VARIABLE SPEED LIMIT SYSTEM'S MICROSCOPIC SIMULATION MODELING: AN OVERVIEW AND CASE STUDY ON PAKISTAN MOTORWAYS

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ISLAMABAD, PAKISTAN.

(2023)

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A thesis submitted to the National University of Sciences and Technology, Islamabad,

in partial fulfillment of the requirements for the degree of

Master of Science
in
Transportation
Engineering

Thesis Supervisor: Dr. Kamran Ahmed

School of Civil and Environmental Engineering

National University of Sciences & Technology

Islamabad, Pakistan

(2023)

THESIS ACCEPTANCE CERTIFICATE

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Dedicated

To

My Loving Parents,

Adorable Sibling,

&

My Dear Grandfather

ACKNOWLEDGEMENTS

First and foremost, I would like to thank Allah Almighty for granting me the skills and knowledge to complete my research and deliver this thesis as part of the M.Sc. Transportation Engineering curriculum.

I would like to show my gratitude to my project supervisor and adviser, Dr. Kamran Ahmad of the National University of Science and Technology, Islamabad, for accepting the responsibility and allowing me to work under his guidance. His advice has been invaluable to me on numerous occasions and in helping me complete my Research.

Despite my intense desire to write this thesis, I do not claim that it will be a flawless masterpiece. Like all human works, this thesis is imperfect and may contain errors and flaws. Consequently, I stay receptive to all criticism and suggestions that will provide me with fresh sources of inspiration as I enhance my research and learning skills.

Lastly, I owe a debt of appreciation to my cherished parents, my lovable siblings, my caring grandfather, and my classmates for their unwavering support and constant encouragement during my years of study and the process of researching and writing this thesis. This achievement would not have been achievable without the assistance of all these kinds of individuals.

Thank you.

ABSTRACT

Driving in major cities during rush hour may be an absolute living hell due to the massive amounts of traffic that accumulate on the roads. Throughout the years, numerous potential solutions to solve the issue of traffic congestion on highways have been evaluated with the help of Intelligent Transportation Systems (ITS). One of the most well-known and generally accepted of the new approaches that have evolved is the Variable Speed Limit (VSL) system. In this study, an advanced method known as microsimulation is used to help recreate the conditions that were present on the field. This is accomplished by simulating the traffic situation with PTV VISSIM software and modifying the default parameters without actually altering the characteristics that were present on the field. Using this method, the plan is incorporated into the system to achieve effective outcomes. This method also assists in the construction of various strategies. The main goal of this research is to develop an algorithm that, in the event of an accident, extreme weather, or road closure, can enhance the occupancy rate, and average speed, and can reduce delay, and total average travel time. The study compares the three possible outcomes: without an incident and VSL, with an incident and without VSL, and with an incident and with VSL. VSL is incorporated into the simulation through the utilization of both the VisVAP and the VISSIM COM interface. According to the data, VSL strategies performed significantly better than non-VSL scenarios in terms of the occupancy rate, the average speed, and the delay. In addition to this, the total amount of time needed for travel to VSL key conditions was cut down.

Keywords: VSL, Microsimulation, Congestion, ITS, Calibration, Validation, Algorithm, VISSIM COM

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LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

VSL	Variable Speed Limit
ATM	Active Traffic Management
ITS	Intelligent Transportation Systems
AI	Artificial Intelligence
CPEC	China Pakistan Economic Corridor
CL	Compliance Level
TTT	Total Travel Time
RSB	Road Sound Barriers
MPC	Model Predictive Control
TTC	Time to Collision
TIM	Traffic and Incident Management
MOE	Measure of Effectiveness
AADT	Average Annual Daily Traffic
WMD	Whitemud Drive
SMS	Space Mean Speed
PHF	Peak Hour Traffic
HGV	Heavy Good Vehicles
CPROB	Cumulative Probability
RMSE	Root Mean Square Error
MANE	Mean Absolute Normalized Error
PCU	Passenger Car Unit

CHAPTER 1: INTRODUCTION

1.1 Background

There is a significant and widespread issue with traffic in many places. Because more people are living in urban areas and using their cars more regularly, there is a huge increase in the amount of traffic on the roadways. To control and accommodate the ever-increasing volume of traffic, it will be necessary to conduct several studies, amass a comprehensive collection of resources, and allocate a sizeable portion of available land. In most circumstances, additional lane bypasses, overpasses, or other solutions are required to deal with the always-increasing demand posed by the accumulation of larger traffic flow. Each tactic necessitates continued efforts whenever there is a rise in the volume of traffic, which occurs around once every few years. Because the procedure must be repeated indefinitely, there is inherent waste of both time and labor. In addition, even if every effort is made, it is possible that the required volume will not be amassed. As a result, the most effective course of action would be to build a system that would not only reduce the congestion problem but would also prevent the recurring waste of time and money that would occur over the years. The solution that will prove to be the most popular will consist of a collection of codes and algorithms that would eliminate the congestion problem and, in addition to that, would make it possible for the code to be easily modified without requiring additional resources when the time comes because of increased volume demand.

The quick advancements made in the automotive sector, together with the lifestyle shifts that have taken place across society as a whole, increased the number of automobiles on the roads. As a direct consequence of this, there has been a rise in traffic congestion on road networks all over the world. The increasing congestion has a detrimental impact on traffic efficiency, resulting in inefficient usage of roads, increased queuing of vehicles during congested periods, and longer travel times, all of which will ultimately result in a significant increase in costs for society. The trend is heading in the same direction regardless of the country, with rising demand for transportation among private automobiles as well as among goods vehicles. This is true for both private and commercial vehicles.

The increased traffic flows not only contribute to an increase in congestion on the roads but also lead to an increase in the likelihood of accidents and incidents. A great number of nations have made it a priority to reduce the number of fatalities and accidents that occur on their roadways and are making concerted efforts to do so. The purpose of the vision is to prevent fatal and major personal injuries by taking all necessary activities in order to achieve this goal. This will bring about the realization of the vision. The view acknowledges that there is no such thing as a perfect person and that as a consequence, accidents will take place; yet, it does not acknowledge that catastrophic personal injuries are acceptable. The concepts that underpinned the vision have also been implemented in other nations, and security-related concerns now make up a significant portion of the focus of research in the field of transportation.

Another topic that is well-known and frequently debated is the damage that our contemporary society has done to the environment. Governments, scientific communities, and other groups from all over the world are attempting to collaborate in order to discover answers to the growing number of environmental issues.

1.1.1. Introduction of ITS Techniques in the Transportation Sector

As a result of the vast number of advantages it offers over human labor, the AI system is becoming increasingly prevalent across all industries as the world moves in that direction. Consequently, as AI systems were being developed in a variety of fields, separate sets of coding and algorithmic strategies emerged. In the field of transportation, it has taken the form of ITS, which has shown to be the most effective answer to the majority of the challenges faced by the Transportation Department in terms of traffic issues[1]. The Variable Speed Limit system is among the most well-known on-the-road quintessential strategies that appeared and also have been used in some countries, such as the United Kingdom, the Netherlands, and Australia. It is also one of the most popular approaches that evolved. It is the method in which in response to a forecast of impending congestion, speed limits are modified to reflect changes in traffic flow conditions, to account for unfavorable weather conditions, to manage the occurrence of an event as a preventative measure addressing periodic activity, wet road surface, and darkness., and do calculation beforehand and then the speed limit is reduced, to reduce or eliminate the congestion shockwaves effects, which can otherwise cause accidents[2], [3].

The microsimulation approach is the most important tool utilized in VSL. Microsimulation is an advanced approach that helps replicate the on-field conditions by simulating the traffic condition using simulation tools like VISSIM and modifying the parameters without actually affecting the on-field parameters themselves[4]. This method not only assists in the formulation of the plan but also in the incorporation of the plan inside the system to arrive at conclusions. All of this is accomplished without actually applying the method to the circumstances that exist in the field. Even though the results may not perfectly reflect the actual conditions that will be encountered in the field, it is still possible to gain a comprehensive understanding of the success or failure of various techniques. When compared to the methods that are typically utilized to reduce the effects of increased congestion, numerous VSL algorithms have been proven with the assistance of microsimulation to be effective in exhibiting an improved level of network performance.

1.1.2. Research in the field of ITS

Considerable study has been carried out in the field of VSL, and its benefits in the reduction of congestion have already been confirmed in nations that are already evolved in the field of Intelligent transportation systems. The actual field-testing investigations have been published in journals of several countries, including the Netherlands, Australia, and specific locations within the United Kingdom. However, because Pakistan is still in the process of developing its infrastructure for transportation systems (ITS), there is not a single article covering variable speed limits. As a result, this study is a pioneering effort in the aforementioned subject of ITS for Pakistan and in accordance with the country's driving practices.

The deployment of VSL has primarily two goals in mind: increasing both capacity and safety. VSL makes the roads safer by reducing speeds gradually in response to potentially hazardous driving conditions and so reducing the risk of rear-end collisions during emergencies and when traffic is very heavy[5]. To reduce the speed differences between cars, VSL ordered the traffic to slow down in a controlled manner. This results in a smoother flow and greater efficiency in the utilization of road space. As a result, VSL possesses the potential to increase the capacity of the freeway network, which, in turn, results in a reduction in congestion and traffic shockwaves while also leading to an increase in the traffic flow throughput[6].

In addition, it has been discovered that key factors contributing to traffic disruptions include short-time average headways as well as broad distributions of headways. There is a possibility that VSL will be able to narrow the gap in headway distributions, which will result in a more consistent and well-balanced traffic flow on the freeway and uniform distribution of headways[7].

The lessening of the fluctuations in speed that occur on the freeway is a precondition for the expansion of the available capacity. This suggests that a component that is harmful to the success of the VSL application is the drivers' reactions (degree of acceptance) and their interactions with other vehicles to the displayed speed limits. Before analyzing the effect that VSL has on the capacity of the highway, it is necessary to first get an understanding of how the variable speed limit (VSL) affects the speeds of cars and the headways between vehicles. To put them all together in a broad idea of VSL dominance, the following advantages of VSL are extracted:

- When a traffic network is near to reaching its full capacity, any interruption in the traffic stream, whether it be caused by an accident, rogue drivers driving, road closure, fog or rain, etc., can lead to congestion shockwaves, which can finally trigger a traffic breakdown. By slowing the speeds of vehicles when they enter the network, VSL can recover some of the capacity that was lost. Therefore, as a result of this procedure, delaying the entry of such cars into the bottleneck sites, thereby preventing the occurrence of traffic breakdowns.

- Additionally, VSL can result in a reduction of overall time spent in the network by cutting down on the amount of time spent in congestion and by eliminating shockwaves that travel along the traffic[8].

- It has been demonstrated through the utilization of a variety of accident models that the installation of VSL can also lead to an increase in safety. It is accomplished by minimizing the variations in speed that exist between cars that are going in the same or neighboring lanes. This speed reduction brings drivers' driving behaviors into harmony and, in the process, discourages drivers' behavior that involves changing lanes, which leads to a decrease in the likelihood of vehicles colliding with each other[9].

- The use of VSL can also lead to a reduction in the number of secondary collisions that occur in conditions with limited visibility, such as fog, severe rain, or snow[10]. Since the primary function of a VSL is to slow down cars, it contributes to increased overall traffic safety in conditions where sight is limited while simultaneously achieving this goal.

- Due to the frequent braking and accelerating that takes place as a result of the increased traffic, congestion is also associated with higher fuel consumption and emissions. Therefore, in addition to the capability of the VSL system to improve conditions regarding traffic flow, there is also a positive indirect effect of it in terms of its impact on the environment. Since then, it has been noticed that the utilization of Fuel Consumption-Aware Variable Speed Limit techniques helped to reduce the amount of greenhouse gas emissions that were produced under conditions of constant flow.

1.2. Problem Statement

Pakistan has the fifth highest population out of all the countries in the world, making it one of the most populous countries overall. In addition, the state of Pakistan's public transportation is in the process of improving, but it is not yet in a position to be universally preferred for a variety of reasons, including unsanitary conditions, demand that exceeds capacity, and availability in various regions. Because of this, the vast majority of people living in the nation favor the option of owning their vehicles over making use of the public transportation system. This, in turn, contributes to the day-to-day increase in the volume of traffic. In light of this, it does not matter how many modifications or road expansions are carried out; the demand will always exceed the capacity. The Intelligent Transportation System (ITS) was recently installed on Pakistan's M-5 motorway, which is a part of the network that makes up the CPEC corridor, and it links Multan and Sukkur. Even while the system that is incorporated into the highway is one of the most advanced systems available, complete with electronic challan production and speed limit check cameras, this does not mean that it is related to the reduction of the congestion problem in any manner. Also, the amount of data published on congestion mitigation practices using ITS is very limited, which makes this study the need of the hour. As a result, this study is the need of the hour to play its part in future endeavors of the country in response to demand that has emerged due to the near future condition of the traffic.

In addition, Pakistan is considered to be one of the developing countries that have limited resources and cash, which makes it difficult for the country to create an effective road infrastructure despite the ever-increasing volume of traffic. Therefore, the introduction of artificial intelligence into the country will assist in the management of the country's resources in a significantly improved manner, without the need to build the infrastructure, which requires ongoing funding and resources.

The algorithm that is used will not only be helpful for congestion reduction, but it will also play its role in foggy weather, which is the primary cause of a number of accidents involving multiple vehicles that take place during the winter on highways.

Fuel resources, which are growing scarce not only in developing nations but throughout the world, are becoming a serious worry as a result of this trend. This VSL system will help in reducing the amount of gasoline that is consumed, which has been proven by many studies and research to be beneficial because fuel prices are continuing to rise beyond the means of the average person in Pakistan. It is because frequent braking and acceleration of the car in response to persistent congestion on the road result in higher consumption of fuel. The reason for this is that fuel consumption is increased.

This research is in line with the significant global concern of environmental deterioration caused by the emission of greenhouse gases, which is leading to the loss of the ozone layer and, as a result, putting the continued existence of human beings in jeopardy. This study will aid in reducing the number of greenhouse gases emitted by decreasing the occupancy rate of automobiles owing to congestion. It will also play a role in addressing the primary concern that has been brought up.

In conclusion, with the assistance of the proposed study, an algorithm that considers the behaviors and reactions of Pakistani drivers can be developed for Pakistan. This algorithm has the potential to serve as a pioneer for the future mitigation procedures that the country will adopt to control congestion.

1.3. Research Objectives

The research was carried out in accordance with a number of primary objectives, the most important of which were as follows.

- The development of a VSL algorithm for Pakistan's Motorways.
- Achieving the design of an algorithm that supports various levels of driver compliance

by establishing a maximum traffic volume/average speed and a minimum occupancy rate.

- Determined the difference in total travel duration between the true time data and the algorithm-adjusted data.
- Confirming that the execution of the algorithm will be advantageous, considering Pakistan's road conditions and driving attitudes.
- Providing evidence that the deployment of the VSL has had favorable effects on the surrounding ecosystem.
- Demonstrating that the ITS technique is an efficient method for mitigating the negative consequences of traffic congestion.

1.4. Dissertation Approach

In the second chapter of the thesis, a review of the relevant literature is presented. This review examines a number of papers and studies to discuss traffic breakdown, general knowledge of variable speed limits and their control methods, the impact of variable speed limits on driver behaviors, and the impact of variable speed limits (VSL) on the traffic moving on highways or motorways.

The processes and methodologies utilized in the research are dissected and discussed in Chapter 3. In addition to that, the data that were utilized in the research will be explained, as will the methods and procedures that were applied to manage and validate the data. In addition to that, the process of algorithm generation and incident generation are both brought up for discussion. In this chapter, we will also illustrate a variety of different circumstances in which the benefits of VSL can be utilized.

This research's analytic outcomes, findings, and subsequent discussions are presented in chapter 4 of the book. This chapter analyzes the effect that VSL has on the scenarios with any incident or setbacks on the motorways. The result has been compared in terms of average speed, occupancy, and travel time.

The findings of the study, as well as its potential repercussions, are discussed in the book's concluding chapter (chapter five). This chapter also provides research ideas for the future.

CHAPTER 2: LITERATURE REVIEW

2.1. General

In this review of relevant literature, the following concepts are covered briefly: traffic breakdown and congestion, as well as how VSL and its control tactics helped to alleviate the congestion problem; the effects of VSL on driver behavior and the flow of motorway traffic.

Significant research has been carried out in the area of VSL, and its effectiveness in reducing the effects of traffic congestion has already been validated in nations that have developed intelligent transportation systems. Several VSL algorithms are validated with the assistance of microsimulation, and they successfully exhibit enhanced Network performance in comparison to the typically utilized solutions for managing increasing congestion. Studies based on real-world testing in the field have been published in academic publications in the Netherlands, Australia, and various parts of the United Kingdom. On the other hand, because Pakistan is still in the process of developing the area of ITS, not a single article about variable speed restrictions was found. As a result, this research is a pioneering effort in the aforementioned subject of ITS for Pakistan and its particular modes of transportation.

As was indicated previously, the significance of VSL in terms of mitigating congestion and increasing safety has already been proven in a variety of study publications. In addition to this, it has been used as a solution to the issues of congestion and safety standards in several countries throughout the world. In addition to these two performance indicators, several studies have also proved the effectiveness of VSL in terms of environmental concerns, such as $CO2$, CO, and NOx emission reduction rates. Different papers based on these three performance measures will be detailed further down in the following sections.

2.2. VSL Role in Congestion Mitigation

There is no one definition of congestion that can be taken as authoritative by all parties. In the majority of instances, congestion is accompanied by a significant decrease in speed (relative to the open flow), an increase in travel time, a decrease in flow, stop-and-go circumstances, and a density augmentation. It is not difficult to spot congestion since the roads are clogged with vehicles (cars, trucks, and buses), and the walkways are packed with people. In the context of transportation, the term "congestion" typically refers to an excessive number of cars that are present on a section of roadway at the same time, which results in lower speeds—sometimes much slower—than the rates that are considered to be "free flow." Because of congestion, the flow of traffic is frequently halted or interrupted. According to Juan and Zhang, (2004)[11], congestion may be broken down into two categories: demand-driven and supply-driven congestion. These two types of congestion are distinguished from one another by the source of the congestion. Congestion that is caused by increased demand happens when there is a rise in traffic demand. This problem becomes even worse when there is also a mix of close time spacing and frequent speed differences. When arrival rates exceed the motorway's maximum flow, vehicles will form queues on the segment of the road with the lowest capacity (generally referred to as the bottleneck section). The state of coordinated traffic flow will emerge when queues stretch outward from the bottleneck-causing locations [12]. The majority of vehicles in that state move at a pace that is near the national average, and vehicles are becoming increasingly dependent on one another. This signifies that the cars are traveling under conditions roughly equal to automobile following, as there are few opportunities to pass.

2.2.1. Effectiveness of VSL with driver's compliance Level

According to Shi and Ziliaskopoulos (2002)[13], conduct characterized by frequent stops and starts was strongly correlated with unstable traffic conditions, which resulted in severe congestion. The highway's low temporal average headway illustrates that disruptions at the front of the platoon cannot be mitigated as they spread upstream. This is because some drivers in the platoon are unable to respond to disruptions promptly. Moreover, traffic with variable time headways is likely to face more frequent disruptions than traffic with constant time headways. In the first scenario, there are more opportunities for lane-changing behavior, Consequently, there are more disturbances.

According to the findings of the vast majority of studies, putting VSL-implemented technologies into place is beneficial for easing congestion-related problems on highways. In one study, the problems associated with reducing congestion were addressed by adding the Compliance level and putting VSL tactics into effect[14]. The research involved performing a microscopic simulation on a stretch of highway in Istanbul, Turkey, utilizing VISSIM's default following model and integrating it with MATLAB through the use of COM. The author has chosen a compliance level of both fifty and seventy-five percent for his work. The performance of the network is measured not only in terms of the overall journey time across the network but also in terms of the traffic volume, speed, and occupancy rate.

The procedure that was adopted by the study is that they first achieved the real-time condition of the road on VISSIM by calibrating the control parameters, such as lane changing behavior, headway, and following behavior until the simulation model speed time graph became more or less equal to the real-time data graph. This was done to ensure that the results of the study were accurate. They used the GEH value as a method of verification, which allowed them to check the results. According to the study, this has value, as it states that for all locations, ninety percent of GEH values are within the error range of equal to or less than 5. The segment of the pipe that was chosen for the investigation was positioned in such a way that it had an input ramp before the proposed detector and an outflow ramp after it. In the study, they have maintained two limitations, which are as follows:

- The difference in the displayed speeds of two VSL signs that are placed one after the other shall not exceed 20 kilometers per hour.

- It is recommended that slower speeds be maintained for at least one minute.

It was decided by the author to apply the limitations to prevent unexpected speed changes and to give the traffic time to recover before changing the sign to reflect higher speed levels.

