Modelling and Simulation of Traffic signal control: A case study of Islamabad city

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Declaration of Authorship

I **Fatima Ghaffar**, declare that this thesis titled ”**Modelling and Simulation of Traffic signal control: A case study of Islamabad city**” and the work presented in it are my own. I confirm that:

- This work was done wholly or mainly while in candidature for a research degree at NUST.
- Where any part of this thesis has previously been submitted for a degree or any other qualification at NUST or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
- I have acknowledged all main sources of help.
- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

Signed: ______________________________

Date: ______________________________

Dedication

To my Parents and Siblings

Acknowledgements

All praise to ALLAH the Almighty, the creator of this universe, who has blessed mewith the sense of thankfulness, humbleness and love. The owner of crown, the repellerof Affliction and disease, the master of Madina, Prophet Muhammad (SAW). I praythat He always keeps me under your supervision.

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Abstract

Traffic congestion is a major issue in many modern cities around the world. Over many years, different solutions have been proposed and tested to solve the problem. One such solution is to build a new traffic infrastructure however this proves to be expensive and may not be possible in some places. Another solution is to optimize the existing traffic network by smartly controlling traffic lights at intersections, to ensure that vehicles move smoothly along transportation routes. Analysing the situation in Pakistan, the current traffic lights in Islamabad city, which are installed across the city, are insufficient to address the congestion issues since they have particular pre-determined times for green and red lights. This results in large queues leading to disruptions in the daily lives of passengers. In this research, we used fixed and actuated traffic light control methods to optimize traffic signal programs generated by SUMO, which is an open-source microscopic simulator. By using delay time and queue length as the parameters to reduce the congestion, one single intersection has been modelled in SUMO.

Actuated traffic light control has shown a strong potential to cater to traffic fluctuations to achieve desired objectives and effectively reduced traffic congestion by adjusting traffic signal plans. To test the efficacy of the used strategy, one single intersection has been used which is controlled by an Intelligent traffic light control plan (ITCS). Further, actuated traffic light control was found to reduce intersection delays by up to 27% relative to fixed traffic light control which can be further improved by using adaptive traffic light control strategies based on machine learning algorithms. Moreover, Fluctuations in traffic flow have been catered better by actuated traffic light control than fixed traffic light plan.

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Abbreviations

ITCS	**I**ntelligent **T**raffic **C**ontrol **S**ystem
DSRC	**D**edicated **S**hort **R**ange **C**ommunication
IoT	**I**nternet **o**f **T**hings
RFID	**R**adio **F**requency **I**dentification **S**ystem
UWB	**U**ltra **W**ide **B**and
SCATS	**S**ydney **C**oordinated **A**daptive **T**raffic **S**ystem
SCOOT	**S**plit **C**ycle **O**ffset **O**ptimisation **T**echnique
OPAC	**O**ptimization **P**olicies for **A**daptive **C**ontrol
RHODES	**R**eal-Time **H**ierarchical **O**ptimized **D**istributed **E**ffective **S**ystem
SUMO	**S**imulation of **U**rban **MO**bility
ATMS	**A**dvanced **T**raffic **M**anagement **S**ystem
IRIS	**I**ntelligent **R**oadway **I**nformation **S**ystem
GPL	**G**eneral **P**ublic **L**icense
SPOT	**S**ystem for **P**riority and **O**ptimisation of **T**raffic
OSM	**O**pen **S**treet **M**ap
minDur	**min**imum **Dur**ation
maxDur	**max**imum **Dur**ation
TraCI	**Tra**ffic **C**ontrol **I**nterface

Chapter 1

Introduction

1.1 Background

In the 21st century, with rapidly increasing world's population, the urban population is projected to rise significantly. It is therefore essential to have managed urban infrastructure to cope with this rise effectively. Modern society depends on the systems of transport for the transportation of people, goods and services to ensure that vehicles can travel efficiently from point of origin to point of destination [18].

More vehicles on road cause traffic congestion that emerged as a very serious issue in populated cities that needs to be dealt appropriately. Traffic congestion leads to problems like fuel consumption, CO_2 emission and wastage of time. The large number of vehicles, improper traffic infrastructure and inefficient traffic control system are the main reasons for traffic congestion. It is impossible to stop people from buying cars and to start building new traffic infrastructure that might cause a huge burden on country's economy. So, the easy way to solve this problem is to optimize the traffic signal timing at intersection.

The demand for road infrastructure has also risen beyond its capacity due to an increase in population and ownership of vehicles which results in congestion, travel delays and excessive emissions of vehicles. Up till now, road infrastructure improvements have been used to reduce traffic congestion [15] [52]. Even then, having strict constraints on financial resources and physical conditions, also environmental concerns, have amplified the need for alternative ways to minimize traffic congestion. We can only proceed with enhancing the utilisation of existing transportation facilities to discover the right signal intersection control algorithm reducing land resources.

Traffic congestion is a challenging phenomenon that hits the everyday life of many people around the world in many countries [14]. At the same time, traffic congestion would also lead to excessive loss of resources and environmental pollution and increase the risk of traffic accidents. Traffic junctions play a significant influence in determining the congestion condition of the road network [31]. Most traffic junctions around the world use pre-defined fixed signal timings which are not equipped to track actual traffic [56]. Recent studies suggest hand-crafted rules based on actual traffic data. However, those rules cannot be dynamically modified according to real traffic data due to pre-defined control in nature. While such a technique is simple to enforce, it does not take into account real traffic conditions and can lead to more congestion.

In this chapter, we will briefly discuss the concept of Intelligent traffic control systems and traffic modelling. After that, we will introduce the problem and discuss the motivation, and finally, we will review the whole thesis.

1.2 Intelligent Traffic Control System (ITCS)

Over the past few years, several Intelligent Traffic Control (ITS) systems [34] have been progressed and illustrated to be one of the most efficient methods to minimize traffic volume. Video cameras or loop detectors are used to get real-time traffic information which can be used to configure the traffic light split-cycle accordingly. Unfortunately, such intelligent traffic signal control systems are costly and thus only operate on the few interchanges of the United States, Europe and Asia.

The most frequently used control systems are pre-timed and actuated traffic signal control systems. Pre-timed signal control is best suited for fixed positioning strategies but not designed to cater to abrupt changes inflow of traffic. Even though simple and do not require professional skills but time-consuming. On the other hand, Actuated signal control response to modification of green time (minimum green to maximum green) varies based on traffic volume. Although it has been shown that actuated signal control can perform better than pre-timed in certain situations but does not give any real-time optimization for fluctuation in traffic conditions. As a result, actuated signal control is not flexible and adaptable to traffic fluctuations and could result in long queues in more than one intersections [7].

Recently, many more economical techniques have been introduced to deploy the ITSC systems through the use of Dedicated Short Range Communication (DSRC) technology which is a significantly less expensive technology for the detection of the vehicle on junctions. However, only a limited portion of vehicles would be fitted with DSRC radios at the early stages of deployment. Even now the rise of the Internet of things (IoT) has developed emerging technologies for tracking vehicles for ITSC. Other than DSRC, the innovations which are more cost-effective than conventional loop detectors or cameras include RFID, Bluetooth, Ultra-Wide Band (UWB), ZigBee, and even cellphone applications such as Google Map. The performance of these devices is better than loop detectors which only detect the existence of vehicles. However, the systems that have not fitted with mentioned communication devices would unable to detect the vehicle [21].

Generally, centralized real-time traffic system like SCATS and SCOOT are broadly utilized traffic signal control systems and dynamic optimization of the system to obtain signal settings represented by OPAC and RHODES.

Implementation of smart traffic management systems is one of the most important factors in the design of modern cities. A traffic management system's main goal is to minimise traffic congestion, which is one of the major issues in mega cities. Effective urban traffic control leads to saving time and finances also the reduction of CO_2 emissions into the atmosphere. Improving traffic conditions will increase city productivity, boost the economy and make people's everyday life easier [68] [10].

So computers can learn to make a reasonable decision by interacting with the environment. With the advancement of the internet and wireless communications, data processing has become more convenient and quicker than ever. The fair use of different traffic data is also crucial to lessening traffic congestion.

1.3 Problem Statement

In developing countries, traffic infrastructure is in a progressive state and changes every day. Old road maps are being changed by establishing new roads. This causes a tremendous change in traffic flow on different routes and leads to traffic congestion problem. The most common approach used to solve congestion problem is to predefine the green phase duration according to historical traffic demands. It fails most of time because it does not consider the fluctuation in traffic demand. Other solution uses the sensors like inductive loop detector to control the traffic signal. Inductive loop detector has poor detection for smaller vehicle and can be damaged by road deterioration. A system is needed that not just controls the traffic flow at intersection but also adopts new control policy according to traffic behavior.

Islamabad is the capital city of Pakistan located in the Potohar Plateau in the north west of Pakistan with an elevation of 500 meters above sea level. Islamabad is located at latitude of 33.71° North and longitude of 73.1 ° East, and is bordered by Margalla hills on one side (North) and plains of an adjunct province (Punjab) on the other side. The city of Islamabad is spread over an area of 906 km2 with a reported population exceeding one million [59] , [71]. Having the status of federal and administrative capital, Islamabad city has a national importance as well. This significance of Islamabad has always invited new dwellers into the city that has resulted in a constant expansion of urban population [6].

One of the consequences of such a population increase is the massive rise in the transportation flux observed during the last decade [66]. Easy availability of passenger vehicles on lease from commercial banks has also contributed towards the increasing vehicle population which in turn has increased the air pollution in the city [23]. Figures for the last five years have also shown an average annual addition of 62,000 vehicles in the city's overall fleet.

Islamabad has a adjoining city, Rawalpindi, which is only a few kilometres away. These cities are linked, and in recent years, approximately 100,000 people drive everyday from Rawalpindi to Islamabad. The daily movement of these 100,000 people to the capital caused traffic congestion, and the absence of a local transportation network made it even most complicated for travellers. Pakistan, still in its early stage of growth, faces a lack of public transportation, such as metros and buses, which are important in any metropolitan city. Besides, a lot of traffic congestion, Pakistan is coping with an electricity shortage, with 35 and 25 per cent of the existing shortfall occurring during peak and off-peak days, respectively. Furthermore, since 1964, the inhabitant of this city has increased from 100,000 to 2 million [67].

In Islamabad, Pakistan's Capital Territory, the Srinagar Highway is a big east-west highway. The highway links the Islamabad International Airport in the west to the E-75 Expressway in the east, providing easy access to Islamabad. The highway is 25 kilometres long in total. There are five interchanges and the width ranges from three to five lanes. This research mainly focuses on the G11 intersection on Srinagar highway, G-11 (North Exit), Sector H-12 (NUST) (South Exit). G11 intersection is selected based on heavy traffic on both sides of the highway.

Due to the main campus of an educational institute, nearly 5000 people daily commute through this highway. On the opposite side, the G11 sector provides a passage to all other sector and has a grand supermarket which also attracts people results in traffic congestion [33] [32].

G-11 intersection is four-way intersection. The east and west side of intersection have 5 lanes while north and south side of intersection has 3 lanes. The road approaching the intersection form north side has curvature. This intersection has separate road for left turn and does not required a traffic light.

FIGURE 1.1: Open Street Map of Islamabad Srinagar Highway

For major cities around the country the problems are worsening, although at a slower rate, but capacity is decreasing to absorb newcomer transportation, causing massive congestion. So, Major reasons for this growth are as follows:

- Leasing/car financing facilities provided by almost all the banks on low interest rates and on easy terms and conditions have contributed the most towards this end.
- Second major factor is domestic car manufacturing industry has also improved a lot in near past. Numbers of leading car manufacturers especially from Japan have started manufacturing their brands in Pakistan.
- Last decade has also seen tremendous improvement in road infrastructure especially the motorways. This has also encouraged people to buy new cars.
- Ever increasing Population

- Inadequate public transport facilities have made car maintenance a necessity rather than a luxury.

For major cities around the country the problems are worsening, although at a slower rate, but capacity is decreasing to absorb newcomer transportation, causing massive congestion.

1.4 Identified challenges

1.4.1 Conduct of commuter

Since Pakistan has much smaller cars than any other country, it causes more traffic congestion. Two small cars usually remain in a single lane and then switch lanes depending on the room they encounter, big vehicle drivers behind them become impatient and find it difficult to pass the smaller cars. While traffic wardens on-site play an important role in guiding commuters to keep lanes clear and often succeed, when they leave, the same situation occurs[69].

1.4.2 Educational Institute

since Islamabad lacks a public transportation system such as buses or subways. Few people use the institute's transportation, which only carries 15 per cent to 20 per cent of the total student body, and the rest travel on their own. So there are two peak times for this type of congestion, one from 8:30 a.m. to 10:30 a.m. and the other from 4:30 p.m. to 8:30 p. m.

1.4.3 Construction/Renovation of Roads and Pavements

This is a universal barrier to smooth traffic flow, however industrialized world have introduced regulations for the building of roads and sidewalks, as well as the repair and filling of sinkholes on a routine basis. Conversely, it has been noticed that during road-building in Pakistan, no such preventive steps are taken, leaving the condition in the hands of travellers.
Many accidents occur during road construction. Typically, when travellers see a heap of concrete or construction material on the road, they apply abrupt breaks, and the car behind them does not respond as quickly, causing many to collide. This occurs most often during peak hours, as everyone insists on arriving at their destination on time and in the fastest manner

possible. On Pakistani highways, it is common to practise to begin construction work without informing commuters, causing significant inconvenience [48].

1.4.4 Traffic Lights (Signals)

Many advanced steps are taken in order to enhance the functioning of traffic signals around the world. In many places, technology involving sensors is being used to enhance traffic flow and increase commuter comfort. In the current scenario, cities such as Islamabad are fitted with traffic signals, but the signal's reliability is very poor. The primary causes are a lack of preventative maintenance, electricity shortage, and defective lighting. When traffic signals fail due to an unplanned power outage, traffic is controlled by a traffic police; if the traffic person is unavailable, traffic navigates on its own. This is in contrast to the West, where the general rule is that when a traffic light ceases to function, drivers should recognise it as a STOP sign, and when they enter the junction, they should completely stop their cars, give everyone access, and then continue to cross the intersection.

In Pakistan, drivers roam freely on roads independent of specified lanes. This creates chaos and clogs up the traffic flow. When managing traffic manually, wardens often cause traffic congestion as they do not control traffic with regard to time, but rather transfer traffic based on the number of vehicles arriving from a single side. They allow about 2-3 minutes from that side, after which the remaining sides become congested, and one is only able to move after about 8-10 minutes. On the other hand, when traffic signals are operational, traffic on each side moves based on a timer set for them [77]. As a result of this operation, more cars are available for the subsequent traffic signal, major roads become congested, and commuters' average travel time nearly quadruples. During power outages, this is a common occurrence, and traffic wardens will often purposefully switch off traffic signals and control traffic themselves. Each day, the traffic department tries new approaches, and numerous traffic lights become inoperable as crossings are closed by hurdles to block traffic on both sides, forcing drivers to make a U-turn [26].

