ANALYSIS OF ISLAMABAD SIGNAL FREE CORRIDOR AS A CONGESTION MITIGATION SOLUTION

BY

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THESIS ACCEPTANCE CERTIFICATE

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Dedicated to my Teachers and Family.

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LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway & Transportation Officials
CO	Carbon Monoxide
BRT	Bus Rapid Transit
EN	Entry Ramp
EX	Exit Ramp
FHA	Federal Highway Administration (FHA)
HCM	Highway Capacity Manual
LOS	Level of Service
MOE	Measure of Effectiveness
NOX	Nitrogen Oxide
PCU	Passenger Car Unit
VMT	Vehicle Mile Traveled
VOC	Volatile Organic Compound
HERS-ST	Highway Economic Requirements System State Version

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Abstract

The uncontrolled growth in urbanization and motorization generally contributes to an urban land use and transportation system that is socially, economically, and environmentally unsustainable. Pakistan has experienced a rapid motorization in last one decade as motorized vehicle population increased from about 5.3 million in year 2002 to 11 million vehicles of all type in year 2012. Also, the largescale migration of people into cities has resulted into urban sprawl and is incurring huge social cost in term of traffic congestion and higher housing prices. The transportation infrastructure of cities like Islamabad is unable to meet the enhanced traffic demand due to increased motorization. A well-planned, efficient and sensible transportation system is necessary to ensure the better traffic movement and operational condition of road system. This study uses Islamabad as a case study, which is one of the largest urban and economic centers of Pakistan, passing through an uncontrolled phase of rapid urbanization and motorization. This research will evaluate the existing Islamabad Expressway, which is in the process of upgradation to signal free corridor from Zero Point to Rawat, as congestion mitigation solution. The design of this corridor is as per traffic count data to cater for next 15 years according to the policy makers. Therefore, the sustainability of this project will be determined. Growth rate modeling and other image processing techniques will be used to determine the traffic growth rate of this region to forecast the future traffic. Finally, some new strategies are suggested, adoption of which will lead to an efficient and sustainable road network.

Key Words: Congestion, Sustainable road network, Traffic growth rate modeling

Chapter 1

1. INTRODUCTION

1.1 Introduction

Recent studies have shown that most of the people that travel on daily basis that is at the morning and noon times are highly affected by traffic jams or congested roadways. They have to face these traffic jams almost daily which not only causes stress, frustration, headaches and extreme exhaustion but also causes material wastage like waste of time and fuel. On large scale the harmful impacts contain wastage of time of large amount of man power plus more fuel burn during increased travel time which results in more pollution released into the atmosphere which further accelerates global warming. The cost that commuters pay for this increased travel time is increasing day by day. It has increased five times since 1982 and was a total sum of 101 billion dollars in 2010 and if it's keeps the same pace it will reach 175 billion dollars by the end of this decade (Shrank et al., 2011). Keeping this increase of cost in mind the authorities have worked hard to help the travelers get some relief from these congestions and have formulated different plans to increase the capability of roads and to adjust more density by encouraging modes of traveling other than personal cars for example using a train or bicycle or a public transport that can contain more people at a time. They have also formulated more developed traffic system like using road metering and spotlight synchronization. These techniques and systems have altering degrees of impact on traffic while all of them are really costly for a third world country like Pakistan. It's hard for these countries to afford these techniques where the authorities have limited budgets. In this Master's thesis it is hoped to bring to light this area by answering the following query: ‘’What are the magnitudes of impact of various mitigation strategies on traffic congestion in Pakistan?’’. It will add a lot to the material present on this topic and will also formulate policies regarding the mitigation of congested roadways. In this chapter light will be thrown on the basic technologies and then the cost that is associated with traffic jams. Mitigation techniques will also be discussed. Problem statement will be presented, followed by project objective and study area and at the end a look at what the next chapters are going to be about.

1.2 Traffic Engineering

Traffic engineering means the science of maintaining and planning of roads. It also deals with the geometric design and operations related to traffic on streets roads and motorways. It also studies the relationship of roads with other modes of transportation in order to know how to ensure both the travelers and goods safety and to increase efficiency.

The definitions of traffic engineering highlight the following objectives:

- Speed
- Comfort
- Convenience
- Economy
- Environmental compatibility

1.3 Traffic Analysis

We need traffic analysis to calculate different variables required for example to find out Levels of Service (LOS), emission of pollutants, travelling time and delays etc. Traffic analysis is very important for road traffic management. A properly built road traffic management system, which is based on the comprehensive analysis of road traffic, can increase the traffic capacity of existing network. Traffic analysis mostly includes the capacity analysis and LOS analysis. The capacity of a facility is the maximum hourly rate at which persons or vehicles can be reasonably expected to traverse a point or uniform segment of a lane or roadway during a given time period under prevailing roadway, the definitions should reflect that perception (Roess, Prassas, & McShane, 2011b). Operative conditions within a traffic stream is depicted by a quality measure known as LOS, generally regarding service measure. Such as speed, travel time, traffic convenience, comfort, ease and freedom to maneuver.

Table 1.1: MOE defining levels of service in HCM 2000 (Roess et al., 2011b)

Type of Flow	Type of Facility	Measure of Effectiveness
Uninterrupted Flow	Freeways	
	Basic Sections	Density (pc/mi/ln)
	Weaving areas	Density (pc/mi/ln)
	Ramp Junctions	Density (pc/mi/ln)
	Multilane Highways	Density (pc/mi/ln)
	Two Lane Highways	Average Travel Speed (mi/h)
Interrupted Flow	Signalized Intersection	Control Delay (s/veh)
	Unsignalized Intersection	Control Delay (s/veh)
	Urban Streets	Average Travel Speed (mi/h)
	Transit	Service Frequency (veh/day)
	Pedestrians	Space (ft^2/ped)
	Bicycles	Frequency of Events (K)

1.4 Traffic Delays

Traffic delays means the extra time that is taken by a vehicle due to heavy traffic congestion or any other possible interruption. Traffic delay is calculated in seconds per vehicle. Traffic engineer should be very cautious while using measurements and criteria that are associated with the same delay definition. Some of the most frequently used forms of intersection delay include:

- Stopped-time delay-the time a vehicle spends stopped waiting to proceed through a signalized or STOP-controlled intersection.
- Approach delay-adds the delay due to deceleration to and acceleration from a stop to stopped time delay.

- Time-in-queue delay-the time between a vehicle joining the end of a queue at a signalized or STOP controlled intersection and the time it crosses the STOP line to proceed through the intersection.
- Control delay-the total delay at an intersection caused by a control device (either a signal or a STOP-sign), including both time-in-queue delay plus delays due to acceleration and deceleration.

Traffic delay can also be used to determine LOS as we may see in the following tables:

Table 1.2: LOS Criteria for signalized intersection (from HCM 2000)

LOS	Control Delay per Vehicle (s/veh)
A	< 10
B	> 10-20
C	> 20-35
D	> 35-55
E	> 55-80
F	> 80

For LOS of multi lane highway the following graph is used.

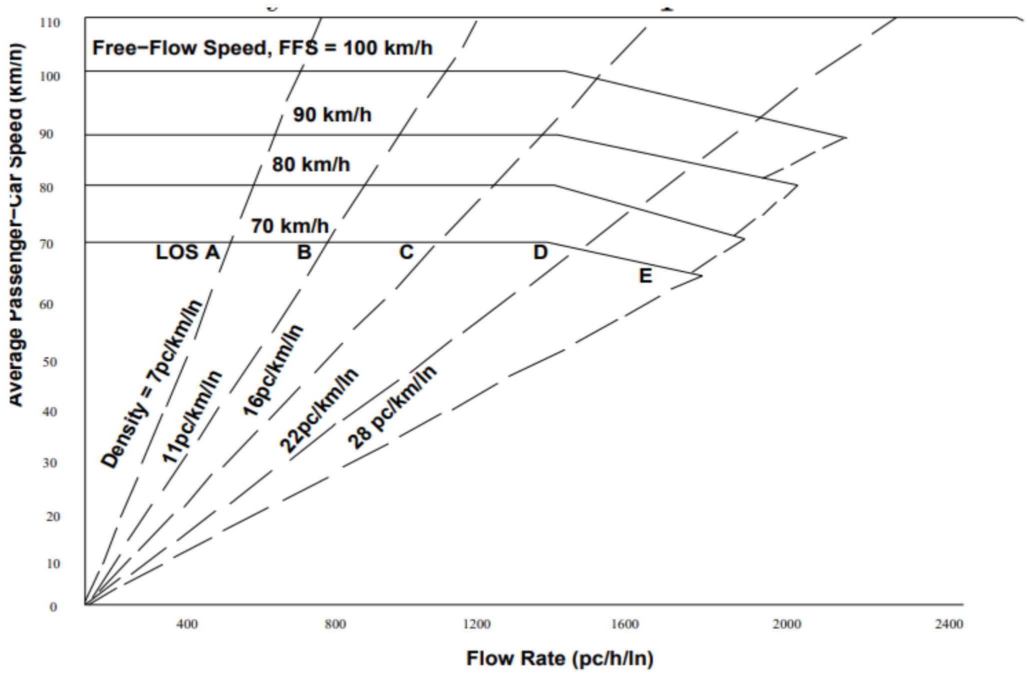


Figure 1.1 LOS for multilane highway

From this graph the following table can be generated:

Table 1.3 LOS density table

LOS	Density (pc/km/ln)
A	< 7
B	> 7-11
C	> 11-16
D	> 16-22
E	> 22-28
F	> 28

1.5 Level of Service

LOS is a means to find out that actual quality of traffic flow in any particular traffic system. This traffic quality is found out with the help of using speed of traffic flow, delays and density of traffic flow. It is further used to find out the performance of a particular traffic system.

Table 1.4: LOS classification

LOS	Type of Flow
A	Free flow
B	Reasonably free flow
C	Stable flow
D	Approaching unstable flow
E	Unstable flow
F	Forced flow

1.6 Fuel Consumption

Fuel consumption means that how much fuel a vehicle consumes on road. There are software present to find out the amount of fuel consumed such as VISSIM. It's a traffic simulation software. The value of fuel consumption dependents upon different variables like composition and speed of a vehicle plus it also varies with time delays. The more time delays the more fuel is consumed.

1.7 Vehicular Emissions

All the residual gases that are emitted from the tailpipe of vehicles during traveling are known as vehicular emissions. These are released into air which are hazardous for human health for example Nitrogen Oxides (NOX) and Sulphur Oxides (SO), Carbon Monoxide (CO) and Carbon Dioxide (CO_2) and some other Volatile Organic Compounds. Some of these oxides like CO, NOX and these VOC can be calculated using VISSIM. Its units are grams per hours. Its value is affected by different variables like traffic delays, vehicle composition and speed of vehicles as said earlier. These vehicular emissions no doubt causes damage to private economy plus great damage to the environment. Some of the damage costs of these emissions calculated earlier are as follows: CO cost $100 per ton, VOC cost 2,750 per ton, NO cost $3625 per ton, SD cost $8,400 per ton, road dust cost 4,825 per ton. These values were recorded by HERS-St Technical Report 2005.

Table 1.5: Damage cost of emissions (HERS-St Technical Report (2005))

HERS-ST estimates of air pollutant damage costs in 2000 dollars.			
Pollutant	**Damage Costs($/ton)**	**Adjustment Factors**	
		Urban	**Rural**
Carbon Monoxide	$100	1	0.5
Volatile Organic Compounds	$2,750	1.5	1
Nitrogen Oxides	$3,625	1.5	1
Sulfur Dioxide	$8,400	1.5	1
Fine Particulate Matter (PM2.5)	$4,825	1	0.5
Road Dust	$4,825	1	0.5

1.8 Passenger Car Unit (PCU)

To assess the rate of traffic flow on roadways transportation engineers uses a term Passengers Car Unit (PCU). The impact of different types of vehicle, as compared to a single car, on traffic variables such as speed and density etc. is called passengers car equivalent or passengers car unit for example some typical values are given as:

- Private car (including taxis or pick-up) = 1
- Motorcycle = 0.5
- Bicycle = 0.2
- Horse drawn vehicle = 4
- Bus, tractor, truck = 3.5

These PCE or PCU values are also used to calculate or find out highway capacity.

1.9 Traffic Congestion

Traffic congestions occurs when roads are physically utilized by vehicles. Some characteristics of traffic congestion are long queuing, slow speeds and longer time periods. When there are a lot of vehicles there is consequently more interaction between them and which resultant lyrics slows down the whole traffic. So, we may say that congestions occur when traffic demand approaches road capacity and when demand is higher and traffic is being stopped for hours it is called a traffic jam. For many years urban congestion has been a very significant issue. Considering the transportation demand cycle expanding the capacity is not always a promising solution to congestion problems. Therefore, traffic engineering is much concerned about developing such strategies and space, and deject growth where needed, as well. Now the question is "how many vehicles or people can be allowed to enter congested areas within indicated time periods?". The capacity rquires to handle demand is not of much concern.