The findings of the study led the researcher to draw a variety of conclusions on the utilization of VSL inside the system. The VSL scenario fared significantly better than the one that did not use VSL. According to the research presented in the publication, the increase in volume is 8.58 percent higher for CL concentrations of 75 percent, and it is 5.75 percent higher for CL concentrations of 50 percent. Also, the average speed and occupancy show an improvement of 8.2 percent and 7.85 percent, respectively, for 75 percent CL. Total Travel Time (TTT) decreased by 8.93 percent for 75 percent and 7.4 percent for 50 percent CL respectively. When using CL at a concentration of 75%, there is a reduction in fuel consumption of 28.5%, whereas using CL at a concentration of 50% results in a reduction of 27.5%. And a drop-in emission of CO and NOx thanks to the VSL system, compared to the scenario before it was implemented. Compliance level is defined as the proportion of drivers who obey traffic signals based on the traffic conditions as measured by VSL. The author demonstrated that the compliance level plays a significant factor in the success of VSL strategies. He demonstrated that an increased level of compliance leads to an increased success rate for the VSL techniques. This research makes use of the algorithm design that was developed by Allaby et al[15]., which was derived from a study that was carried out in Toronto, Canada, and which established the advantages of VSL control techniques through the use of microsimulation as well as a crash model.

2.2.2. Determining benefits of VSL using crash models

The research that was carried out in Toronto, Canada, was carried out by establishing the advantages of VSL control techniques through the use of a crash model. The research that was carried out in Toronto, Canada, was accomplished by determining the benefits of VSL control strategies by utilizing a crash model. This was done as part of the study that was carried out. Traffic scenarios with higher degrees of congestion are more likely to benefit from the VSL system in terms of bigger positive RSBs and fewer negative travel time impacts. This is because the VSL system is designed to prioritize lanes of traffic with the highest volume. This is because the VSL system has a greater chance of cutting down on the amount of time lost due to congestion-related delays. The frequency and severity of the shockwaves caused by the backed-up traffic appeared to have decreased, at least in part, as a result of these modifications. This occurs as a result of the stop-and-go oscillations being dampened, resulting in a decrease in the frequency and intensity of shockwaves. Positive RSBs were more likely to occur at the busiest places, as well as in areas where speed limit reductions occurred. Additionally, these locations had less of an impact on travel time. Even though these places triggered reductions in the speed limit, this was nonetheless the case. When few people were using the VSL response zones, the likelihood of receiving a negative RSB at a station that was located upstream from those response zones increased. Vehicles that travel greater distances are more likely to experience detrimental effects on their travel times as a result of the current VSL control algorithm. This is in contrast to vehicles that travel shorter distances. This is because it takes more time to accomplish longer journeys.

2.2.3. Research studies conducted in a controlled vehicle environment

With MPC's assistance, researchers were able to conduct another investigation that maximizes the safety, mobility, and environmental benefits of individual driver behavior in a controlled vehicle environment[16]. This research is the pioneering study to excogitate an algorithm that simultaneously maximizes the advantages to safety, mobility, and the environment, but it does so within the context of a controlled vehicle environment[17]. To put it more simply, they attempted to develop an algorithm that was based on the specific actions of each unique driver. Although the algorithm is best suited for the case in which technological advancement in autonomous vehicles is more likely to make a connected environment, this study is still considered a pioneering effort because it attempted to simultaneously increase all of the beneficial features of the variable speed limit implementation. To implement the individual driver behavior, they utilized the concept of model predictive control. Calculating Total Travel Time (TTT) required the use of a microscopic traffic flow prediction model; measuring instantaneous safety required the use of a surrogate safety measure called Time to Collision (TTC), and measuring the values of environmental impact required the use of a microscopic fuel consumption model called VT-Micro[18]. They integrated the individual driver behavior system to get the highest possible level of compliance from the driver, which is the single most important factor in determining the level of success achieved by any VSL system installation. Nearly all of the studies have, in particular, underlined how very important it is for drivers to maintain a certain degree of compliance. The best speed restriction was determined by adjusting the real-time drivers' compliance with the listed speed limit, which was the focus of this study. It was advised that the technique be implemented using VISSIM, which was integrated with MATLAB utilizing COM. According to the findings of the study, with a 100 percent penetration rate, the developed VSL approach consistently outperformed the uncontrolled scenario. This resulted in a reduction of up to 20 percent in total travel time, an improvement of 6–11 percent in safety, and a reduction of 5–16 percent in fuel consumption. In addition to the findings described above, the paper concluded that optimizing for a single criterion, such as safety, yields more positive and optimized results compared to multi-criterion optimization, which considers all three criteria at the same time. This finding was presented as a main statement in the paper.

2.2.4. Artificially created congestion using parking space method

One of the studies, in which the author created an incident by using a parking space in a simulation model to create virtual congestion, demonstrated the increased bottleneck throughput that could be achieved through the implementation of VSL strategies during both the morning and the afternoon peak hours. This study's concept of causing traffic congestion was also utilized in this research study[19]. The simulation for the case study was run for a portion of a multi-lane motorway that was approximately nineteen kilometers long and was located between interchanges in the Sultanate of Oman. To determine whether or not VSL is an effective TIM approach, several different M.O.E.s were chosen based on criteria including ease of movement and security/ safety. In addition, the B/C and NPV approaches were utilized so that an assessment could be made about the practicability of putting the strategy into action within the context of an economic review. In contrast to the No-VSL case, the proposed VSL method increased bottleneck throughput by 0.7 percent and 22.5 percent, respectively, there is a general rise in output throughout both the morning and afternoon hours and were 7.8 percent and 11 percent, respectively. In addition, the time taken for a car to move and the amount of time it takes for a vehicle to be delayed have both decreased by 3 percent, respectively, to 90 percent and 60 percent. In addition, there was a decrease of 87 percent in fuel usage and a reduction of 3.5 percent in overall emissions. Last but not least, the total number of pauses delays as well as the average number of stops throughout the morning commute decreased by 14.4 percent and 10 percent respectively, as well as 0.2 percent and 16.6 percent respectively. The study concludes that the VSL method offers a cost-effective option in the management of traffic incidents, which can increase the traffic's efficiency, safety, and mobility while also providing an approach that is favorable to the environment. Over all of the MOEs, there was an overall trend toward improvement. But it was far more substantial in the areas where the volume of traffic was large. In addition, the author concluded that the effectiveness of the strategy was dependent on other factors such as the location of the incident and the severity of the incident. It was found that the effectiveness of the VSL strategy was higher in cases of high severity when it came to improving the mobility of the highway. This was determined by considering the severity of the incident. It was discovered that the VSL strategy yields better results in terms of mobility when the incident occurs near to diverging area as opposed to the same incident occurring at the merging area, while it also showed better improvement in terms of safety and environmental impact when the incident occurs near the merging area. This was discovered while taking into consideration the location of the incident.

2.3. VSL Role in Safety

On the topic of the advantages of VSL in terms of safety, numerous studies have been conducted and the lowering of the accident occurrence rate. Active traffic management strategies (ATM) strategies like Harmonization of speed, peak shoulder usage period, and ramp metering, are used as an alternative to non-ITS techniques because they allow for more effective management of congestion while making use of the available capacity of the freeway. This is because non-ITS techniques are limited by other factors, such as financial and land availability constraints. But before we can make it work in the real world, we need to first consider the implications that these methods will have on our safety before we can put them into action.

2.3.1. Analysis of ATM methods based on interdependent models

There is a study that was conducted in which the author constructed a set of interdependent models as well as a simulation framework to analyze the positive effects that ATM methods have on traffic operations and safety. In that particular study, four different ATM scenarios were analyzed, including variable speed limits (VSL), shoulder use during peak periods, combined VSL and shoulder use, and ramp metering. According to the findings of the study, these ATM measures, when taken as a whole, were able to standardize traffic and make driving conditions safer, but they did not boost the throughput of the road. According to the findings of the study, there is a potential for a sudden one-lane reduction at the end of the shoulder-use section to harm both the efficiency with which traffic operations are carried out and the level of traffic safety that is maintained. In addition, the article discusses the ITS devices that are necessary to put these tactics into action, as well as enforcement difficulties, potential obstructions in their implementations, and a framework for a cost-benefit analysis to establish the economic sustainability of the techniques.

2.3.2. Practically implemented VSL systems research studies

In terms of risk reduction, several practically implemented VSL systems in some countries, such as the United States, the Netherlands, Canada, and some regions of the

United Kingdom, have carried out real-time studies To comprehend the benefits provided by VSL, it is necessary to conduct the following research and to determine whether or not there is a need for any adjustments to be made to the system. One of the studies carried out a real-time investigation on Whitemud Drive (WMD), which is an urban motorway in Edmonton, Alberta, Canada, and serves as the study corridor for that particular piece of research[20]. The length of the corridor is approximately 11 kilometers, and it consists of 7 video cameras, 9 loop detector stations, and 12 ramps. In addition, the article discussed the directional average annual daily traffic (AADT), which reached up to about 100,000 cars. This figure was included in the range of data presented. Each of the nine loop detector stations was comprised of two loop detector groups per traffic lane and was all situated on the mainline of WMD, which is where all of the stations were located. Data on the movement of traffic was collected every 20 seconds by these detectors and cameras. According to the author, the current VSL control was implemented to reduce the amount of traffic congestion that occurred during peak hours. The time period that the data records cover under the VSL control ranges from 16:00 to 19:00 and has various speed limits (ranging from 30 to 80 kilometers per hour). During those other time periods, the maximum allowed speed was 80 kilometers per hour. To direct this investigation, a technique based on spatial-temporal analysis is being created. The significance of the result is then evaluated with the help of a t-test based on an independent sample. The author compared the crash risks associated with VSL control schemes to those associated with not using VSL. This comparison was carried out to determine the most effective VSL control scheme and identify the crash risks associated with WMD from a spatial and temporal perspective. In addition to that, they also consider traffic congestion. According to the findings, there is a correlation between being under the influence of VSL and a reduction in average crash chance in WMD that is greater than 20%. In general, after the implementation of VSL, the risk degree of the station that posed the greatest threat was drastically decreased and was kept at an acceptable level. In the meantime, the relatively safe stations are getting even safer[21]. Additionally, the congestion of WMD is improved under the control of VSL scheme l, making this a win-win situation. This enhancement is recognizable as an increase in the speed of the flow of traffic as well as the flow itself. The research led to a very significant finding, which was confirmed by the t-test[22]. The most successful VSL control strategy has a greater impact on the moderate-risk zone than the high-risk zone and a greater impact on the most congested station than the comparatively uncongested zone. This was found to be the case when comparing the high-risk area to the moderate-risk area.

CHAPTER 3: RESEARCH METHODOLOGY

3.1. Overview of Methodological Approach

The research's approach is shown in figure 3-1 below. First, there is a part for data collecting, where crucial data extraction and data analysis are done. The process for creating the model in PTV VISSIM is then documented. Calibration and validation are also covered here. The creation of scenarios is covered in the next section. The VISSIM COM interface and VSL control algorithm are explained in the methodology's last part.

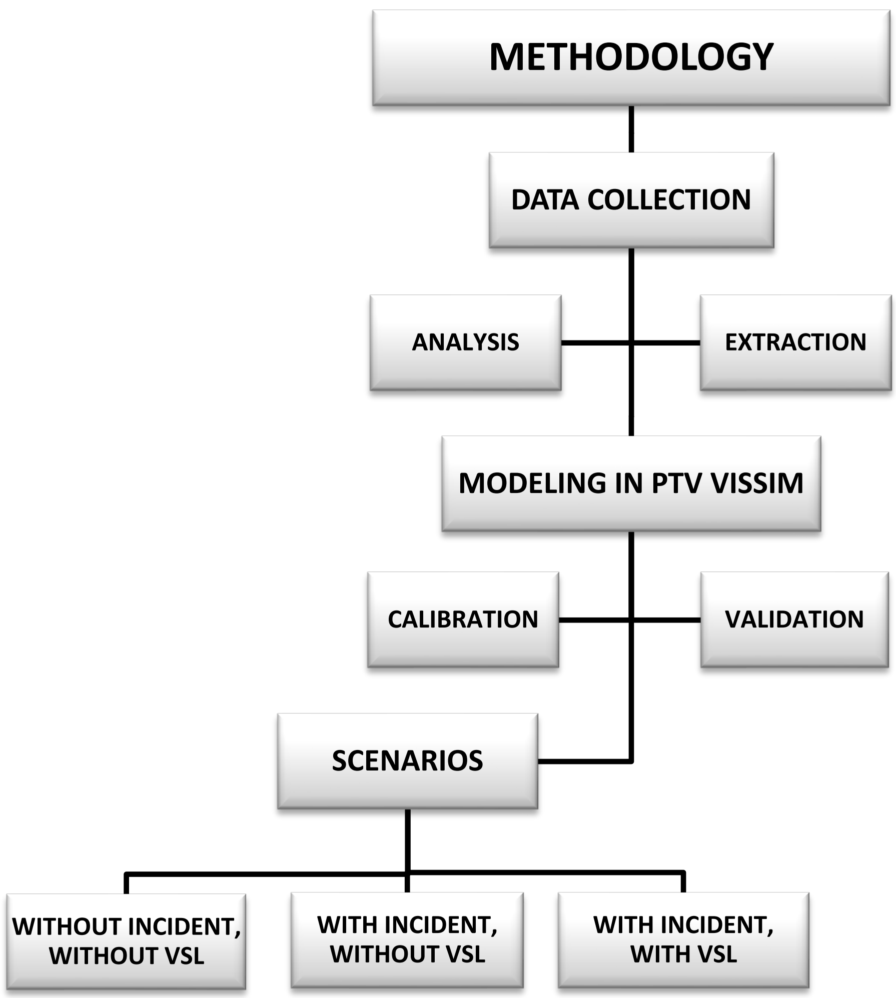

Figure 3-1: Methodology Tree Diagram

3.2. Data Collection

Pakistan's M-1 Motorway, popularly known as the Islamabad–Peshawar Motorway, connects Peshawar with Islamabad–Rawalpindi along an east-west route. This research utilized the information obtained from the M-1 highway as one of its data sources. It was utilized as a resource because it was not only readily available but also had all of the data that was necessary for the research. At the intersection with the Peshawar Ring Road, which is located to the northeast of Peshawar, the M-1 begins its journey. After then, it travels to the east, going over the Kabul River, and then it passes through the cities of Charsadda, Risalpur, Swabi, and Rashakai on its way to the Indus River. After exiting Khyber Pakhtunkhwa province, the M-1 enters Punjab province and travels through Attock, Burhan, and Hasan Abdal on its way to the city of Hasan Abdal. Near Islamabad, the M-1 motorway comes to an end and becomes an extension of the M-2 highway.

The entire stretch of the M-1 is comprised of six lanes, and there are several rest spots along the route. There are 14 interchanges along the M-1: at the Airport Link Road, Islamabad, AWT/ Sanjiani/ Paswal, Burma Bhatar, Burhan (Hassan Abdal/ Kamra), Hazara Expressway (E-35), Ghazi, Chachh, Sawabi, Rashakai, Charsadda, the Peshawar Northern Bypass, and the Peshawar Ring Road. The M-1 also connects to the Hazara Express at the Brahma Bahtar Interchange, the Brahma Bahtar-Yarik Motorway headed in the direction of Dera Ismail Khan officially started. Figure 3-2 depicts the position of the data collection, which is near the AWT exchange. The statistics are available thanks to the supervisor who made them available.

Pneumatic tube detectors are placed on both sides of the freeway to collect the necessary data. Because the M-1 is a three-lane dual carriageway, the data collection for both sides of the motorway was collected using two pneumatic tubes. Specifically, one detector covered the fast lane traffic and was given the name fast lane, while the other detector covered the remaining two lanes and was given the name slow lane. This was done because the M-1 is a six-lane divided highway with three lanes in each direction.

The time period for collecting data was different for each of the lanes, with the fast lane collecting data from the 24th of November 2019 until the 23rd of February 2020, the slow lane collecting data from the 22nd of November 2019 until the 23rd of February 2020 for the northbound fast and slow lanes. In addition, the time range for collecting data heading southbound was from the 24th of November 2019 through the 23rd of February 2020 for the fast lane and from the 22nd of November 2019 until the 22nd of February 2020 for the slow lane.

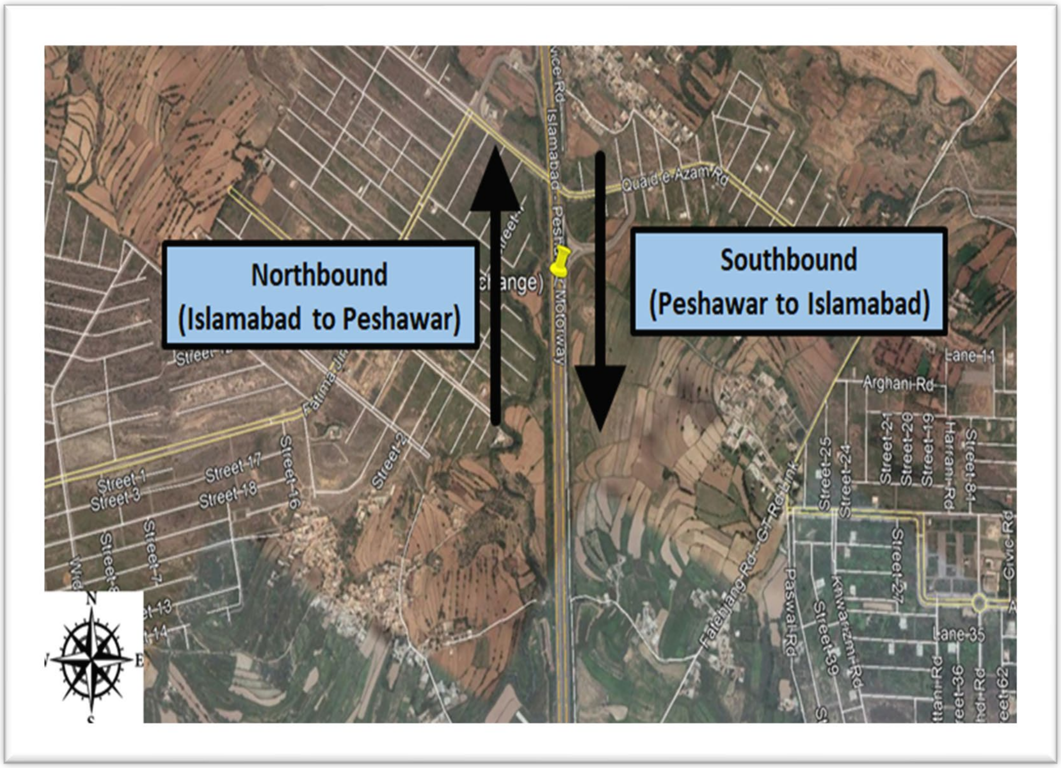

Figure 3-2: Location M-1

3.2.1. Data Description

The information was given to us in the form of an Excel spreadsheet, and within that spreadsheet were multiple sheets labeled with the headings "northbound lane" and "southbound lane" for lanes 1 and 2, respectively. Figure 3-3 provides a visual representation of it below. The information is organized into four columns, which are titled "data," "time," "vehicle type," and "speed." The data was gathered for each of the 24 hours of the day, for each day of the period of the study, which lasted for three months beginning on November 22, 2019, and ending on February 23, 2020.

Passenger cars, buses, Hiace, vehicles with two, three, four, five, or six axles, as well as motorcycles, were the types of vehicles that the pneumatic tubes were able to identify. These kinds of vehicles were found to be operating on both carriageways. Some vehicles were not able to be identified from one another, and these vehicles were placed in the "others" category. In this instance, as bikes are not permitted to be driven on motorways, the detections listed as motorcycles are passenger vehicles that are shorter in length, or a vehicle has been detected more than once in a short amount of time.

The fast lane in the northbound direction has a maximum speed of 212 kilometers per hour and an average speed of 123 kilometers per hour. While traveling in the slow lane heading northward, the maximum speed that has been achieved is 159 kilometers per hour, while the average speed is 87 kilometers per hour. Similarly, the maximum speed of the vehicle obtained in the southbound fast lane is 213 kilometers per hour, and the average speed is 105 kilometers per hour. On the other hand, the maximum speed detected in the southbound slow lane is 160 kilometers per hour, and the average speed is calculated as 86 kilometers per hour.

DATE	TIME	VEHICLE TYPE	SPEED
11/24/2019	8:25:14 AM	Car	96.59
11/24/2019	8:25:17 AM	Car	114.86
11/24/2019	8:25:23 AM	Car	110.56
11/24/2019	8:25:25 AM	Car	98.34
11/24/2019	8:25:33 AM	Car	106.92
11/24/2019	8:25:46 AM	Car	114.80
11/24/2019	8:26:38 AM	Car	116.44
11/24/2019	8:26:40 AM	Car	115.51
11/24/2019	8:28:10 AM	Car	93.84
11/24/2019	8:28:11 AM	Car	91.86
11/24/2019	8:28:23 AM	Car	111.41
11/24/2019	8:28:25 AM	Car	108.59
11/24/2019	8:28:26 AM	Car	117.30
11/24/2019	8:28:53 AM	Car	108.79
11/24/2019	8:28:58 AM	Car	125.90
11/24/2019	8:29:26 AM	Car	108.56
11/24/2019	8:29:43 AM	Car	124.78
11/24/2019	8:29:49 AM	Car	108.21
11/24/2019	8:30:20 AM	Car	141.56
11/24/2019	8:30:52 AM	Car	114.64
11/24/2019	8:30:55 AM	Car	121.65
11/24/2019	8:31:02 AM	Car	113.09
11/24/2019	8:31:30 AM	Car	116.70
11/24/2019	8:33:05 AM	Car	100.03
11/24/2019	8:33:41 AM	Car	114.64
11/24/2019	8:34:04 AM	Car	98.66
11/24/2019	8:34:23 AM	Car	112.40
11/24/2019	8:34:27 AM	Car	100.42

Location M-1 | Northbound_Lane-1 | Northbound_Lanes-2 | Southbound_Lane-1 | Southbound_Lanes-2 | Southbound_Lanes-2_2

Figure 3-3: Excel data sheet

3.3. Data Analysis

3.3.1. Data Extraction

To get this research project off the ground, the first thing that needs to be done is an examination of the data. The purpose of the data analysis was to isolate the busiest day of the entire set of data and extract it for consideration. This action is taken because VSL will be better suited to roads that are more likely to experience congestion. Therefore, to have a sense of the level of congestion and also to get the data necessary for the calibration of the PTV VISSIM, the data analysis, and data extraction process is done. In addition, a general picture of the direction in which the traffic situation and traffic volume are changing can be gleaned from this information. In simple terms the point of analysis was:

- choose the month, day, and hours with the highest congestion.
- select a time period for calibration that is more manageable and straightforward to carry out within PTV VISSIM.
- Determine the density of the traffic, the volume of the individual vehicles, the flow rate, the PHF, the occupancy rate, and the relative flow.