1.5 Motivation

Simulation modeling is an increasingly popular and effective tool for analyzing and evaluating different alternatives/solutions. Most of the simulation models were developed in Europe and US. Model parameters are based upon their local conditions. If we want to use them in Pakistan, then these model parameters should be perform according to local traffic conditions. Although, most of the time in developed and advanced countries, driver behavior have similar algorithm, but when we are comparing these with third world countries it may differ significantly. Hence to use these micro simulation models in Pakistan, we must calibrate and validate these models.

1.6 Research Objective

The main goal of this research is to investigate and minimize the congestion at the selected junction of Islamabad city by selecting different configurations based on the input of vehicles. The main objectives of this research work are:

- Modelling of G11 intersection in Eclipse SUMO Software
- Four different configurations depend on vehicle input is used for the same model
- Traffic plans are subjected to optimisation by using Fixed and Actuated traffic light plans

The research methodology adopted for this thesis was as following:

1. Literature Review.
2. Selection of the suitable microscopic simulation model from:
   (a) Available simulation models/software and research carried out in this regard.
   (b) Selection of the suitable microscopic simulation models based on network flexibility
3. Collection of all the relevant data from the field
   (a) Geometry data (Number of lanes, Lane width and Distance)
4. Modelling on the selected microscopic simulation model
5. Generation of real world traffic data by using probabilistic distribution
6. Collection of results

7. Analyzing and evaluating the results

8. Comparison of different configurations in the model

Two types of traffic light plans are used for the configurations. Following are the configurations

- Configuration with vehicle input of Cars only
- Configuration having two lanes fixed for heavy traffic
- Configuration with Equally distributed traffic in 5 lanes

The flow chart highlighting the methodology adopted for this study is shown in Figure 1.1.

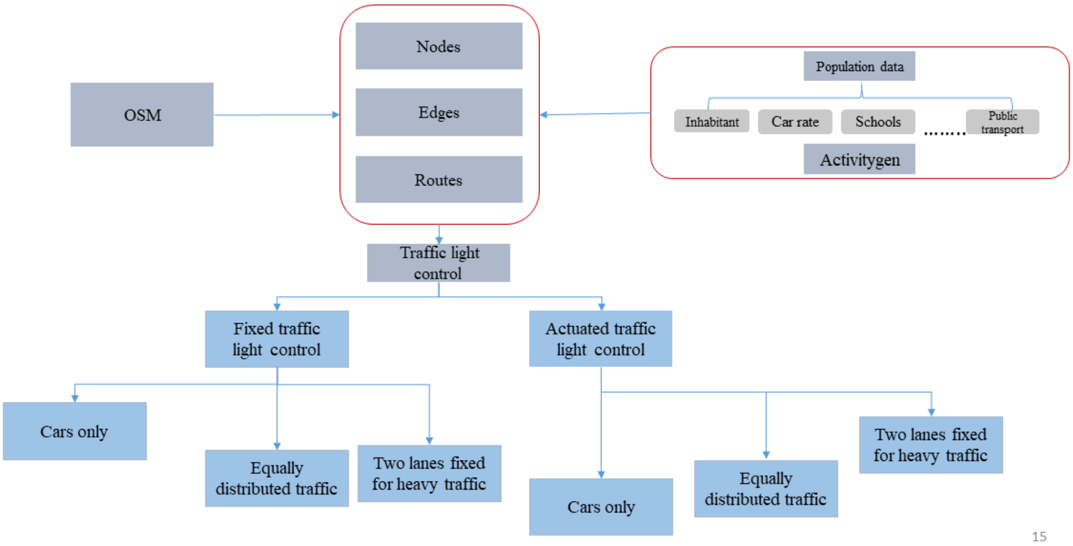

FIGURE 1.2: General Methodology Flow Chart

1.7 Organization of the Thesis

Chapter 1: Introduction Chapter 1 summarizes the whole research work. It starts with an overview of the background and area of research, then presents objectives of this research study, a brief description of the methodology opted to carry out this research work is given and at the end contribution of this research study made to the scientific literature are penned down.

Chapter 2: Literature Review Chapter 2 presents an in-depth review of the related literature. It starts with an overview of the Traffic light control system and then, it discusses the already used traffic light control methods. The core component of this research work i.e. Traffic problem in an intersection in city Islamabad have been studied in detail and the previous methods have been used to control traffic in Islamabad in depth both theoretically and experimentally. Similarly, the concept of traffic control and its implementation were also discussed.

Chapter 3: Problem Formulation Chapter 3 gives a detailed overview of the computational setup of intersection in SUMO Eclipse. Various stages involved to carry out a complete study are comprehensively discussed which includes modelling of the intersection, generation of the vehicular routes, selection of appropriate traffic control method, the input of vehicular parameters and choosing the appropriate time step size for the simulation.

Chapter 4: Results and Discussion Chapter 4 focuses on the explanation of the results for both fixed and actuated traffic light control in a very comprehensive manner. In the subsequent part of the chapter, visualization of simulation data is presented. Similarly, results of all configuration with cars, equally distributed vehicles and 2 lanes fixed for heavy vehicles were also presented for both traffic light control methods. Results of all configurations with fixed traffic light control have been compared with different lanes and then with actuated traffic control.

Chapter 5: Conclusion and Future Recommendations Chapter 5 concludes the findings of this research study and presents possible future directions to extend this work.

Chapter 2

Literature Review

In this chapter, an intensive amount of effort was made to explore every theoretical aspect of this research work. To meet this milestone a detailed literature survey was done on Traffic light control systems. A comprehensive study was done to understand the traffic condition in Islamabad city, the challenges associated. The core component of this research work i.e. Traffic light control methods have been studied in detail and the previous work done on traffic control have been studied in depth both theoretically and experimentally.

The amount of traffic on the roadways is constantly increasing, and the highway infrastructure is carrying more vehicle miles than ever before. The pressure on the transportation system is increasing faster than efficiency can be improved. To prevent this, transportation planners, engineers, and analysts are focusing more on increasing the operating efficiency of highway networks. This necessitates identifying difficulty areas and bottlenecks in a system that require capacity enhancements, as well as developing strategies that address the system's demands, which are frequently constrained by social, environmental, and economic considerations. Modeling traffic operations with computers has unrivalled advantages, allowing traffic engineers to provide acceptable solutions for addressing a particular problem at a cheap cost and with minimal work. As a result, traffic simulation models are becoming increasingly common in transportation facility development and operational analysis.

Traffic light control systems have been extensively researched and implemented in operation. To forecast vehicle density at an intersection, physical sensors and devices such as loop detectors and video cameras bearing content-analysis capabilities) can be used to detect and identify vehicles [65] [27].

2.1 Simulation

Oxford Dictionary defines simulation as the technique of "imitating the behavior of some situation or process" by means of "a suitably analogous situation or apparatus".

[46] describes simulation as "a numerical approach for doing computer experiments that may have stochastic features, be microscopic or macroscopic in nature, and use mathematical models that explain the behaviour of a transportation system over long periods of time." Computer simulation can be defined as the process of:

- Designing a computerized model of a system
- Conducting experiments with this model
- Understanding behavior of system of evaluating various strategies for the operation of the system

2.1.1 WHY SIMULATE?

Traffic simulations has shown valuable analysis and evaluation tool for evaluating transportation systems. It can be useful in many areas like transportation system designing, traffic operations, and evaluation of management alternatives. Simulation's advantages includes cost effectiveness, risk-free nature, and high-speed benefits. Figure 2.1 shows applications and benefits of microscopic simulation models.

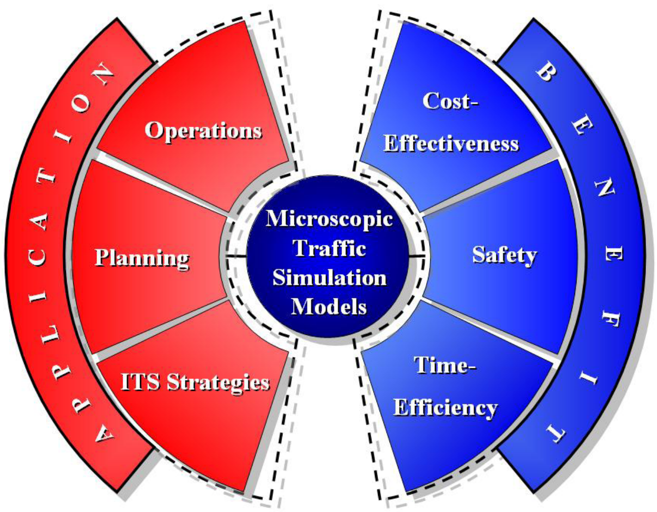

FIGURE 2.1: Application Area and Benefits of Microscopic Traffic Simulation Models [55]

It is not always possible to test transportation projects in the field. Rather, It's not always doable. In such conditions simulation models are great advantage. Field testing is more costly, less safe, and less versatile than simulation. More over, it also provides an objective framework in which to evaluate different alternatives. Advantages of simulation modeling cited by [12] and [16] are as following:

- field implementation are much expensive than simulations. In addition, Simulating traffic operations eliminates the disruptions that typically accompany field studies.
- Other analytical approaches may not be appropriate
- Many factors that cannot be controlled in the field can be maintained constant in simulation modelling. This may reveal which factors are most significant and how they interact
- Experiment can be done offline instead of time taking trail and error approach
- Can use future parameters to do predictions
- Time limits can be set according to time frame available
- Can handle interacting queuing processes
- Traffic demand can be varied according to time and space

2.1.2 TYPES OF TRAFFIC SIMULATION

Traffic simulation is the "Process of applying simulation for traffic applications" Depending on purpose of modeling traffic; it can be "Macroscopic", "Mesoscopic" or "Microscopic" models. The simulation model chosen should be appropriate for the intended application. This decision is usually based on a compromise between the model's accuracy and precision and the development expenses, data requirements, and simulation time.

2.1.3 Macroscopic (macro) models

Individual vehicle movements are not included in macroscopic models; instead, aggregate representations of traffic flow are used. As a result, they consume considerably fewer computer resources, yet they are unable to predict vehicle-level readings accurately. A deterministic macroscopic simulation is important for network design and optimization because of its deterministic character. Macroscopic models, on the other hand, can measure speed, flow, and density.

2.1.4 Microscopic (micro) models

Microscopic models capture the behavior of vehicles and drivers in much more detail and are capable to capture individual vehicle movements. Traffic is simulated using car-following relationships, lane-changing, and other processing logic, which describes the vehicle behavior. This technique is useful for a wide range of applications but requires more computational resources. Random number generators are involved and calibration of these models requires more effort, and are difficult to optimize model parameters, e.g. signal settings.

2.1.5 Mesoscopic (meso) models

Mesoscopic models include features from macroscopic and microscopic models. Usually, results from microscopic models are aggregated for Results from microscopic models are usually combined and used in mesoscopic models.This cuts down on the amount of time it takes to run the simulation. Mesoscopic models have a lower degree of resolution than macroscopic models when it comes to tracking individual cars. They don't represent lane change or automobile following behaviour, for example, whereas microscopic models do. Hybrid Simulation is a term used to describe this method.

2.2 Traffic Signal

Traffic congestion was a part of city life as far back as Roman times. Roads were built out in such a manner to carry traffic from all directions to a single centre point which leads to bad city planning, which was a major problem back then, as it is today. Julius Caesar restricted wheeled traffic from Rome during the daytime in the first century BC, a measure that was eventually applied to cities in the provinces. Emperor Hadrian was pushed to reduce the overall numbers of carts allowed into Rome late in the first century AD.

Congestion was serious enough in European cities in 17^{th} century that ordinances banning parking on some streets and enforcing one-way traffic were imposed. While the railroad provided immediate relief from the increasing issue of road traffic control, it also caused congestion at city terminals. With its exponential rise in speed and number of cart's transportation, the invention of cars was one of the characteristic problems of urban industrialized society in the twentieth century [49].

The innovations of traffic signal control were conducted by the British Admiralty in the fields of communications and maritime navigation.

2.2.1 Communications

In the late 18^{th} century, a chain of optical telegraph stations were built to allow the Admiralty in London to communicate quickly with the naval ports along the southern coast of England. General Pasley's work in the early nineteenth century improved the telegraph's operation by observing the device perfected in France by Claude Chappe, which led to the UK's introduction of the semaphore type of telegraph in 1816. In response to rising accident rates, General Pasley later became Inspector General of Railways, and it was during this period that he started using the semaphore signal to improve contact with locomotive drivers. The London and Croydon Railway's Charles Gregory built the first of these at New Cross in 1842 [4].

2.2.2 Maritime Navigation

With the onset of steamships around the mid-nineteenth century, there was a significant rise in at-sea accidents, resulting in the loss of many ships. A variety of studies were conducted following the work of a Parliamentary Select Committee, which first looked at the subject in 1831. One of the studies used coloured lights to make way for a ship, allowing it to be more visible to other vessels after dark. Oil lamps particularly with clear, red, and green lenses were found to be the most easily seen from a distance, with the least chance of misinterpretation. The study concluded that for navigation sidelights on boats, red and green lights should be used, a proposal that was unanimously accepted in 1858.

These two studies culminated in two collections of inventions, all of which were cutting-edge innovations at the time.

- The widespread use of semaphore signals to monitor railroad traffic
- Red and green lights are used as visual warning signals

2.2.3 Goal of Traffic Signal Control

By regulating time in space, traffic lights can improve safety at junctions by preventing traffic conflicts between different vehicles and pedestrian movements. People must wait for the green light in order to prevent dangerous confrontations and optimum control. In the meanwhile, they lose time, which causes annoyance, and cars burn more fuel and emit more emissions.

The goals of signalized intersection change with time and according to the traffic enforcement authority's current policy.

The traffic light control as we know it now has its origins in the manual operation of police signalmen. The first automated traffic light appeared around the turn of the twentieth century. The objective of the traffic light at the time was to promote safety by minimising collisions between cars and pedestrians at crossings by providing alternate right of way to opposing movements using an uniform colour code. The influence of traffic lights in terms of network efficiency, given the same degree of safety, has been realised by the research community throughout the years as traffic demand and congestion have increased. So, in addition to grouping conflicting movements at various periods to ensure the safe operation of an intersection, a method to split green time and movements grouping is required to get the best results.

To summarise, the fundamental goal of traffic control is to ensure road safety, which cannot be overlooked or overlooked in any situation. However, if an effective and appropriate control approach is used, signal timing has the potential to increase mobility while also contributing to environmental advantages.

2.2.4 Highway signals

London's traffic congestion was getting worse in the mid-nineteenth century. On December 10, 1868, in front of London's Parliament, the first traffic signal with gas lightening was mounted. Gas signal was handled manually by a police officer using semaphore guns, as recommended by Rail transportation expert J.P. Knight to manage horse carriage traffic. Gas-lit red and green lights were used at night, but they were always changed by a cop. The lights caused a safety risk since they occasionally burst, injuring wardens. Later on in 1912, at other intersection in Paris, a traffic control system with a rotating four-sided metal box placed atop of a glass showcase with the words ”Stop” in red and ”Go” in white was installed on top of a tower.