1.10 The Cost of Traffic Congestion

Traffic congestions are somehow very costly as well. It is very important as well as very difficult to find out the private as well as the cost that is born by groups or the whole society. For example, the time wasted during long hours congestions and the extra gasoline used by vehicles are the costs borne by a person and while the greenhouse gas and pollutants emissions into atmosphere are the costs borne by the whole society. As a result, both of these values must be combined together to know the overall value of the cost of traffic congestion. Or we may say that total Cost of driving is equal to the amount of private cost added with the cost that is paid by the society not by the driver. Mathematically it is represented as:

Total cost on single driving = *private cost of single driving + social cost to society from driving that is not paid for by the driver*

Private cost and social cost are discussed in detail in the upcoming sections of this chapter.

1.10.1 Private cost

Whenever there is congestion on roadways the normal free flow rates are immediately changed into more slower and hindered or we may say restricted-flow rates. This is consequently bore by every car that is facing the following congestion on that roadway. And this congestion causes a staggering cost. In 2001 congestion caused 4.8 billion hours delay and cost 1.5 billion gallons of fuel. When these costs were added up an amount of $101 billion were estimated as total cost of congested in the given year. These calculations are based on Shrank *et al.* (2011). These estimated values were further divided by different authors to calculate the values of commuter's prices that came to be $713 in 2010. As per this amount the local taxes and total per capita state paid were calculated as $4160 (Tax Foundation, 2012). This traffic congestion cost added up to 17 percent gain in tax burden on every commuter.

Although Shrank *et al.* (2011) calculated the private cost of the traffic congestion but still it didn't include or presented the personal cost bear by the companies. Traffic congestions cost the companies in two ways. First because of long delays the company's products are not delivered to the desired designation on time hence disturbing and decreasing the company's efficiency specially when they are claiming to provide in time products and services delivery. Secondly if the travel time is doubted and not known exactly that it further increases the transportation cost. Winston and Shirley (2004) mentioned that no doubt it is tricky to find the exact values of these costs but it can be approximately done by the model that they presented. They added that the transportation cost added up by traffic congestion is approximately equal to daily reduction rate on the price of product being sent multiplied by the whole value of dispatch further multiplied by the total delay in dispatch. They estimated the transportation cost as 25 percent of the total cost of traffic congestion.

1.10.2 Social cost

Besides the private cost traffic congestion generates a good amount of cost to the society as well for example extra travel time for business transit and commuters, air pollution and hazardous emissions are released into the atmosphere. Social cost is also termed as negative externalities by popular Economists like Levitt and Dubner (2009), and Mintrom (2011). Because this is not paid by the driver but inflicted upon other drivers and the whole environment. Hence, we my say that the private cost paid by the driver is much lower than the price paid by the whole society.

According to a statement by Federal Highway Administration (2006b) vehicles emissions become much less when vehicles speed up and it is considered to be operating most effectively. Barth and Boriboonsoms (2009) studied the vehicle emissions-speed data graph and said that vehicle emissions followed a parabolic curve and with the end of the curve having greater emissions. While emissions were the lowest at the mid of the curve which means an average speed of 40-60mph. It was stated by the Federal Highway Administration (FHA) that these emissions were greater at stop and go travel which often happens at congestion and much less during continuous travel where there is no congestion. In vehicle emissions Nitrous Oxide (NO) and Volatile Organic Compounds (VOC) are mainly the sources of air pollution. The Environmental Protection Agency (EPA) (1994) said that modern cars produce less VOCs and NOX as compared to the old ones but still when the overall impact of thousands of cars is seen it is hazardous for our environment. These VOCs and NOX when react with sunshine produces ground level ozone 03 which is also called the smog which is very hazardous for human health and causes serious diseases like asthma or it can also permanently damage human lungs if exposed for so long. According to Romley *et al.* (2010) smog related pollution cost California a $193 million in between 2005 and 2007. Vehicles are not the only source of these emissions they release 26 percent VOCs and 33 percent NOX and are the main source while there are other sources as well.

1.11 SYNCHRO

SYNCHRO is a software initially developed by Traffic Ware Inc., It is used to generate coordinated signals and their timing plans for roadways and arteries etc. It is also used to produce coordinated signal timing parameters for intersections. It is the most widely used software so for the analysis of signalized intersection SYNCHRO software was used. When an intersection or arterial is built SYNCHRO, software is used to facilitate the process. The main objective of this software is to minimize travel delay by adjusting the optimal timing. Some other main features of synchro are stated below:

Other features of SYNCHRO Studio comprises of following:

- It is easy to use and determine effectiveness. It allows the observer to identify traffic trend in minimum possible time.
- It also supports the methodology of Highway Capacity Manual (HSM) for roundabouts intersections and U-Turns.
- It can also measure the amount of fuel used which helps in selecting the best route.

It is basically programmed to optimize split times, cycle lengths, phase orders and intersection delays. While in coordinating signals it determines which signal to be coordinated and which one should run free. It helps to design and modify intersections. The diagrams angle graph that it displays helps vary the delays and offsets and to observe its impact on travel delays LOS and different stops. User may compare those alternatives and the best route or intersection or the entire network. It's also helps the user to make optimum time plans by changing the input value to get a different result automatically.

1.12 PTV VISSIM

This software was made by a German company, Planing Transportation Verkher (PTV) AG. It is a microscopic multimedia traffic flow simulation software. It is meant to simulate each entity individually, an entity could be a car, a train or even an individual. Every entity is considered correspondingly in order to consider all possible property. Its main characteristic is multi-modality which means it can simulate more than one kind of traffic for example:

- Vehicles (Cars, Buses, Trucks)
- Public Transport (Trams, Buses)
- Cycles (Bicycle, Motorcycles)
- Pedestrians
- Rickshaws

This software has a wide scope in fields like:

- Traffic Engineering (Transport Engineering, Transport Planning, Signal Timing)
- Public Transport
- Urban Planning
- From Fire Protection (Evacuation Simulation) to 3D Visualization (Computer Animation, Architectural Animation) for public information.

1.12.1 Benefits of VISSIM

Some other characteristics, that make it more effective, of this software are discussed in detail below:

1. Maximum accuracy

This software can be used to map any kind of network and to achieve any desired geometry and hence it can be achieved maximum accuracy for a project. It can be used to design a complex intersection and also a standard node. Study of realistic behavior of road user of existing and planned infrastructure is possible through this software.

2. Ease of use and productivity

VISSIM is very user friendly because it's different interfaces could use to efficiently build networks. Interfaces like driver model and driving simulates could be used to import existing networks. It's flexible and dockable windows allows for efficiently creating and editing networks and their attributes. It can also give results for different variables which makes it more user friendly.

3. Flexibility and integration capacity

It has another interface named generic COM interface which help the user to interact with external applications. It helps you to have manual settings on different levels for the drivers and vehicles properties.

4. Visualization in 2D and 3D

There is also the switch perspective which enables us to analyze our results in both 2D and 3D. This detailed analysis helps in public decision-making process. These salient features make traffic simulation more appealing and understandable to the users.

1.13 Study Scope

Islamabad Expressway for this research study. This expressway is going through the process of upgradation to a signal free corridor from Zero point to Rawat intersection with the aim to reduce congestion at a cost of Rs 24 billion approx. It was divided into three sections i.e. Zeropoint to Faizabad, Faizabad to Koral and Koral to Rawat. The first two portions are almost completed and founds for the last portion are approved by the Government and work will be started on it as soon as possible.

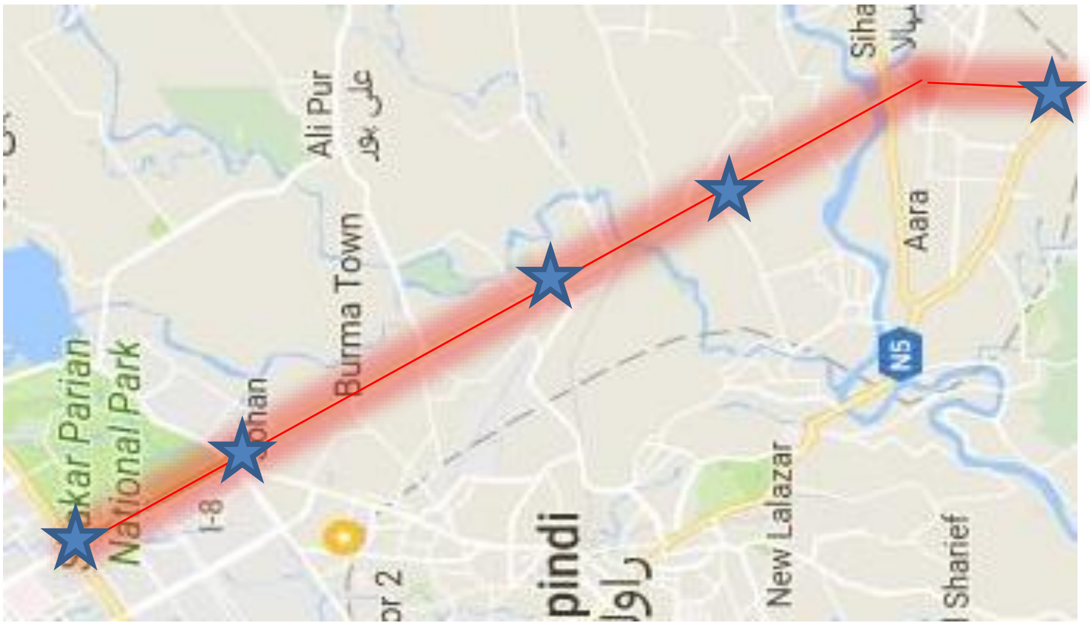


Figure 1.2: Islamabad signal free corridor map

During the initial survey the distances between the intersections were measured which are as follows:

Table 1.6: Travel distances between intersection.

Travel Node	**Travel Distance**
Zero Point to Faizabad	3.88 Km
Faizabad to Koral	7.74 Km
Koral to Rawat	11.88 Km

1.13.1 Zone Formation

For the calculation of urban growth rate, the twin cities (Islamabad & Rawalpindi) has to be divided into zones to make the study more comprehensible. The size and number of zones will also depend in part on how the data was collected and how it will be used. Usually the zones are based on census tracts or political subdivisions, the study area was divided in five zones I-8, Koral, PWD, Soan Gardens and DHA. There zones were selected based on the fact that most of the traffic coming to the Islamabad Expressway is from these zones.

1.14 Project Objectives

- To evaluate the project in terms of improved LOS and reduced delays after converting it to Signal Free Corridor.
- To evaluate the project in terms of reduction in emissions and fuel consumption after converting it to Signal Free Corridor.
- To evaluate the project in terms of cost recovery and reduction in social and private costs.
- To evaluating the distance between ramps (ramp analysis), a design feature contributing to congestion.
- To evaluate future strategies like addition of lanes, providing alternative routes and introducing efficient public transport.

1.15 Organization of Report

The report has been arranged in five chapters.

Chapter 1: Introduction

Chapter 2: Literature Review

Chapter 3: Research Methodology

Chapter 4: Analysis and Results

Chapter 5: Conclusion and Recommendations

CHAPTER 2:

2. LITERATURE REVIEW

2.1 Introduction

In this chapter the existing literature on traffic congestion and mitigation strategies were studied in detail. The main aim was to know what the researchers already know about these problems and what they still don't know or understand and wat is missing in their literature. To further organize the research Down's (2004) assertion were used that these mitigation strategies have two main categories that are the demand strategies and supply strategies. The demand strategies would be discussed in section 2. The demand strategies focus on influencing the demand for capacity like increasing residential densities, fall into this category. Using ramp metering and toll ways also fall in this category. In section 3 the supply strategies will be discussed. These strategies tend to increase the capacity of transportation for example expanding transit capacity and expanding roadway capacity.

Researchers have always tried to use different methods and measures to find out the impact of these mitigation strategies of traffic congestions. In the next chapter the methods and the strategies used in this research will be discussed in detail.

2.2 SUPPLY STRATEGIES

2.2.1 Expand Roadway Capacity

Expanding roadway capacity is the first thing comes to the minds of politicians (especially in Pakistan), transport agencies and other authorities when it comes to solve traffic congestion problems. Supporters of this strategy believe that it is the only effective solution to the problem of traffic congestion for example Balacker and Staley (2006), Hurtgen and Fields (2006). There is some proof that really shows that expanding roadway capacity actually mitigates traffic congestion in a short run. A study was done by Balacker and Staley (2006) which concluded that by quadrupling the freeway lanes in number in the period between 1986 and 1982, the average annual traffic delay per commuter was reduced by 50 percent in Houston, Texas. Similarly, Cabanatuan (2011) studied the annual average traffic delay for San Francisco between 2006 and 2009 and reported that the delay decreased by 32 percent for Bay area commuters as the freeway capacity was increased during this period. However, these reports were simply observations of these authors because none of these authors used the analysis techniques like the regression analysis technique. In the aggression analysis we actually separate the amount of reduction in traffic delay caused by expanding capacity technique from the decline caused by other factors like the population increase or decrease in that area, unemployment rate and other factors. When the regression analysis is used these results become less significant. For example, Curvero (2001) employed the regression technique and found out that 10 percent increase in freeway lanes capacity increased the freeway speed by 4.2 percent. Furthermore, if we consider the cost of expansion it's benefits would automatically become much smaller. For instance, it was reported that 1 percent spending on increasing highway capacity reduced only $0.04 congestion cost for per capita commuters. He further explained that the reason behind this ineffectiveness of freeway expansion is the increase in demand. Curvero (2001) further explained that when a roadway capacity is increased the travel delay automatically decreases and the speed increases which attract more commuters to the highway during the peak hours. As he believes the cost upon, him because of travel delay and less speed, is decreased. This increase in demand is known as the induced demand and the Curvero literature along with Duranton and Turner (2011), Fulton *et al* strongly. (2000), Hansen and Huang (1997), Noland and Covart (2000), supports this theory.