To begin, the percentiles of the vehicular speed were determined as indicated in table 1 below so that a basic sense of the traffic condition and the average speed of the cars could be obtained. As can be seen from Table 3-1, the speed of 90 percent of the vehicles traveling on the highway in the fast lane was 148.66 kilometers per hour, while the speed of 90 percent of the vehicles traveling in the slow lane was 106.18 kilometers per hour for northbound traffic. However, when traveling southward, the speed at the 90th percentile is 120 kilometers per hour, whereas it is 107 kilometers per hour accordingly. The simplest approach that was adopted to determine the date and time of the hour with the most congested traffic was to analyze the data after it was first extracted with the date that had the greatest number of vehicles in a day. This was done to find the date and time of the hour with the most congested traffic. Therefore, the number of vehicles on the road was counted using Excel for each of the 24 hours that make up each day, which enabled us to determine which day had the highest volume overall.

Table 3-1: Speed profile of M-1

	Speed Percentile		
	Percentile	**Speed**	**Lanes**
NORTHBOUND	90	148.66	Fast
	50	123.83	
	25	108.96	
	90	106.18	Slow
	50	87.6	
	25	77.07	
SOUTHBOUND	90	120.89	Fast
	50	104.99	
	25	96.11	
	90	107.95	Slow
	50	88.43	
	25	74.87	

The count of vehicles encompasses all categories and subcategories of automobiles for the entire twenty-four-hour period. The 22nd of December 2019 was the day that had the biggest amount of volume when compared to all of the other days across all three months.

The next thing that was performed was to investigate whether the direction of travel, either northbound or southbound, had a bigger number of vehicles moving through it. On the M-1 motorway, the southbound traffic, which refers to traffic traveling from Peshawar to Islamabad, was found to be more congested than the northbound traffic, which refers to traffic traveling in the opposite direction, from Islamabad to Peshawar. This was discovered after a separate count of the data was performed on both ends of the motorway. This can be seen in Table 3-2 below.

Table 3-2: Vehicles volume in Northbound and Southbound Direction

Direction	Fast Lane	Slow Lane	Total
Northbound	410482	818924	1229406
Southbound	556835	1083823	1640658

In this, it is visually observable that the volume of traffic traveling in the southbound direction of the M-1 is greater when compared to the volume of traffic traveling in the northbound direction. So, this bound traffic is used in consideration for this research article.

3.3.2. Congested day analysis

On December 22nd, 2019, the total count of the vehicles that were obtained was 8,809 Vehicles in the fast lane, while a total count of 14,965 Vehicles was gained in the slow lane. As a result, the number of cars that traveled on the highway during its whole operation was 23,774 in total. After this, the subsequent stage was to separate the entire volume into several categories of vehicles, such as passenger cars, buses, Hiace, and trucks with 2, 3, 4, 5, and 6 axles.

Because 15 minutes is the typical time span considered while doing traffic studies, this is the time period that was chosen. Here, separate counts of the vehicle type are done at 15-minute intervals during the 24-hour period that encompasses the 22nd of December 2019, after the time period has been selected using the filter function of Excel. This activity was carried out for the lanes of traffic moving at high speeds as well as those moving at moderate speeds. The evidence of this is depicted in Figure 3-4 down below.

time interval		Cars(Fast)	cars(slow)	total	2-Axle(fast)	2-Axle(slow)	total	3-Axle(fast)	3-Axle(slow)	total	4-Axle(fast)	4-Axle(slow)	total	Bus(fast)	bus(slow)	total	Hiace(fast)	Hiace(slow)	total	5-axle(slow)	6-axle(slow)	small cars
12:00:00 AM	12:15:00 AM	27	65	92	0	3	3	0	1	1	0	1	1	2	8	10	0	5	5	0	1	0
12:15:00 AM	12:30:00 AM	17	58	75	0	6	6	0	0	0	0	1	1	0	4	4	0	6	6	1	0	3
12:30:00 AM	12:45:00 AM	24	46	70	0	4	4	0	0	0	0	0	0	0	3	3	0	1	1	0	2	0
12:45:00 AM	1:00:00 AM	15	40	55	0	5	5	0	0	0	0	0	0	1	3	4	0	0	0	0	1	0
1:00:00 AM	1:15:00 AM	16	39	55	0	4	4	0	0	0	0	0	0	0	3	3	0	4	4	0	1	2
1:15:00 AM	1:30:00 AM	16	38	54	0	4	4	0	1	1	0	0	0	0	6	6	0	3	3	0	2	3
1:30:00 AM	1:45:00 AM	14	37	51	0	4	4	0	0	0	0	0	0	2	2	4	0	0	0	1	1	0
1:45:00 AM	2:00:00 AM	12	32	44	0	2	2	0	2	2	0	0	0	0	2	2	0	0	0	0	0	0
2:00:00 AM	2:15:00 AM	3	18	21	0	4	4	0	0	0	0	1	1	0	1	1	0	0	0	1	1	0
2:15:00 AM	2:30:00 AM	10	33	43	0	2	2	0	0	0	0	0	0	0	3	3	0	1	1	0	0	0
2:30:00 AM	2:45:00 AM	9	26	35	0	3	3	0	1	1	0	0	0	0	0	0	0	3	3	0	0	0
2:45:00 AM	3:00:00 AM	4	18	22	0	2	2	0	0	0	0	1	1	0	0	0	0	0	0	0	1	0
3:00:00 AM	3:15:00 AM	3	21	24	0	2	2	0	2	2	0	1	1	0	0	0	0	1	1	0	1	0
3:15:00 AM	3:30:00 AM	2	16	18	0	1	1	0	1	1	0	0	0	0	1	1	0	1	1	1	0	0
3:30:00 AM	3:45:00 AM	2	9	11	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	0	0	0
3:45:00 AM	4:00:00 AM	2	17	19	0	0	0	0	0	0	0	1	1	0	3	3	0	0	0	0	0	0
4:00:00 AM	4:15:00 AM	2	12	14	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
4:15:00 AM	4:30:00 AM	3	19	22	0	1	1	0	1	1	0	1	1	0	0	0	0	1	1	0	1	0
4:30:00 AM	4:45:00 AM	7	17	24	0	3	3	0	1	1	0	0	0	0	2	2	0	0	0	0	0	0
4:45:00 AM	5:00:00 AM	1	11	12	0	3	3	0	1	1	0	1	1	0	3	3	0	0	0	0	0	0
5:00:00 AM	5:15:00 AM	3	11	14	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5:15:00 AM	5:30:00 AM	0	16	16	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0

Figure 3-4: Volume of different types of Vehicles based on the interval

It is clear looking at figure 3.4 that there are no trucks with five or six axles traveling in the fast lanes. After that, the total volume is determined by combining the volumes at each interval of 15 minutes together to get the total volume.

This volume of data also allowed for the estimation of the percentages of heavy vehicles and passenger vehicles. To calculate the percentage of heavy vehicles, the volumes of all of the axle trucks and buses are summed. On the other hand, automobiles and Hiaces are used for the calculation of the percentage of passenger cars. The passenger cars percentage came in at 94.99 percent, while the percentage of heavy vehicles came in at 5.01 percent.

After tallying up the total number of vehicles, the next step in arriving at the ultimate result, which is the occupancy rate, is started. This occupancy rate is required at a later stage for comparison with the model of the simulation. The formula for occupancy is as follows:

$$Occupancy = \frac{density\ \times (L_V + L_D)}{5280}$$

Here, Lv is the length of the vehicle while the L_D is the length of the detector.

To calculate the Lv, the harmonic mean of the vehicle lengths that are typically employed is utilized, and the length of the detector is assumed to be 1 meter which gives us the L_D in the above equation. The density is the next component of the equation that is lacking and to calculate density, one must first determine the flow rate from the previously determined volume, then divide that number by the space mean speed (SMS), as the following equation demonstrates.

$$Density = \frac{Flow\ Rate}{Average\ Speed}$$

Here, the number of cars passing through a specific point within an hour is referred to as the flow rate in this situation, while the average speed refers to the space mean speed (SMS), which is the average speed of vehicles traveling a given segment of the roadway during a specified period of time and is calculated using the average travel time and length for the roadway segment. Flow rate is measured in vehicles per hour, while average speed is measured in kilometers per hour.

As flow rate refers to the pace at which Vehicles pass a particular place on the road, and it is typically measured in terms of the number of vehicles that pass that point in one hour. Therefore, because a period of 15 minutes was chosen as the time interval, the flow rate can be calculated by multiplying the volume by four. After that, the space mean speed is determined by determining the harmonic mean of the 15-minute speed intervals of the original data. This is done for the fast lanes as well as the slow lanes on the roadways. The formula of density as shown above is then utilized to perform the calculation of density, which is followed by the utilization of this density in the computation that ultimately determines the occupancy. It can be seen in figure 3-5 below:

time interval		Volume	Flow Rate(veh/hr)	AVG SPEED (fast)	AVG SPEED (slow)	Total (km/hr)	SM SPEED (fast)	SM SPEED (slow)	SMS Total (km/hr)	SMS Total (mph)	DENSITY	HEADWAY (sec)	SPACING (ft)	PEAK HOUR FACTOR	OCCUPANCY	OCCUPANCY(%)
12:00:00 AM	12:15:00 AM	113	452	104.08	85.31	94.69	102.50	79.11	89.30	55.50	8.14	7.96	648.34	0.78	0.04	4.45
12:15:00 AM	12:30:00 AM	96	384	96.88	72.98	84.93	91.91	65.10	76.21	47.37	8.11	9.38	651.30	0.81	0.04	4.43
12:30:00 AM	12:45:00 AM	80	320	102.57	83.78	93.18	101.36	79.05	88.82	55.20	5.80	11.25	910.87	0.90	0.03	3.17
12:45:00 AM	1:00:00 AM	65	260	103.33	79.49	91.41	101.63	72.14	84.38	52.44	4.96	13.85	1065.00	0.92	0.03	2.71
1:00:00 AM	1:15:00 AM	69	276	104.38	80.99	92.68	102.24	75.23	86.68	53.87	5.12	13.04	1030.62	0.87	0.03	2.80
1:15:00 AM	1:30:00 AM	73	292	104.38	77.75	91.07	100.84	72.18	84.14	52.29	5.58	12.33	945.56	0.73	0.03	3.05
1:30:00 AM	1:45:00 AM	61	244	101.43	75.73	88.58	99.97	69.71	82.14	51.05	4.78	14.75	1104.72	0.77	0.03	2.61
1:45:00 AM	2:00:00 AM	50	200	109.30	83.94	96.62	105.46	78.06	89.71	55.76	3.59	18.00	1471.95	0.85	0.02	1.96
2:00:00 AM	2:15:00 AM	29	116	123.65	77.11	100.38	121.55	67.41	86.73	53.90	2.15	31.03	2453.40	0.74	0.01	1.18
2:15:00 AM	2:30:00 AM	49	196	112.12	86.28	99.20	110.48	74.95	89.31	55.51	3.53	18.37	1495.25	0.76	0.02	1.93
2:30:00 AM	2:45:00 AM	42	168	103.96	80.38	92.17	102.55	71.14	84.00	52.21	3.22	21.43	1640.83	0.73	0.02	1.76
2:45:00 AM	3:00:00 AM	26	104	98.71	72.88	85.80	96.75	63.15	76.42	47.49	2.19	34.62	2411.25	0.75	0.01	1.20
3:00:00 AM	3:15:00 AM	31	124	99.27	74.21	86.74	98.96	66.78	79.74	49.56	2.50	29.03	2110.37	0.73	0.01	1.37
3:15:00 AM	3:30:00 AM	23	92	121.66	84.17	102.92	118.69	75.14	92.02	57.19	1.61	39.13	3282.30	0.80	0.01	0.88
3:30:00 AM	3:45:00 AM	13	52	98.21	83.58	90.89	97.75	79.61	87.75	54.54	0.95	69.23	5537.62	0.72	0.01	0.52
3:45:00 AM	4:00:00 AM	23	92	95.54	76.02	85.78	93.36	72.03	81.32	50.54	1.82	39.13	2900.58	0.79	0.01	0.99
4:00:00 AM	4:15:00 AM	15	60	93.91	81.85	87.88	93.89	77.25	84.76	52.68	1.14	60.00	4635.71	0.77	0.01	0.62
4:15:00 AM	4:30:00 AM	27	108	83.27	75.88	79.57	82.97	69.02	75.35	46.83	2.31	33.33	2289.62	0.77	0.01	1.26
4:30:00 AM	4:45:00 AM	30	120	110.09	85.85	97.97	109.34	76.29	89.87	55.86	2.15	30.00	2457.69	0.69	0.01	1.17
4:45:00 AM	5:00:00 AM	20	80	72.93	76.11	74.52	72.93	67.82	70.28	43.68	1.83	45.00	2882.97	0.78	0.01	1.00
5:00:00 AM	5:15:00 AM	15	60	98.69	86.37	92.53	95.37	81.54	87.91	54.64	1.10	60.00	4808.16	0.82	0.01	0.60
5:15:00 AM	5:30:00 AM	18	72	0.00	77.75	38.87	0.00	72.14	36.07	22.42	3.21	50.00	1644.06	0.89	0.02	1.75

Figure 3-5: Occupancy calculation

Also, the peak hour factor (PHF), spacing, and headways are found for relationship purposes. The formula used to find the PHF, Spacing, and headways are as follows:

$$Headway = \frac{3600}{Flow\ Rate}$$

$$Spacing = \frac{5280}{Density}$$

$$Peak\ Hour\ Factor\ (PHF) = \frac{Hourly\ Volume}{Maximum\ Rate\ of\ Flow}$$

Finding the relative flows of each vehicle type during the congested day is the final step in the completion of the process of analyzing the congested day. These relative flows will subsequently be utilized in the PTV VISSIM as vehicle input relative flows. To arrive at these relative flows, simply divide the volume of a particular traffic count by the overall volume of traffic. On a congested day, the overall volume count of all sorts of vehicles reached 23,747, and along with this, the volumes of all types of vehicles are found separately. After that, the relative flows of each of the different types of vehicles are calculated. These findings are demonstrated in the Table 3-3 below.

Table 3-3: Relative flow of Vehicles

Vehicle type	Relative flow
Car	0.92749
2-axle	0.018444
3-axle	0.005559
4-axle	0.005095
5-axle	0.001053
6-axle	0.002737
Bus	0.017139
Hiace	0.022487

3.3.3. Characterization of data

To further segment the data to discover the timing that will later have to be compared with the simulated data, that was produced, following the calibration of PTV VISSIM. Therefore, a window of time consisting of three hours will be chosen on the 22nd of December 2019, which will be consisting of the three consecutive busiest hours of the day. The process was done step by step until the most congested three hours are obtained.

Initially, the volume of each of the 24 hours divided into one hour is computed, and then the analysis is started. A chart is constructed with time on the x-axis and volume on the y-axis. Following that, it was examined by the naked eye. This may be visually verified by looking at figure 3-6, which shows that the latter part of the graph has a comparatively higher volume of traffic than the beginning part of the day.

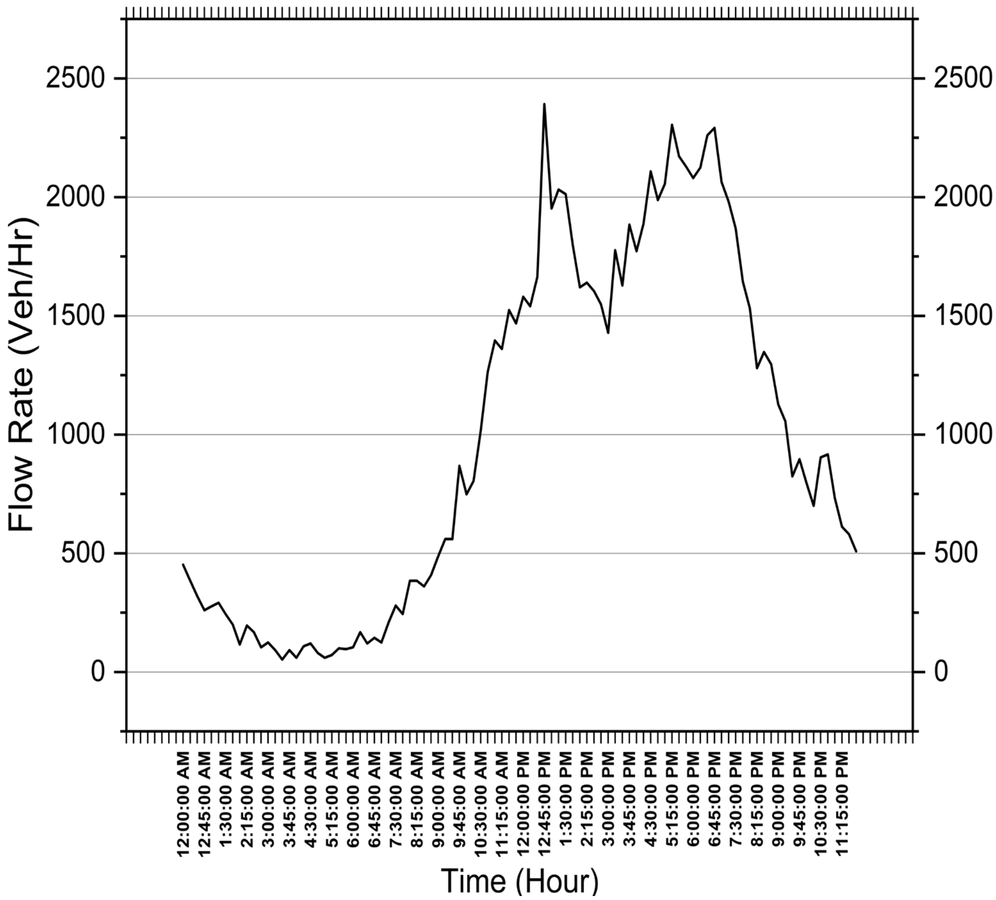

Figure 3-6: 24 hours flow rate graph

The time that is often employed for morning and evening rush hours is now being utilized for the process of dividing the day into the morning and the evening. The peak hours of the morning and evening each take up a total of seven hours. The timing for the morning is considered to be from 9 AM to 4 PM, while the timing for the evening is considered to be from 4 PM to 11 PM. These timings were chosen because they were able to accommodate the majority of the day's peak volumes, which was a factor in selecting the most congested hours of the day.

After this, the number of automobiles on the road from nine in the morning until four in the afternoon was added up to determine the total amount of automobiles on the road during the morning commute, and the total came to be 10,039 Vehicles. The volume of traffic that is experienced from four in the afternoon until eleven at night is referred to as evening hour traffic. And the final tally was 11,351 automobiles. These statistics make it abundantly evident that the volume during the evening hours of the day is significantly higher in comparison to the volume during the morning hours. To provide a visual representation of the fact that the evening portion of the day sees a higher volume and results in a lower average speed of traffic in comparison to the morning timing, a chart for average speed is also generated separately for the morning and evening times. This can be verified by figure 3-7 below.