In the same year in 1912, Lester Wire, an American police officer, invented the first electric traffic light as vehicle traffic grew. It was first built on August 5, 1914, at the intersections in Cleveland, Ohio. Later on, In Salt Lake City, the first integrated traffic signal system was built, with six connected intersections operated at the same time by a manual switch. A few years later in 1920, the first tetra directional and three-coloured traffic lights were invented by William Potts, a Detroit police officer. He used yellow lights to show that the light would soon change. The city of Detroit was the first to use four-way and three-coloured traffic signals and in the same year, The Acme Traffic Signal Co. install five signals on Broadway in Los Angeles. The signals consisted of semaphore arms with “Stop” and “Go” messages.

Garrett Morgan received a copyright for his design of an electric traffic light in 1923. After witnessing a tragic tragedy, the African American inventor invented his autonomous traffic signal system.For his invention, GE charged him $40,000.

Experiments in the use of vehicle actuation to make traffic signals open to vehicles using a junction were carried out in the 1930s. An early attempt at this included placing a microphone along the side of the road and having the lights respond to vehicles honking their horns (left). Even though the scheme operated, it was extremely controversial among the locals. Later experiments used electrical pressure mats and pneumatic tubes, which were widely used until the 1970s when they were replaced for permanent installations with inductive loops. Pneumatic tubes, however, are still used for temporary count sites where they are attached to the carriageways floor.

2.3 Traffic Control Settings Overview

The design and timings of traffic signals are among the settings for traffic control. In order to design suitable signal groups, phase composition, and phase sequencing for traffic signal control plans, the structural design of the junction must be specified. Aside from defining the strategy for green time split, there is a requirement to set bounds for timing variables when it comes to traffic signal timing. The geometric arrangement, traffic vehicle characteristics, and driver conduct all have an impact on these factors.

Three colours are used for road traffic and two colours are used for pedestrian traffic. The order and meaning of the colours varies significantly between nations, but the overall goal remains the same and is constant within the country. The traffic controller has three durations: permissive, change, and clearance, which are represented by the colours green, yellowish /flashing green, and red for all traffic lights, accordingly.

2.3.1 Design of Signal Plan

The traffic flow in the junction, or more precisely, in the stop line, is controlled by traffic signal control. During recurrent periods, permission is provided for traffic to cross from one or more lanes (or traffic streams) of one intersection approach. A phase is a period of time during which a certain set of lanes (or traffic streams) gets access to the intersection.

The definition of the term ”phase” requires more clarification. In an examination of the literature on traffic control, the words ”stage” and ”phase” caused considerable confusion because they are used interchangeably. The term ”phase” is used in the United States and Australia to represent the concepts of ”stage” and ”reverse.” Furthermore, to add to the confusion, several nations employ a similar term (for example, “fase” in Portuguese) with similar spelling, increasing the chances of misinterpretation. Another argument stems from the fact that under simple traffic control, the two phrases can be interchanged without repercussions because they can have the same meaning in some situations. The right usage of both words is critical in more complicated traffic control when the number of phases does not equal the number of signal groups (stages). To simplify and avoid misunderstanding, this paper uses American language, with the term ”stage” being substituted with ”signal group.”

2.3.2 Timing of Signal Plan

Green time (minimum and maximum for actuated phases), Yellow time, All Red time, Vehicle Extension for actuated cycles, Green time for pedestrian and Flashing green time for pedestrian phase, and Cycle length must all be specified as part of the signal design timing.

Green Interval:

The green time, also known as the permissible period, signifies that a traffic stream is permitted to enter the junction.

The minimal green duration should be sufficient for drivers to react to the green light and satisfy their expectations. If the minimum green duration is too lengthy, it might cause delays at the junction, and if it is too short, it can disappoint drivers' expectations and compromise pedestrian safety.

Only the pedestrian reaction time and time to leave the curb can be included in the minimum value for green time for pedestrians, after which the clearing time can be utilised to cross. Local agency policy generally determines the length of the walk interval.[35].

Method	Value (s)	Description
TRB (2010)	Major-street: 10 s Minor-street: 8 s Left-turn movement: 6 s	Vehicle signal group
Koonce et al. (2008)	Major-street: 7s to 15s Minor-street: 4s to 10s Collector, Local: 2s to 10s	Minimum green time to satisfy driver expectancy
	Distance between sensor and stop-line: 0 to 7.5m → 5s; 23 to 30m → 11s 7.5 to15m → 7s; 30 to 38m → 13s 15 to 23m → 9s; 38 to 46m → 15s	Minimum green time to satisfy queue clearance can be dependent of sensor location to stop-line
Manual of Uniform Traffic Control Devices, MUCTCD (2003)	≥ 7s; ≤15s 4s, if pedestrian volumes are low	Pedestrian
Pavel (1974)	Vehicle signal group: 5s-10s Pedestrian signal group: 5s	Values recommended in Germany (Guberinic et al., 2007)

FIGURE 2.2: Green interval

Yellow Interval:

Yellow time, also known as change interval, indicates that the permission to enter the junction is about to expire through the yellow colour, giving drivers enough time to perceive and react to traffic light colour changes, as well as the distance required to safely stop or travel through the intersection. As shown in Table 1, there are a variety of suggestions for setting the yellow time..

All red Interval:

The period between the end of the yellow and the start of the green of the opposite signal group is known as all red time. A signalised junction's all-red phase is defined for safety reasons, allowing cars that cross the stop line at the conclusion of the yellow phase to exit the crossing before the following phase. The clearing time is thus determined by the junction

Method	Value (s)	Description
McGee et al. (2012)	$t_{yellow} = t_r + \frac{1.4v}{2a_{dec} + 64.4g}$	t_r = 1s a_{dec} = 3.0 m/s^2
Tarnoff (2004)	t_{yellow}=3s , v < 36 km/h t_{yellow}=4s, 36km/h < v < 55 km/h t_{yellow}=5s, 55 km/h < v	Based only on speed.
Manual of Uniform Traffic Control Devices, MUCTCD (2003)	t_{yellow} [3; 6] s	Longer intervals for high-speed approaches.
Pires da Costa (1987)	$t_{yellow} = t_r + \frac{v}{2a_{dec}}$ $t_{yellow} = 1 + 0.19v_{cruise}$	t_r = 1s a_{dec} = 3.0 m/s^2
Transportation and Traffic Engineering Handbook, ITE (1982)	$t_{yellow} = t_r + \frac{v}{2\,a_{dec} + 2gG}$	Sum of driver reaction time and deceleration time. t_r = 1s a_{dec} [3.0; 4.6] m/s^2
"Rule-of-thumb method"	$t_{yellow} = v/10$	Based only on speed.

Note: t_r = reaction time (s), v = approach speed (m/s), v_{cruise} = speed before intersection (m/s), a_{dec} = average deceleration (m/s^2), g = gravity acceleration (m/s^2), G = grade of approach (%)

Figure 2.3: Yellow interval

layout, road speed, and municipal laws. As shown in Table, there are a variety of recommendations for how to establish the all-red period.

2.4 Different techniques used for traffic signal control

Many traffic management systems have already been developed in the real world. They've used a variety of methods to manage traffic flow. These methods are listed further down.

2.4.1 Manual traffic control management

This is the most basic type of traffic management, and it relies heavily on human intervention. In this system, a traffic police officer stands at each cross-section of the road and uses a signboard to monitor traffic flow. If there is a high volume of traffic on the lane, the traffic police will send the vehicle driver a signal to move or not. He may also identify an emergency vehicle on the road and assign priority to the lane in which the emergency vehicle is travelling [28]. However, in the event of several cases, she or he will become disoriented and unable to control traffic flow. This process is more effective than any other method, but it is inefficient since it involves humans as part of the system. In several cities, the lack of qualified traffic police officers exacerbates the problem. Since traffic vehicle pressure does not equalise across all

Method	Value (s)	Description
McGee et al. (2012)	$t_{clearance,allred} = \frac{W+L}{1.47v} - 1$	
Manual of Uniform Traffic Control Devices, MUCTCD (2003)	≤ 6 s	Reduction of 1s to account the delay of reacting to green signal by conflicting movement
Traffic Control Devices Handbook (ITE) (2001)	$t_{clearance,allred} = \frac{P+L}{v}$-1	Reduction of 1s to account the delay of reacting to green signal by conflicting movement
Pires da Costa (1987)	$t_{clearance,allred} = \frac{d_t+L}{v_t} - \frac{d_a}{v_a}$	*t* is vehicle leaving of intersection *a* is vehicle entering at intersection
Transportation and Traffic Engineering Handbook, ITE (1982)	$t_{clearance,allred} = \frac{W+L}{v}$	When there is no pedestrian traffic. Time to place the vehicle outside the area of conflict
	$t_{clearance,allred} = \frac{P}{v}$	Used when there is low pedestrian traffic. Time to place the vehicle at a point directly in front of pedestrians waiting to use the crosswalk.
	$t_{clearance,allred} = \frac{P+L}{v}$	Significant pedestrian traffic. Time for the vehicle to clear both the cross street and the pedestrian crosswalks.

Note: W= width of stop line to far side no-conflict point along the actual vehicle path (m); L = length of vehicle (m); P = width of the stop line to the far side of the farthest conflicting pedestrian crosswalk along the actual vehicle path (m); d = distance between stop line and conflict point of vehicle *i* (m);

Figure 2.4: All-Red Clearance Interval

roads at the same time, a traffic light should be operated that detects the traffic conditions and adjusts traffic plan correspondingly. The efficacy of the system is determined by the person's expertise and ability [8].

2.4.2 Automatic Traffic Management Technique

An electronic traffic management method is recommended to remove the majority of the flaws in the manual traffic control system. Simple three-colour traffic signals are used in this system: Red, Green and Amber. The green light is normally for 120 seconds at each lane [63], but in certain parts of the city where there is less traffic, the duration of green timing is less than 120 seconds. It is entirely dependent on the density of traffic in specific area. Amber light glows for 20 seconds before the green light; signalling that you should accelerate. The red light is illuminated at all times, signalling that all vehicles must come to a complete half. This system is unable to identify the emergency vehicles such as ambulances, VIP cars, and other similar vehicles. It is uniform in the treatment of all vehicles.

Since red and green duration have been set, and both signals change in order and for midnight, all red and green signals are manually turned off and amber light id turned on. As a result, there is a chance that emergency services will be delayed at peak hours. As a result, this approach can be ineffective at times.

2.4.3 Image Processing based Intelligent Traffic Management Technique

Cameras are used in this method to cater images of the traffic volume on the lane. These are mounted on a tall pole so that they can cover a larger area. A computer chip examines the camera's picture to detect cars on the road [63] which is used to analyse traffic density and transmit this data to traffic signals. Then, traffic plans will automatically get update based on this information. This method isn't always suitable because the camera can't cover long stretches in heavy traffic, and the picture taken by the camera isn't always visible in heavy rain.

2.4.4 Traffic Management system using Wireless Technologies

The emergency vehicle is fitted with an RF transmitter, and the RF receiver is placed on the signal pole in this procedure. When an emergency car approaches the junction, it sends a signal to the RF receiver and then sends a signal to the main control system. The control system will then measure the estimated time for the green signal when an emergency car is going while leaving the red light to the remaining lane. The car would then be able to pass with ease [53]. This method effectively manages traffic congestion while also providing options for emergency vehicles. It collects vehicle density on the road using sensors, load cells, and other devices.

2.4.5 IRIS (Intelligent Roadway Information System)

The Minnesota Department of Transportation created an open-source Advanced Traffic Management System (ATMS) software initiative. Transportation authorities use it to keep track and control traffic congestion. Previously, the system lacked traffic statistics and was primarily used to monitor traffic congestion. However, IRIS can offer actual information on traffic to detect traffic densities, regulate traffic flow, and broadcast traveller information [8]. Advanced Traffic management System (ATMS) functionality is used by IRIS under GPL licence. ATM aids in the reduction of time, the enhancement of highway capacity, and the provision of safer travel directions in general. ATMs is made up of a number of expensive tech implementations. The costs of routine repairs have also been increasing.

2.5 Intelligent Transportation Systems

Intelligent Transportation system (ITSs) have been developed to reduce the amount of time spent or making decisions when driving by offering creative services such as high-tech traffic controllers and various modes of transportation. TLC includes a 4-way traffic intersection to simulate traffic light control. In a four-leg junction, the simulation involves a junction of four different entrances and 4 distinct exits. Furthermore, all roads in the simulation have three lanes. For each strip, two detectors are positioned in the road.

A signalised junction is designed to separate competing traffic movements in time instead of space, allowing them to proceed effectively and safely. The signal group, a series of lights that corresponds to a specific movement in the intersection, is the fundamental unit of a traffic signal control system. During the phase's green-time, a phase is a collection of signal groups that relate to a specific set of movements that have the right of way. These movements have been selected so that they can run in parallel without interfering with other traffic flows.

when each phase of a signal loop has been served once, it is called cycle time (also known as cycle length). Signal control algorithms are typically designed to optimise the traffic flow using the phasing scheme, the split, and the offset settings. The right-of-way signal groups and their subsequent order in the cycle are determined by the phasing scheme. The green-time allocated to each phase is represented by a break, which is a distribution of the cycle time to the different phases. An offset is a difference in time between the start of a new cycle and a reference point in time. Offsets have been effectively used to achieve success along a corridor by generating a ”green wave” for vehicles travelling in one direction or reducing the number of stops and waiting times at intersections along the corridor.

Traffic signal control (TSC) has been optimised using a variety of methods, according to researchers. Several high-quality reviews have previously been published on the subject of TSC settings [36] [9]. Fixed-time controllers, actuated controllers and adaptive controllers are three major types of traffic controllers.

Pre-timed: During a loop, the traffic signal gives each approach a set duration of green time. This green cycle is set for each interval for a certain amount of time, whether it's an hour, a few days, or forever.

Actuated: During a loop, the traffic signal gives each approach a certain amount of green time. This duration can be increased depending on the number of vehicles arriving at the green-lit approach as detected by a detection system. A maximum green time definition also limits the length of each green interval.

Adaptive: The traffic signal gives each intersection approach green time dependent on expected arrivals for a loop. The amount of green time given to each solution varies as arrivals shift from cycle to cycle.

2.6 Fixed time Control (Pre-Timed Control)

Based on historical traffic data, an off-line fixed signal timing plan is developed. Just once, off-line, are the loop length and splits optimised based on historical traffic counts, and then deployed. These systems do not run in real-time and are only effective when the traffic flow at the intersection is steady and consistent during the day. However, a variety of factors, such as accidents or road maintenance, may cause traffic to change. As a consequence, a predetermined control system is unable to respond in real-time to traffic demand. Following that, the length and order of all green phases remain constant and do not respond to traffic demand fluctuations. Fixed-time controllers do not need loop detectors at intersection approaches to operate, so they are much less expensive to implement than actuated or adaptive controllers.