Hansen and Huang (1997) studied 30 counties and 13 metropolitan statistical Areas in California over a period of 17 years. The authors employed regression analysis and reported 10 percent increase in freeway capacity with 6-7 percent increase in VMT for the counties and 9 percent increase in VMT for metropolitan statistical Areas. This report was an important point in the study of field of transportation and an important critique of using freeway expansion as mitigation strategy for combating traffic congestion. A similar study of this technique was done by Noland and Cowart (2000) and they reported the same increase in induced demand but comparatively less as to that of Hansen and Huang (1997).

2.2.2 Expand Transit Capacity

The transportation supply could be increased in two ways using expand transit capacity technique. As it has the ability to transport additional number of passengers hence expanding the supply of public transportation system. Secondly as it helps in shifting some trips onto the public transportation system hence it also helps in increasing the roadway capacity and this is how actual traffic congestion reduction is achieved. A case study on Minneapolis St. Paul was conducted by Kim *et al.* (2008). He assessed the traffic volumes in that area eight years before opening a light rail transit system in the metro area and also for two years after opening the light rail transit system. The researchers recorded that there was a steady rise in traffic volume by 4.65 percent annually in the twin cities metro area major freeway system. But that maintain that the increase rate fall by 2.1 percent in the first year after opening the light rail transit system in 2004 and 4.3 percent in the second year. But unfortunately, the researchers did not consider other factors that could have helped in reduction of the traffic flow like increase or decrease in population, the unemployment rate and percentage of people above age 65. So, it is difficult to know to what extent actually the expansion of transit capacity helped in reduction of the traffic volumes increase rate in the metro area. However, Duranton and Turner (2011) used the regression analysis technique and found out that public transport system has no notable impact on travel demand. Transit systems were also studied in a different way that they were shutdown to calculate the severity of traffic congestion in some areas. The Texas Transportation Institute, in its annual study, also attempted to calculate the cost of traffic congestion in the absence of any kind if transit system or public transport. Shrank *et al.* (2011) also reported that traffic congestion would increase drastically if public transport and transit system were shutdown, for example traffic delay would rise up to 17 percent which means 796 million hours of delay. The overall conclusion of this study is that some people who chose to drive in the absence of transit system would go back to transit system when available which would help in decreasing traffic congestion and in the absence of transit system users of public transport would choose to drive which would aggravate the condition of traffic congestion. But it is still not clear that if expansion of transit system would help in reducing traffic congestion or not. A few researchers also tried to find out to what extent does transit system helps in reducing traffic congestion. Most prominent among them is Aftabuzzaman *et al.* (2010). The researcher studied 60 cities around the world that concluded that transit system could reduce traffic congestion cost by $0.45 per vehicle kilometer if travel.

The researcher also added that the impact of transit system would be more in areas where there is more traffic congestion and would be lesser in areas where there is less traffic congestion. He also added that more research is needed to draw strong conclusions about the relief transit system provides in areas of traffic congestion.

2.3 DEMAND STRATEGIES

2.3.1 Use of Toll Ways

Toll ways have been the center of attention for the last couple of decades. Specially from the Economists point of view it is an effective strategy to overcome traffic congestion. While opposing material can be found on toll ways and toll ways have gained a positive support, from several case studies, as an effective congestion mitigation strategy. Sullivan (2000) studied one of the best-known tollways in California i-e SR-91 the Hot lanes, opened in 1995 and studies for 5 years. He noted that with in short period of six months after opening the peak delay in evening decreased from 30-45 minutes to only 5 to 10 minutes. But again, towards the end it again rose to an average of 30 minutes. The conclusion was that flexible pricing on demand had failed to reduce the delay significantly. After this incident a more comprehensive study was carried throughout the whole country by the Government Accountability Officials (2012). The study was based on 5 HOT lane projects which found out that the travel speed, travel time and throughput increased on the following HOT lanes while this increase was not seen on the adjacent lanes that were toll free. While in some cases when increase was seen on the non-tolled lanes it was great in magnitudes for example 19 percent increase was noted on SR-16 in Seattle and in Miami I-95 saw 11 minutes fall in travel time. There is a complete list of demand strategies in table 2.2 at end of section. The studies of tollways have always been a unit level analysis which means that at a time impact of a single tollway on particular roadway or an adjacent roadway is analyzed. Only few studies were based on a whole system who analyzed the whole network of roadways of a metropolitan area.

One of this kind of studies was conducted by Munroe *et al.* 2006. Who analyzed the Los Angeles metropolitan area? In 2004 he calculated the tollways reduced peak period travel time for about 3200 hours in 2004 on major roadways of the whole metropolitan area. But this amount was totally insignificant when compared with the 641 million hours of peak period delay. Downs and Stopher (2004) acknowledge that the tollways are effective in a short-term. But they were suspicious of the long-term effectiveness of this strategy. While Downs stated the reason is that tollways do not raise the prices enough in order to mitigate traffic congestion in a long run. The cause behind this is some political pressure said Downs. Stopher also said that increases in public wealth and demand would decrease the efficiency of toll ways in a long run if prices are not raised accordingly. These observations were also acknowledged by Sullivan (2000) which believe that most of the decreased in travel time delay was due the SR-91 HOT lanes and vanished after a short period of four years. But we need to go further in depth to evaluate the impact of tollways on roadway congestions in long run.

2.3.2 Use of Ramp Metering

Ramp metering is considered less expensive when we talk of mitigation strategies to combat the roadways travel time delay. Also supported by the Texas Transportation Institute's urban mobility data set. The effectiveness of ramp metering is strongly supported. There is strong evidence present but unfortunately, we have a very limited amount of literature present on ramp metering. Kang and Gillen (1999) said that most of the literature present on ramp metering is outdated, which dates back to even before 1980's. These also fail to analyze the cost associated with ramp metering like ramp queues and lost time in waiting on ramps. Piotrowicz and Robinson (1995) conducted a case study regarding ramp metering in total of eight cities. The result they concluded was that the freeway throughput increased by 17-25 percent of vehicles per hour and the travel speed by 16-62 percent. But they failed to mention or calculate any cost being generated from the metering.

An experiment carried out on ramp metering systems in Minneapolis St. Paul, Cambridge systematics inc. (2001b), concluded that the benefits of ramp metering in the form decrease in travel time and increase in speed are outweighing as compared to the minimal costs associated with it.

While Kwon *et al.* (2006), presented a more recent study. He used a regression analysis to calculate the impact of ramp metering on traffic congestion. This experiment was carried out in a six-month period on the Bay Area on I-880 California. The author concluded that ramp metering reduces travel delay by 33 percent when it was used different traffic incidents like rain special events and increased demand etc.

2.3.3 Increase Residential Densities

The main theory behind using this strategy is that higher residential density could better utilize the transit system. These areas are also closer to amenities and services which also allows for different modes of travel for example using a bike or walking on foot. Some researchers have concluded that transit system use is much more in higher residential densities Ewing *et al.* (2002). But most of the findings, in research on using higher residential densities as traffic congestion mitigation strategy, are mixed up. They do not give a single result. For example, Ewing *et al.* (2002) concluded that 25 unit increase, which is equal to one standard deviation from mean, in residential densities resulted in 5.4% decrease in VMT per capita but it did not affect the travel delay per capita. While Sarzynski *et al.* (2006) concluded a totally opposite result. He noted that residential density had a positive relationship with annual traffic delay per capita. He said that one unit increase in residential density increased the traffic delay by one standard deviation from mean and the delay is increased by 2.28 hours per capita. He said that residential density strategy will worsen the situation if people continue to use their personal vehicle frequently without using the other alternatives and may cause traffic congestion.

Another case study of four residential densities in Phoenix, Arizona was done by Kuzmyak (2012). He found that high density settlements had volume to capacity ratio higher than that of lower density settlements. Lais (2004) conducted a study of urbanized area with low density settlements. He concluded that these urbanized low-density settlements had worse traffic congestion. He further said that 10 percent increase in the area caused 0.6 percent increase in the areas traffic congestion rate.

The reason for these divergent results could be that these researchers used a lot of different methods to measure the impact of traffic congestion. We will discuss these methods in detail in section 2.4 of this chapter.

2.4 How Traffic Congestion is Measured

Five major types of traffic congestion measures were identified: demand for road space (e.g. vehicle miles traveled), traffic volume (e.g. annual total traffic volume, and volume to capacity ratio), throughput (e.g. vehicles per hour, and average daily traffic per lane), travel time and speed, travel delay, and congestion indices (e.g. travel time index, and roadway congestion index). Each measure captures a different component of traffic congestion and has inherent strengths and weaknesses. However, the most widely used type of traffic congestion was travel delay. Travel delay represents the difference in travel times during peak traffic periods and non-peak periods, with the additional time taken during peak periods accounting for congestion related delay. In contrast to travel time, travel delay allows for a computation of the cost of traffic congestion, which is useful to policy and decision makers. However, more importantly for research purposes, travel delay values are easily comparable on a unit level of analysis, system-wide level of analysis, and between geographic regions or designations.

CHAPTER 3

3. RESEARCH METHODOLOGY AND DATA COLLECTION

3.1 Introduction

The findings of literature review provided an overview of different methods of congestion mitigation and its analysis, LOS analysis, importance of travel time, safety and VOC savings. The methodology adopted in this this is well discussed in this chapter. It helps finding a way to achieve the objectives of this research as stated in Chapter 1. The research work has been carried out in six distinct phases as stated under the heading of “Research Design”.

3.2 Research design

In first phase, after development of research proposal, extensive literature review was carried out to understand the basics of congestion mitigation, highway capacity analysis, LOS and software’s like SINCHRO and VISSIM. Google Scholar and other prominent internet sites like Science Direct or ResearchGate etc. were used as a search tools for different scholarly research papers and writings.

In second phase, comprehensive literature/data/documents were collected on Islamabad Expressway from CDA, traffic counts data for the year 2017 was collected at six intersection using video recording for several hours at each intersection. This traffic data was used as an input in LOS analysis of existing infrastructure using VISSIM and SINCHRO. Moreover, data was collected form historical imagery of Google Earth from 2006 to 2017 for the calculation of traffic growth rate for four zones.

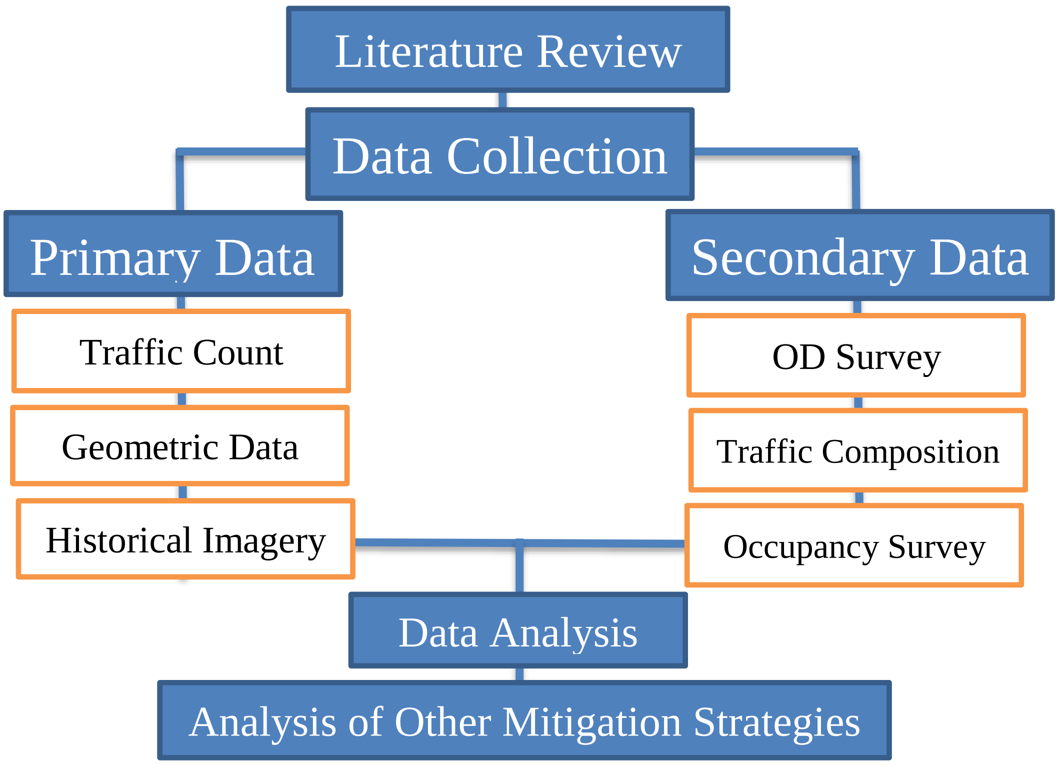
In third phase, rate of urbanization was determined using image processing and historical imagery data obtained from Google Earth. Furthermore, the model of Islamabad Expressway before intervention was calibrated in VISSIM and SINCRHO for LOS and emissions analysis. Unsignalized intersections were calibrated in VISSIM V7 which uses micro simulation for analysis. Signalized intersections were modeled in SINCRO 9 which uses HCM 2000 for analysis.