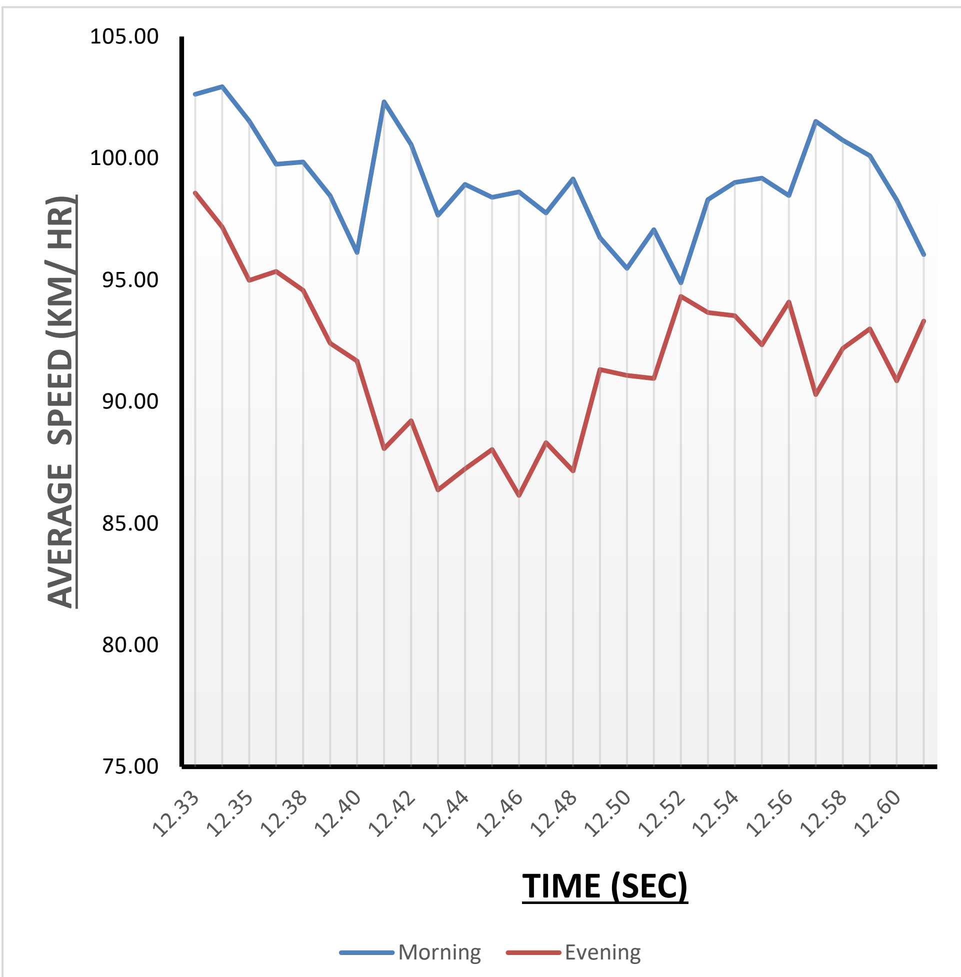

Figure 3-7: Average Speed based on Morning and Evening Timing

The following phase, which comes after dividing the day into morning and evening hours and determining that the evening is the most crowded part of the day, is to choose the hours that will be required for the subsequent step, which involves the calibration of PTV VISSIM. For this aim, the evening timing hours from four in the afternoon to eleven at night are monitored to determine which hours experience the highest volume of traffic (Table 3-4). The choice of three consecutive hours was made since any more than that would result in an overestimation, while any less than that would not produce accurate data. To determine which three hours, have the most congestion, a computation is performed every three hours. And by looking at it, it was revealed that the most crowded three hours of the evening time of the day on the 22nd of December 2019, are from five to eight o'clock in the evening.

Table 3-4: Volume of Traffic for 3 hours in the Evening Hours

FROM	TO	VOLUME
4:00:00 PM	7:00:00 PM	6193
5:00:00 PM	8:00:00 PM	6243
6:00:00 PM	9:00:00 PM	5442
7:00:00 PM	10:00:00 PM	4229
8:00:00 PM	11:00:00 PM	3169

3.4. Modeling in PTV VISSIM

3.4.1. Model Framework

Following the completion of the data analysis, the subsequent phase was the development of the model. Since the data set did not contain any information regarding the entrance or exit ramps. Therefore, the model will need to be created in PTV VISSIM at the location where there is no ramp inclusion in the model. As a result, the initial stage of the design process for the model consisted of selecting a place that was situated away from any entrance or exit ramps that might be nearby the model.

Therefore, to accomplish this goal, the PTV VISSIM must initially have its map files loaded. After then, the M-1 is magnified on the map and checked from its beginning to its conclusion to pinpoint the locations on it where there are either no or very few ramp sections. The model that was developed is a portion of the motorway that is 7.7 kilometers long and straight with fewer turns, for increased speed. The model is constructed on the portion of the highway that is facing southward, and it consists of three lanes that are connected via several connectors that are located near the curves. When modeling the model in PTV VISSIM, there are a total of 10 links utilized, and these connections are joined together by a total of 9 connectors.

3.4.2. Vehicle Input

The subsequent phase, which follows the placement of the model's framework, is to input the automobiles into the model. Cars, Buses, and Hiaces along with 2, 3, 4, 5, and 6-axle trucks are the types of vehicles that are represented in the data set. The PTV VISSIM comes with a pre-built vehicle composition that includes a variety of different types of vehicles, such as cars, HGVs, buses, and trams, as well as men, women, bike men, and bike women. It is important to develop models that correlate to the data collection. Therefore, to make the vehicle composition, a new vehicle composition from scratch using vehicle types that correspond to those that are typically found moving on the interstate.

Now to make the vehicle type, firstly the vehicle 2D/3D models are altered according to the vehicles available in the data set. Here, there are limited default vehicles 2D/3D models integrated with PTV VISSIM. So, from the PTV VISSIM Website, a pre-made vehicle 2D/3D model file is downloaded and then opened in PTV VISSIM. Now a total number of 5 cars type that generally scenes in Pakistan is selected while three small length cars are also selected along with them. 2 bus types are selected as a model from the file while two 2-axle trucks are selected. For Hiaces, three of the 2D models of it were selected. As for as 3,4,5,6 axle trucks are concerned they were not present in the preset 2D/3D models' folder, so they had to be made manually by merging two of the 2D/3D models. These can be seen in figure 3-8 and figure 3-9 which are provided below. By requirements of the Pakistani road network, two types of models are selected for every type of vehicle with 2,3,4,5, or 6 axles.

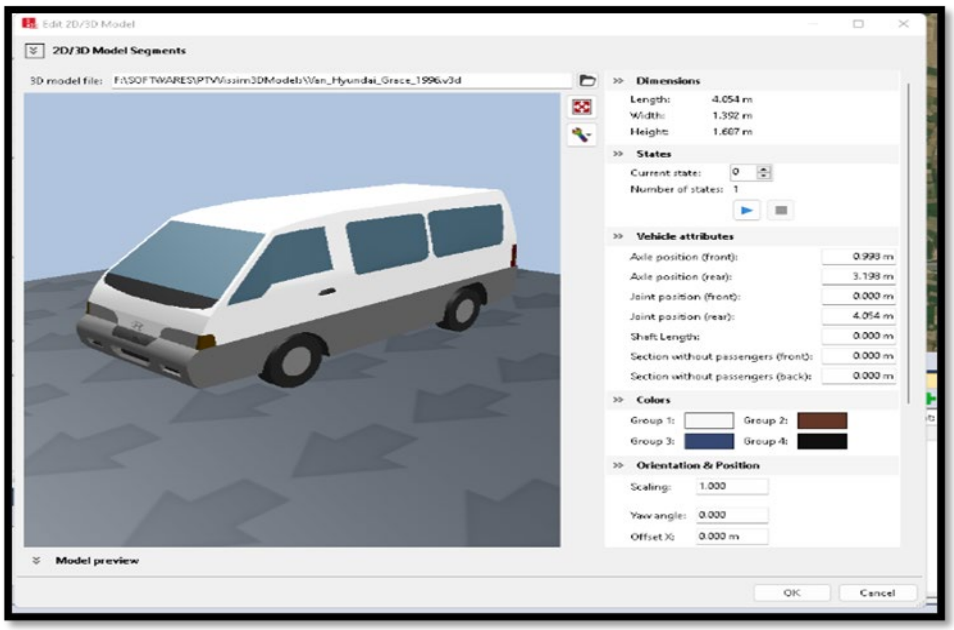

Figure 3-8: Hiace 3D Model

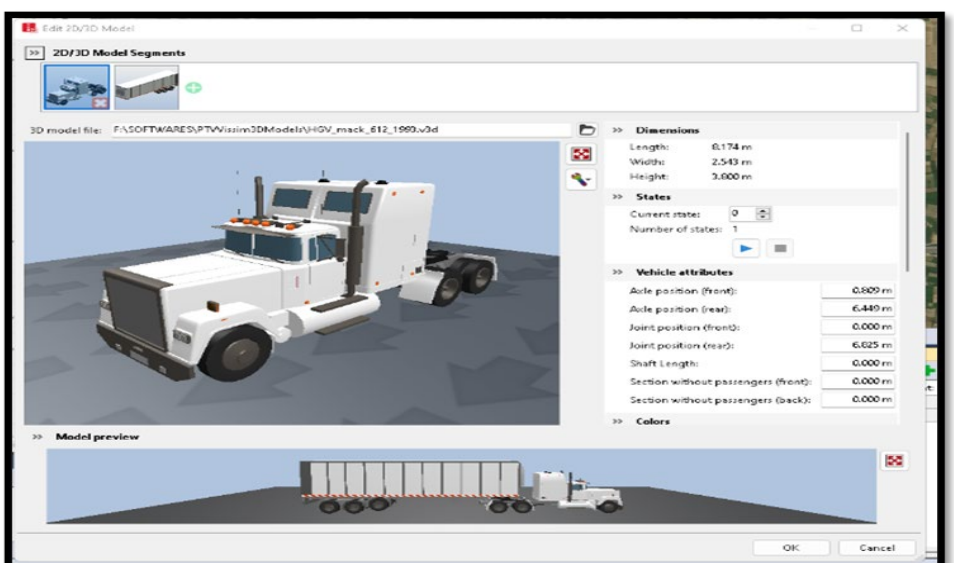

Figure 3-9: 6-Axle truck 3D Model

After then, all of these vehicles are separated into three different vehicle classes, which are cars, buses, and Heavy Goods Vehicles (HGV). Both passenger vehicles and compact automobiles are considered to be under the umbrella of the car category, whereas only buses are considered to fall within the bus class. In addition to that, under the category of heavy Goods vehicles (HGVs), trucks with 2, 3, 4, 5, and 6 axles are included.

Next, in the traffic section of PTV VISSIM, the vehicle composition is compiled under the new name M-1. The vehicle kinds that are included in this compilation are Cars, Buses, Hiace, Small Cars, and Trucks with 2, 3, 4, 5, and 6 Axles.

In addition, the relative flow of real field data, which was exhibited earlier in table 3-3, is inserted in the vehicle composition relative flow column. This is illustrated in figure 3-10 below.

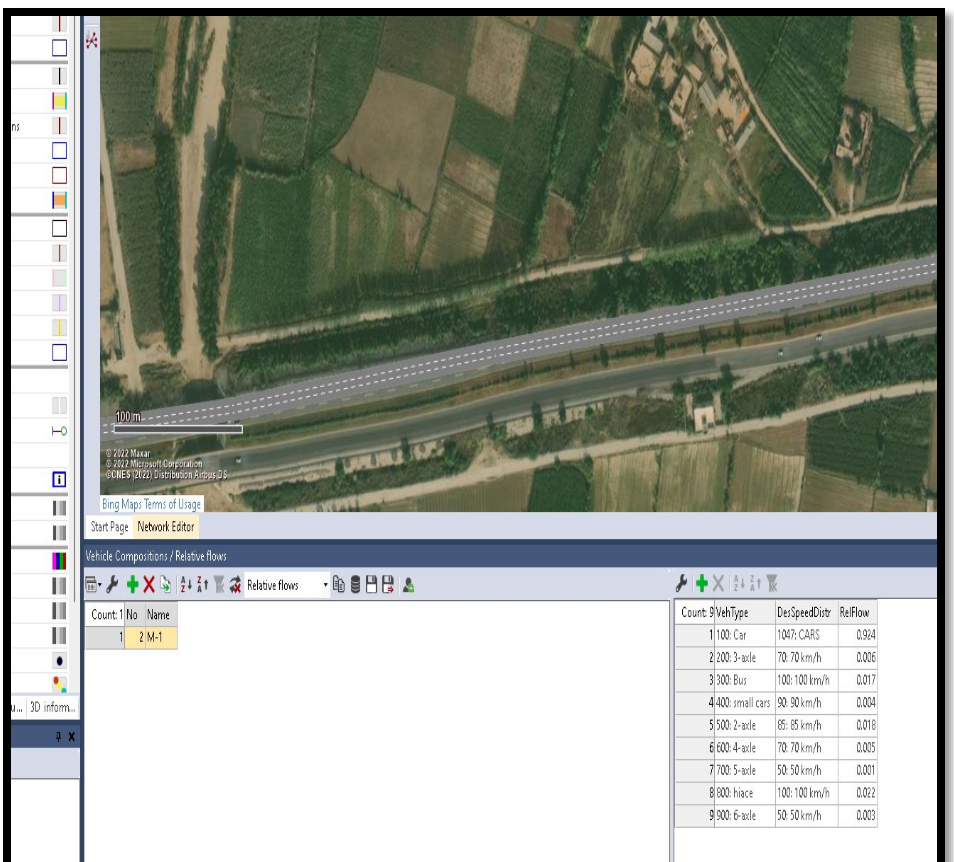

Figure 3-10: Vehicles composition and relative flows

For calibration, the volume data from the real data set must be input into the PTV VISSIM for the vehicle volume input to properly calibrate the simulation. However, before it can be inputted, the volume data for the three hours that were previously chosen must first be divided into time intervals. This is done so that the time interval in PTV VISSIM can be made according to the data, and the data can then be inputted with the volume that corresponds to the real data time interval volume. The data on volume from 5:00 PM to 8:00 PM is broken down into 10-minute intervals of time.

Therefore, while using PTV VISSIM, a time interval is set with a warm period that begins at 0 seconds to 900 seconds at the start and then after the 10 mints interval periods, collectively as 3 hours. The volume type in PTV VISSIM is kept "Exact" for the 3-hour intervals of the real data that is inputted in PTV VISSIM, while it is kept "Stochastic" during the initial warm-up phase run. This is done so that the model can represent real-world circumstances more precisely. In this instance, the warm period is provided to maintain as close an analogy as possible between the conditions of the real field and those of the simulation run.

3.5. PTV VISSIM Calibration

3.5.1. Microscopic traffic simulation modeling tools

The lane-changing model and the car-following model are the two primary core models that make up a microscopic traffic simulation tool. The car-following model specifies how a single vehicle in the simulation interacts with vehicles in front of it, or how the intended speed should be selected in free flow if there are no vehicles in front of the vehicle. The lane-changing model determines whether or not a lane change should occur and how the vehicle should react in that circumstance. The fundamental core models that are utilized in the various microscopic traffic simulation tools are diverse from one another.

The lane-changing model determines whether or not the vehicle should behave differently if a lane-change situation arises. The fundamental core models that are applied differ from one traffic simulation tool to the next on a microscopic level.

The car-following model constitutes the other primary component of a microscopic traffic simulation instrument. In their comprehensive historical examination, Brackstone and McDonald provide a summary of several car-following models (1999). One of the first car-following models was developed in the 1950s as part of research conducted by General Motors. This research led to the creation of the GHR model, which was given its name in honor of the original authors, Gazis, Herman, and Rothery. Since its initial publication in the 1950s, the model has undergone numerous iterations of expansion and improvement thanks to the work of a wide variety of contributors over the years. One type of model is known as a stimulus-response model, and one such model is the GHR model. In the case of the GHR, the stimulus is the vehicle's speed, the difference in speed between the vehicle and its leader, and the space headway between the vehicle and its leader. As a response to this stimulus, the vehicle will accelerate.

Another category of the model is known as the safe distance model, which is also known as the collision avoidance model. In this model, the notion is that drivers should keep a safe distance between themselves and the vehicles in front of them to prevent accidents. One of the most well-known iterations of a model for determining an appropriate safe distance is the one that Gipps (1981) proposed. According to Brackstone and McDonald (1999), the primary benefit of using this model is the realism of the model, which is achieved as a result of the directly quantifiable model parameters. However, there are also a lot of assumptions that may be questionable, such as the premise that a driver only considers one leader and does not look further ahead while adjusting the safe distance between themselves and the leader in front of them.

In psycho-physical models, also known as action point models, thresholds are used below which it is anticipated that drivers will change their behavior. The thresholds are determined by both speed and location in relation to one another. The driver adjusts their speed based on how they perceive the gap in speed that exists between themselves and the car in front of them. To accomplish this, one approach is to assume that a vehicle calculates the difference in speed between itself and the vehicle in front of it based on the change in the perceived size of the car in front of it. When the relative speed can no longer be seen, the speed modification will be based on differences in the spacing between the objects. The calibration of the thresholds and individual elements has not been successful, even though Brackstone and McDonald (1999) state that this model is considered to be the one that best represents typical driving behavior. Because of this, the authors are implying that it is difficult to demonstrate both the model's usefulness and its realistic accuracy. The authors Wiedemann and Reiter (1992) and Fritzsche offer the psychophysical models that have received the most attention and use (1994).

There is a wide variety of software for simulating traffic, both commercial and open source, and each of these tools has its own set of advantages and disadvantages. The most well-known technologies have often been developed over several years, and they have undergone ongoing improvement and adaptation to accommodate new types of traffic behaviors. These microscopic traffic simulation tools include PTV VISSIM, MITSIM, Paramics, Aimsun, and SUMO. Some of the most prevalent microscopic traffic simulation tools are described in Table 3-5 along with the model's origin and the car-following model employed.

Table 3-5: Microsimulation Tools and their Car-following Models

SIMULATION TOOLS	CAR-FOLLOWING MODEL
VISSIM	Wiedemann and Reiter Model (1992)
MITSIM	GHR Model
Paramics	Fritzsche Model (1994)
Aimsun	Gipps Model (1981)
SUMO	Krauss model (1997)

PTV VISSIM is employed as a microsimulation tool in this study work, and its car-following model, which is known as Wiedemann 99[23], is used as the car-following model. PTV VISSIM was conceived by the German software developer PTV AG. PTV VISSIM is the most advanced multimodal traffic simulation program in the world, and it digitally reproduces the patterns of traffic generated by all types of road users. PTV VISSIM is an application that analyses and improves the functionality of traffic infrastructure, and it is relied on by traffic planners and engineers all around the world. The judgments that are made regarding traffic planning are based on the results that are established from the software. These decisions handle the difficulties that are presented by road traffic, such as congestion and emissions.

3.5.2. Simulations settings

To calibrate the GEH model, first of all, simulation settings need to be conducted[24]. This involves establishing the time period, which requires converting 3 hours to seconds, which results in 10300 seconds. The resolution of the simulation is maintained at ten-time steps for every simulation second. The value 10 is used in the factor category, and it is used to keep the simulation speed constant. In addition, for each scenario, a total of ten simulations are carried out, each with an increasing number of random seeds at predetermined intervals. It is carried out as a consequence of the fact that PTV VISSIM generates distinct outcomes following distinct simulations and values for random seeds. It follows from this that a total of ten simulations are run for each of the situations, and the outcomes of the calculations based on these results are based on the average value of these ten simulations. In the simulation scenario, ten runs of the simulation have been chosen.

After the simulation settings, the next step is to configure the evaluation, during which multiple types of simulation run outcomes are picked for the result list. These characteristics consist of simulation runs, the results of network performance (for Vehicles), the results of Data collection, the results of Delay, the results of Links, and the results of the vehicle's travel time. After this, under the heading of measurement defined in the evaluation tab, the data collecting points are added. The configuration of the simulation will be finished after this.

3.5.3. Calibration Method Employed

The term "calibration" refers to the process of matching actual and simulated data sets by modifying numerous variables, including driver behavior, speed distribution, lane-changing behavior, car following behaviors, headway, lane-changing distance, etc. The technique calibration is carried out on a model to determine whether the model is capable of accurately representing the real field data on the simulation software. After the calibration of the software has been finished and checked, subsequent work and scenarios on the model can be carried out. The benefit of calibrating is that it enables one to conduct all simulations in the simulation software as if they were being conducted on the field without incurring any additional costs. Additionally, the simulations can be run and checked an unlimited number of times until the results that are required are reached. Because of all of this, the process of microsimulation is completely risk-free and also does not require any resources that will be required in case of real field testing.

In most cases, the majority of the microscopic model calibration is accomplished by comparing any of the speed profile or volume profiles of the real field data with the simulation run data of the microsimulation model. This is done to ensure that the model is accurately representing the real field conditions. However, the matching of the data is carried out with the assistance of threshold formulas and values. The following is a list of some of the methods that are used for the evaluation of calibration processes:

- GEH statistical technique (It works by comparing the volume profiles of the actual field data with those of the simulated data sets.)
- The speed difference between the simulated and actual data should be within 8 kilometers per hour for at least 85 percent of the sites, which is the threshold value for speed profile matching between the real field data and

the simulated data[25].

- Visual verification was accomplished with the assistance of charts and graphs in Microsoft Excel.

The "Geoffrey E. Havers (GEH) statistical technique" is, out of all the other statistical processes, the one that is most commonly employed and also the one that is considered to be the most appropriate evaluation method by the vast majority of researchers. The following is the formula that is used for GEH:

$$GEH = \sqrt{\frac{2(V_{Field} - V_{Model})^2}{V_{Field} + V_{Model}}}$$

Here, the volume of Vehicles based on the actual data is denoted by V_{Field}, whereas the volume determined by the simulation model is denoted by V_{Model}.

The threshold value that establishes whether or not the calibration procedure was successful is derived from the degree to which the volume data of the real field data and the simulated model data are comparable. To faithfully reproduce the actual flow data conditions in the field, the rule mandates that at least 85 percent of the simulated traffic volume at every site must have GEH values of 5 or lower. GEH values in the range of 0-5 communicate the message that the simulated volume is closely associated with the observed traffic volume, while those in the range of 5-10 convey the message that there is a good match between the modeled and observed traffic volume. However, if the value is larger than ten at any one point or location, the model is thought to have a poor calibration, and it has to be reviewed for mistakes and maybe a change in the values of its calibration parameters.