Fixed-time Traffic signal control techniques are best suited for traffic signals with a relatively steady and predictable flow of traffic. These strategies use offline optimization algorithms for TST and end up with a preset cycle length and split setting plan based on previously observed traffic data. The main aim of this strategy is to accomplish a broad goal, such as minimising average delay or increasing network power.[73] [50] built the first models, which laid the groundwork for fixed-time traffic management techniques by reducing average delays. Since the traffic system in cities is extremely complex, any minor disruption, such as a traffic accident or construction activity, may drastically alter traffic volumes and make a predetermined traffic signal plan ineffective.

The traffic light controller optimises phase timings based on real-time inputs from loop detectors mounted near or immediately before the intersection's stop line using this method [53] [60]. The presence of loop detectors is detected, and the number of vehicles passing over them is counted. The light controllers changes travel intervals based on the vehicle density at an intersection using data obtained in real-time.

2.6.1 Webster Method

Webster suggested mathematical model for determining the optimal cycle length to reduce vehicle delay. Other researchers discovered that when the maximum flow ratio is close to unity, this model fails. As demand is roughly equal to lane availability, this occurs[64]. Webster created a stochastic delay model to estimate the total vehicle delay. Webster calculated the optimum cycle length based on this model to reduce overall vehicle lag. Other researchers have found that when the maximum flow ratio is close to unity, this model fails. As demand is roughly equal to lane availability, this occurs [79].

Webster's method necessitates the calculation of vehicle density 'q' for all movements on all paths to the junction, as well as the saturation flows 's' of the approaches. The flow ratio is calculated as the ratio of demand of traffic flow rate to the saturation flow rate of specific lane groups. Saturation flows are calculated based on lane width [73] [72]. These variables are utilized to calculate signal cycle length, which is the amount of time it takes to finish a signal series. The cycle period contains both phases' missed cycles as well as the green time.

Since drivers without the right of entry must wait for the green signal, traffic signals cause delays [61] [51]. Long delays at signalised intersections, according to [76] and [30], facilitate red-light running as drivers become impatient. As a consequence, the calculation of delays and queue lengths that may occur as a result of the implementation of a strategy for signal control is sacred and forms an integral part of the design of traffic signals. Since delay is the additional travel time encountered by drivers, passengers, or pedestrians in addition to the actual travel time, it is essential to transportation management agencies for policy and decision making [58]. It's a crucial factor in calculating junction productivity and network capacity [25].

For the study and design of road junctions for optimal control systems, advanced societies have developed highly sophisticated tools that they use instead of mathematical models. Surprisingly, the majority of today's junction analysis and design software has either a direct or an indirect connection to Webster's analytical models, which were developed in 1958. The Split Cycle Offset Optimization Technique (SCOOT) and SPOT, a decentralised, social as well as economic optimization method for real-time signal settings real-time specifically for separated junctions based on arrival flow pattern predictions, are two examples of software. SCOOT and SPOT are currently being used in the United Kingdom and Italy, respectively; other countries have also implemented them[54] [45].

2.7 Actuated Time Control

Information collected through actuated control, the process of detecting the presence of a vehicle through sensors in a traffic signal system, is used to adapt the control operation based on any fluctuations in traffic demand. It helps decide the time for which a green signal operates depending on traffic demand at the time. This value can differ from cycle to cycle since the cycle length and green time allocation is unknown in advance. The parameters on which this process is based, for each signal group, are as follows:

- Maximum green time
- Minimum green time
- Vehicle extension

During the minimum green time, traffic signals are green independent of the demand of traffic. After a minimum green time, actuated control uses the gap-seek logic to respond to traffic fluctuations, the green signal is extended until the presence of vehicles is detected or until the maximum green time has been reached [78].

For intersections almost in saturated conditions, actuated control behaves like a fixed-time control intersection, with signal groups assuming the maximum green time value permitted by the traffic signal control timing.

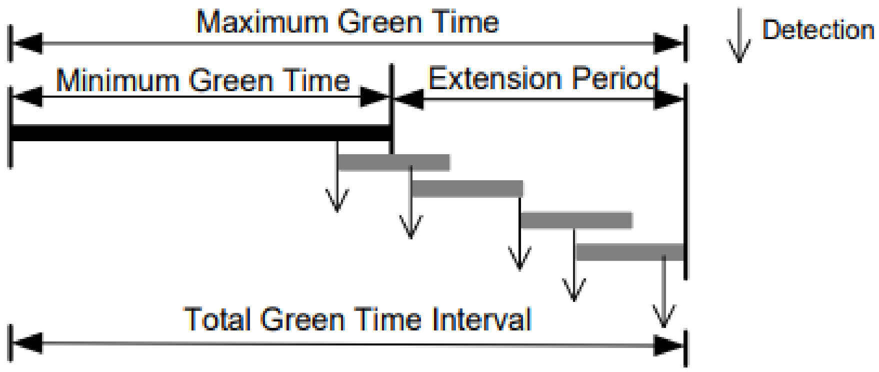

FIGURE 2.5: Green time extension

There are also others features regulation options for actuated control, namely phases can be skipped, if there is no call in the sensor, thus allowing the controller to reallocate the unused time to a subsequent phase. Another approach is incorporating decision-making, where a timing plan is selected from a library according to actual traffic conditions collected through sensors in intersection.

When timed to prioritise vehicle movements only, actuated signals prioritise movement along the primary corridor and can create barriers for cross traffic and pedestrians. Where actuated signals are used, they should be timed to be as sensitive to activation as possible, with as little delay as possible. Actuated traffic controllers are designed to assess real-time traffic conditions using vehicle detection and respond appropriately to preserve the highest possible level of efficiency under varying traffic conditions [62].

Modern traffic controllers, on the other hand, are advanced electronic timers that are programmed to respond in a specific way when a sensor's switch (or detector) is actuated. Beyond the fact that a service request occurs, the traffic controller has no idea what the actual state of the traffic is, and it has no specified aim to accomplish by objectively changing its performance. The output is solely controlled by the stimulus-response relationship, with little regard for the intersection as a whole.

2.7.1 Traffic Actuated controller

Inductive detectors are used in traffic-actuated monitoring methods to observe the current traffic condition. During the red process, the traffic-actuated controller must be able to decide if the last vehicle in the queue created at the stop line has left [81]. This detection is done by calculating the distance between vehicles and is useful for extending or terminating green time efficiently. If the distance between the vehicles exceeds the threshold limit gap, the green time is over [5]. The efficiency of the actuated system is influenced by the optimum location of detectors at an intersection.

2.7.2 Traffic Simulator

Simulations are done using traffic simulator SUMO. Simulation of Urban Mobility SUMO [2] is an open-source road simulation package, developed by the German Aerospace Center (DLR), that simulates traffic behaviour, allows for road construction, traffic light policy implementation, and traffic data collection. In comparison to other simulation tools, SUMO [1] offers more model expansion options with less complexity. Furthermore, Sumo allows users to simulate traffic using geographic data.

SUMO has a tool ActivityGen that allows to simulate individuals travelling to and from work or school. As a result, extremely comprehensive information such as where inhabitants live and work, as well as the location of schools, is required. Previous studies focus on using geographical population distribution to create traffic demand. Codeca et al. [17] reconstructed a 24 hour scenario of Luxembourg city including geographic population distribution, morning and evening rush hours, as well as buses and bus terminals. However, accuracy cannot be proven without a real-world comparison and correction. Asano et al. [11] used ActivityGen to produce OD data for a scenario in Kobe, Japan and discovered that adjusting the speed limit of the road brought the simulated data closer to the traffic census data using the default parameters.

Chapter 3

Methodology

An overview of the whole process is discussed in this chapter, which is used to achieve the desired target. The description of all the major steps that were performed is also shown.

A virtual experiment employing traffic simulation is an efficient technique to address current and future issues. The most critical factors in creating a real-world simulation are a detailed road network and the associated traffic demand. Other factors that influence simulation accuracy include the road choice algorithm [47], simulation software package selection [57], traffic light control methods [43], and so on. Although most of the modelling software packages can import an open-source city map as a road network [57], real-time traffic demands are not easy to cater.

First, we modelled the desired intersection by using Eclipse SUMO which is a microscopic traffic simulator [44]. There are six major steps in the signal design process. They contain the following:

- Designing of Phase
- Calculation of yellow time and clearance time
- Persistence of cycle length
- Assigning of green time
- The performance evaluation of the above design

It is difficult to model traffic flow directly from the microscopic information that controls individual vehicle motion. Microscopic traffic flow modelling aims to explain the dynamics of individual vehicles as a function of its neighbouring vehicle's positions and speeds [29]. Certain characteristics of traffic flow, on the other hand, are independent of the details of the underlying processes. To avoid collision between vehicles requires the average velocity V in a locally uniform traffic flow to decrease with an increase in vehicle density ρ. To find the averages, some relations between V and ρ have to be known.

$$\frac{dV(\rho)}{d\rho} < 0 \tag{3.1}$$

V reaches a finite value ,v_{max}, for very low traffic volumes, while no motion is possible at the maximum density ,ρ_{max}, when every vehicle stands bumper to bumper.

$$V(0) = v_{max} \tag{3.2}$$

$$V(\rho_{max}) = 0 \tag{3.3}$$

The resulting average flux of the vehicles which is defined as the average number of vehicles passing a given cross section per unit time $Q(\rho) = \rho V(\rho)$, is a function that disappears at $\rho = 0$ and $\rho = \rho_{max}$ and has a maximum at a certain intermediate density.

3.1 Model Formulation

Phase design aims to divide opposing movements in a junction into different phases so that movements within each phase are not in collision. A large number of steps are needed to isolate all of the movements without causing conflicts. We have considered a four-legged junction with through traffic and right turns to demonstrate the different phase plan choices. Moreover, turning left isn't taken.

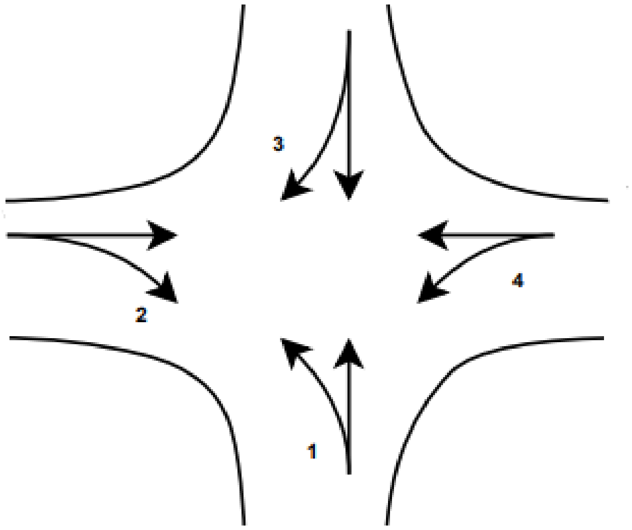

FIGURE 3.1: Description of Phases on an intersection

3.1.1 Four Phase Signals

This phase's plan is suitable for urban areas where turning movements are comparable to through movements where through and turning traffic must share the same lane. When turning movements are poor, this plan could be inefficient. A third step is formed by the non-conflicting right turn flows of 7 and 8.

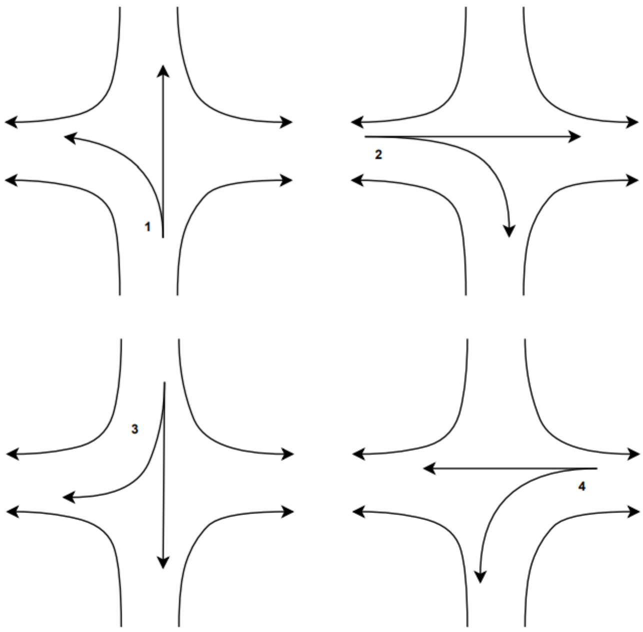

FIGURE 3.2: Detailed Description of Phases on an intersection

3.1.2 Roads Network

The intersection is comprised of 4 roads with 5 lanes. A lane includes geometry, knowledge about the vehicle classes allowed on it, and highest speed that can be reached. Hence, more than two edges are used to represent lanes of the roads [40]. SUMO provides tool that allows to communicate with Python program. In order to simulate the traffic behavior, SUMO requires the simulation files that are written in xml format containing configurations regarding to simulation.

Name	**Extension**	**Description**
Node	<NAME>.nod.xml	Describes all the node in the simulation network
Edge	<NAME>.edg.xml	Describes all the edges between the nodes
Type	<NAME>.xml	Describes number of lanes and speed limit of roads
Network	<NAME>.net.xml	Describes the environment (roads and intersections)
Route	<NAME>.rou.xml	Describes the route of all vehicles that are in network
Configuration	<NAME>.sumocfg	Describes the configuration of simulator

Table 3.1: Simulation files description

Network, route and configuration files are essential for simulation. Node, edge and type files are required to construct the network file. SUMO provides some additional packages that allow user to edit every element of road infrastructure. Among these packages provided by sumo, following are used in this thesis research.

Road network can be created with the help of a tool "netgen" or "netconvert". Other popular formats, such as shapefiles and Open Street Maps, are also supported. We have used Open Street maps with network files for model formulation. These applications import digital road network from different sources for example: google map or open street maps and generate road networks that can be used by other tools from the package [39].

3.1.3 Netconvert

It is command line tool that come along with SUMO software. It is used to convert the node, edge and type files into network file. It is also used for the conversion of map file from other sources like OpenStreetMap (OSM) and VISUM-network. In the case of singe agent, the network is constructed from node and edge files while in the case of multi-agent, network is constructed from OSM file.

3.1.4 Polyconvert

It is command line tool used to import geometrical shapes (polygons or points of interest) from different sources. It is used to improve the visual experience of simulation. The map of multi-agent environment is improved by polyconvert tool. The Figure 3.3 compare the basic and improved network of multi-agent environment.