Moreover, the model of Islamabad Expressway after conversion to signal free corridor was also calibrated in VISSIM and analyzed for LOS and Environmental impact analysis. Both the scenarios were compared for different intersections before and after intervention.

In fifth phase, LOS and Environmental Impact of the eight intersections of Islamabad Expressway was determined for next 5, 10, 15 and 20 years respectively by applying growth factor to existing traffic counts. It was tried to establish as what would be the LOS and Environmental Impact of this alignment if the same infrastructure continues to exist without any expansion in geometrics i.e. lane addition. The interchanges will also be checked design wise. Distance between successive ramps will be checked. Which is the governing criteria for effecting the congestion at interchange.

In sixth phase, an attempt was made to determine the effect of other strategies like introduction of BRT, addition of lanes and divergence of the fright traffic and passing traffic to an alternative bypass to keep the LOS between "C" and "D" for next 20 years i.e. till 2035.

Conclusions and recommendations were proffered in the last. Analytical framework for the research design is shown in Figure 3.1.



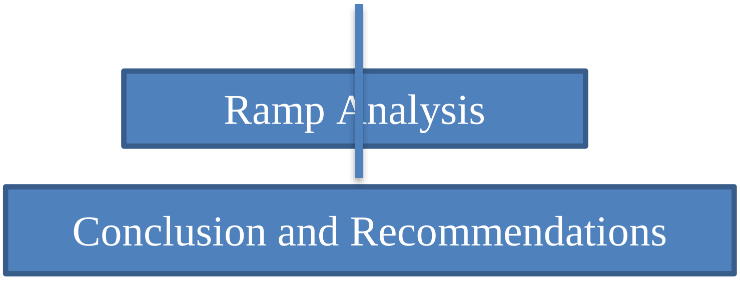


Figure 3.1: Flow chart

3.3 Data Collection

After the selection of site, second step in the research methodology comprises of data collection. This section includes the methods used and the results involved in field data collection. The field data includes:

- Traffic Volumes (Turning movements)
- Geometric Features (Lane usage, link distances)
- Historic Imagery
- OD-Survey
- Average Occupancy Survey

3.3.1 Outline of Surveys

Following surveys were conducted in order to collect data regarding passenger volume, vehicle volume and traffic movement patterns:

Table 3.1: Outline of survey

#	Survey	Objective	Methodology	Scope
1	Traffic count survey	Traffic count volume by vehicle type at key junctions.	Manual classified vehicle count.	6 key locations
2	Average occupancy survey	Determine the utilization of public and private transport.	Manual count of passengers of 100 vehicles of each type than dividing it by total number of vehicles counted	At one location where, highest peak volume was obtained during traffic count
3	Historic Imagery	Historic Google Earth Images of key location	Growth rate calculation using image processing tools	6 Key locations subjected to increase in population

3.3.2 Traffic Count Survey

Traffic count survey was conducted at the selected intersections with the help of video recordings. Video of traffic was recorded for almost the three hours at each intersection in such a way to cover maximum number of ramps and through traffic. Tally sheets were used for the traffic count manually. Tally marks are the basic units of unary numeral system used for counting purpose. They are grouped in five so that calculation may become easier and legible.

Figure 3.2: Manual count (Tally Bar)

Peak hour was identified from the hour having maximum traffic in 15min. The traffic composition was also calculated from the video footage. Vehicles were classified into the following categories:

Table 3.2: Vehicle composition

No	**Description**
1	Car
2	Motorcycle/Cycle
3	Vans/Hiace/Mini Bus
4	Bus/Truck

Average occupancy of each category is also calculated. By multiplying the traffic volume of each category on hourly basis with its average occupancy gives the number of passengers per hour in that direction. Peak hour was also identified which is the most important value that tells us about the maximum number of passengers travelling in an hour in the direction of survey. These surveys gave us following information:

1. Traffic volume
2. Passengers per hour

3.3.3 Passenger Car Unit (PCU)

Passenger Car Unit (PCU) is actually the traffic volume count data which is gathered through survey. The traffic intensity in various locations of the corridor is assessed by analyzing the collected data. The PCU equivalents adopted for the purpose, by different vehicle types are as follows:

Table 3.3: Table of PCUs

S. No.	Model	PCU
1	Motor Cycle	0.5
2	Car/Jeep	1
3	Wagon/Minibus	1.5
4	Bus/Truck	3

3.3.4 Peak hour Volumes

Peak hour volume is the traffic volume that occurs during the peak hour. It is expressed in vehicles per hour and it represents the highest traffic volume for that intersection. According to our site studies, peak hours of those intersections are 7am – 10am (Morning Peak Hours) and 5pm – 8pm (Evening Peak Hours).

3.3.5 Peak Hour Factor

Peak Hour Factor is an important factor in analyzing the capacity. It should be applied in capacity analysis according to HCM. It selects 15-minute flow rate as the basis of its procedures. It is calculated as the average volume during the peak 60-minute period divided by four times the average volume during the 15-minute period. Usually, the average PHF for the intersection as a whole is applied.

$$PHF = \frac{\text{Volume During Peak 60 Minute Period}}{4.0 * \text{Peak 15 Minute Volume}}$$

3.3.6 Points for Conducting Survey

The survey was conducted at following four points:

Table 3.4: location duration of traffic count

#	Location	Duration
1	Zero Point	6hr
2	Faizabad	6hr
3	Koral Choke	6hr
4	PWD	6hr
5	I-8	6hr
6	Sohan	6hr

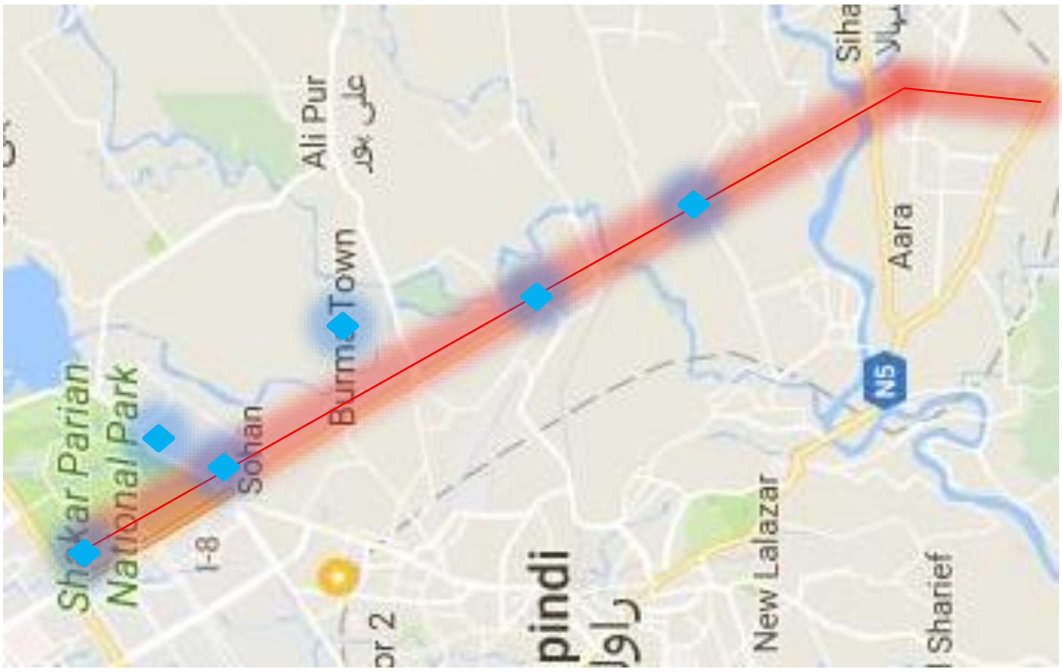


Figure 3.3: location of traffic count

3.3.7 Signal timings

Signal timings for each phase have been observed manually using stop watch. Timings which have been observed are Cycle Lengths, Red Time, Yellow Time, Green Time, and All Red Time. Traffic volumes along with signal timings and peak hour factors are presented in the next section.

CHAPTER 4

4. DATA ANALYSIS

Vehicle count surveys were conducted on the intersections mentioned above using video footages and number of vehicles were counted. The survey was conducted for both the directions i.e. north bound direction and south bound direction for each intersection separately along with the connecting ramps. Time intervals were selected basing upon on ground reconnaissance. Those time intervals were selected in which huge volume of traffic was observed. The time intervals are:

Table 4.1: Time Intervals for Traffic Count

Morning	07:00 AM – 10:00 AM
Evening	05:00 PM – 08:00 PM

All the vehicles thus counted are converted to Passenger Car Unit (PCU). Its purpose is to bring all the traffic volume to one single design vehicle. The traffic counts were done at the following locations as shown in the map.

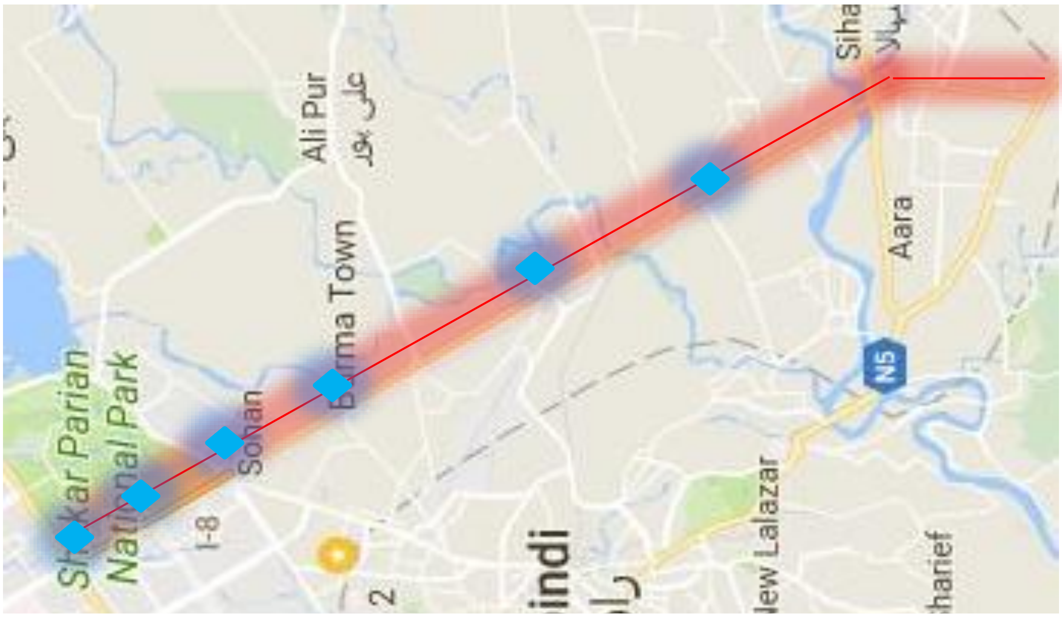


Figure 4.1: Locations of Survey Points

4.1 Before and After Traffic Analysis:

In before and after traffic analysis, the first step is the collection of classified traffic counts by using video recording and then counting the vehicles manually. For interchange, the days selected for traffic counts are Tuesday, Wednesday and Thursday and the timings are 8 AM - 10 AM and 5PM - 8 PM. Vehicle classifications are:

- Cars
- Trucks/ Buses
- Motorcycles
- Wagons

The second step is the determination of peak hour volume in the form of PCU/hr. and vehicles composition. The final step is the traffic analysis of intersection and interchange using SYNCHRO and VISSIM. PCU are obtained from following discussed in the previous section.