3.5.4. Calibration Procedure

There are now various algorithms that have been devised by researchers that accomplish the automatic calibration of the values. Some examples of these algorithms include the genetic algorithm and others. However, the tried-and-true method of calibrating known as the "trial and error" approach is utilized in this investigation. In this approach, the values of the relevant parameters are adjusted very slightly before the outcomes of the process are examined. If the intended level of results is not achieved, the process will be redone several times over until the desired level of results is achieved. Therefore, adjusting the values of the parameters is essential to get an accurate result.

The driver's behavior, speed distribution, lane-changing behavior, automobile following behaviors, headway, and lane-changing distance were the characteristics that required the greatest alterations for the calibration process. These were the parameters that were the most popular and crucial.

The simulation was run many times, and the values were tweaked following the results of each run using the approach of trial and error until the desired results were attained. The calibration process was evaluated for all three points that were explained earlier i.e., GEH value, Speed difference, and visual clarification.

To begin, there were some adjustments made to the driver behavior element of the PTV VISSIM model. In this part of the process, adjustments were made to the "following" section, specifically the values for "Look Ahead" and "Look Back." After this, adjustments are made in the tab of the driver behavior that is designated for the automobile following model. The car-following model used in PTV VISSIM is controlled by a total of ten coefficients in Wiedemann 99. These factors include: CC0, CC1, CC2, CC3, CC4, CC5, CC6, CC7, CC8 and CC9. The CC0, CC1, and CC2 coefficients of the factors are used for most of the calibration work. The only variables that were altered in this study were the values of CC1 (Gap time Distribution), which went from having a value of 0.9 seconds to 0.5 seconds, and CC9 (Acceleration at 80 kilometers per hour), where the values went from having a value of 1.5 meters per second to 5.5 meters per second. The variations in the values held by other coefficients are not of considerable concern because they had a negligible impact on the accomplishment of the goals that were set. There is a setting in the car-following model tab called "following behavior dependent on vehicle class of leading vehicle." In this setting, the vehicle class "cars" are given an increased acceleration of one hundred percent. After making this modification, the lane change behavior tab will be the location of the subsequent change in driver behavior. In this instance, the values for the "safety distance reduction factor" are adjusted from 0.6 to 0.10. All these modifications may be checked in Table 3-6 below:

Table 3-6: Driver behavior Modifications

PARAMETERS	DEFAULT VALUES	MODIFIED VALUES
Look Ahead Distance	250 m	350 m
Look Back Distance	150 m	250 m
CC1 (Gap Time Distribution)	0.9 sec	0.5 sec
CC9(Acceleration at 80 Km/hr.)	1.5 m/sec^2	5.5 m/sec^2
Behavior Depending on leading class	nil	Car Class
Safety Distance Reduction Factor	0.6	0.10

The next modification was made to the feature of PTV VISSIM known as the “Desired Speed Distribution”. During the process of calibrating the software, it is one of the most crucial factors that is taken into consideration, as even a minor variation in the numbers could result in a significant difference in the results section. The default speed distribution in VISSIM begins at 5 kilometers per hour and steadily climbs up to 140 kilometers per hour. In addition to this, there are a few additional distributions as well. However, to obtain the speed distribution that corresponds to the actual field data, it is necessary to add several different speed distributions according to the vehicle type in the data. Therefore, with the assistance of the cumulative probability distribution (CPROB), the desired speed distributions for each of the vehicle types that were included in the data were prepared in excel. The procedure that was modified consisted of first of all distributing the speed values of the particular vehicle type according to their ascending order, and then using the cumulative probability formula. Following that, a chart is constructed to verify the S-curve. Figure 3-11 provides an illustration of these S-curves for reference:

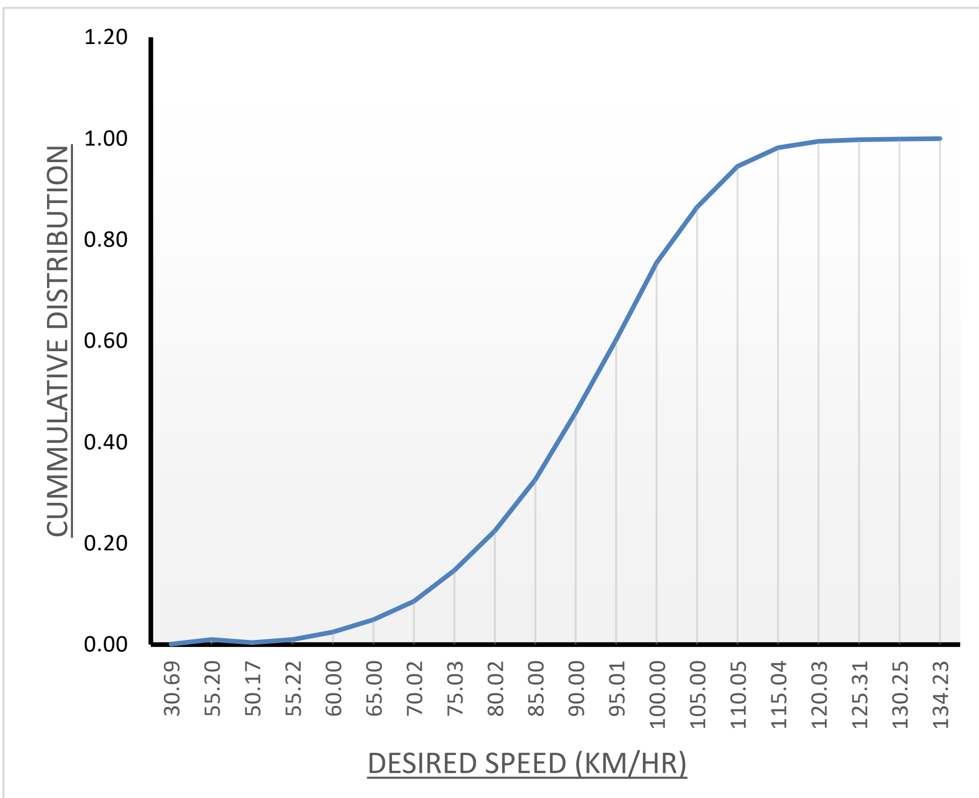

Figure 3-11: CPROB for Cars in Excel

This was done for all of the different types of vehicles, including automobiles, buses, Hiace, and trucks with 2, 3, 4, 5, and 6 axles.

After that, the required S-curve for each vehicle was entered into the PTV VISSIM as a new desired speed distribution category. This can be illustrated in figure 3-12 below for Cars (Vehicle type):

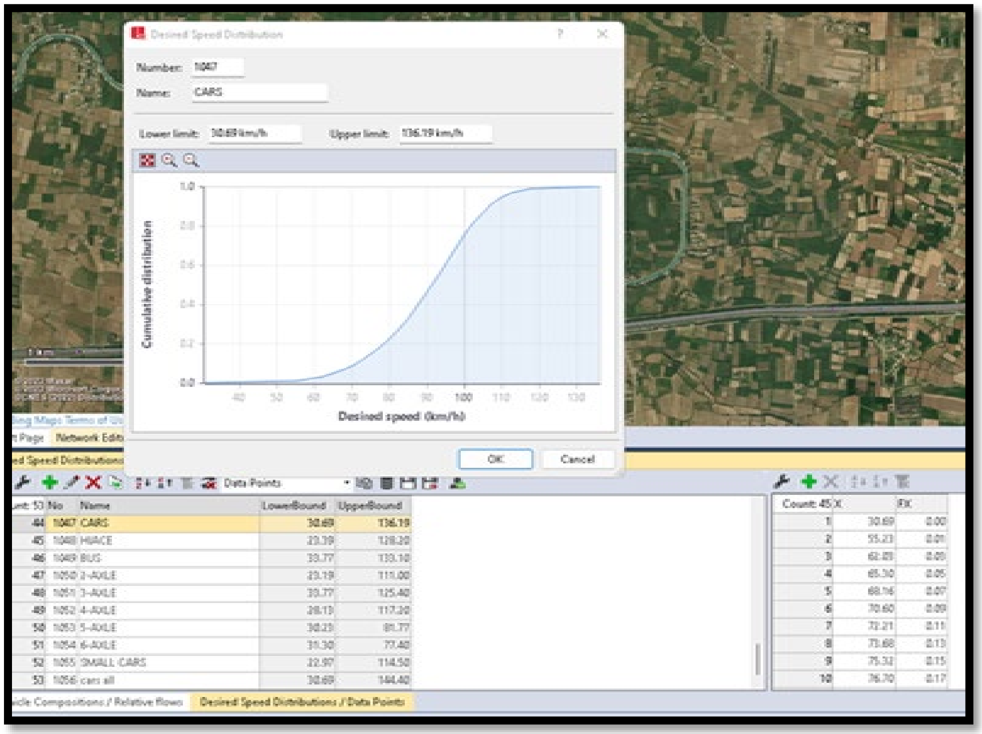

Figure 3-12: Desire Speed Distributions for Cars in PTV VISSIM

The results of the calibration process will be presented in the next section.

3.5.5. Evaluation of Calibration Process

To begin the process of GEH calibration evaluation, an Excel table must first be crafted. This table contains the following columns: real field volume flow rate data column, simulation run volume flow rate data column, GEH values column, and then passing rate column. The passing rate column must check the GEH values column and provide a result of the passing rate expressed as a percentage. After forming the excel table, the values of the volume flow rate for three hours that were chosen earlier from the data collected in the real field are fed into the column.

Before making any adjustments to any of the parameters, simulation runs are carried out using the parameters' default values from VISSIM's data. After that, the results of the simulation are inputted into Excel, which is then used to determine the GEH values as well as the passing rate. In the end, the passing percentage was only 45 percent, which is significantly lower than the required threshold figure of 85 percent.

After this, adjustments were made to the driver behavior first, as shown in table 6, and subsequently to the intended speed distribution. the results that were acquired are input into the Excel table. Now, the percentage of passing the GEH test at each of the time intervals selected is determined.

Following the determination of passing rates and GEH values, the results of this study showed a passing rate of one hundred percent, which is sufficient to meet the GEH formula requirement of a passing rate of more than eighty-five percent. In addition, the value of GEH was below the threshold value of less than 5 GEH values throughout every one of the time intervals, as indicated by the equation of GEH that was presented earlier. This can be illustrated by table 3-7 below:

Table 3-7: Calibration Result

time interval		Flow Rate (real)	Flow Rate (simulated)	GEH	Passing rate
5:00:00 PM	5:10:00 PM	1986	1890	0.8903	100.00
5:10:00 PM	5:20:00 PM	2220	2178	0.8956	
5:20:00 PM	5:30:00 PM	2328	2304	0.4987	
5:30:00 PM	5:40:00 PM	2388	2250	2.8657	
5:40:00 PM	5:50:00 PM	2058	2232	3.7570	
5:50:00 PM	6:00:00 PM	1986	2088	2.2600	
6:00:00 PM	6:10:00 PM	2082	2040	0.9251	
6:10:00 PM	6:20:00 PM	2010	1902	2.4420	
6:20:00 PM	6:30:00 PM	2208	2250	0.8896	
6:30:00 PM	6:40:00 PM	2148	2094	1.1725	
6:40:00 PM	6:50:00 PM	2352	2286	1.3705	
6:50:00 PM	7:00:00 PM	2418	2436	0.3654	
7:00:00 PM	7:10:00 PM	1938	2154	4.7753	
7:10:00 PM	7:20:00 PM	1968	1788	4.1536	
7:20:00 PM	7:30:00 PM	2046	2022	0.5322	
7:30:00 PM	7:40:00 PM	1926	1980	1.2219	
7:40:00 PM	7:50:00 PM	1740	1932	4.4809	
7:50:00 PM	8:00:00 PM	1602	1692	2.2177	

Within the confines of the PTV VISSIM, the calibration of the PTV VISSIM was carried out. It was accomplished with the "User specified attribute" feature of the PTV VISSIM software. Definitions were added with the help of formulae in this section, which is part of the user-defined attribute settings. The formula in question was a floating-point value, and it was designed to search for the solution after the simulation had been completed. It would check every link volume with the added real field volume column. If the value was lower than 5, the GEH check specified attribute would return the "YES" result; otherwise, it would return the "NO" result. In this case, every single GEH check came back with a positive result. The GEH calibration in PTV VISSIM can be demonstrated with the help of the following figure 3-13:

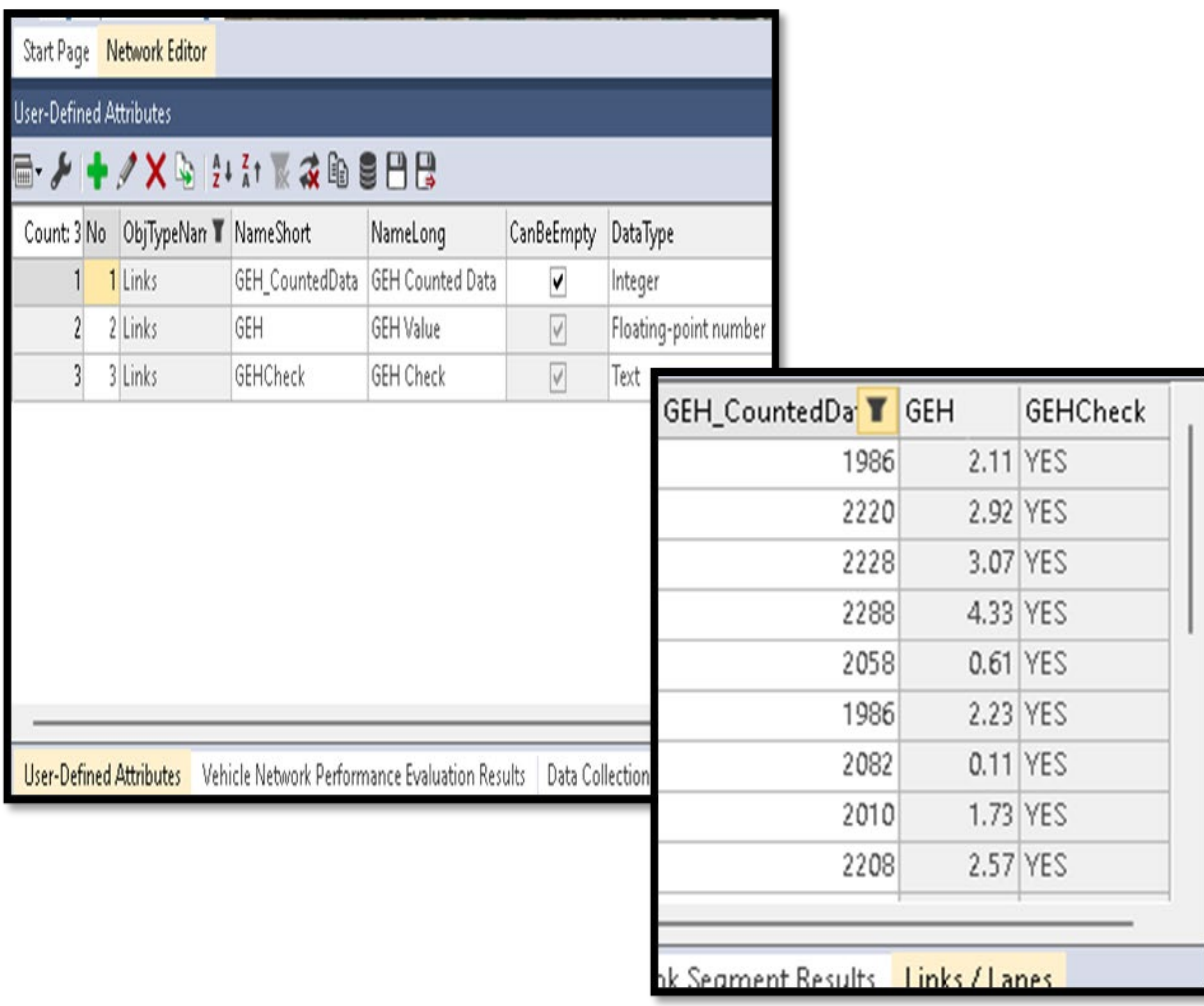

Figure 3-13: GEH Calibration in PTV VISSIM

The following step in the process of evaluating that the calibration was successful involved determining whether or not the average speed difference between the simulated data and the real field was less than 8 kilometers per hour. In this investigation, the discrepancy between the average speeds obtained from real data and those obtained from simulations is well within the allowable range of being less than 8 kilometers per hour for every location point.

The visual confirmation is the last step that must be completed before the calibration evaluation can be considered complete. On a chart, the calibration is considered to have been successful if the volume data of both the real field data and the simulated data correspond with one another and move near one another throughout the chart. The following figure 3-14 can verify that both sets of volume data are very near together.

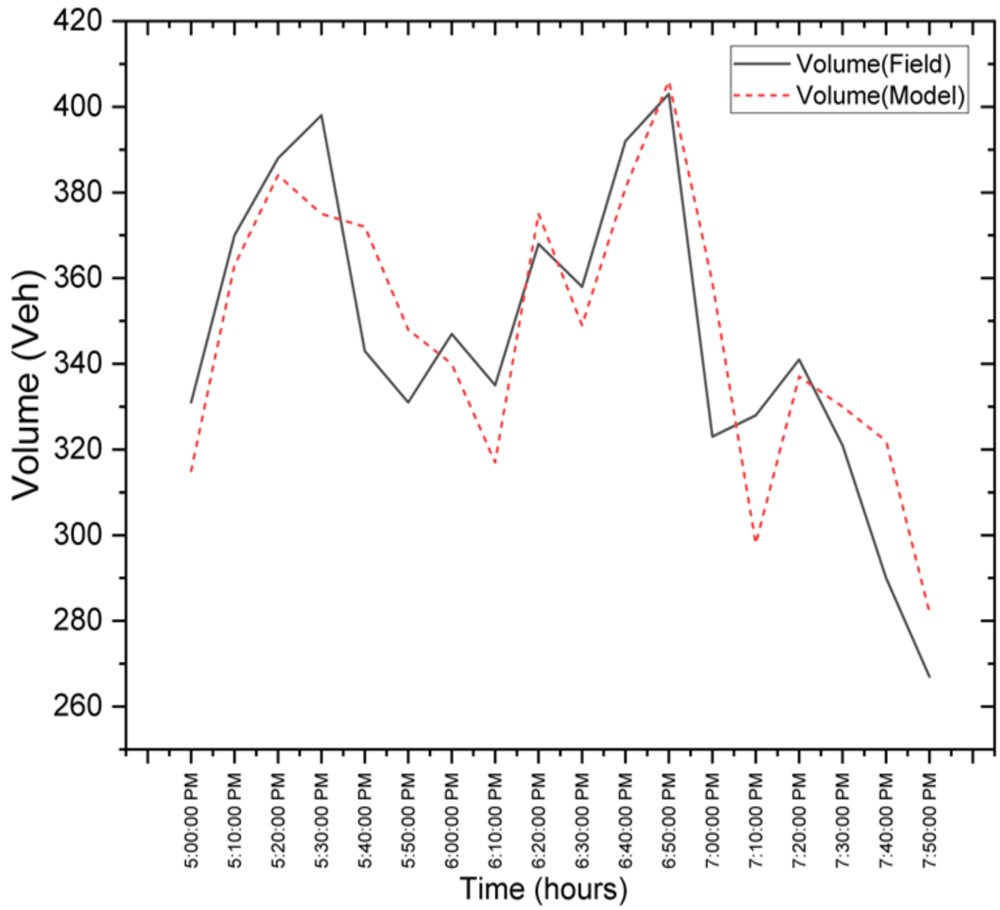

Figure 3-14: Visual Verification of the calibration success of PTV VISSIM

3.6. Validation of Calibrated Model

After the GEH formula has been applied to the results of the PTV VISSIM calibration evaluation. Following this, the calibrated model is validated utilizing the statistical analysis procedures (methods for measuring the model's goodness of fit)[26]. These approaches consist of:

- Root Mean Square Error (RMSE)
- Mean Absolute Normalized Error (MANE).

A standard deviation of the prediction errors, also known as residuals, is referred to as the root mean square error (RMSE). The residuals provide a measurement of how far away the data points are from the regression line. The root-mean-square error (RMSE) is a statistic that evaluates how dispersed these residuals are. As a result, it indicates the degree to which the data are concentrated around the line of best fit. It is a widespread practice in the fields of climatology, forecasting, and regression analysis to use root mean square error as a verification tool for experimental data. While on the other hand, the MANE, also known as the Normalized Mean Absolute Error (NMAE), or the Coefficient of Variation of MAE, is a measure that is used to make it easier to compare the MAE of datasets that have various scales. The instrument for evaluating the performance of the model employs the mean of the measured data to provide a standard for normalization.

The data from the calibrated model's evaluations are subjected to a process of validation, during which various parameters, such as Travel Time, average occupancy, and average speed, are examined.