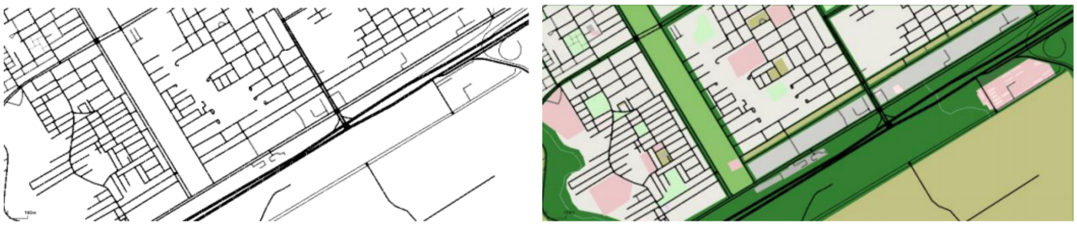

FIGURE 3.3: Improved network

3.1.5 NetEdit

NetEdit is GUI based network editor. It is used for editing all aspects of existing network. In this thesis it is used to edit attribute related to intersection and roads. For intersection, it is used to edit name, routing, phase, phase cycle and phase duration and for roads, it is used to edit name, width and incorrect connections. It is the best tool to edit those networks that are imported from other sources like OSM and VISUM-network.

3.1.6 TraCI

TraCI is the short term for Traffic Control Interface. It gives access to simulation values like vehicle position, velocity, acceleration, intersection phase etc. It is imported in Python programming language as a module and gives access to simulation in Python program. By using TraCI useful information like state is obtained from the simulation environment and action is send to simulation environment.

3.1.7 Simulation

SUMO provides two type of simulations, one is terminal based and other is Graphical User Interface (GUI) based. Terminal based simulation works in background and does not show road network and traffic. It is used to retrieve simulation data. On the other hand, GUI based simulation is used for presentation purpose as it shows the road network and traffic on it. Terminal based simulation is much faster than GUI, that is why it is used in training process of reinforcement learning agents.

3.1.8 Population Definition

Traffic data are crucial when simulating real-world traffic. Some people look for the real-world data to develop a model, while others use real-world data to validate their simulation results. The majority of current research uses three ways to obtain real traffic demand: trajectory data from cameras, speed data from induction loops detectors, and floating car data (FCD) from data loggers [70]. It is becoming increasingly difficult to acquire approval to place cameras on public highways due to increasingly severe privacy policies. Installing induction loop detectors has various problems, and paving induction loops on each lane is an additional and frequently impossible amount of research work.

For many researchers, obtaining real traffic data is always a challenge. The majority of research projects involving the creation of traffic scenarios benefit from working with the government to access data sources.

It is important to generate traffic with high reliability. In order to maintain this, different types of distribution are used to mimic traffic Experimental Setup behavior. Three type of distribution are common in use. These are Uniform, Gaussian and Weibull distribution.Uniform distribution is one of the simplest distribution and it generates almost equal number of vehicles at every timestep of simulation. This is not usually the case of real-world traffic generation. So, it is not a good idea to use this distribution to generate traffic in simulation. Gaussian distribution generates different number of vehicles but does not mimic the real-world traffic as it gradually increases and decreases. In real-world, traffic flow is high in peak hours especially in morning and then decreases slowly. Such type of behavior is shown in Weibull distribution and that is why it is used in this thesis research.

Traffic Scenario	Traffic Generation
Low	600
High	3000
East-West(EW)	1500
North-South (NS)	1500

Table 3.2: Traffic generation in different traffic scenarios

The total number of cars generated in each traffic scenario and timestep at which these cars entered the simulation environment is known and this information is used to define the source and destination of generated cars. Let start with the simplest case of four-way intersection. Each compass direction of intersection has some probability that defines the portion of cars being generated at that side of intersection. This probability distribution of cars in different traffic scenarios are listed in Table 3.3.

Traffic Scenario	East	West	North	South
Low	0.25	0.25	0.25	0.25
High	0.25	0.25	0.25	0.25
East-West (EW)	0.40	0.40	0.10	0.10
North-South (NS)	0.10	0.10	0.40	0.40

Table 3.3: Traffic generation in different traffic scenarios

In the case of low and high traffic scenarios, car generation probability is same for all directions (East, West, North and South). The Table 3.3 defines the source of generated car, but destination of car still needed to be defined. In this thesis research, it is decided that 60% of cars goes straight, 20% of cars goes left and the remaining 20% of cars goes right. Table 3.4 lists the exact probability distribution for all possible combination of source and destination for low and high traffic scenario.

East-West and North-South traffic scenarios are generated to mimic the busy roadways in big cities. These scenarios also force the reinforcement learning agent, not to be biased towards one compass direction of intersection. In the case of EW traffic scenario, 80% of the traffic is coming from East and West directions and remaining 20% is coming from North and South directions. The cars generated on East and West directions have the same destination probability that is described in low and high traffic scenarios. In the case of NS traffic scenario 80% of the traffic is coming from North and South directions and remaining 20% is coming from East and West directions. Exact probability distribution for all possible combinations of sources and destinations for East-West traffic scenario is given in Table 3-5 and for North-South traffic scenario, it is given in Table 3-6.

Directions	Source	Destination	Probability
Straight	East	West	0.15
	West	East	0.15
	North	South	0.15
	South	North	0.15
Left	East	South	0.05
	West	North	0.05
	North	East	0.05
	South	West	0.05
Right	East	North	0.05
	West	South	0.05
	North	West	0.05
	South	East	0.05

TABLE 3.4: Low and High traffic scenario probability distribution

Directions	Source	Destination	Probability
Straight	East	West	0.24
	West	East	0.24
	North	South	0.06
	South	North	0.06
Left	East	South	0.08
	West	North	0.08
	North	East	0.02
	South	West	0.02
Right	East	North	0.08
	West	South	0.08
	North	West	0.02
	South	East	0.02

TABLE 3.5: EW traffic scenario probability distribution

Directions	Source	Destination	Probability
Straight	East	West	0.06
	West	East	0.06
	North	South	0.24
	South	North	0.24
Left	East	South	0.02
	West	North	0.02
	North	East	0.08
	South	West	0.08
Right	East	North	0.02
	West	South	0.02
	North	West	0.08
	South	East	0.08

TABLE 3.6: NS traffic scenario probability distribution

To generate traffic in SUMO simulation environment, route file is required. This file contains all the information about source, destination, vehicle departure time and route Experimental Setup between source and destination for each car. The above discussion describes when the car is generated in network and what is its source and destination location. The missing information is the optimal route between source and destination location. Finding optimal path does not seems to be good in the case of one intersection, SUMO provides package named DUAROUTER (Dynamic User Assignment Router). This package provides pathplaining algorithms (Dijkstras, A^*, Contraction Hierarchies and CHWrapper) to find the shortest path between source and destination location. In this thesis research A^* algorithm is used to find the optimal path between source and destination location.

Activity based demand generation (activitygen) generates demand from a description of the population in the network [20]. It is comprised of the network file which is the SUMO .net file, statistics .sat file contains the description of the population, .trips file generates the routes of the vehicles [13]. The statistics file contains the information related to inhabitants, households, children age limit, retirement age limit, car rate, unemployment rate, foot distance limit, coming and outgoing traffic. This file generates the vehicle as per the demand of the population. All these parameters related to Islamabad city are listed in the table given below.

Parameters name	Value type	Value
Inhabitants	Integer	1.015 million
Households	Integer	336,182
Children age limit	Integer	18
Retirement age limit	Integer	60
Car rate	Float [0,1]	0.5
Unemployment rate	Float	4.45
Foot distance limit	Float	350
Incoming traffic	Integer	5000
Outgoing traffic	Integer [0,inhabitants]	5000

Table 3.7: Population parameters used to generate vehicular input

Figure 3.4 and 3.5 demonstrate how to import networks from OpenStreetMap (osm) [3] and the flow chart used to import network files combined with OpenStreetMap file respectively. Additionally, netconvert reads the ”XML” representation of a road network that offers the readable form when defining a road network.

FIGURE 3.4: Original OpenStreetMap network of Srinagar Highway

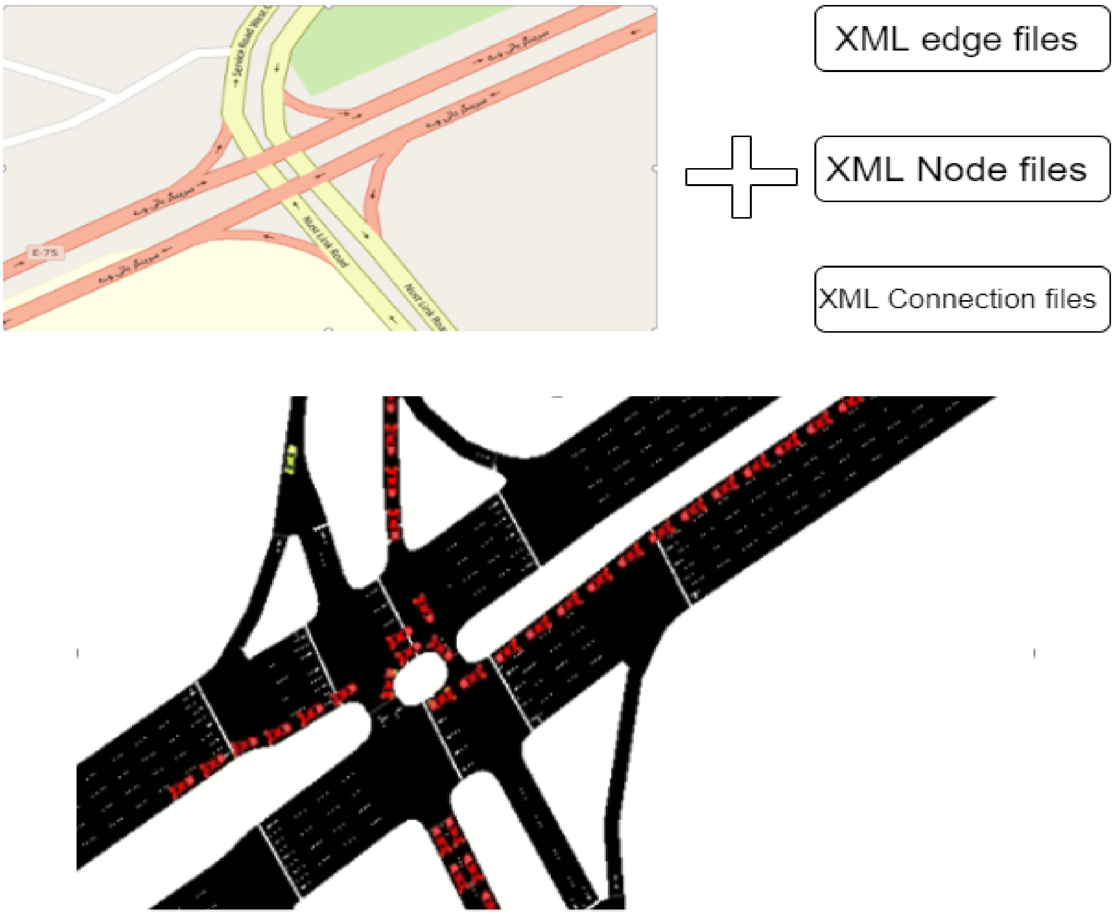

FIGURE 3.5: Road Network using Open street map with link of .net files

The goal of microscopic traffic flow modelling is to explain the dynamics of each vehicle as a function of its neighbours' positions and speeds. Car-following and Lane-changing are two dynamic processes that must be considered in general.

We'll start by describing car–following models, assuming a road with a single lane, as a much more sophisticated methods is required when multiple lanes are involved. All cars' positions and velocities are denoted by x_i and v_i, respectively, with the index i increasing in the downward direction.

3.1.9 Car Following Model

The development of a car-following theory will always begin with the reasonable assumption that any change in the velocity is solely made if the current velocity does not coexist with a desired velocity V_{des}, determined by safety considerations, legal constraints, and other factors. A relaxation on some time scale d is the simplest dynamic that explains attempts of a driver to approach the desired velocity.

$$\frac{dv_i(t)}{dt} = \frac{v_{des} - v_i}{\pi} \tag{3.4}$$

This basic concept form the basis of almost every car-following theory. This dynamical relationship is usually understood as a stimulus-response–ansatz rather than a relaxation process. The reciprocal of π is commonly referred to as the "sensitivity" in this case.

$$\frac{dv_i(t)}{dt} = \frac{v_{i+1}(t) - v_i(t)}{\pi} \tag{3.5}$$

Pipes was the first to propose this dynamical equation. He derived this equation through the statement that the space between cars needs to increase in a linear manner with speed and then the resulting relationship is to be differentiated. When one solves this equation, it is easily realizable that steady-state solution, in which every car moves at an identical speed, is always stable, implying that effects due to clustering are not present[41].

Since delay times are known to destabilise initially stable systems, the instability of the the steady-state in this model is not surprising when $\Delta t/\pi$ is large enough. The thorough analysis reveals that for $\Delta t/\pi = 1/2$, the stability limit has been reached.

Although random grouping is modelled in this way, the model's applicability is limited to the fact that the dynamics are unaffected by the vehicle distances. Two problems can arise from this fact. Firstly, the cars collide in this model, and secondly the vehicle dynamics are not density-dependent, so the speed-density relationship cannot be obtained from it.

Gazis, Herman, and Potts solved this problem by introducing a relaxation time (sensitivity), which is dependent on the distance between the cars

$$\frac{dv_i(t)}{dt} = \alpha \frac{v_{i+1} - v_i}{x_{i+1} - x_i}\Big|_{t-\Delta t} \tag{3.6}$$

The equations of the model can be combined, and because the right-hand side is the derivative of alpha with respect to time $ln(x_{i+1} - x_i)$, the density–dependent homogeneous steady-state solution is

$$v \propto \ln(\frac{\rho_{jam}}{\rho}) \tag{3.7}$$

where ρ_{jam} represents the density of jam, with a velocity of zero. Greenberg's macroscopic theory is supported by this finding. The flux $q = \rho v$ disappears for vanishing density, however, since the divergence is logarithmic, we have a qualitatively right fundamental diagram.

Edie suggested that a vehicle's sensitivity is also affected by its momentary velocity. He hypothesised that velocity sensitivity is inversely proportional to spacing, giving rise to the following equation.

$$\frac{dv_i(t)}{dt} = \alpha' v_i(t) \frac{v_{i+1} - v_i}{(x_{i+1} - x_i)^2}\Big|_{t-\Delta t} \tag{3.8}$$

However, the most interesting aspect of Edie's work was that he noticed a discontinuity in the fundamental diagram, being the first to do so. This contributed to the concept of distinguishing amongst two separate "modes of action," free flow and congested flow, which correspond to two different sensitivity α' values.

$$\frac{dv_i(t)}{dt} = \alpha' v_i(t)^m \frac{v_{i+1} - v_i}{(x_{i+1} - x_i)^l}\Big|_{t-\Delta t} \tag{3.9}$$

The exponents l and m are free parameters in this case. Obtaining these exponents from empirical evidence, however, proved difficult. The speed–density–relation of a homogeneous flow can be obtained by directly integrating the dynamical equations. As an example, for l=2 and m = 0, the relationship between speed and density is linear, agreeing with Greenshields' findings.