4.1.1 Summary of PHV and Vehicle Composition on Intersection

Table 4.2: Zero-point traffic volume

Zero Point Interchange			
Approach	**Movements**	**PCU/hr. 2014**	**PCU/hr. 2017**
NB (From Faizabad to Islamabad)	NBT	3999.0	4438.9
	NBL	1115.3	1238.0
	NBR	465.9	517.1
SB (From Islamabad to Faizabad)	SBT	5038.7	5593.0
	SBL	585.9	650.3
	SBR	1526.9	1694.8
EB (From NUST)	EBL	630.6	700.0
	EBR	1592.8	1768.0
WB (From Abpara)	WBR	488.5	542.2
	WBL	1325.9	1471.8

Table 4.3: I-8 traffic volume

I-8 Interchange			
Approach	**Movements**	**PCU/hr. 2014**	**PCU/hr. 2017**
NB (From Faizabad to Islamabad)	NBT	4402.3	4886.5
	NBL	314.4	349.0
	NBR	508.6	564.5
SB (From Islamabad to Faizabad)	SBT	5546.8	6157.0
	SBL	314.4	349.0
	SBR	508.6	564.5
EB (From I-8)	EBL	396.4	440.0
	EBR	158.6	176.0
WB (From Shakarparian)	WBT	314.4	349.0
	WBR	125.8	139.6

Table 4.4: Faizabad traffic volume

Faizabad Interchange			
Approach	**Movements**	**PCU/hr. 2014**	**PCU/hr. 2017**
NB (From Koral to Islamabad)	NBT	7132.8	7917.5
	NBL	1658.8	1841.3
	NBR	1132.2	1256.7
SB (From Islamabad to Koral)	SBT	8987.4	9976.0
	SBL	1426.6	1583.5
	SBR	2090.1	2320.0
EB (From Faizabad)	EBL	1321.7	1467.1
	EBR	2192.0	2433.2
WB (From Rawal Dam)	WBT	2365.1	2625.3
	WBR	1198.3	1330.1

Table 4.5: Sohan traffic volume

Sohan Interchange			
Approach	**Movements**	**PCU/hr. 2014**	**PCU/hr. 2017**
NB (From Rawat to Islamabad)	NBT	4692.5	5208.7
	NBL	521.4	578.7
SB (From Islamabad to Rawat)	SBT	5912.6	6563.0
	SBL	94.9	105.3
	SBR	1791.7	1988.8
WB (From Sohan)	WBL	40.9	45.5
	WBR	1556.0	1727.1

Table 4.6: Koral traffic volume

Koral Choke Interchange			
Approach	**Movements**	**PCU/hr. 2014**	**PCU/hr. 2017**
NB (From Rawat to Islamabad)	NBT	5986.3	6644.8
	NBL	427.6	474.6
	NBR	136.1	151.0
SB (From Islamabad to Rawat)	SBT	7542.7	8372.4
	SBL	121.1	134.4
	SBR	2329.7	2586.0
	SBU	45.9	50.9
EB (From Airport)	EBT	121.1	134.4
	EBL	127.4	141.5
	EBR	526.4	584.3
	EBU	93.1	103.4
WB (From koral)	WBT	52.2	58.0
	WBR	1984.9	2203.3

Table 4.7: PWD traffic volume

PWD Interchange			
Approach	**Movements**	**PCU/hr. 2014**	**PCU/hr. 2017**
NB (From Rawat to Islamabad)	NBT	3068.8	3406.3
	NBR	90.3	100.2
SB (From Islamabad to Rawat)	SBT	3866.7	4292.0
	SBR	1017.5	1129.5

The vehicle composition of the traffic approaching intersection is shown in following pie-charts:

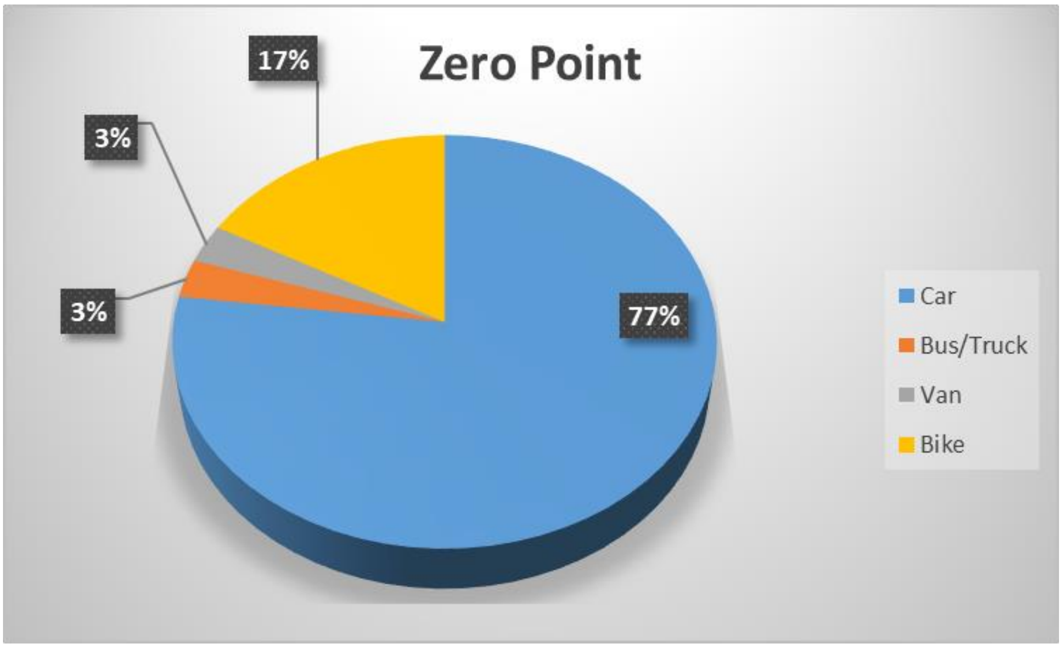


Figure 4.2: Zero Point Interchange Vehicle Composition

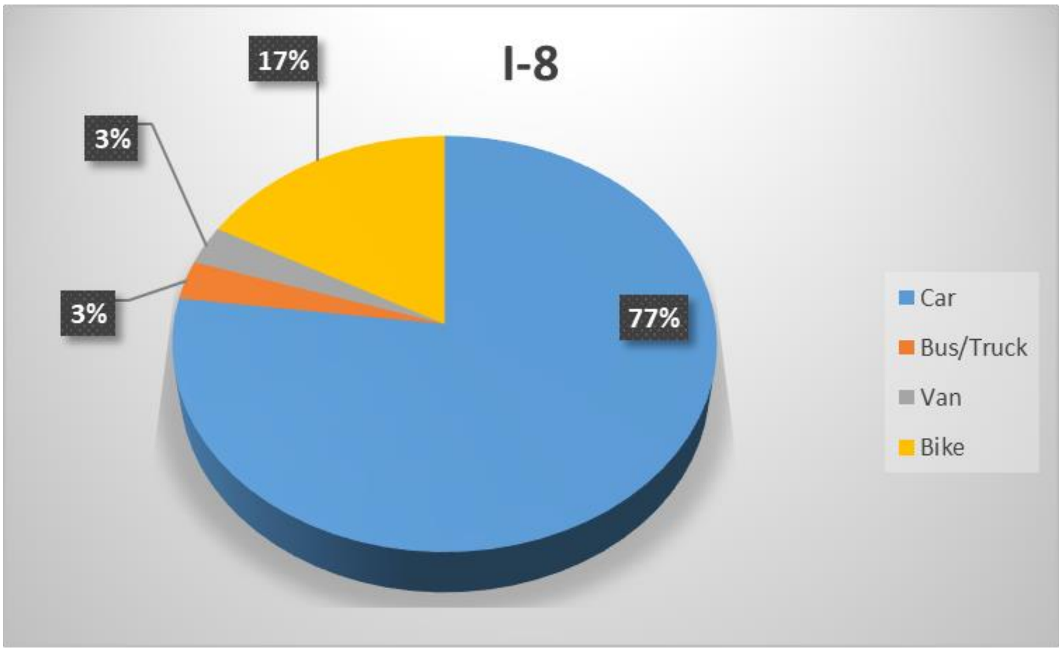


Figure 4.3: I-8 Interchange Vehicle Composition

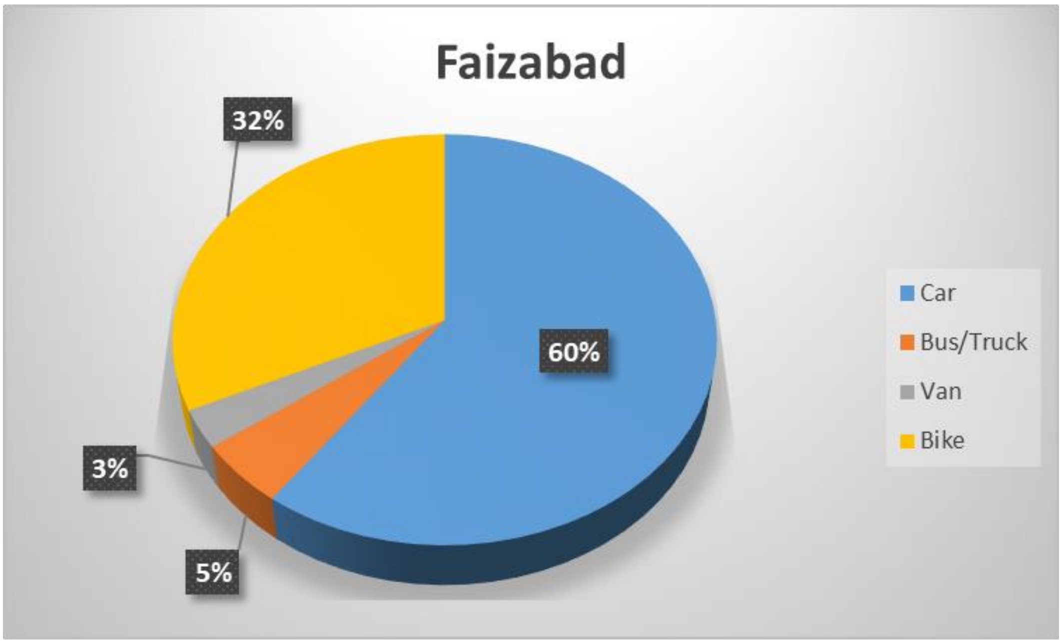


Figure 4.4: Faizabad Interchange Vehicle Composition

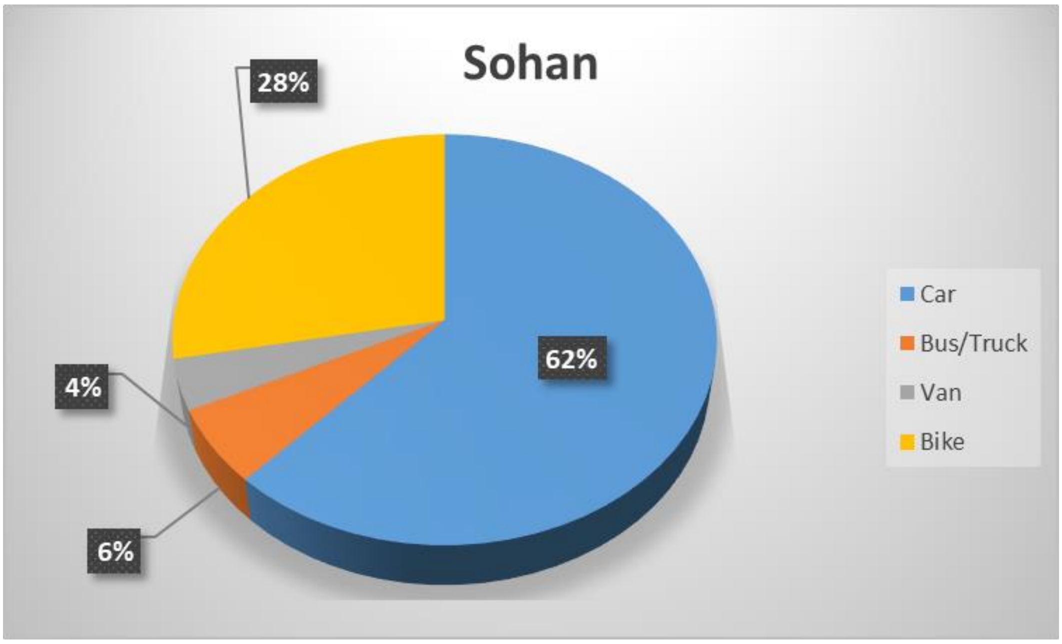


Figure 4.5: Sohan Interchange Vehicle Composition

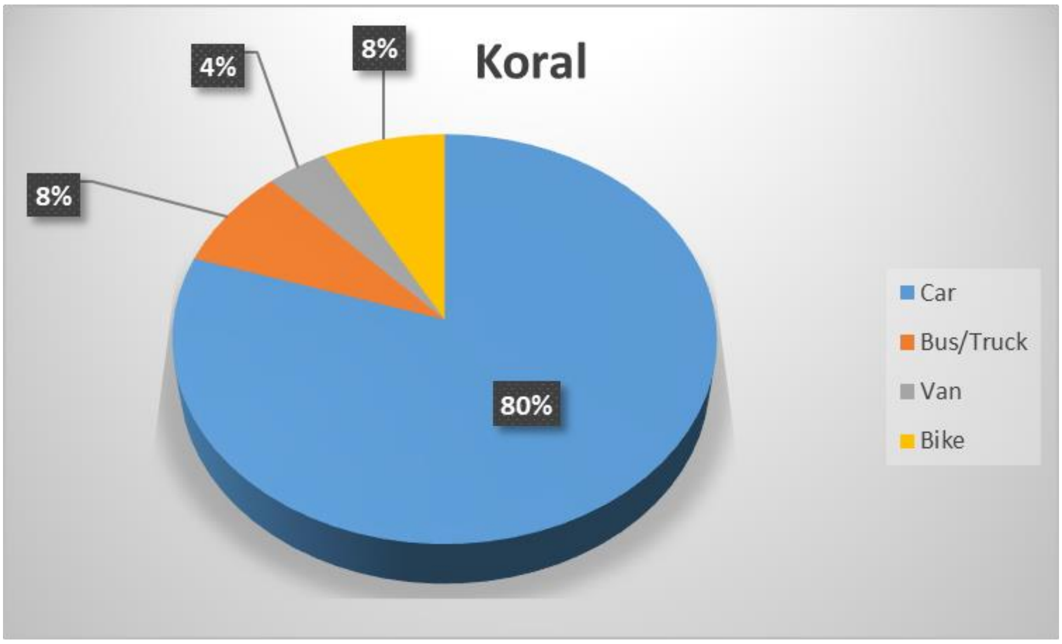


Figure 4.6: Koral Interchange Vehicle Composition

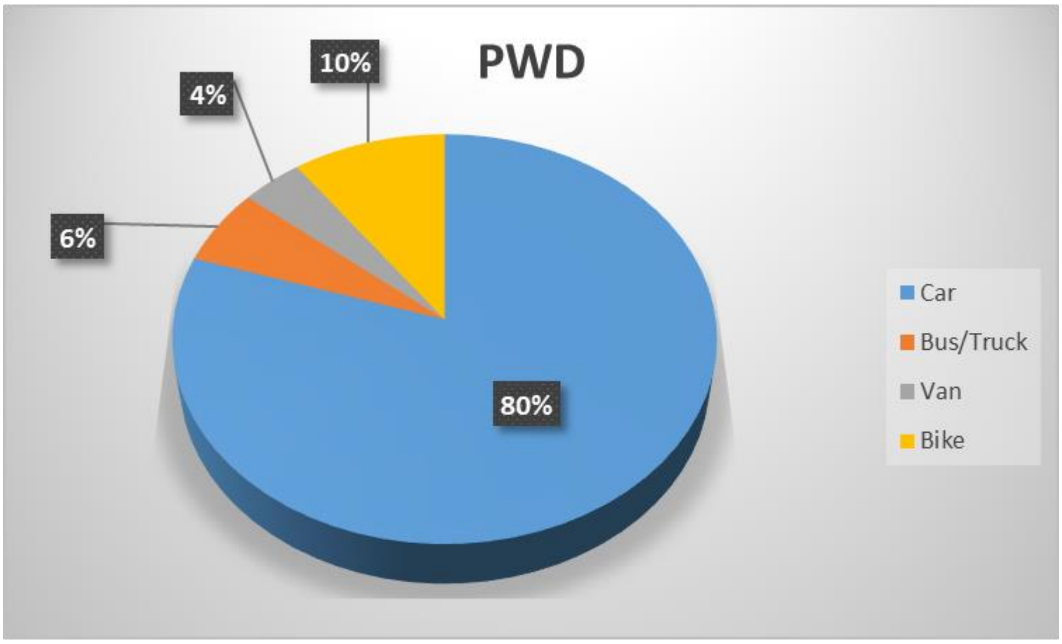


Figure 4.7: PWD Interchange Vehicle Composition

It was concluded from the traffic composition survey that on average there are 5.375% truck/bus, which will be used in next chapter for analysis of the area if the heavy traffic is diverted to other routes. Similarly, it was also concluded from traffic composition survey that we have 3.625% of public transport. Sum of both truck and public transport is 9%.

4.2 Growth Rate Analysis:

Calculation of traffic growth rate requires variables like no. of lanes, vehicle registration, population density, employment, type of road, traffic volume and school enrolment. Most of these independent variables can be determined, however the most important variable, which in our case is also dependent variable, i.e. traffic volume which is unavailable. Therefore, another technique was used in this research to assume the growth rate. Historical Imagery tool of google earth was used to get the images of five locations from 2008 to 2018 with 5 years of interval and the rate of urbanization was estimated using ImageJ, an image processing software. The pixels of roof area were counted and divided by pixels of one roof for each year and each location. In this way number of houses were counted in each location. From the increase in number of houses the urbanization growth rated was estimated.

The growth rate of each location was separately calculated and then the average growth rate of all the location were used for further calculations. For growth rate analysis image processing was used in order to calculate the number of houses. Google Earth images were obtained for different years from Google Earth Historic Imagery option.