3.6.1. Validation Procedure

Creating a table in Microsoft Excel is the first step in doing the validation method through RMSE and MANE. There is a column in this table that has been built for the real field data for the specified factor, such as the average occupancy, average speed, or travel time. This column exists for each of the set time intervals of ten minutes of the three hours of selected data. The simulated model results for that factor are going to be made in the next column. Following this step, the residual is determined by first subtracting the model data from the real field data, then dividing the result by the real field data. After this, the RMSE is determined by applying the following formula to the data:

$$RMSE = \left(\sqrt{\frac{(Sum\ of\ Residuals)^2}{N}} \right) \times 100$$

In this case, the number of observations is denoted by the letter N

To proceed with the calculation of MANE, a column for the absolute values of the residuals must first be created. After that, these absolute residual values are normalized using a formula, and it also gets its column to store its results. Last but not least, the MANE can be computed by dividing these normalized residual values by the total number of observations value. It can be verified from the following equation:

$$MANE = \frac{Normalized\ Residuals}{N}$$

The computation and validation process has now been finished successfully. Now, these statistical methods are the common methods of calculating error in an experiment; therefore, the general assumption will be to keep the error as little as possible for the sake of an experiment's correctness and validity. However, there is a general rule of thumb that is utilized most of the time for checking calculations and also for keeping track of errors while staying within the permissible range of tolerance. The following are the rules that apply:

- The value of the mistakes should be less than 5 percent, as recommended by the general thumb guidelines that are utilized for these statistical processes, namely RMSE and MANE. If there is an amount of error in the validation process that is less than 5 percent, then the process is said to be successful.

The results of the validation process for the metrics, such as average occupancy, average speed, and journey time, can be found in the following table 3-8.

Table 3-8: Validation of Calibrated Model Results

PARAMETERS	RMSE (%)	MANE (%)
Occupancy	4.25	2.7
Average Speed	2.9	2.7
Travel time	4.6	4.3

The fact that the values for all three of the parameters that were chosen for the validation procedure fall within a range that is considered acceptable are shown by the percentage of error that is displayed in the Table 3-8 above. So, therefore it demonstrates that the calibrated model has been successfully validated.

3.7. Scenarios Generation

It is preferable to compare the traffic conditions that involve the variable speed limit phenomenon with those that do not involve the variable speed limit phenomenon to achieve a more accurate interpretation of the Variable Speed Limit (VSL) as it relates to the alleviation of the problem of traffic congestion. As a result, it was determined to contrast the traffic scenario that was executed using VSL with a scenario that did not use VSL while maintaining the same conditions[27].

Now, as was discussed before, the VSL congestion mitigation strategy works most effectively in a transportation environment that is already crowded. To simulate a situation in which there is heavy vehicular traffic congestion, an artificial scenario is produced in PTV VISSIM. In accordance with this scenario, during the simulation, one of the lanes will be blocked off to vehicle traffic, which will represent the occurrence of an accident. In this way, an artificially congested environment in PTV VISSIM is produced to test the performance of the VSL in mitigating the congestion issue[28].

The condition is generated by utilizing a method known as the parking lot method, in which a parking lot is placed on the required position of the motorway, and it is then activated during the precise time interval while the simulation is being conducted. And a connector is used to reroute the traffic onto the appropriate lanes at the appropriate times. By doing things in this manner, the desired outcome of the creation of fake congestion on the highway is accomplished in the simulation model.

In order to simulate an artificially congested state using the microsimulation model, many adjustments need to be made to the model. In this research, the creation of an incident is desired at the innermost lane of the motorway. So, therefore parking lot is placed on it. After that, a partial connector is created that connects the three lanes before the parking lot with the two lanes excluding the parking lot lane, and acts to converge traffic to these two lanes. And then finally these two lanes diverged into three lanes again. This segment of the road is only going to be accessible once the parking lot has been opened to vehicles during the predetermined window of time in which an incident needs to be reported. The following phase, which comes after the placement of the link for the partial rerouting of the traffic, is to make a partial vehicle route. After it has been placed successfully, the next step is to position a parking route in front of the parking lot. This parking route will become active at the specified time interval and will direct a vehicle to halt in the parking lot that was constructed previously.

Now that some adjustments to the model have been made, the next step that needs to be done is to choose the time interval during which the occurrence of the incident needs to take place[29]. To accomplish this goal, it was planned to create an incident period that would occur for 1 hour. Now, within the time span of the three hours, the incident one-hour period was chosen to take place during the second hour of the three hours. It was chosen because it is hoped to have a true field condition reached before the occurrence, and as a result, the first hour is set aside to enable the simulation to obtain its natural flow. This was the primary factor in its selection. The incident hours will begin immediately after that. Throughout the hour-long incident, the time gap between openings of the parking lot was kept at 100 seconds at the start of the incident duration period. The section of the route in question was rerouted so that it now travels via a connector that is in use only between the hours of 630 and 990.

During the simulation runs, there is a constraint that must be dealt with. It was because after the incident takes place[30], there is frequently no open way for the vehicles that are confined in the parking lot lane of the simulation model, and at the same time, the vehicles traveling on the other lanes travel at a high speed, so a long queue is generated in the lane that has been closed to traffic in the simulation model. This was the cause of the problem. Now since the waiting period that occurs before the diffusion feature in VISSIM is set at sixty seconds by default. Therefore, the car is removed from the network after one minute. So, the disadvantage of this comes that, even though a bigger volume of traffic is delivered into the network it takes advantage of the VSL's ability to produce the best outcomes in very congested traffic conditions. But here, after a waiting time of 1 minute, the vehicles are removed from the network one by one. The original goal of the incident, which was to generate congestion in the first place, will not be achieved as a result of this in the end. Therefore, the diffusion period needs to be modified in the PTV VISSIM, so that the vehicle has sufficient time to exit the queue before it is removed from the network. This is necessary to prevent the car from being disconnected from the network. As a result, a dispersion time of 180 seconds, which is equivalent to three minutes, has been decided upon to provide a more accurate representation of the real-time scenario during the time of the incident. This configuration is carried out under the lane change behavior tab of the driver behavior feature found in PTV VISSIM. The incident generation can be illustrated in figure 3-15 below.

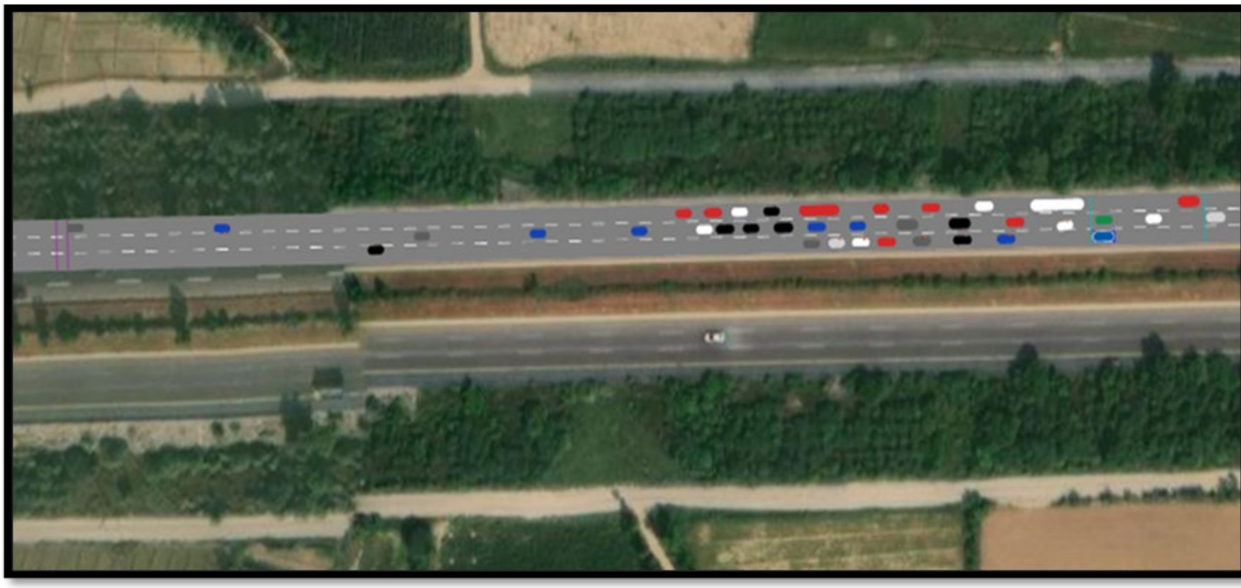

Figure 3-15: Incident generation in PTV VISSIM

3.8. VISSIM COM Interface

Following the stage setting for the incident, the introduction of variable speed limit (VSL) codes into the microsimulation program is the next step. These codes allow for the speed limit of the network to be managed in a manner that is responsive to changes in requirements. The PTV VISSIM program has a feature known as the COM interface, which enables the software to be interpreted by any third-party software. The majority of the time, coding applications such as VisVAP, MATLAB, PYTHON, and other programming languages are utilized as the third-party software that connects up with PTV VISSIM over the COM interface. The variable speed limit algorithm can be understood in PTV VISSIM by utilizing the VISSIM COM interface, which enables the implementation of the variable speed limit, which can then be used to comprehend the VSL algorithm.

Now, to incorporate an algorithm into the network, it is necessary to know the present status of the network, which should include the volume of traffic, the average speed, and the occupancy. The utilization of detectors is by far the most prevalent approach to gathering information regarding a network in any microsimulation software[31]. PTV VISSIM represents the detectors as network objects on its links in its simulations. However, for placing the detector on the links, the software asks for a way to communicate with the detector and record the output of the detector measurements. Therefore, a signal controller is necessary for the transmission of the detector's output for a network detector to convey the speed restriction and routing decisions.

Users of PTV VISSIM have access to a wide range of signal controllers, including VAP, fixed time, ramp metering controller, external, ring barrier controller, and others. The fixed kind of controller is the one that is most commonly used for traffic signal controllers, whereas ramp metering controllers are the ones that are used for ramp control signs. Also, the majority of external addons are controlled via the VISSIM COM interface by the VAP or external controllers.

In this research, a signal controller of the type VAP is used, and it receives input from VisVAP in the form of an external add-on-built control algorithm logic file. VisVAP is an easy-to-use application that can define the program logic of VAP signal controllers in the form of a flow chart. It is also known as the Flow Chart Editor for VAP. The VisVAP programming software was designed to simplify the process of writing code by incorporating graphically controlled switches and settings. It is supplementary software that is included with the PTV VISSIM software package.

In this study, a detector for each vehicle class, such as automobiles, buses, and HGVs, is defined in each lane of the microsimulation model. A signal controller in the form of a VAP logic file is created in VisVAP before the detectors are placed, as was previously stated. This file is added in the signal controller tab of PTV VISSIM. At this point, the signal controller is provided with a copy of the logic file that was created earlier in VisVAP, as well as a dummy file for the interstage file. interstage files are required so that even if the main logic file becomes corrupted for whatever reason, the controller can continue to function by making use of the interstage files. Additionally, the ".dll" file associated with the software is picked. Now that the detectors can be placed as a temporary version of the signal controller is being developed. It will undergo a further change soon, so the word temporary is used for it. So, now detectors can be placed in the model. The location of the detectors is moved around in a randomized fashion along the micro-simulation model until a position that provides a suitable fit for the detector placement can be found. According to the findings, the detector that was installed at the beginning of the network produced more positive readings. The following is a list of some of the advantages:

- It is no longer necessary to go to the trouble of putting detectors at arbitrary locations.
- It does its job, which is to count the number of vehicles at the beginning, and it does this independently of any incident that may occur.
- Even if the decrease in the delay is not the most beneficial aspect of the arrangements of the detectors that are presented, the fact that it contributes to a smooth flow at a constant speed and occupancy is demonstrated in the results section.

After determining the location where the detectors should be installed, step one is complete. After that, the features tab of PTV VISSIM is navigated to select the detectors. Separate detectors are installed on each lane of the model for the Cars and HGV classes of vehicles. If detectors for the HGV class are triggered, buses will also be included in this group.

An additional link object is added onto the model and made a part of the detectors in addition to the detectors themselves. It is the desired speed decision. After the vehicles have traveled through the detectors, the desired speed decision determines the speeds at which they continue their journey. It is positioned on all three of the simulation model's lanes at the same time. The recommended speed limit for automobiles is set at 130 kilometers per hour (kmph), while the speed limit for buses and heavy goods vehicles (HGV) is set at 120 and 100 kilometers per hour, respectively. The below figures 3-16 and 3-17 show the setting of detectors and desired speed limit.

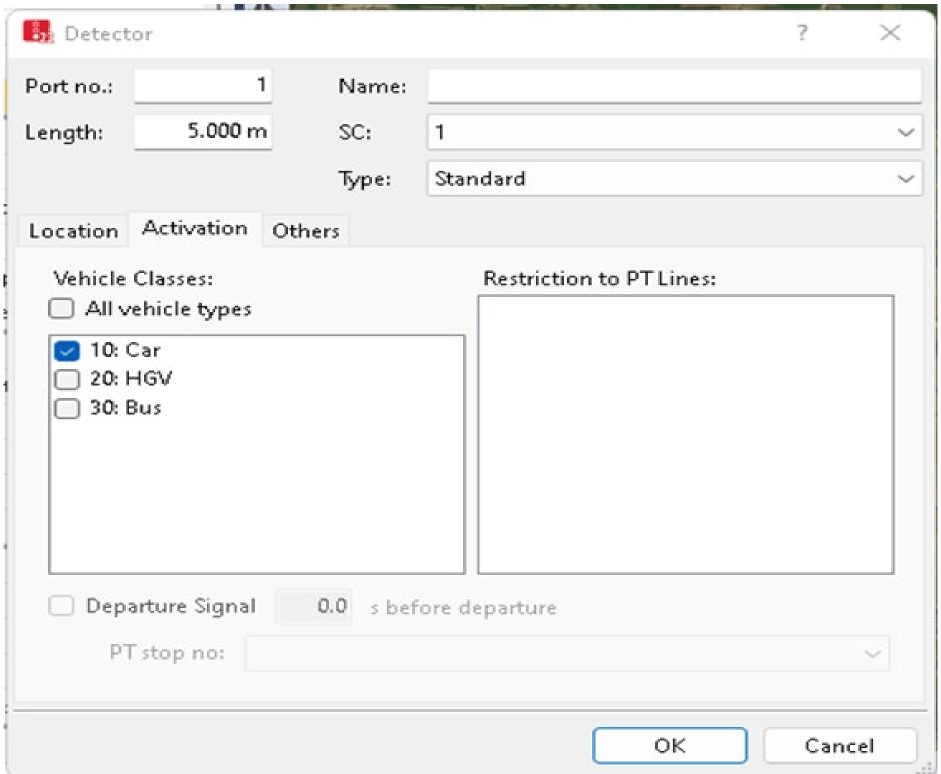

Figure 3-16: Detectors settings

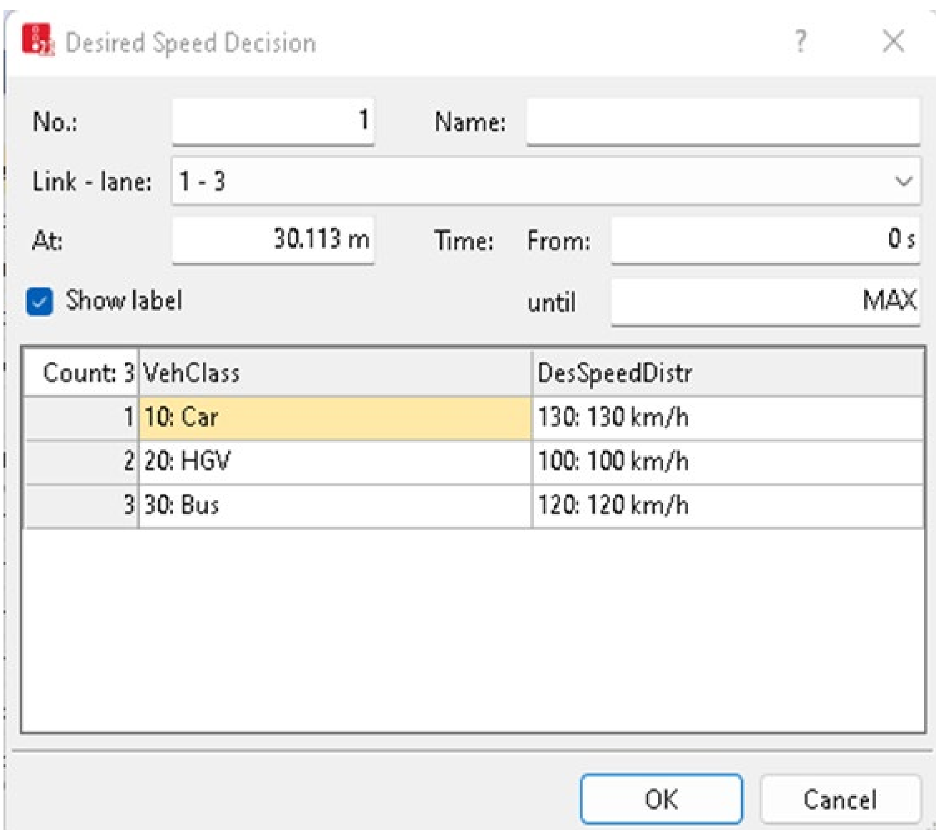

Figure 3-17: Desired Speed Decision settings

3.9. VSL Control Algorithm

To implement the Coding switch, the PTV VISSIM ATM model is implemented through VisVAP. This model is also used as a reference for the VSL algorithm modified for Pakistani traffic conditions. Within VisVAP, there is a plethora of control settings that may be configured for a variety of circumstances, such as for converting the shoulder lane into a regular lane if there is a greater volume of traffic, for the layout of the traffic lights, or for the variable speed restriction that was employed for this study. The VisVAP software allows for an almost infinite number of additional customizations to be performed.

The PTV VISSIM ATM model database was utilized as the source for the algorithm design reference model. Following that, it was modified appropriately, including the detector switches and the way it will respond to alterations in speed and volume. The control algorithm is nothing more than a control switch that allows the detectors in VISSIM to set the speed limits and decisions based on parameters. The speed limit of 130 kilometers per hour for cars and 120 kilometers per hour for buses and heavy goods vehicles (HGV) via the logic file is set through the control algorithm. This limit is implemented via the desired speed decision link objects that were already incorporated into the simulation model previously. After then, the detectors in each lane for each vehicle class (cars, trucks, and buses) measure the volume of traffic as well as the average speed over one full minute. After that, the resulting average speed is compared to the speed limit that had been established beforehand (a speed limit of 130 kilometers per hour for automobiles, and a speed limit of 120 kilometers per hour for buses and HGV). The volume is compared to the parameters that have been set, and the required switch is engaged if it is found that the average speed is lower than the speed limit.

This study's parameter definition considers the conversion factor from the heavy-duty vehicles and bus units to the passenger vehicle unit (PCU). In this context, the PCU factor for HGVs and buses is represented by the value 2. The smoothing factor is the next parameter that is utilized. This element helps to make the traffic adjustments and switching that take place in a short amount of time go more smoothly. As control switches, the following three types of variable speed restrictions have been selected for use in this investigation: 80 km/h, 100 km/h, and 120 km/h. In VisVAP, these control switches are also utilized as parameters under the names QON120, QON80, QON80, QOFF120, QOFF100, and Q0FF80 respectively. In this parameter section, the PCU factor and the smoothing factors are held constant during the entire trial-and-error method algorithm design process to achieve the best possible results. Variations, on the other hand, are carried out in the QONx and QOFFx sections.

These parameters were changed through a process of trial and error until an algorithm that produced the best possible match was found. After all of the settings have been configured, a VAP logic file is generated and then given to the signal controller in PTV VISSIM software so that it can be simulated. Because VISSIM produces unique findings for each simulation, a total of ten simulations were run to calculate the typical results of the different situations. Also, until an algorithm yielding the best results is discovered, a large number of simulations with varying sets of control parameters and VAP files are executed.

Before being able to zero down on the algorithm that delivered the best outcomes, it was necessary to go through a significant amount of testing and analysis. Throughout the process of trying things out and seeing what works, many observations were made. It was observed that limiting the parameter input from VisVAP to smaller values results in a significant delay when the simulation's incident period occurs but at a constant and slower rate. Even though the parameter input with greater values caused a shorter delay, speed and occupancy remained the same as they would have been in the absence of an occurrence. This was the most important of these observations. A breakdown of the algorithm structure that yielded an overall best results can be found in Figure 3-18 below.