3.2 Traffic light control methods

Two types of traffic signal plans have been used for Traffic light control:

- Fixed traffic light control
- Actuated traffic light control

The traffic light control at the intersection is designed according to the following assumptions and limitations:

- 5000 number of vehicles are routed on each leg at the intersection
- No left turn is allowed at the intersection however separate road is used for left turn only
- The minimum time for the green time in fixed traffic control is 50 seconds and 25 seconds for actuated traffic light control
- The yellow light for both traffic light control is set for 5 seconds during the transition from red light to green light
- The main phases are given equal amounts of green time

The Webster method has been used to calculate the least cumulative delay for vehicles at a signalized intersection. Mostly during the approach of development, the fieldwork consists of determining (i) Saturation flow S per unit time on each approach of the intersection (ii) the normal flow "q" on each approach. Traffic lights are generated with a fixed cycle time of the 90s. Webster's algorithm works by first optimizing cycle duration by minimizing vehicle delay for a given intersection and then allocating efficient green times to the given green period phases accordingly.

3.2.1 The traffic light control Algorithm

The key concept is that each traffic light tries to solve the traffic congestion in its front. He does this by looking through the incoming lanes and measuring the lengths of the jams on these lanes. if traffic develops in one of these lanes, the lanes become green for a long period. Apart from these assumptions, a range of factors keeps the device from fluctuating and evolving too rapidly or too strongly. This is accomplished by extending the size of a green period only if a traffic jam exceeds a threshold. Furthermore, the traffic jam must last for a certain period[37] [75] [22].

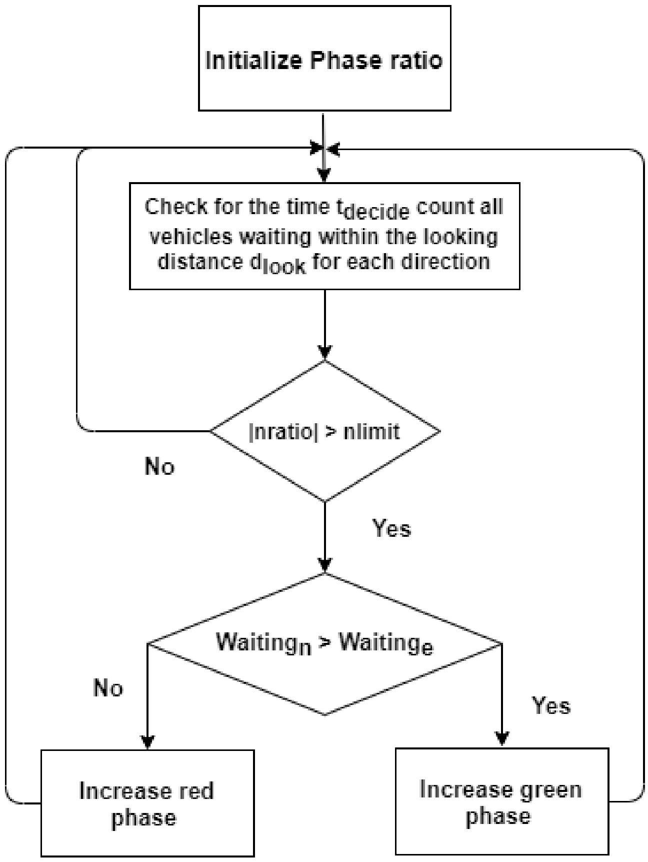

FIGURE 3.6: Traffic light control flow chart

Where **tr** and **tg** are proportions for red and green phases, **dlook** represents looking distance, **tdecide** represents decision time interval. **nratio** is calculated as (waiting n - waiting e) / waiting n and **nlimit** is decision threshold.

3.2.2 Fixed traffic light control

Every traffic light was generated using a fixed cycle and a default cycle time of 50 seconds. Programs were generated wit 4 green phases:

- Srinagar_highway_ISB _RWP
- Srinagar_highway RWP_ISB
- Service_road_G11 _NUST
- Service _road _NUST _G11

lightgray **Phases Names**	**Duration**
Srinagar_highway_ISB _RWP	50 sec
Yellow Time	7 sec
Srinagar_highway RWP_ISB	50 sec
Yellow Time	7 sec
Service_road_G11 _NUST	50 sec
Yellow Time	7 sec
Service _road _NUST _G11	50 sec

TABLE 3.8: Duration plan for Fixed Traffic light control

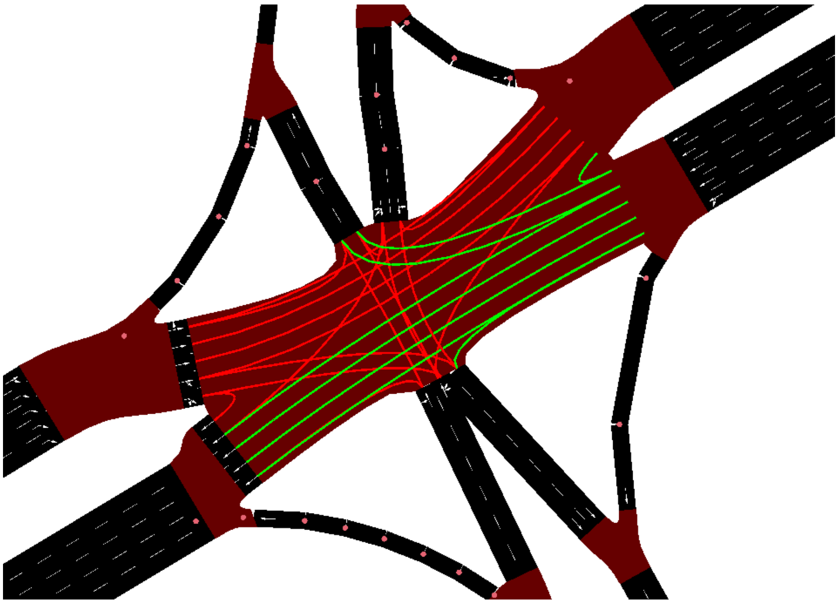

Figure 3.7: Green lines showing fixed Signal plan of Srinagar highway facing Islamabad to Rawalpindi having straight and right turn directions

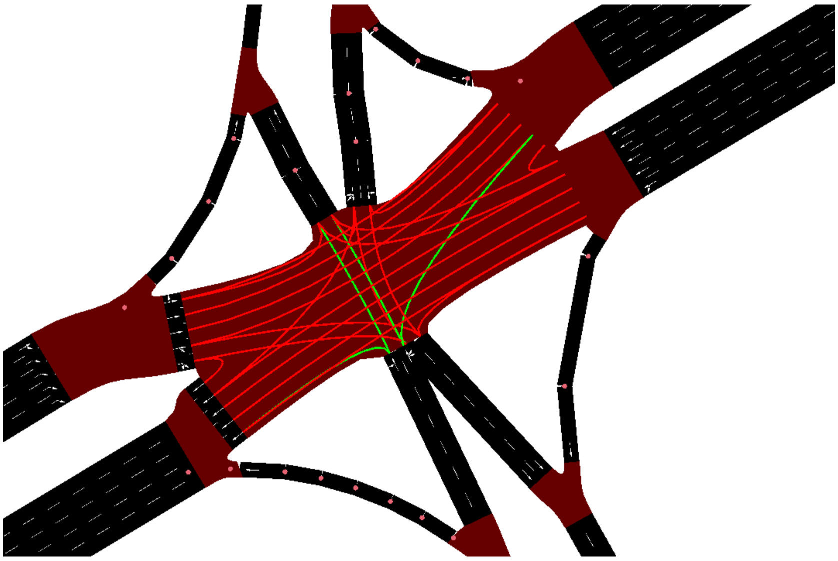

Figure 3.8: Green lines showing fixed Signal plan of Service road facing NUST to G11 having straight and right turn directions

3.2.3 Actuated traffic light control

Actuated traffic control is used whenever continuous traffic is detected and it works by extending traffic phases[24]. Subsequent to detecting a sufficient time gap between consecutive vehicles, it switches to the next phase allowing for improved distribution of green-time amidst phases as well as affecting cycle duration against dynamic traffic conditions. It uses phase attributes minimum duration “minDur” and maximum duration “maxDur” rather than duration to define the acceptable range of time duration for every phase. The detectors are placed which

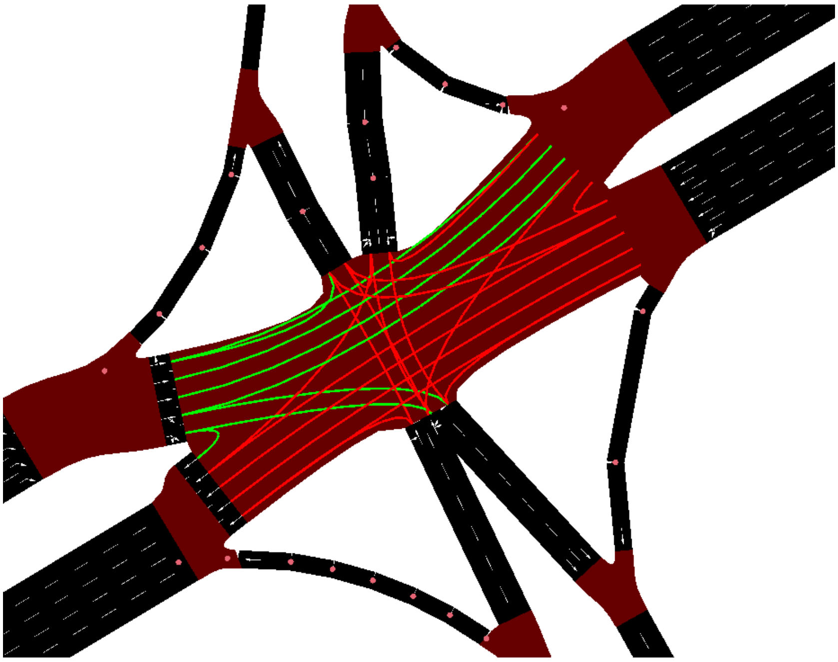

FIGURE 3.9: Green lines showing Fixed Signal plan of Srinagar highway facing Rawalpindi to Islamabad having straight and right turn directions

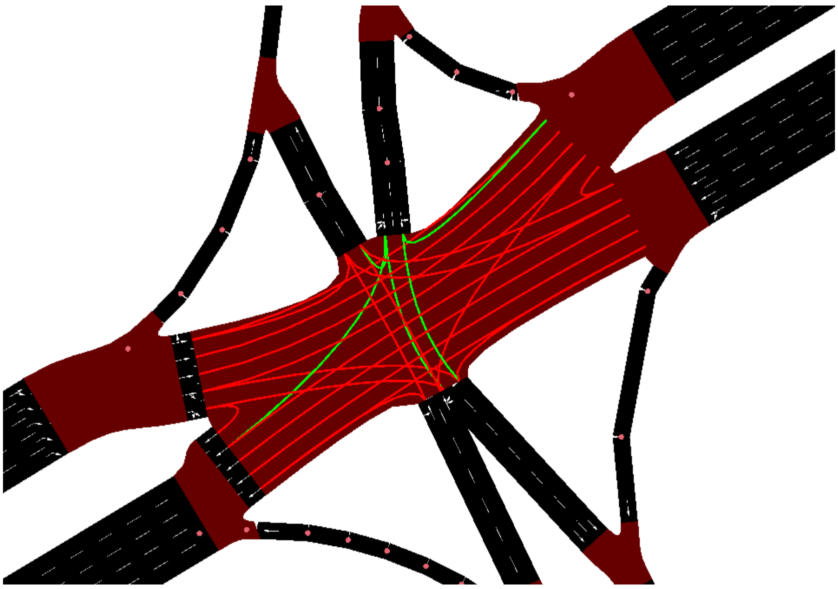

FIGURE 3.10: Green lines showing Fixed Signal plan of Service road facing G11 to NUST having straight and right turn directions

determine the lengths of incoming lanes. The detector will be positioned on the predecessor lane at a computed distance if the coming lanes are overly short and if there is a series of unique former lanes. A phase's length must not be longer or shorter than predefined thresholds, in addition to the standard value given at the start. The entire algorithm is described below.

Like fixed light control, the actuated traffic light control has also 4 set of green phases same as mentioned above.

lightgray **Phases Names**	**Duration**	**Maximum**	**Minimum**
Srinagar_highway_ISB _RWP	50 sec	50 sec	17 sec
Yellow Time	7sec		
Srinagar_highway RWP_ISB	50 sec	50 sec	17 sec
Yellow Time	7sec		
Service_road_G11 _NUST	50 sec	50 sec	17 sec
Yellow Time	7sec		
Service _road _NUST _G11	50 sec	50 sec	17 sec

TABLE 3.9: Duration plan for Actuated Traffic light control

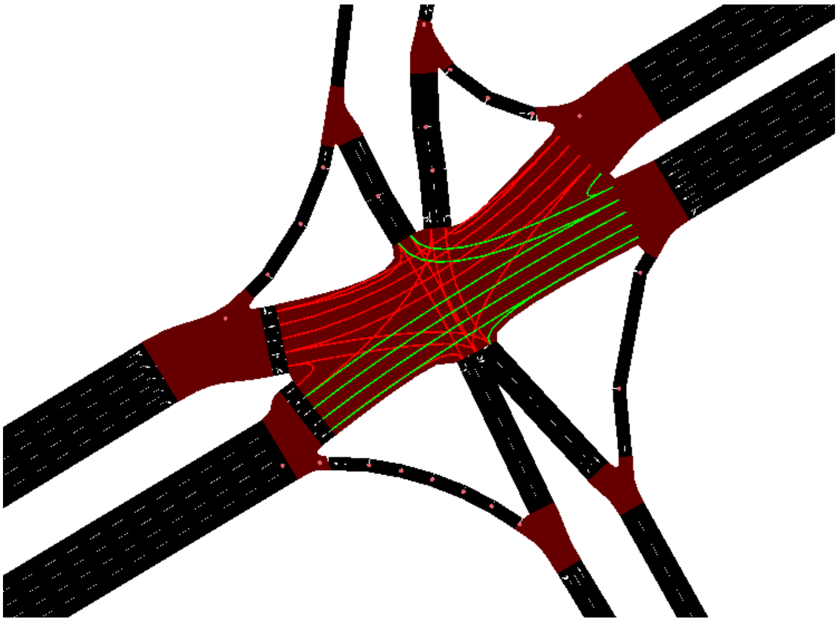

FIGURE 3.11: Green lines showing Actuated Signal plan of Srinagar highway facing Islamabad to Rawalpindi having straight and right turn directions