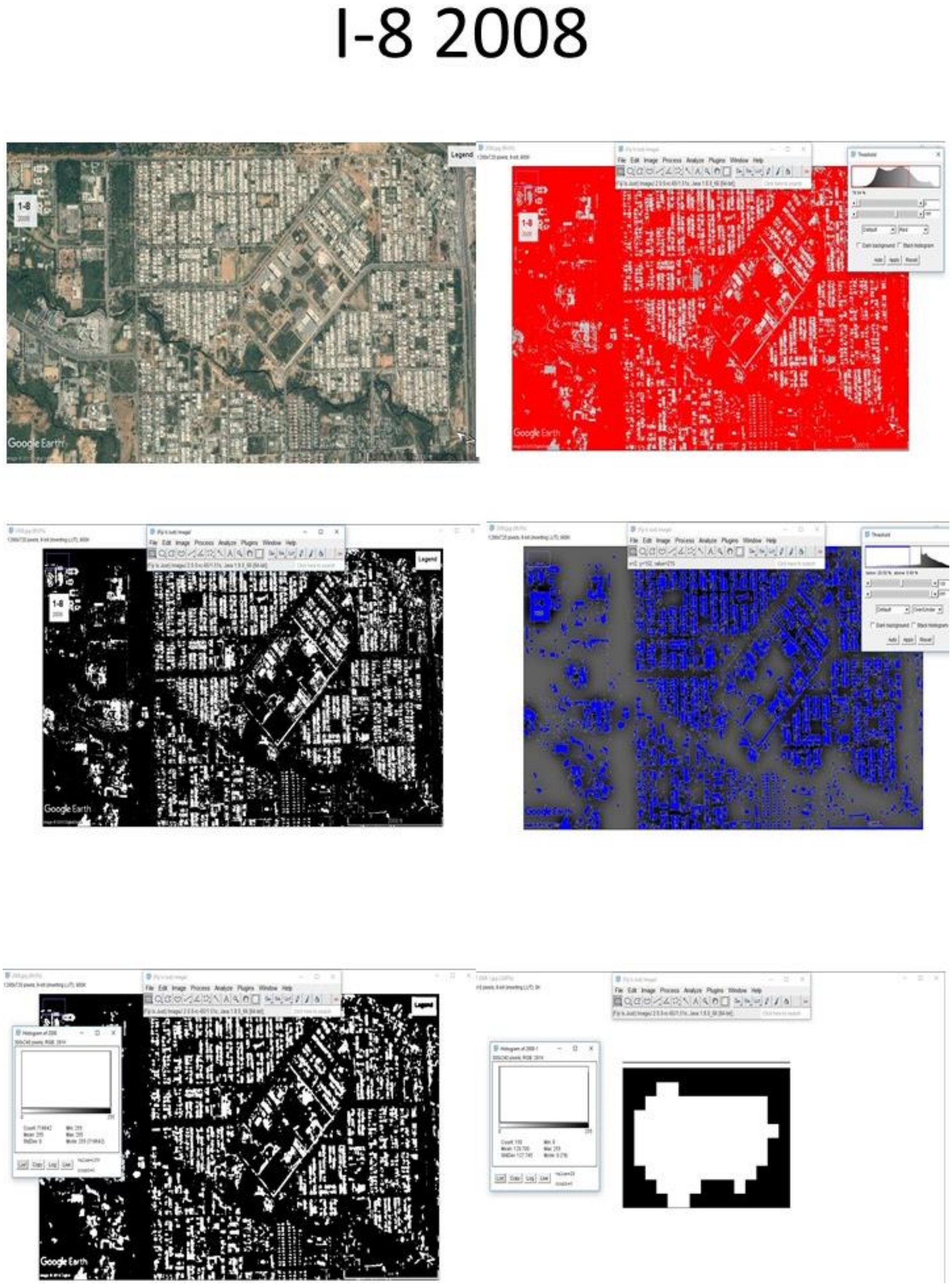


Figure 4.8: I-8 Image processing 2008

I-8 2013

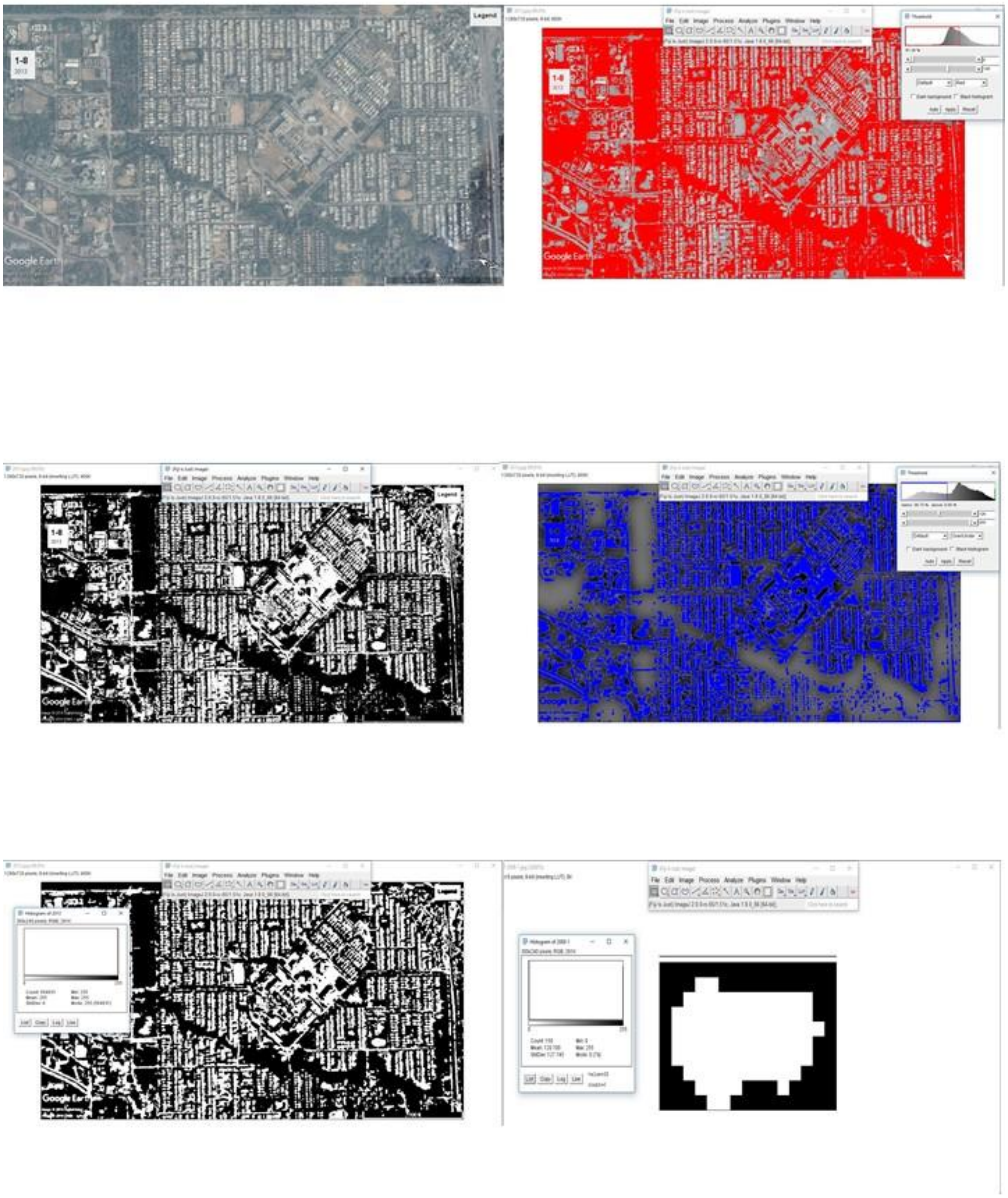


Figure 4.9: I-8 Image processing 2013

I-8 2018

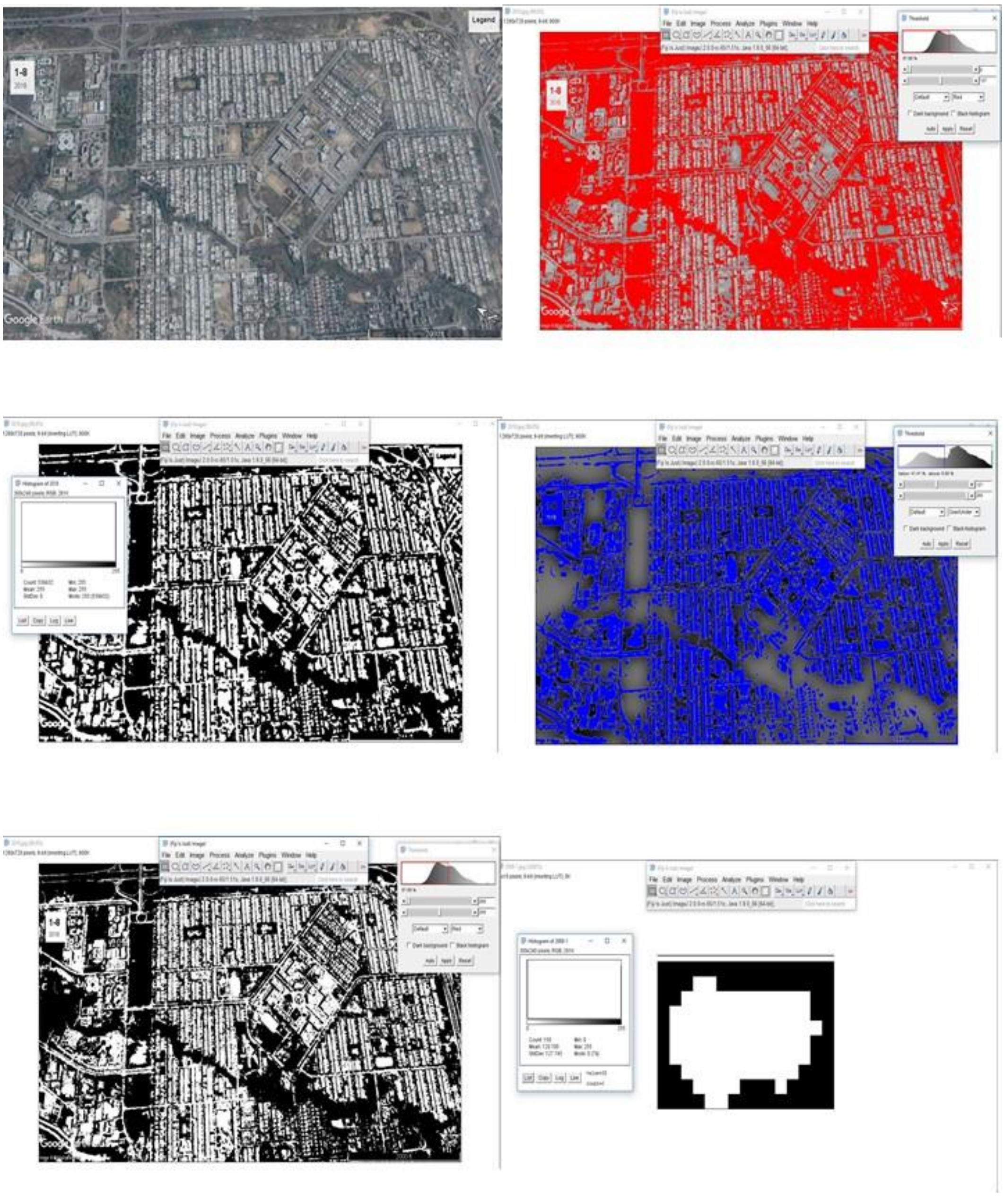


Figure 4.10: I-8 Image processing 2018

The summary of number of houses per year in each zone is given in the table below:

Table 4.8: Growth rate summary

Zone	2008	2013	2018	Growth Rate
I-8	2030	2930	3827	1.57
Gulberg	3010	3845	4680	4.51
PWD	4177	4530	4884	2.57
Soan Gardens	3652	4216	4783	6.55
DHA	4532	4552	4572	3.51
Avg. Growth Rate				3.95

4.3 Future Traffic Analysis:

The purpose of future traffic analysis is to evaluate the performance of interchange in future. In future traffic analysis, the first step is the determination of projected traffic counts. In order to find projected traffic counts traffic growth at rate of 4% per year was used as calculated in the previous step. The final step is the traffic analysis using VISSIM. We have done future traffic analysis for the year 2023, 2028, and 2033. Traffic growth factor is calculated by following method:

Traffic growth factor = $(1+4/100)^n = 1.04^n$, where n is number of years from now.

So,

For 2023 traffic growth factor = $1.04^5 = 1.2167$

For 2028 traffic growth factor = $1.04^{10} = 1.4802$

For 2033 traffic growth factor = $1.04^{15} = 1.8009$

These traffic growth factors are multiplied with present (2017) traffic counts to get projected traffic counts for the years mentioned above.

4.4 Capital Cost Recovery in terms of Public Benefits

In capital cost recovery, the first step is to find out the reduction of following parameters per year due to conversion of intersection into interchange:

- Fuel consumption
- Vehicular Emissions

These parameters change every year due to increasing traffic. The second step is the extermination of savings per year by using above reduction parameters. The final step is to find out the capital cost recovery period by using capital cost and savings per year. The fuel cost is Rs. 85/litre and in order to convert emissions into cost following table was used:

Table 4.9: Damage cost of Emissions (HERS-ST Technical Report (2005))

HERS-ST estimates of air pollutant damage costs in 2000 dollars.			
	Damage Costs ($/ton)	**Adjustment Factors**	
Pollutant		**Urban**	**Rural**
Carbon Monoxide	$100	1	0.5
Volatile Organic Compounds	$2,750	1.5	1
Nitrogen Oxides	$3,625	1.5	1
Sulfur Dioxide	$8,400	1.5	1
Fine Particulate Matter (PM2.5)	$4,825	1	0.5
Road Dust	$4,825	1	0.5

4.5 Origin Destination Survey

The origins destination survey was conducted by Sanwal Ali et. al. students of NUST. The final results of which are as under:

Table 4.10: OD Survey

16x 16			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Name		Saddar	Lalkurti	aklala Sche	Airport	h Faisal Co	azaya Color	aja Iqbal tov	Faizabad	Westridge	Bahria Town	hakshahza	Blue Area	shmir Highw	Taxila	Rawat	dyala Roa
		Sum	2999.00	2904.00	4982.00	1706.00	4392.00	4611.00	3273.00	2745.00	518.00	1614.00	974.00	1703.00	1111.00	306.00	1281.00	560.00
1	Saddar	2537.00	108.00	176.00	242.00	72.00	270.00	451.00	184.00	204.00	164.00	216.00	37.00	55.00	32.00	66.00	143.00	117.00
2	Lalkurti	2756.00	88.00	106.00	232.00	232.00	497.00	184.00	388.00	349.00	134.00	177.00	32.00	45.00	26.00	54.00	117.00	95.00
3	Chaklala Scheme	5839.00	1246.00	513.00	447.00	312.00	603.00	970.00	817.00	603.00	17.00	55.00	42.00	42.00	21.00	32.00	13.00	106.00
4	Airport	3919.00	164.00	891.00	839.00	292.00	400.00	402.00	388.00	260.00	13.00	45.00	34.00	34.00	17.00	13.00	41.00	86.00
5	Shah Faisal Colony	3496.00	332.00	418.00	220.00	104.00	350.00	837.00	348.00	116.00	35.00	37.00	99.00	133.00	19.00	44.00	347.00	57.00
6	Fazaya Colony	4086.00	795.00	336.00	418.00	96.00	548.00	410.00	556.00	302.00	29.00	31.00	81.00	109.00	15.00	29.00	284.00	47.00
7	Raja Iqbal town	6352.00	88.00	188.00	959.00	352.00	765.00	528.00	440.00	529.00	69.00	579.00	357.00	707.00	540.00	37.00	185.00	29.00
8	Faizabad	6694.00	178.00	276.00	1625.00	246.00	959.00	829.00	152.00	382.00	57.00	474.00	292.00	578.00	441.00	31.00	151.00	23.00
9	Westridge	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	Bahria Town	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	Chakshahzad	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	Blue Area	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	Kashmir Highway	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	Taxila	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	Rawat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	Adyala Road	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

From this matrix it can be seen that 9% trips are due trips generated at Airport and ending at Faizabad and 4% trips are due to trips generated at Faizabad and ending at Airport. For our study we will use 4% for both sides as the airport will be still operational under Pakistan Aviation and for VIP flights.

4.6 Average Occupancy Survey

Traffic survey for application of different mitigation strategies like Tollways etc. cannot be completed without knowing the current traffic movement and demand on the route. For this purpose, average occupancy of each vehicle is calculated by a very simple and easy method. Count the passengers in continuous 100 vehicles and then divide the figure obtained by 100. The average occupancy will be obtained for that particular type of vehicle. This survey was conducted on near Khanapul. Results are displayed in following table.

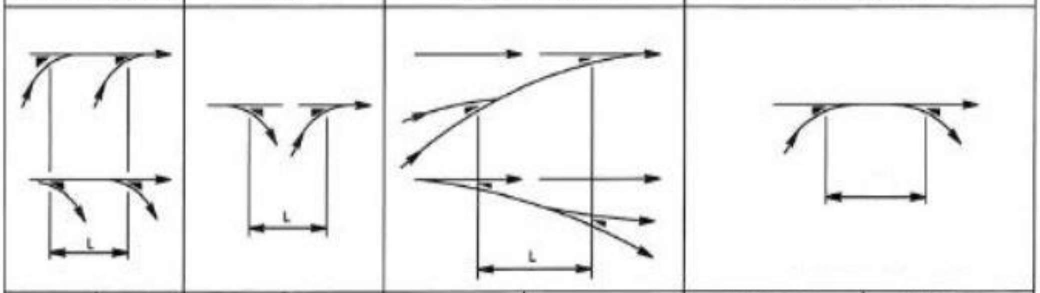
Table 4.11: Average Occupancy

Vehicle type	**Average Occupancy**
Cars/Taxis	1.37
Wagons	13.6
Buses	34.43
Motorbikes	1.35

4.7 Distance Between Successive Ramps

Weaving sections are highway segments where the pattern of traffic entering and leaving at contiguous points of access results in vehicle paths crossing each other. Weaving sections may occur within an interchange, between entrance ramps, followed by exit ramps of successive interchanges, and on segments of overlapping roadways. Because considerable turbulence occurs throughout weaving sections, interchange designs that eliminate weaving entirely or at least remove it from the main facility are desirable. Weaving sections may be eliminated from the main facility by the selection of interchange forms that do not have weaving or by the incorporation of collector-distributor roads. Interchanges that provide all exit movements before any entrance movements will eliminate weaving.

On urban freeways, two or more ramp terminals are often located in close succession. To provide sufficient weaving length and adequate space for signing, a reasonable distance should be provided between successive ramp terminals. Spacing between successive outer ramp terminals is dependent on the classification of the interchanges involved, the function of the ramp pairs (entrance or exit), and weaving potential. The five possible ramp-pair combinations are: (1) an entrance followed by an entrance (EN-EN), (2) an exit followed by an exit (EX-EX), (3) an exit followed by an entrance (EX-EN), (4) an entrance followed by an exit (EN-EX) (weaving), and (5) turning roadways. The table below presents recommended minimum ramp terminal spacing for the various ramp-pair combinations as they are applicable to interchange classifications.



EN-EN OR EX-EX		EX-EN		TURNING ROADWAYS		EN-EX (WEAVING)			
						SYSTEM TO SERVICE INTERCHANGE		SERVICE TO SERVICE INTERCHANGE	
FULL FREEWAY	CDR OR FDR	FULL FREEWAY	CDR OR FDR	SYSTEM INTER-CHANGE	SERVICE INTER-CHANGE	FULL FWY.	CDR OR FDR	FULL FWY.	CDR OR FDR
MINIMUM LENGTHS MEASURED BETWEEN SUCCESSIVE RAMP TERMINALS									
300 m [1000 ft]	240 m [800 ft]	150 m [500 ft]	120 m [400 ft]	240 m [800 ft]	180 m [600 ft]	600 m [2000 ft]	480 m [1600 ft]	480 m [1600 ft]	300 m [1000 ft]

NOTES: FDR - FREEWAY DISTRIBUTOR ROAD EN - ENTRANCE
CDR - COLLECTOR DISTRIBUTOR ROAD EX - EXIT

Figure 4.11: ASSHTO guide line for distance between ramps

CHAPTER 5

5. ANALYSIS AND RESULTS

5.1 Introduction

This chapter includes the output/results of analysis performed for level of service, delays, travel time and emissions. For analysis purposes two software's were used:

- SYNCHRO 9
- PTV-VISSIM V7

5.2 Analysis Methodology

This section describes the methodology used to handle the data in Synchro and VSSIM then comparison of results among different alternatives. First of all, the study area was divided into three parts based on the traffic compositions and areas these sections are serving. The first potion starts from Zero Point and ends at Faizabad, having very less volume of heavy vehicles. The second section starts form Faizabad and ends at Koral Choke, having large volume of heavy vehicles and main connection road at Koral choke from Rawalpindi. The third section starts form Koral Choke and ends at Rawat serving mainly the residential area. Existing traffic conditions were fed in the Synchro and VISSIM to determine LOS and emissions etc. for these five intersections and three sections. Synchro has windows for different types of data including lane, volume, timing, phasing and simulation settings. The signalized intersection of Koral choke, was analyzed using SYNCHRO and the other intersections were analyzed using VISSIM. For each intersection the following four scenarios were analyzed and compared:

- Before intervention analysis.
- After interventions analysis.
- Analysis for increased traffic for the next 5, 10 and 15 years.
- Analysis of alternatives.