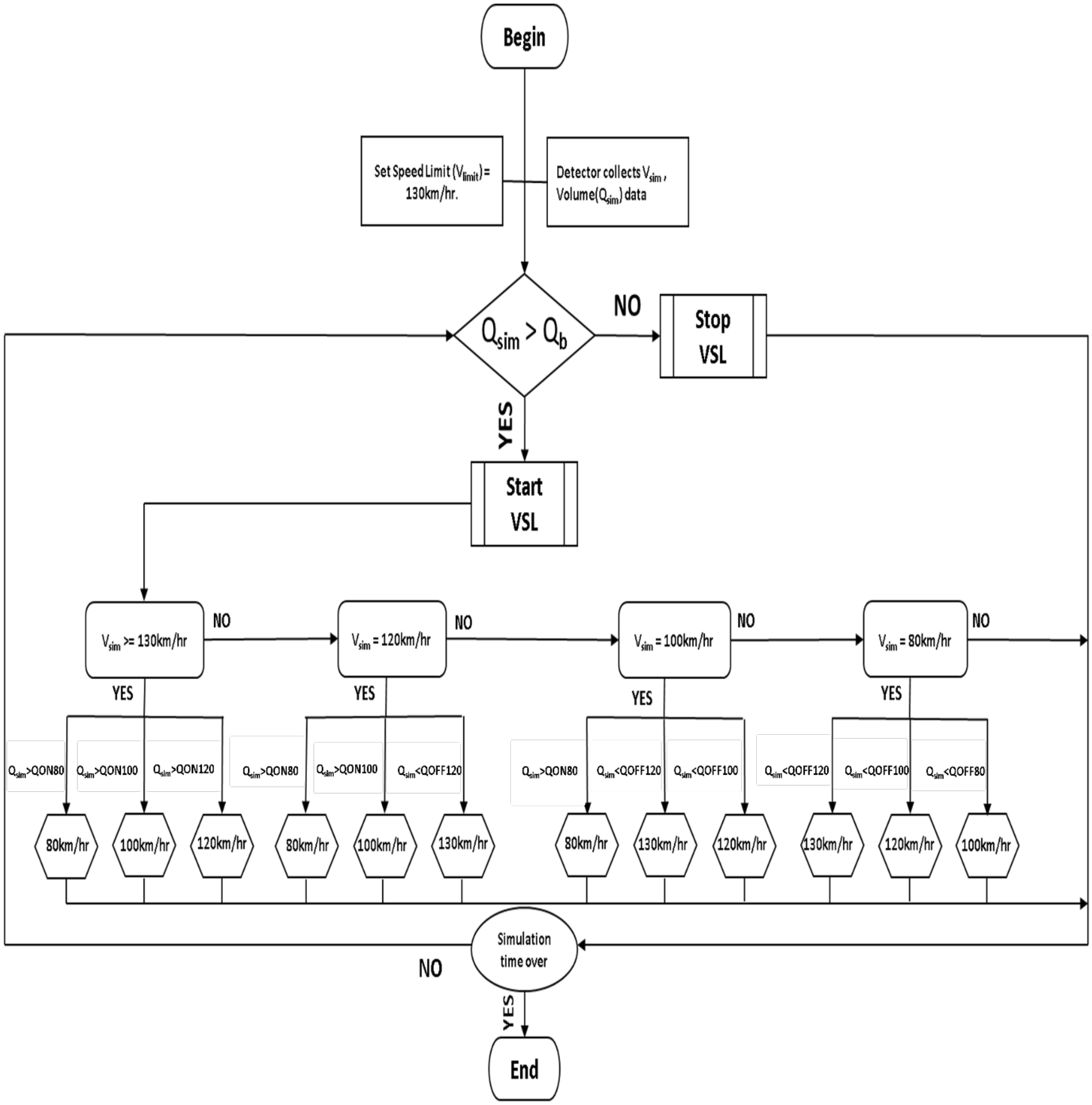

Figure 3-18: Control Algorithm Design

In this algorithm, Qb is the input for the Volume in the VISSIM, Q_{sim} is the flow rate counted by the detector, and QONx and QOFFx are the inputs for the parameters from VisVAP.

Table 3-9 provides a visual representation of the algorithmic settings that contributed to the highest possible performance.

Table 3-9: control parameters for the desired algorithm

PARAMETERS	Gen	Comments
F	2	PCU-conversion factor for HGV
TI	1	Time interval for Data collection(min)
ALPHA	0.5	Smoothing factor
QON120	5700	
QON100	6100	
QON80	6400	
QOFF120	5100	
QOFF100	5900	
QOFF80	6200	

CHAPTER 4: RESULTS AND DISCUSSION

4.1. General

In this section, VSL-implemented algorithm strategies are contrasted with those of other possible scenarios to provide a clearer understanding of the positive results and advantages produced by the VSL phenomenon. In the course of this investigation, three possible outcomes have been taken into consideration. Among these possible outcomes are:

- Scenario 1: No incident occurrence is included in the model, also no VSL logics are implemented.
- Scenario 2: Incident occurrence included in the model, but no VSL logics are implemented.
- Scenario 3: Incident occurrence included in the model, also VSL logics are implemented.

Following the selection of multiple situations, these three scenarios are put through a series of different tests to determine how they stack up against one another, and the findings are then presented in this result section. Additionally, the VSL-applied solutions can be found standing amid the other possible cases. As performance indicators for the outcomes of the VSL implementation, the variables of average Occupancy, Average Speed, Delay, and Total Travel Time have been chosen.

4.2. Scenario # 01: No Incident, No VSL

For the sake of constructing the other two situations, this scenario serves as a point of reference. Since this scenario does not include the incident, the effect of the accident on a traffic condition, in terms of Average occupancy, average speed, delay, and total travel time can be judged more clearly after comparing both scenarios together.

The calibrated model was applied to this situation; however, no incidence was accounted for by the model. The driving behavior desired speed distribution of vehicles, vehicle class, and other aspects of the driving experience are all maintained here in the same manner as they were in the calibrated model. On every lane, the data-collecting points are appended at an arbitrary point in time. Additionally, desirable speed decision link objects are being added, and the speed decision is being maintained as the desired speed distribution values for the vehicle classes.

The same amount of time that was used before the simulation was used during the simulation, which was three hours. In addition, the simulation parameters were left unchanged, and the assessment settings included the recording of specified values for the number of cars on connection, data for collecting places, and trip duration. To obtain an average result that will be more accurate than a single result of a simulation run, ten separate simulations are conducted on the model using a variety of random seeds. These random seeds are used to generate random outcomes.

In this particular case, the vehicle input is altered. Because the model has already been calibrated, there is no longer a requirement for actual volume data. As a result, the volume for every time interval has been adjusted to 5000 Vehicles. The exact volume type is maintained for each of the time intervals of 10 minutes that span all three hours; however, the stochastic volume type is preserved for use throughout the warm phase.

4.3. Scenario # 02: Incident Included, No VSL

The chaotic nature of the occurrence of the traffic conditions may be seen in this scenario since it is implied by the titles that the event described farther up is part of this scenario. It demonstrates the diabolical consequences that an incident has on the speed of vehicles and the delay they experience as a result. However, no VSL is being applied in this scenario as it was constructed only to explain the impact that the occurrence of any incident, such as an accident, construction work, adverse weather conditions, etc., has had on the existing traffic circumstances. As a result, one can gain a better understanding by analyzing the findings and determining whether or not a variable speed limit is a viable solution to the congestion that was caused by an occurrence.

In this situation as well, the calibrated model that was utilized in the earlier scenario is applied. While the simulation settings have been updated to include the event length time, the volume input has been maintained at the same value of 5000 as it was during the first scenario. The duration of the occurrence is maintained between the hours of 6:30 and 7:30 PM. In this scenario as well, a total of ten distinct simulation runs were carried out with different random seed values, and after that, the results that were averaged out were the ones that were used for comparison between the three scenarios.

In addition, the driving behavior category is where the adjustment to the diffusion time is made. The time has been increased from 60 seconds to 180 seconds. As was described before, this phase is required to be carried out to ensure that no vehicle can be removed from the simulation too soon, hence not preventing the formation of congestion.

4.4. Scenario # 03: Incident Included, VSL Included

Due to the inclusion of both the incident and the VSL in the model used for the microsimulation, the research was able to arrive at this verdict as the last possible outcome of the situation. This scenario determines whether or not the implementation of VSL in a traffic condition can aid in mitigating the challenges associated with congestion. Because prior studies have demonstrated, the fact that VSL conditions can help mitigate a traffic environment that is prone to congestion concerns. In this part of the process, conditions such as a scenario without VSL implementation and a scenario with VSL are often compared, and the outcomes are deduced from those comparisons. However, in the interest of better conforming to the results of this research is that this scenario incorporates the occurrence of an incident. The variable speed limit system is going to be put to the test by this occurrence, which will take place under these challenging traffic conditions. This will therefore actually aid to determine if the VSL system can perform equally better throughout the circumstances of a scenario without an accident occurring as well as a scenario with an accident occurrence.

In this situation, the calibrated model that was used previously is used, together with the same traffic behavior, intended speed distribution, and vehicle class as before. While the duration of the occurrence is factored into the simulation, the simulation settings have been kept unchanged. There is a total of ten runs of the simulation, each of which uses a different number for the random seed. For the sake of calibration, the genuine field data that was previously entered into the vehicle input has been replaced with a value of 5000 precise volume type.

Additionally, additional time is allowed for diffusion in this circumstance. This is because although the VSL scenario is supposed to prevent the effect of the occurrence of the incident, there is still a chance that it could result in a minor delay. As a result, the driver behavior component found in PTV VISSIM has incorporated a diffusion time of three minutes into the simulation.

In this case, the first step that must be completed is to position the detectors on the links in accordance with the criteria that were discussed before. However, for the detector to be placed onto the link and to function properly, a control switch in the form of a signal controller is required. As a result, the VAP file that contains the control algorithm is included within PTV VISSIM in the capacity of a signal controller thanks to VisVAP. After that, detectors are installed on each of the three lanes, together with the speed decision network objects that are desired.

Figure 3-18 and Table 3-9 each provide a visual representation of the control algorithm and the control parameters that this scenario employs.

4.5. Comparison Results Between Scenarios

In this section, we compare the VSL-implemented algorithm methods to the two Scenarios, which are "without incident" and "with the incident but without VSL." As performance indicators for the outcomes of the VSL implementation, the variables of Occupancy, Average Speed, Delay, and Total Travel Time have been chosen.

Since the time of the occurrence is estimated to have taken place between 6:30 and 7:30 PM, it is possible to make fairly unambiguous observations between those hours. It is important to bear in mind that there is no event participation in scenario 1, yet despite the occurrence of an incident, “scenario 3 (which includes VSL)” continues to run relatively identically in comparison to “scenario 1” for one hour.

After that, the values are entered into Microsoft Excel so that they may be compared through charts and tables. Following that, a comparison of various situations is carried out based on average occupancy, average speed, delay time, and journey time. Table 4-1 that follows presents a comparison of the outcomes of scenarios that include and do not include accidents regarding occupancy, speed, delay, and total travel time. After repeating the simulation ten times for each of the three outcomes and calculating their averages, we came to the following conclusion in table 4-1 below.

Table 4-1: Comparative results between Scenario 1, Scenario 2, and Scenario 3

Performance measure parameters	Without Incident, without VSL (Scenario 1)	With Incident, without VSL (Scenario 2)	With Incident, with VSL (Scenario 3)
Average Occupancy Rate (%)	19.98	21.70	20.57
Average Speed (Km/hr.)	114.25	107.08	111.85
Average Delay (Sec/Veh)	0.00	7.08	5.87
Total Average Travel time (Sec)	4462	4728	4604
Note: In this case, the total travel time is the amount of time that the vehicle spent in the model.			

It is possible to conclude from the data presented in the preceding table that when an incident is added to a network, there is, as might be anticipated, an upward trend in all of the performance parameters, including the average occupancy rate, average speed, average delay, and total travel time.

When Scenario 1 is used as a point of reference, there is an increase in average occupancy of 8.59 percent in the case of Scenario 2, whereas there is only an increase of 2.95 percent in the case of the VSL implemented scenario (scenario 3). Because of this, the average occupancy in situations with VSL applied is improved by a total of 65.56 percent compared to those without VSL (including the impact of incidents).

In the same vein, considering scenario 1 as a point of reference, scenario 2 causes a drop in average speed equal to 6.27 percent, whereas scenario 3 causes a drop in average speed equal to merely 2 percent. Because of this, there is a 66.58 percent gap between scenario 2 and scenario 3, using scenario 2 as a point of reference.

Since scenario 1 does not feature any incidents, it is impossible to use it as a point of reference for the average delay. Therefore, scenario 2 is used as the point of reference, and there has been a 17-percentage point reduction in the amount of delay that occurred. This can be considered an impressive achievement for VSL-implemented scenarios given that there is a delay reduction of about 2 seconds for every vehicle traveling in the VSL-integrated simulation model.

In conclusion, the travel time a vehicle spent in the network, the total average travel time is 1 hour and 14 minutes for Scenario 1, 1 hour and 19 minutes for Scenario 2, and 1 hour and 17 minutes for Scenario 3. When compared to scenario 1, which serves as a reference point, it reveals that there is an increase of five minutes or six percent in the case of scenario 2. In case scenario 3, there is an increase in total average travel time of three minutes, which is equivalent to an increase of three percent, when scenario 1 is used as a reference. This indicates a reduction in travel time of two minutes if VSL implementation scenarios are considered.

Below are the charts of the performance measures i.e., Average Occupancy, Average Speed, Average Delay, and Total Average Travel Time where all three scenarios are compared (Figure 4-1, Figure 4-2, Figure 4-3, and Figure 4-4).

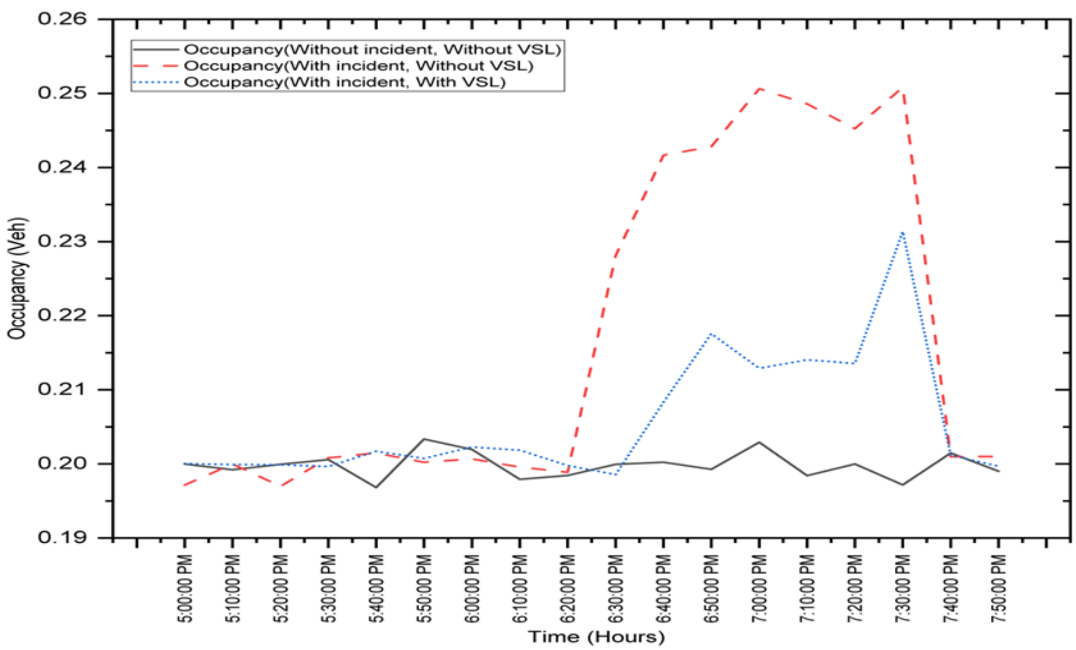

Figure 4-1: Average Occupancy Comparison of the 3 Scenarios

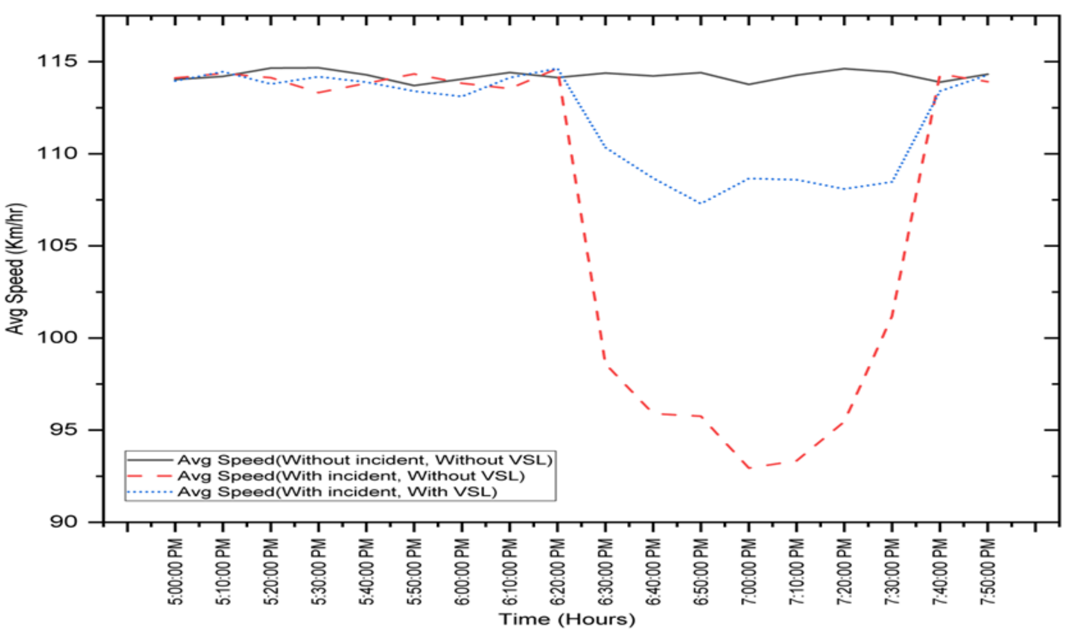

Figure 4-2: Average Speed Comparison of the 3 Scenarios

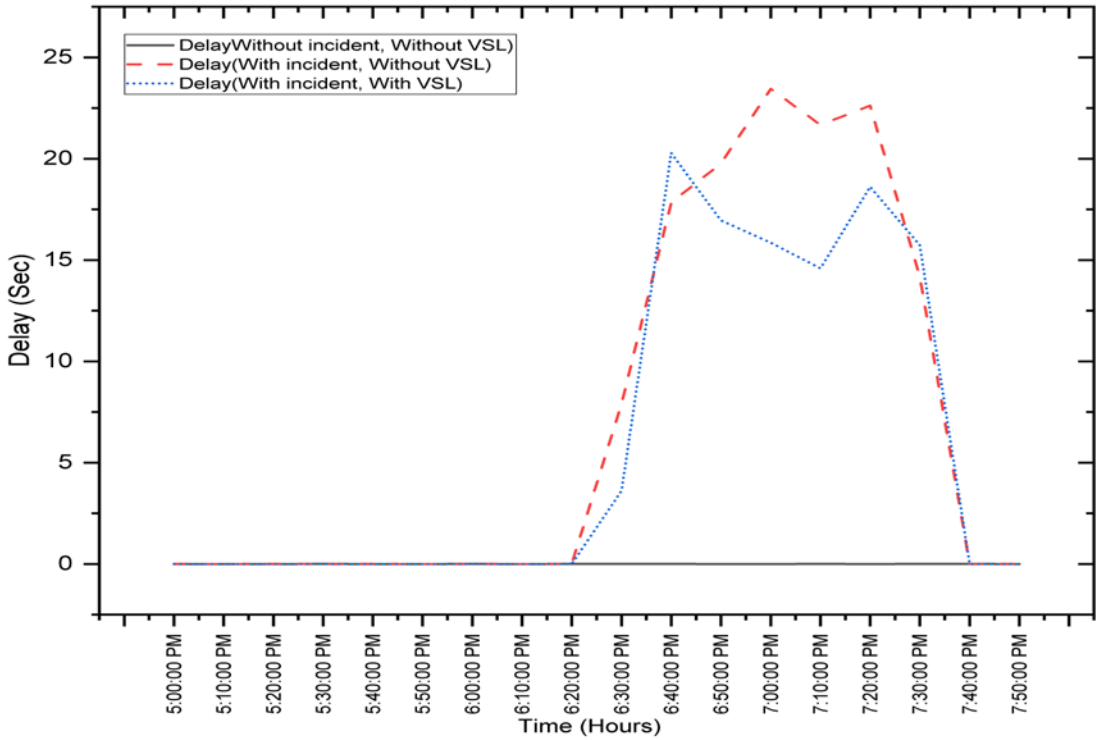

Figure 4-3: Total Delay Comparison between 3 Scenarios

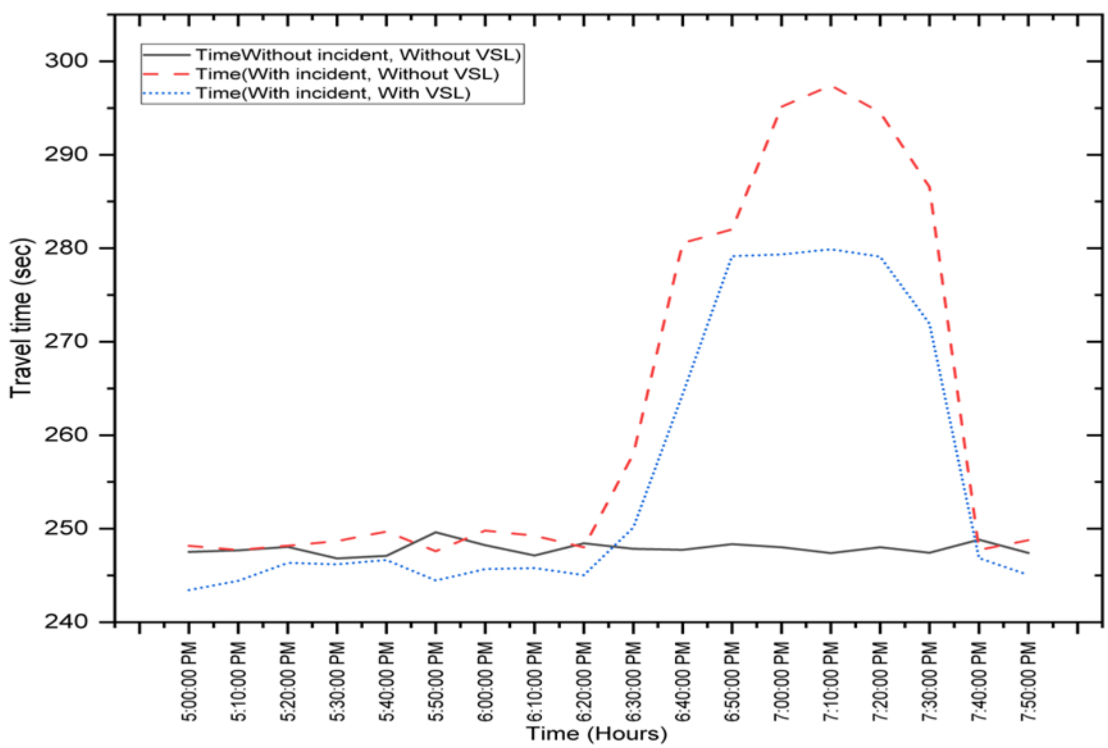

Figure 4-4: Average Travel Time Comparison between the 3 Scenarios

CHAPTER 5: CONCLUSION AND RECOMMENDATION(S)