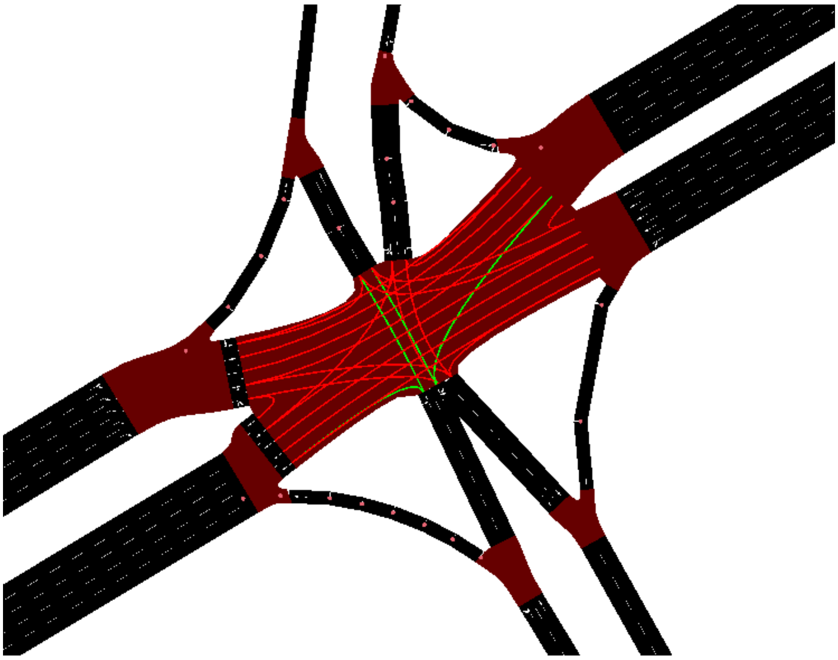

FIGURE 3.12: Green lines showing Actuated Signal plan of Service road facing NUST to G11 having straight and right turn directions

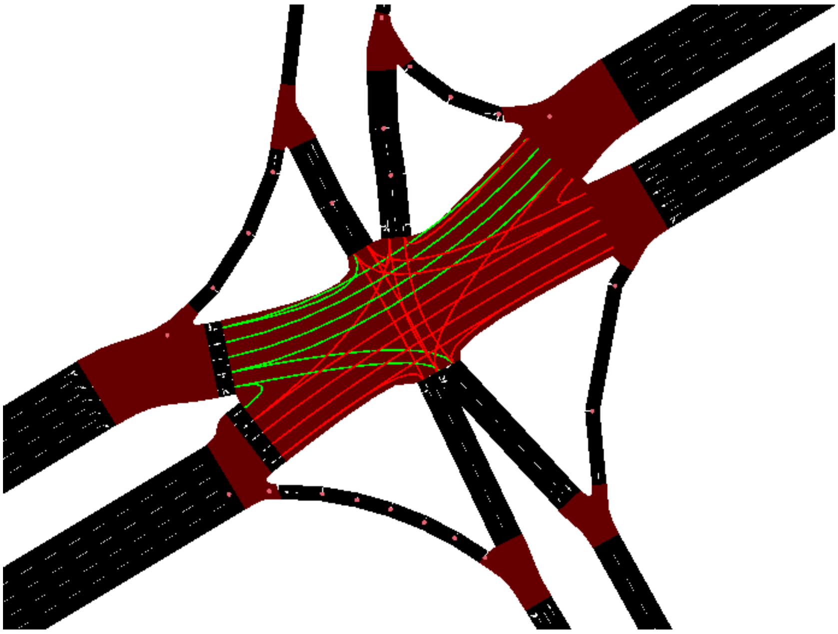

FIGURE 3.13: Green lines showing Actuated Signal plan of Srinagar highway facing Rawalpindi to Islamabad having straight and right turn directions

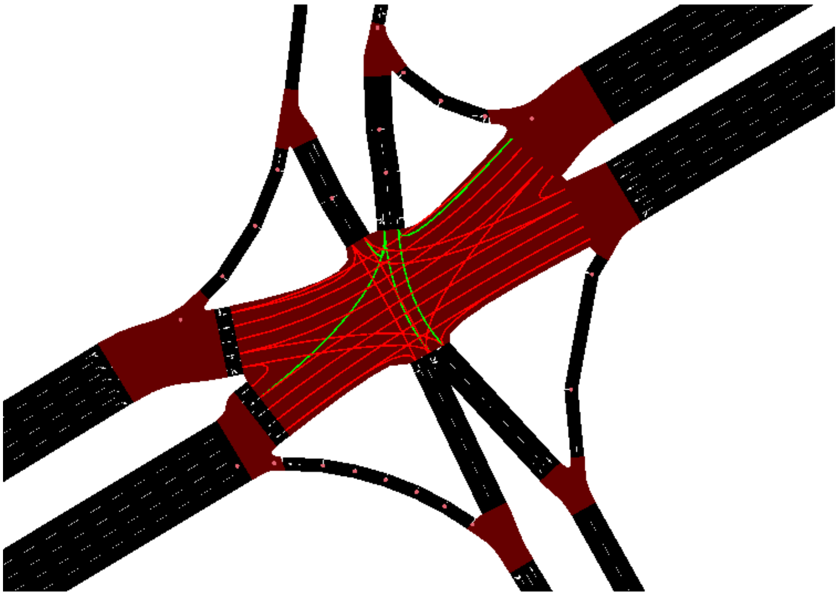

FIGURE 3.14: Green lines showing Actuated Signal plan of Service road facing G11 to NUST having straight and right turn directions

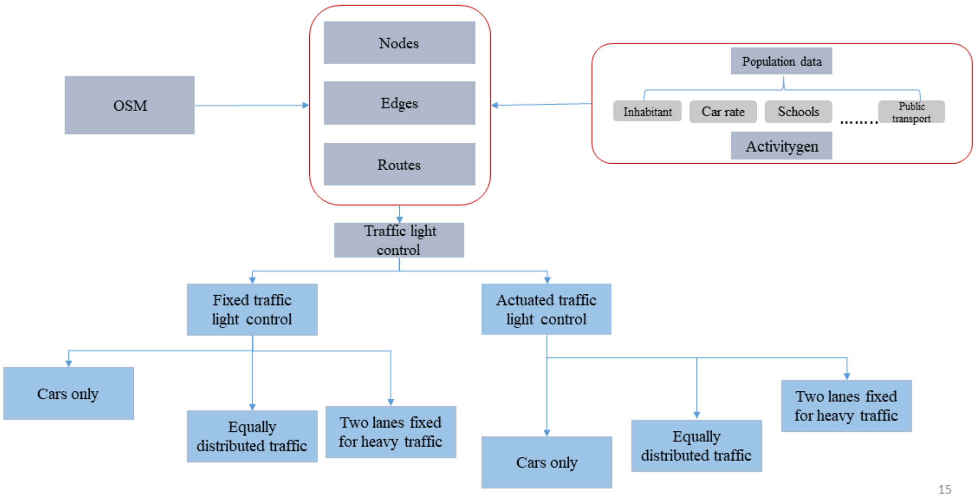

FIGURE 3.15: Flow chart of Methodology

Chapter 4

Results

In a large-scale two-dimensional urban network, particularly in the fourth largest Islamabad-Rawalpindi metropolitan area in the country with a population of about 3.1 million, the greatest challenge is to monitor and organize traffic lights. The results of fixed and actuated traffic control methods, on an intersection of Srinagar Highway at the east-west of Islamabad, are discussed in this chapter. The intersection comprises 4 roads that have 5 lanes and 1 single road for left turn only. The goal of this research is to minimize vehicle staying time at the intersection by reducing the queue length of each side of the junction.

The SUMO simulator is a C++-based open-source highly portable microscopic road traffic simulation package designed to handle large road networks. SUMO can be integrated with Open Street Map (OSM) and can use various road network maps. It is possible to import distinct map scenarios from OSM. OSM is an online world map service that enables the export of maps along with various data formats. To find the optimal routes, we import a city map from the OSM map library and incorporate it into SUMO.

We also implemented SUMO TraCI (Traffic control interface) extension which allows for dynamic control for the traffic lights at runtime [74]. Running as a client, and calling the SUMO simulation tools as a server, TraCI not only allows for modification of traffic light timings while in simulation, but it also allows for information access of individual objects, such as vehicles. This makes it possible to extract the vehicle position and velocity matrices needed to calculate delays and queue lengths.

4.1 Fixed-Time control (Pre-Timed control)

Fixed time signal control uses predetermined time intervals that, irrespective of changes in traffic levels, is the same every time the signal cycles. Based on historical knowledge, fixed time control offering the highest green period to the heaviest traffic flow. The duration, regardless of the existence or absence of traffic demand, is replicated over and over. Adjacent intersections run at the same cycle length when functioning as part of a system and have fixed backups.

In general, for reasons of regularity, network organization, predictability, and reducing unwanted delays, fixed-time signals are the standard in urban areas. Less initial and continuous maintenance costs are covered for fixed time traffic signals. For the prediction of traffic demand, pre-defined traffic control methods are most preferable. The most commonly used measure of effectiveness for signalized intersections is a delay. Delay to the traffic is computed by counting the number of vehicles in the queue at fixed intervals of time and multiplying this number by the value of the time interval A delay is most commonly used quality for measure the effectiveness of signalized intersection which is to calculate by finding the number of cars in the specified junction [38].

The current signal control method is fixed control where 1 signal and 8 phases are defined. The phase duration varies from one to fifty seconds. There were 10000 vehicles during the simulation run. In the simulation, the speed deviation is set as 0.1 for vehicles. Three sets of configurations are used to evaluate the behaviour of fixed traffic light control. These are

- Cars only in fixed traffic light control
- Equally Distributed traffic with fixed traffic light control
- 2 lanes fixed for heavy traffic in fixed traffic light control

In SUMO fixed-time signal control is optimized using the Webster method (1958). Parameters used for fixed traffic control are:

Saturation Flow S = 1900 veh/lane

Green Time = 50 s

Yellow Time = 7 s

Red time = 150 s

Around 10000 vehicles were simulated over a given period of about half an hour during each simulation run, roughly reflecting a typical traffic load during rush hour traffic.On the dominating approaches, the minimal delay for traffic at a junction is determined by setting the green intervals of the phases in accordance to the respective ratios of flow to saturation flow.

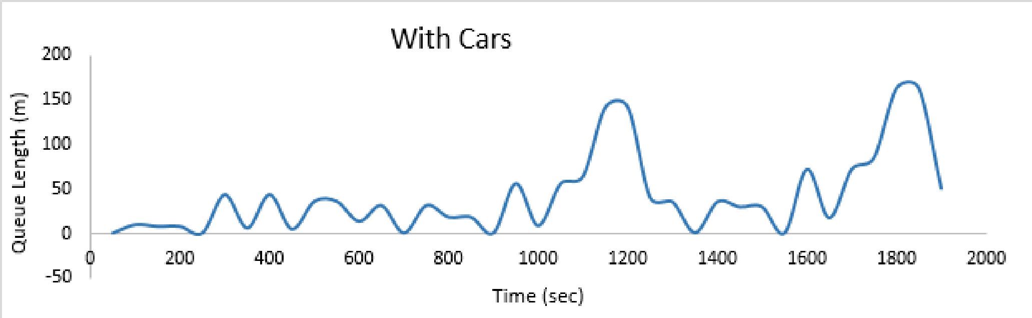

FIGURE 4.1: Configuration of cars in fixed traffic light control

This graph shows the simulation with the restriction of cars only in the traffic. The traffic light is selected as a fixed control. The highest value of queue length for fixed traffic light control is 163 m against 1850 s time step and the lowest value is 0 m of queue length at 50, 250, 700, 900 and 1550 s time step. Every phase in the traffic light plan has 50 s of green time.

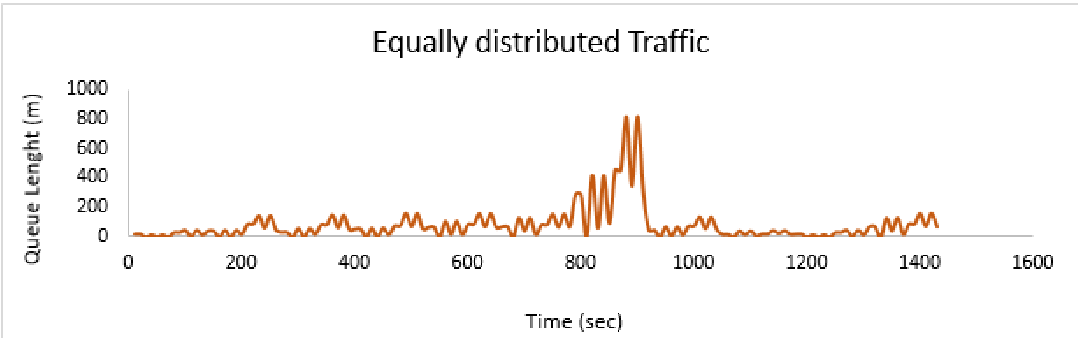

FIGURE 4.2: Configuration of equally distributed traffic in fixed traffic light control

This graph shows the simulation with all types of vehicles such as cars, trucks, buses, bikes and bicycles. The traffic light is selected as a fixed control. The highest value of queue length for fixed traffic light control is 817 m against 880 and 900 s time step and the lowest value is 0 m of queue length at 50, 160, 180, 290, 310, 440, 550, 680, 810, 1070, 1220 and 1330 s time step. Every phase in the traffic light plan has 50 sec of green time.

This graph shows the simulation with the setting of the last 2 lanes fixed for heavy traffic like bus, trucks and loading vehicles. The traffic light plan is selected as a fixed control. The

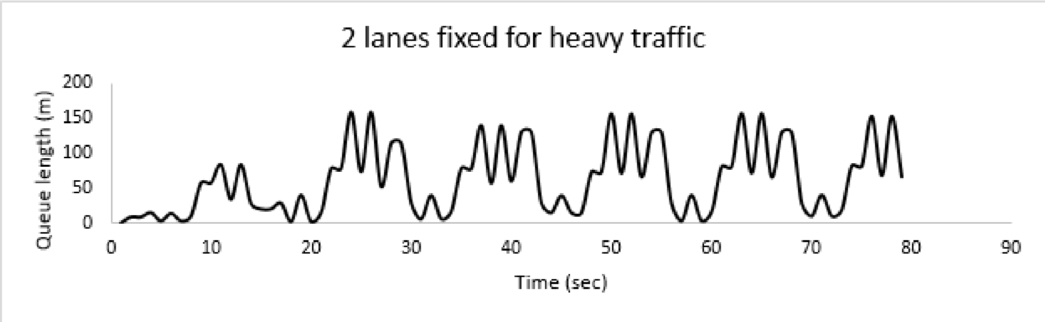

Figure 4.3: Configuration of 2 lanes fixed for heavy traffic in fixed traffic light control

highest value of queue length for fixed traffic light control is 160 m against 24 and 26 sec time step and the lowest value is 0 m of queue length at 50, 250, 700, 900 and 1550 s time step. Every phase in the traffic light plan with 50 s of green time.

The aforementioned graphs show the queue length is affected when the number of vehicles increases gradually. Traffic congestion is heavy during peak hours in the morning and at night. The peak hours of the morning are usually from 7:00 AM to 9:00 AM when people going to their places of employment and 5:00 PM to 10 PM. By comparing this configuration of cars only, equally distributed traffic and 2 lanes fixed for heavy traffic, only cars configuration showing less vehicular delay by minimizing queue length.

