	0:22:22	0:25:49	0:28:18	0:12:53	0:10:13	0:02:39	0:22:21	0:28:11	0:08:02	0:14:22	0:02:00
5	0:28:47	0:22:22	0:25:51	0:28:18	0:12:52	0:10:13	0:02:39	0:22:18	0:28:11	0:08:02	0:14:22	0:02:01
6	0:28:48	0:22:22	0:25:47	0:28:18	0:12:52	0:10:13	0:02:39	0:22:20	0:28:12	0:08:02	0:14:22	0:02:00
7	0:28:48	0:22:23	0:25:50	0:28:18	0:12:52	0:10:13	0:02:39	0:22:21	0:28:12	0:08:02	0:14:22	0:02:00
8	0:28:49	0:22:23	0:25:50	0:28:17	0:12:52	0:10:13	0:02:39	0:22:20	0:28:12	0:08:02	0:14:22	0:02:00
9	0:28:51	0:22:23	0:25:53	0:28:17	0:12:52	0:10:13	0:02:39	0:22:20	0:28:12	0:08:02	0:14:01	0:02:00

CONCLUSIONS

The findings of this research are explained in this section. The aim of this thesis is to model and analyze traffic flows from suburban areas to Genoa as well as to consider an approach to traffic management. The results of traffic flow modeling are serviced for traffic management. This thesis provides a comprehensive and quantitative study of traffic flow to Genoa for intelligent transportation systems in terms of traffic management, road and passenger safety, and traveler information.

Principally, the model building begins with observing the workspace: this step is essential to understand and analyze the network, possible routes, boundaries of network, etc. The model enables analysis of traffic flow from suburban areas, providing beneficial information to managers such as traffic flow and traffic density at bottleneck locations, and to users such as general information about the road and travel time.

The model was simulated using data obtained from demographic population information of regions located in suburban areas and included in the system as traffic flow. The applicability of these calculated data on the model was tested. Hereby, it revealed that the model is expected to generate adequately relevant results for its targeted modeling area.

Following the input phase, the decisions regarding the output data should be well defined, taking into consideration the performance indices of concern. The output data to be produced will differ based on the case study. The models investigated for simulation are categorized based on whether or not there is a delay. The model is simulated without delay in the first case. The delay time is applied to the model in the other two cases. The simulation data should be examined to understand the output data of the cases.

ExtendSim 10.0.7 is used to construct simulation for a traffic flow distribution model, which consists of a simulation system functional framework, application route, simulation processes, and simulation models. A simulation is an effective tool for optimizing traffic flow, planning, and design. It provides graphical representations as well as numerical statistics of the activities that happen from the time a traveler begins their route till they arrive in Genoa.

The created model can be applied to assess other parameters by accepting the average travel time as a key performance indicator. Different scenarios can be evaluated, the critical areas are identified and then analyzed to improve performance indicators by changing routes or applying the best possible traffic flow distribution.

The following are the primary advantages of this sort of model:

- The ability to identify infrastructure bottlenecks in order to improve traffic management and safety.

- Developing roads according to multiple criteria, especially traffic density, speed, and travel time.
- To optimize the travel time, the projected traffic density can be estimated according to a different time and route alternatives and travelers can be informed about this.

The necessity to better evaluate and regulate traffic flow to Genoa from the suburbs motivated this thesis. In this perspective, the outcomes reported thus far are just the basis of a wider research study. Further work may be configured in a variety of areas, especially models, and data.

- Data: The currently used data are artificial data generated from population-based demographic statistics compared to real-time collected data. Points that may have been dismissed due to the fact that data acquired in real-time is not integrated into the model is a major drawback that must be considered.

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