5.1. Summary

To better comprehend the benefits and advantages brought about by the VSL phenomenon, the strategies of VSL-implemented algorithm are compared to those of other potential situations. Three alternative outcomes have been considered: no incident occurring and no VSL logics being applied, incident occurring and no VSL logics being applied and incident occurring and VSL logics being applied incident. These three scenarios are subjected to a series of tests to see how well they perform in comparison to one another, with the first scenario serving as a baseline. Average Occupancy, Average Speed, Delay, and Total Travel Time variables have been selected as performance indicators for the results of the VSL deployment. The driving experience is preserved in the same way as it was in the calibrated model, including the ideal speed distribution of the cars, vehicle class, and other driving-related factors. During these tests, the simulation parameters were left as were during calibration process, and the assessment settings called for the collection of specific values for the number of automobiles on the link, information about the locations where the data would be collected, and the length of the journey were modified. Ten different simulations of the model are performed using various random seeds in order to generate an average result that will be more accurate than a single result of a simulation run. The number of vehicles is changed to 5000, and the stochastic volume type is kept for usage during the warmup phase. As it is inferred by the titles that the incident detailed further up is part of this scenario, the chaotic character of the occurrence of the traffic circumstances may be observed in it. The prior scenario's calibrated model is used, and the simulation parameters have been changed to take the event duration time into account. The length of the event is kept between 6:30 and 7:30 PM. In order to compare the outcomes of the three situations, the findings that were averaged were utilized. The average occupancy in situations with VSL applied is improved by a total of 65.56 percent compared to those without VSL (including the impact of incidents). Scenario 1 does not feature any incidents, so it is impossible to use it as a point of reference for the average delay. Instead, scenario 2 is used as the point of reference, and there has been a 17-percentage point reduction in the amount of delay that occurred. This is an impressive achievement for VSL-implemented scenarios, as there is a delay reduction of about 2 seconds for every vehicle traveling in the VSL-integrated simulation model. The total average travel time for a vehicle spent in the network is 1 hour and 14 minutes, with scenario 2 having an increase of five minutes or six percent, while scenario 3 has an increase of three minutes. This indicates a reduction in travel time of two minutes if VSL implementation scenarios are considered.

5.2. Conclusions

This study offers a complete analysis of the effects of events on traffic flow conditions as well as the possible advantages of implementing VSL scenarios. The efficiency of minimizing the congestion that was caused by the incident is considered in this research article as the benefit of the implementing VSL system minimizing the congestion caused by these incidents. This research is also based on recovery from the incident through VSL system integration. According to the findings, the deployment of VSL led to improvements in all measurements of effectiveness criteria, including Average Occupancy, Average Speed, Average Delay, and Total Average Travel Time. This was the case regardless of the measure of effectiveness. In addition to this, the impact of an occurrence can be seen in terms of the delay, speed, and occupancy in scenario 2, and then its mitigation in scenario 3 is discussed.

In the course of this research, the compliance level was adjusted by changing the desired speed distribution in accordance with the conditions of the traffic in Pakistan, and this adjustment was kept throughout all of the simulations and scenarios. It is important to highlight that the compliance level is the proportion of drivers who follow traffic signals and signs based on the traffic circumstances, as determined by VSL. This is something that should be kept in mind. In addition, the algorithm that was presented in the study was developed while keeping the compliance level that was derived from data that was taken from the real world. According to the driving styles of Pakistani motorists, the findings therefore most correctly reflect the field conditions and compliance level in Pakistan. A sufficient compliance level by the pavement User will result in much superior VSL outcomes. This is true even though a compliance level of one hundred percent is never going to be achievable on a road.

In light of the data, one more conclusion that can be reached is that the VSL techniques do help in minimizing the consequences of congestion, but this benefit is restricted to situations in which there is an exceptionally high volume of traffic. This takes place as a consequence of the fact that the VSL shifts take place in reaction to variations in the volume and the speed of the vehicles. Therefore, when there is little traffic congestion, there is often not a large amount of change that takes place in terms of volume.

5.3. Future studies recommendations

The on-ramp and the off-ramp were not taken into consideration in the study since there was a shortage of data; however, studies will include the ramps and ramp metering in any future studies that are done. In addition, even though this research was conducted on a motorway that did not have an especially high level of congestion problems, future research will be conducted on highways or local road networks that do have higher levels of congestion, and this will make it possible to find additional VSL strategies. Along with it, in the research that will be carried out in the future, the occupancy factor will be included in the algorithm, joining other parameters like speed and volume.

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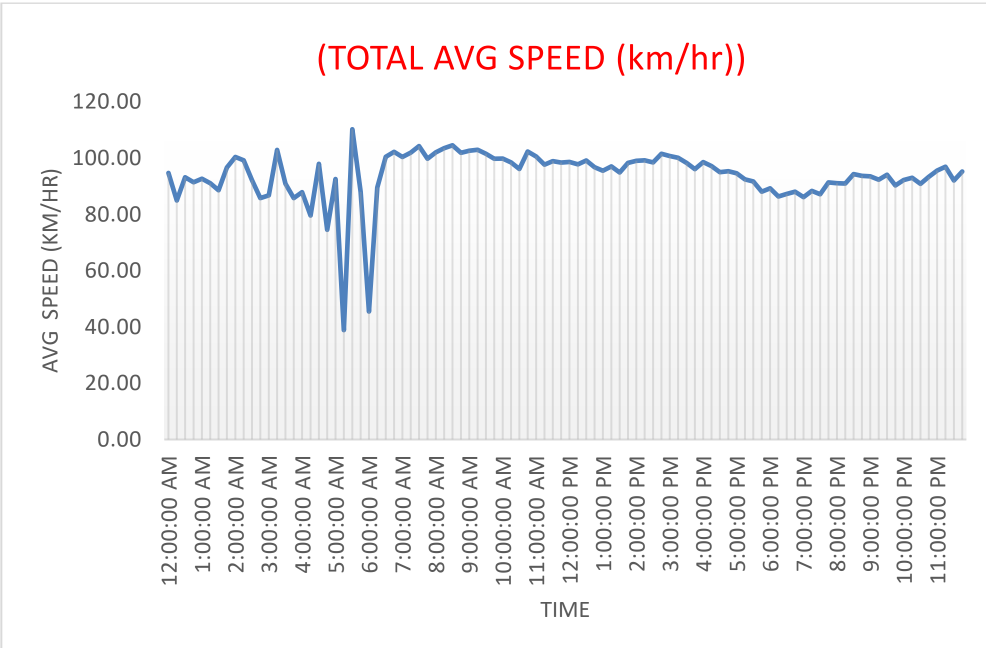
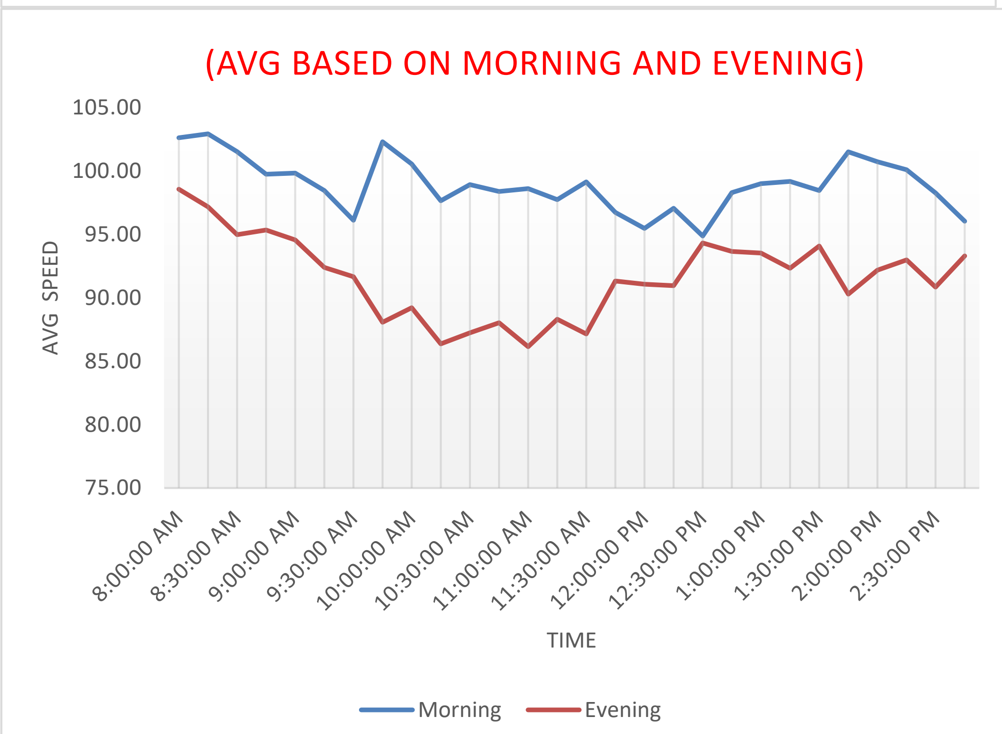
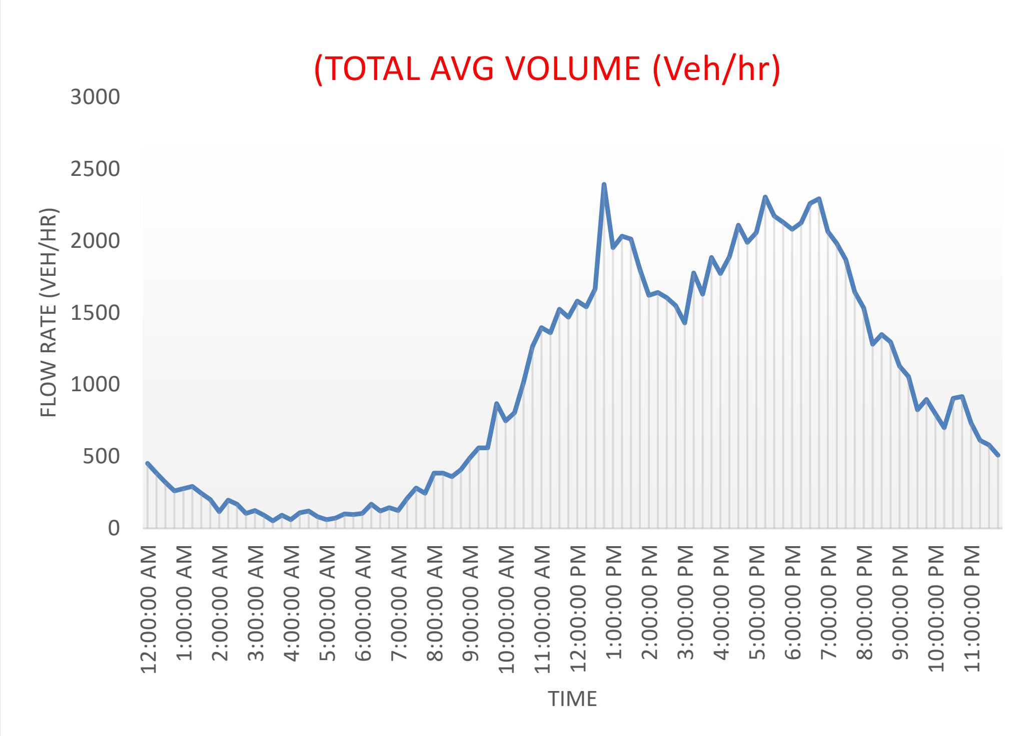
APPENDICES

Appendix A: Data Extraction






(TOTAL AVG VOLUME (Veh/hr)
FLOW RATE (VEH/HR)
3000
2500
2000
1500
1000
500
0
12:00:00 AM
1:00:00 AM
2:00:00 AM
3:00:00 AM
4:00:00 AM
5:00:00 AM
6:00:00 AM
7:00:00 AM
8:00:00 AM
9:00:00 AM
10:00:00 AM
11:00:00 AM
12:00:00 PM
1:00:00 PM
2:00:00 PM
3:00:00 PM
4:00:00 PM
5:00:00 PM
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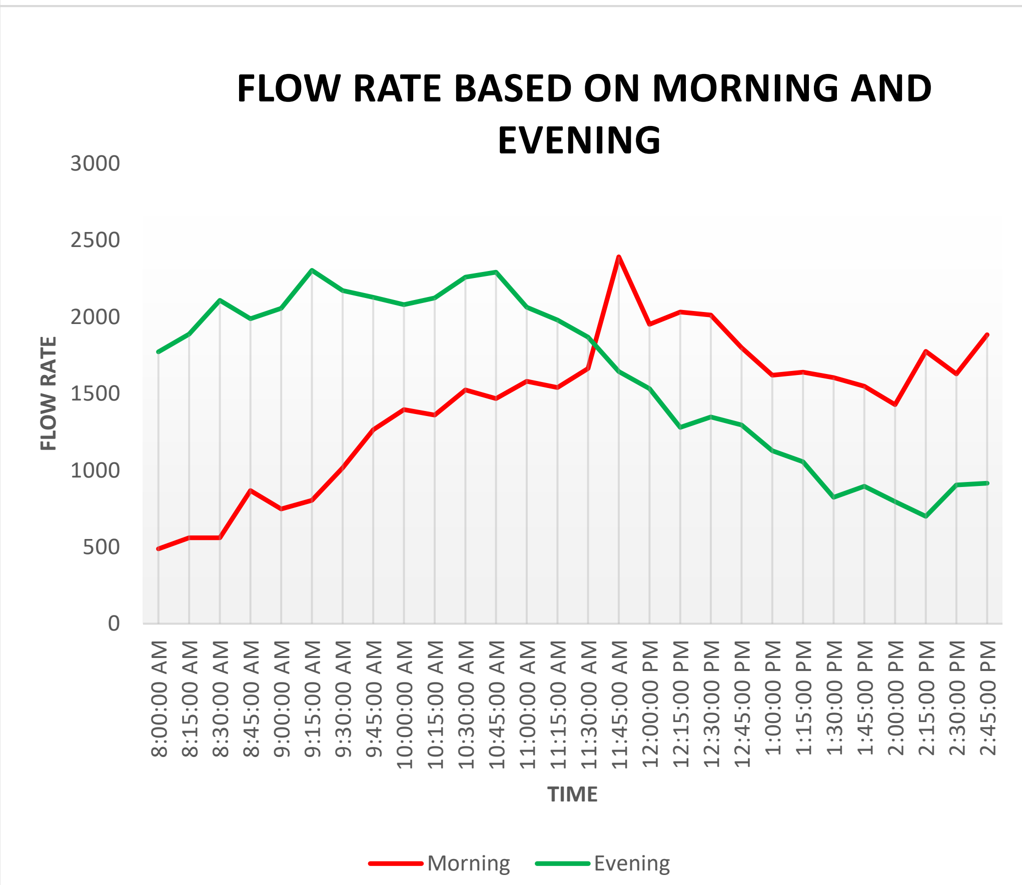
7:00:00 PM
8:00:00 PM
9:00:00 PM
10:00:00 PM
11:00:00 PM
TIME


FLOW RATE BASED ON MORNING AND EVENING
FLOW RATE
3000
2500
2000
1500
1000
500
0
8:00:00 AM
8:15:00 AM
8:30:00 AM
8:45:00 AM
9:00:00 AM
9:15:00 AM
9:30:00 AM
9:45:00 AM
10:00:00 AM
10:15:00 AM
10:30:00 AM
10:45:00 AM
11:00:00 AM
11:15:00 AM
11:30:00 AM
11:45:00 AM
12:00:00 PM
12:15:00 PM
12:30:00 PM
12:45:00 PM
1:00:00 PM
1:15:00 PM
1:30:00 PM
1:45:00 PM
2:00:00 PM
2:15:00 PM
2:30:00 PM
2:45:00 PM
TIME
Morning
Evening

Appendix B: Comparison between the 3-scenarios

Table of Average speed comparison between the 3-scenarios

Speed (with incident)	Speed (without incident)	SPEED (with VSL)
114.12	114.03	113.95
114.36	114.20	114.46
114.13	114.66	113.79
113.32	114.66	114.18
113.83	114.29	113.89
114.33	113.71	113.40
113.82	114.05	113.11
113.54	114.41	114.13
114.63	114.14	114.64
98.60	114.38	110.34
95.89	114.23	108.68
95.76	114.40	107.29
92.94	113.76	108.66
93.34	114.26	108.59
95.46	114.62	108.09
101.19	114.43	108.47
114.33	113.89	113.40
113.91	114.32	114.28

Table of Average occupancy comparison between the 3- scenarios

Occupancy rate (with incident)	Occupancy rate (without incident)	OCCUPANCY rate (with VSL)
19.72%	20.00%	20.00%
20.00%	19.92%	19.99%
19.70%	19.99%	19.99%
20.08%	20.06%	19.96%
20.15%	19.68%	20.17%
20.02%	20.34%	20.07%
20.07%	20.19%	20.23%
19.96%	19.79%	20.19%
19.89%	19.84%	19.98%
22.81%	19.99%	19.86%
24.17%	20.02%	20.83%
24.28%	19.93%	21.76%
25.06%	20.29%	21.29%
24.86%	19.84%	21.41%
24.52%	20.00%	21.35%
25.08%	19.72%	23.13%
20.10%	20.15%	20.12%
20.10%	19.90%	19.97%

Table of Average delay comparison between the 3- scenarios

queue delay (without incident)	queue delay (with incident)	Queue delay (with VSL)
0.00	0.00	0.00
0.00	0.00	0.00
0.00	0.01	0.00
0.00	0.00	0.00
0.00	0.00	0.00
0.00	0.00	0.00
0.00	0.00	0.00
0.00	0.00	0.00
0.00	0.00	0.00
0.00	7.91	3.61
0.00	17.84	20.28
0.00	19.75	16.95
0.00	23.45	15.85
0.00	21.67	14.59
0.00	22.62	18.61
0.00	14.18	15.74
0.00	0.00	0.00
0.00	0.00	0.00

Table of Average travel time comparison between the 3- scenarios

Time interval (with incident)	time interval (without incident)	TIME (with VSL)
248.16	247.53	243.44
247.72	247.69	244.44
248.18	248.05	246.34
248.68	246.82	246.19
249.69	247.09	246.66
247.59	249.62	244.47
249.80	248.23	245.68
249.25	247.13	245.80
248.01	248.45	245.04
258.02	247.85	250.14
280.58	247.74	264.40
282.01	248.35	279.15
295.14	248.03	279.35
297.42	247.40	279.90
294.54	248.02	279.10
286.55	247.44	271.93
247.74	248.84	246.87
248.78	247.42	245.06

Appendix C: Results calculation

Table for results calculation for scenario 2, taking scenario 1 as reference.

PARAMETER	without incident	without VSL	Without VSL / With incident
speed	114.2464437	107.0836393	6.26960819
occupancy	0.199808925	0.216976932	-8.592212396
delay	0.000486389	7.079949	
travel time	247.8720809	262.6581159	-5.96518777
total travel time	4461.697456	4727.846087	-5.96518777

Table for results calculation for scenario 3, taking scenario 1 as reference.

PARAMETER	without incident	with VSL	With VSL / With incident
speed	114.2464437	111.8530576	2.094932704
occupancy	0.199808925	0.205721231	-2.958979713
delay	0.000486389	5.868109	
travel time	247.8720809	255.7754597	-3.188490937
total travel time	4461.697456	4603.958275	-3.188490937

Table for results calculation for scenario 3, taking scenario 2 as reference.

PARAMETER	without VSL	with VSL	Without VSL / With VSL
speed	107.0836393	111.8530576	66.58590712
occupancy	0.216976932	0.205721231	65.56207439
delay	7.079949	5.868109	17.11768345
travel time	262.6581159	255.7754597	46.54835591
total travel time	4727.846087	4603.958275	46.54835591