Gradually, results show the optimum value of performance rather than rapid decline variations with time as the congestion increases. During the non-congested hours, performance is almost the same, but it shows the variations when the roads are exposed to traffic congestion. When coming to measure the benefits of using bus lanes for private vehicles in the configuration of 2 lanes fixed for heavy vehicles, the simulation did not prove any benefits at all. The major reason for this is because cars that utilise bus lanes either slow down or are blocked by buses. This would cause congestion and results in an increase in queue lengths.

Also, comparison of queue length has been done for four side of intersection to check vehicle input and vehicular delay. Following graph shows the queue length fluctuations for 5 lanes of all sides.

This graph shows the variations in queuing length for Srinagar_highway_ISB_RWP, Srinagar highway_RWP_ISB, Service road_G11_NUST and Service road_NUST_G11. The Left and right sides of the Srinagar highway show the same behaviour of queuing length as both sides have almost equal daily vehicular input. But for the other two sides that are Service road_NUST_G11 and Service road_G11_NUST, there are varying queue lengths. Also, results show that there is

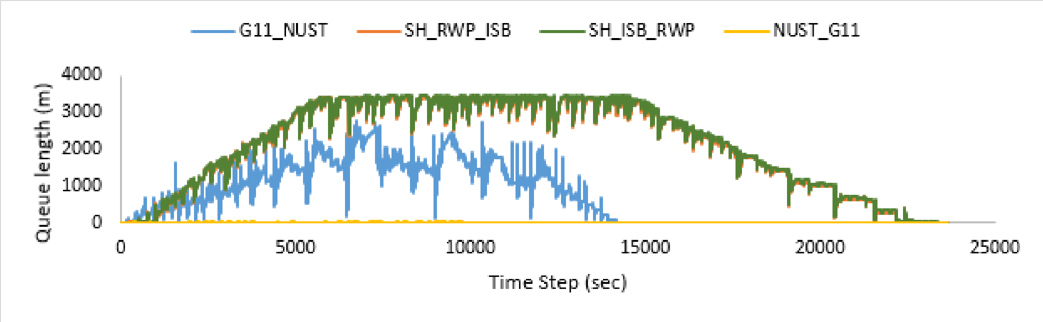

FIGURE 4.4: Comparison of all four sides of an intersection with taking different vehicular input

a small amount of traffic coming from NUST to G11 so that it has the smallest queue length from all of the other directions. So, there is no need of whole 50 sec green time for the phase NUST_G11.

4.2 Actuated time traffic control

The amount of green time can be adjusted by an actuated signal controller based on information from loop detectors, for every cycle. Actuated signals are suitable where traffic levels fluctuate greatly throughout the day.

Pre-timing signal control implements optimized plans but they have fixed timing, hence, it is not intended to respond to rapid fluctuations in traffic flow. The old practices of pre-timing traffic signals, while simple and without requiring professional workers, are laborious, time-consuming and repetitive. Besides, it is understood that signal timing plans age with time i.e. many traffic lights operate with timing plans built months and even years ago. On the other side, actuated signal control responds to change in demand trends by applying a green time window (minimum green to maximum green) in contrast to the green time in pre-timed signal control. Also unlike pre-timed signal control, actuated traffic signal control systems are responsive to traffic flow fluctuations[42]. In Actuated controllers where phases can be skipped or shortened, depending on the demand and where the minimum and maximum green times for each phase are considered.

The Actuated controller is based on three timers to control the green phase as discussed below: minimum green, vehicle extension and maximum green.

- **Minimum green**: The green period that must be covered by the chosen process, usually regulated by the minimum green time for a pedestrian crossing to ensure that the selected phase secure pedestrian passage
- **Extension time (passage time)**: The amount of green time which the controller extends when a vehicle is detected during a green interval. During the green interval, the passage time is extended to a vehicle travelling from the extension detector to the stop line. If the minimum green has expired, the passage time only comes into effect. Based on a 40 kph speed and the distance between the spot line detector and the extension detector with a normal 3-5 s range, it is measured
- **Maximum Green**: Maximum green period for the selected phase. As soon as a conflicting vehicle is identified during which the selected stage is orange, the maximum green period commences [19]

For movements with the highest volume between the minimum and maximum green window, actuated regulation often gives greater priority.

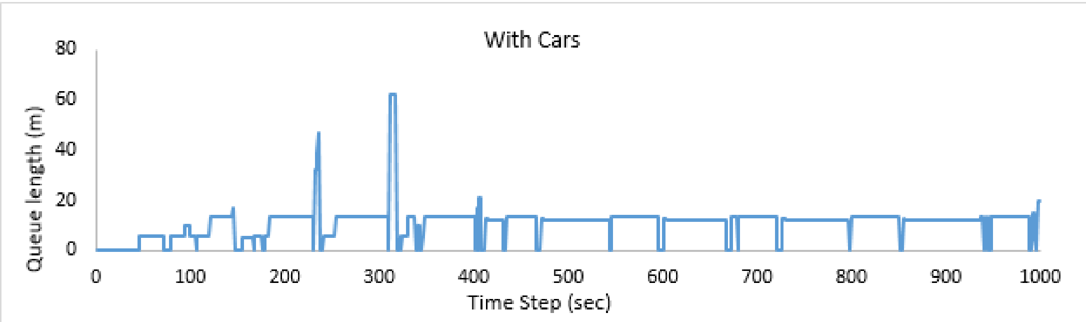

Figure 4.5: Configuration of Cars as vehicular input in Actuated traffic light control

Like fixed time traffic control, all three configurations have been done for actuated traffic control. The aforementioned graph depicts the simulation with Cars and showing fluctuation in queue length with time. The maximum value of queue length for actuated traffic light control with Cars is 61 m in the time step of 316 s. likewise, minimum value for same configuration is 0 m for 0-44, 75, 106, 153, 176, 178, 237, 239, 310, 321, 345, 411, 432, 433, 469, 544, 596, 671, 680, 726, 799, 853, 941 and 995 s.

By comparing with Car's configuration of fixed traffic light control, there is a reduction in the queue length of Car's configuration of actuated traffic light control. There is a sudden increase in number of traffic which results in long queue but gradually getting reduced for to fluctuation in time of actuated control [80].

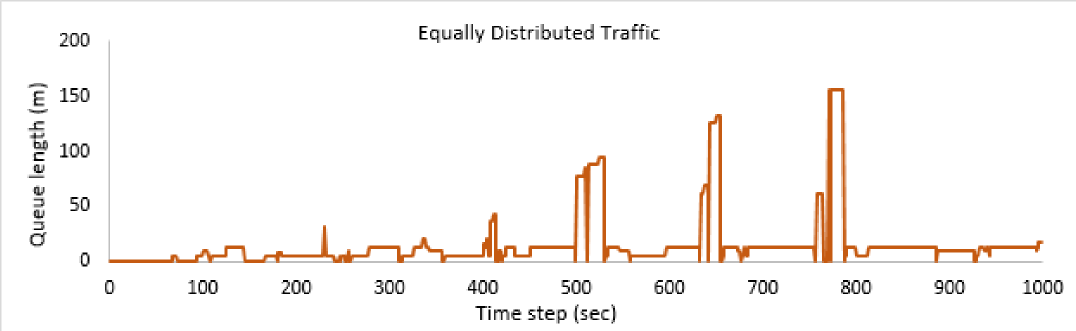

FIGURE 4.6: Configuration of Equally distributed traffic as vehicular input in Actuated traffic light control

For Equally distributed traffic's configuration, the maximum value of queue length is 155m across 786 s time step and the minimum value is zero for many time steps. By comparing this configuration with fixed traffic control, actuated traffic light control shows better performance. The queue lengths are comparatively higher than the only cars configuration but this fluctuation has been seen after some interval.

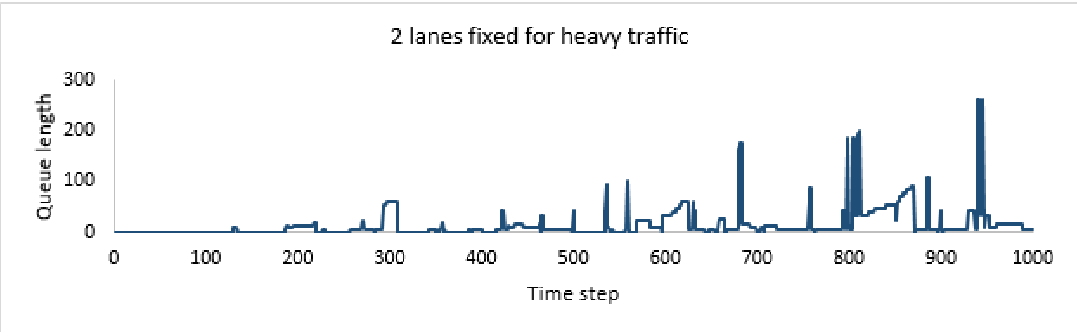

FIGURE 4.7: Configuration of 2 lanes fixed for heavy traffic as vehicular input in Actuated traffic light control

The queue length is affected when the number of vehicles increases gradually. By comparing the configuration of actuated traffic light control with fixed control, it shows different patterns and fewer values of queue lengths. There is rapid fluctuation after the time step of 500 s. The highest value of Queue length is measured to be 260 m and the minimum is 0 m.

4.3 Comparison of all Configurations

By comparing all these configurations, configuration of cars with actuated traffic light control has smallest value of queue length than other two. In the configuration of 2 lanes fixed for traffic light, buses blocked the way for other vehicles which tends to increase the queue length than other configurations. There are also fluctuations in equally distributed traffic, buses and truck would decelerate the speed of cars which results in waiting delays and increment in queue length.

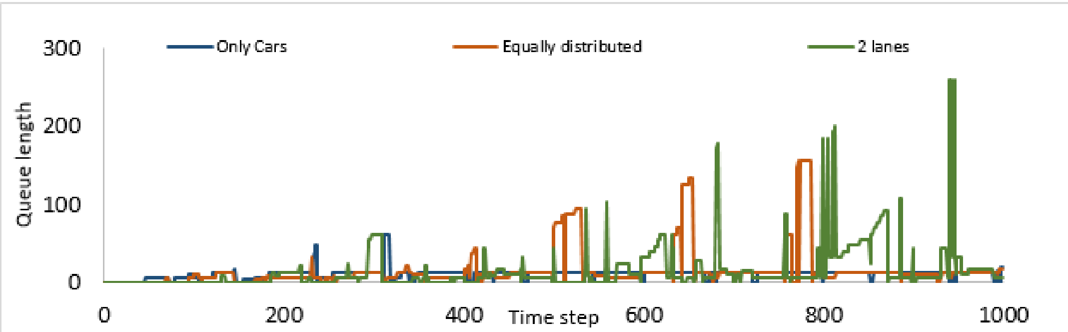

FIGURE 4.8: Comparison of all configuration for actuated traffic light control

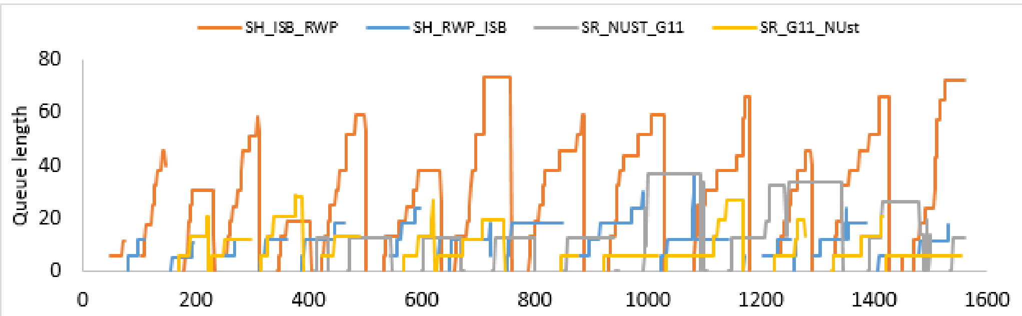

FIGURE 4.9: comparison of four phases at an intersection of G11

This graph shows about the variations in queuing length for Srinagar_highway_ISB_RWP, Srinagar_highway_RWP_ISB, Service_road_G11_NUST and Service_road_NUST_G11.

Srinagar_highway_ISB_RWP have highest queue length fluctuations throughout the simulations but unlike fixed traffic signal control, Srinagar_highway_RWP_ISB have decrease in volume of queue length with small amount of fluctuations.

Chapter 5

Conclusions and Recommendations

This thesis has proposed and evaluated a general modelling procedure for microscopic simulation models for traffic optimization. For this purpose, different simulation platforms were studied and evaluated to select one, which best suites the traffic conditions of Pakistan. After going through the literature and previous research, micro simulation software SUMO was selected for its obvious advantages over the other available micro simulation platforms. The thesis proposed a flow chart to conduct any micro simulation study.

5.1 Conclusions

The validity of the proposed procedure was demonstrated through a case study of 1.5 km long road stretch and one signalized intersections with SUMO. Major conclusions, which merge from the thesis, are as following:-

- There is major flow of traffic in Srinagar Highway than the other two side of junctions i.e: Service road facing G11 and Nust. Priority should be given to main highway but at the peak hours 8 am to 10 am in morning and 4 pm to 6 pm at evening there is increase in traffic volume to the service road of Nust.
- Complete follow up of Traffic condition concludes that there is continuous increase in traffic volume which is leading to traffic congestion. Data for last 5 years showed an average addition of 62,000 vehicles each year to city's overall vehicle fleet.
- Passenger cars had the largest vehicle share followed by motorcycles, taxis and vans.

- Simulation based results showed that actuated traffic light control perform better than fixed traffic light control. Actuated traffic light control was found to reduce intersection delays with up to 27% relative to fixed traffic light control. Actuated traffic light control cater fluctuations in traffic flow better than fixed traffic light control.
- The microscopic calibration and validation results show, that simulation platform such as SUMO based on the psycho-physical car-following model can reproduce traffic flow very realistically under different real-world conditions. But for this it is necessary to adapt the model to the local traffic situation i.e. National traffic regulations, driving styles and characteristics of the traffic mix must be taken into account.

5.2 Recommendations

Data Collection: In this research Probabilistic distributions are used to generate traffic data by using population parameters i.e: Inhabitants, households, children age limit, car rate and so on as input. On the basis of that data simulations are performed. The calibration of microscopic simulation models depends on the quality of the observed data. A major concern in modelling and simulation is error inherent in the generation of input data which can be improved by using real time data.

Purchase of Data Collection Equipment: Purchase of modern data collection equipment like, electronic counters, GPS, video cameras and speed guns etc. can improve the data collection process and authenticity of data.

Training on Simulation Packages: Considerable amount of time was consumed to learn the simulation software SUMO with considerable difficulty. It is recommended that two to three simulation packages be purchased and training on these be arrange t get full access full features of SUMO which will produce better results.

Recommended area of Application for Pakistan: Due to their cost effectiveness, risk free nature and high speed benefits, the use of Microscopic traffic simulation models is highly recommended to be used in Pakistan. The recommended area of application is as following:

- Transportation system design
- Traffic operations

- Management alternatives evaluation

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