5.2.1 VISSIM Analysis of Zero Point

Starting from Zero Point Intersection which is a 4-legged intersection is located at the junction of Islamabad Expressway and Kashmir highway.

Figure 5.1: Zero point

5.2.1.1 Analysis of Zero Point before intervention

The analysis was performed by using PHV in the form of Veh/hr. vehicle classes and composition is also used in this analysis. The following base data was used:

Table 5.1: Zero-point traffic count

Approach	No of lanes	Lane Width ft.	PHV
NBT	4	11.5	3999.0
NBL	2	11.5	1115.3
NBR	2	11.5	465.9
SBT	4	11.5	5038.7
SBL	2	11.5	585.9
SBR	2	11.5	1526.9
EBL	2	11.5	630.6
EBR	2	11.5	1592.8
WBR	2	11.5	488.5
WBL	2	11.5	1325.9

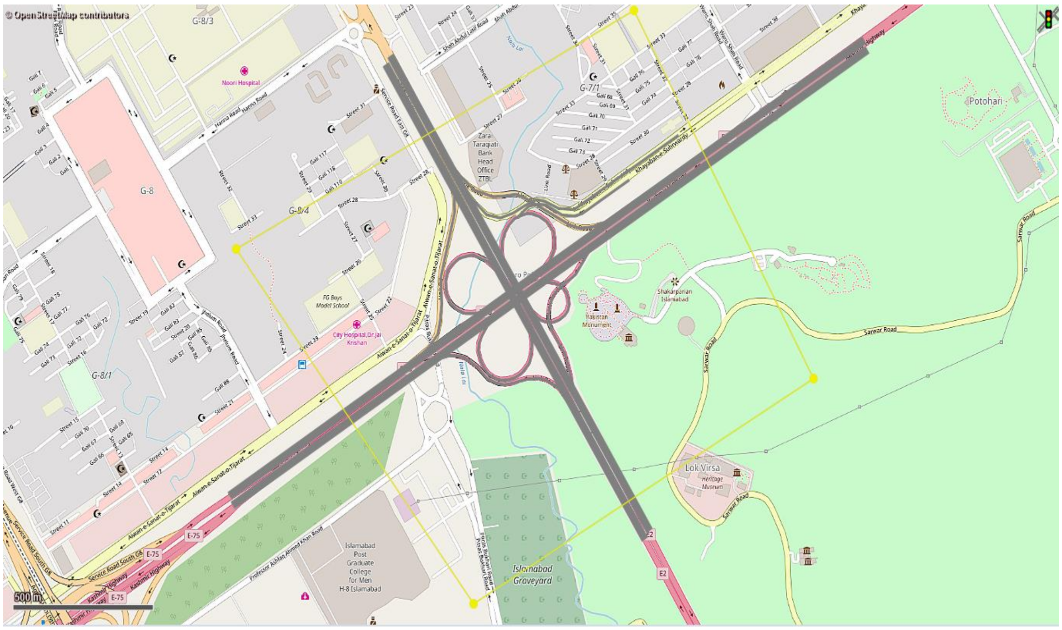


Figure 5.2: Zero-point VISSIM model

The results are shown in following table;

Table 5.2: VISSIM results of Zero-point before intervention

Delays(s/veh)	36.38
Density(pc/km/ln)	20.76
LOS	D
Stop Delays(s/veh)	117.18
Fuel consumption(gal/hr)	640.926
Emission CO(grams/hr)	44800.64
Emission NOX(grams/hr)	8716.578
Emission VOC(grams/hr)	10382.98

The above table is the result summary of intersection developed on **VISSIM.** According to this table delays are **36.38 s/veh.**, LOS is **E**, stop delays are **117.18 s/veh.** fuel consumption is **641** gal/hr. emissions of CO, NOX and VOC's are **44800, 8717 and 10383 grams/hr.** respectively.

5.2.1.2 Analysis of Zero Point after intervention

Similarly, analysis was run after intervention for present year, next 5, 10 and 15 years using the following base data:

Table 5.3: Zero-point traffic count from 2018 to 2033

Approach	No of lanes	Lane Width ft.	PHV for current year	PHV for next 5 year	PHV for 10 years	PHV for 15 years
NBT	6	11.5	4268.2	5193.1	6317.7	7686.5
NBL	2	13	1190.4	1448.3	1762.0	2143.8
NBR	2	13	497.2	605.0	736.0	895.4
SBT	6	11.5	5377.9	6543.3	7960.3	9685.0
SBL	2	13	625.3	760.8	925.6	1126.2
SBR	2	13	1629.7	1982.8	2412.2	2934.9
EBL	2	13	673.1	818.9	996.3	1212.1
EBR	2	13	1700.0	2068.4	2516.3	3061.5
WBR	2	13	521.3	634.3	771.7	938.9
WBL	2	13	1415.2	1721.9	2094.8	2548.6

Table 5.4: VISSIM results of zero-point after intervention

Parameter	**2018**	**2023**	**2028**	**2033**
Density(pc/km/ln)	9.13	11.59	15.15	21.78
Delays(s/veh)	2.98	9.56	18.82	28.67
LOS	B	C	C	D
Stop Delays(s/veh)	5.34	16.2	13.74	27.3
Fuel consumption(gal/hr)	216.726	272.49	373.152	593.796
Emission CO(grams/hr)	15149.09	19047.02	26083.15	41506.14
Emission NOX(grams/hr)	2947.464	3705.858	5074.836	8075.586
Emission VOC(grams/hr)	3510.948	4414.332	6045.024	9619.446

This table shows that after intervention the LOS of the intersection is reduced to A and will remain A till 2023. However, in 2028 it will be shifted to B and in 2033 the LOS will be C.

5.2.2 VISSIM Analysis of Fiazabad intersection

Faizabad interchange is a 5-legged intersection located at the junction of

Islamabad Expressway and Murree Road. IJP road is also connected to the Murree Road.

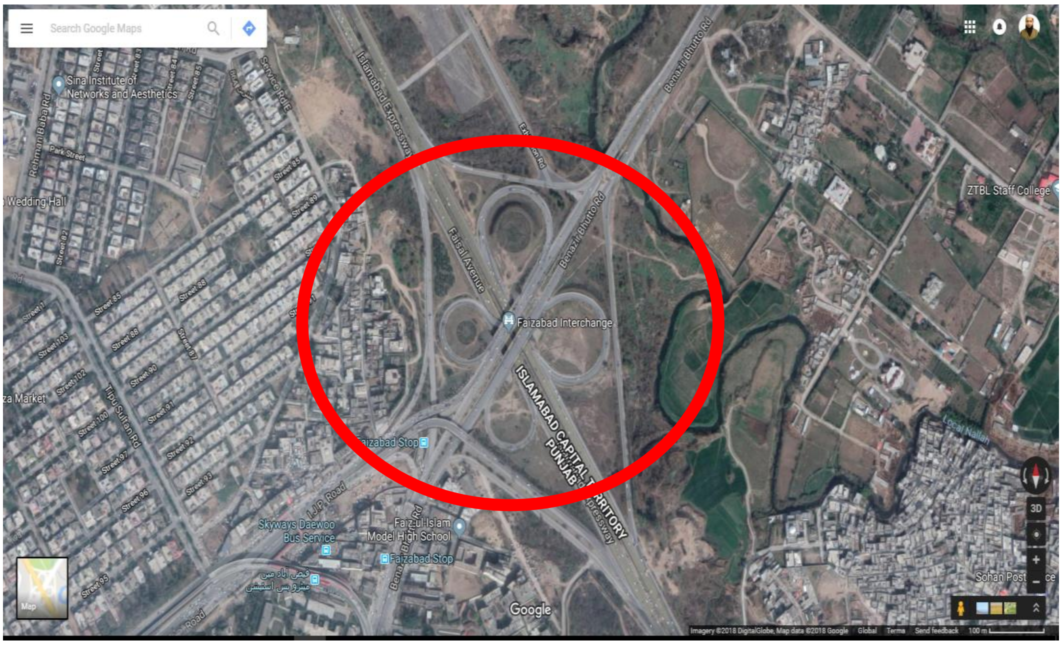


Figure 5.3: Faizabad

5.2.2.1 Analysis of Faizabad Interchange before intervention

The analysis was performed by using PHV in the form of Veh/hr. vehicle classes and composition is also used in this analysis. The following base data was used:

Table 5.5: Faizabad traffic count

Approach	No of lanes	Lane Width ft.	PHV
NBT	5	11.5	7132.8
NBL	1	11.5	1658.8
NBR	2	11.5	1132.2
SBT	5	11.5	8987.4
SBL	2	23	1426.6
SBR	1	11.5	2090.1
EBL	1	11.5	1321.7
EBR	2	11.5	2192.0
WBR	1	11.5	2365.1
WBL	1	11.5	1198.3

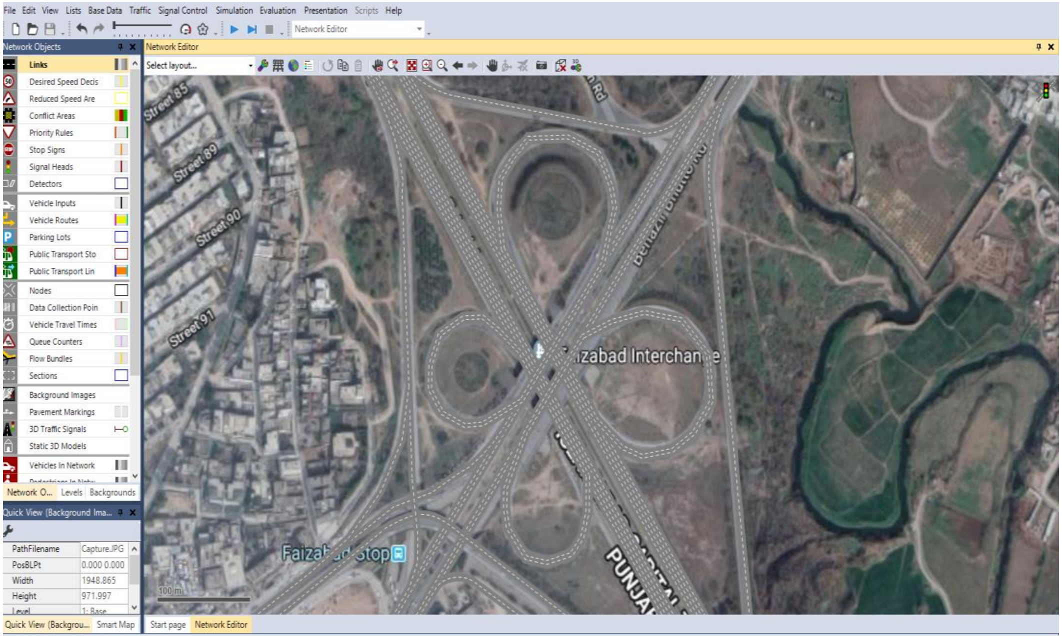


Figure 5.4: Faizabad VISSIM model

The results are shown in following table:

Table 5.6: VISSIM results of faizabad before intervention

Delays(s/veh)	64.58
Density(pc/km/ln)	26.32
LOS	E
Stop Delays(s/veh)	84.96
Fuel consumption(gal/hr)	775.932
Emission CO(grams/hr)	54237.49
Emission NOX(grams/hr)	10552.64
Emission VOC(grams/hr)	12570.06

The above table is the result summary of intersection developed on **VISSIM.** According to this table delays are **64.58 s/veh.**, LOS is **E**, stop delays are **84.96 s/veh.** fuel consumption is **775.932 gal/hr.** emissions of CO, NOX and VOC's are **54238, 10553 and 12570 grams/hr.** respectively.

5.2.2.2 Analysis of Faizabad after intervention

Similarly, analysis was run after intervention for present year, next 5, 10 and 15 years using the following base data:

Table 5.7: Faizabad traffic count from 2018 to 2033

Approach	No of lanes	Lane Width ft.	PHV for current year	PHV for next 5 year	PHV for 10 years	PHV for 15 years
NBT	6	11.5	7612.9	9262.7	11268.7	13710.1
NBL	2	11.5	1770.5	2154.1	2620.6	3188.4
NBR	2	11.5	1208.4	1470.3	1788.7	2176.2
SBT	6	11.5	9592.3	11671.0	14198.5	17274.8
SBL	2	23	1522.6	1852.5	2253.7	2742.0
SBR	2	11.5	2230.8	2714.2	3302.0	4017.4
EBL	2	23	1410.6	1716.3	2088.0	2540.4
EBR	2	11.5	2339.6	2846.6	3463.1	4213.4
WBR	2	11.5	2524.3	3071.3	3736.5	4546.0
WBL	2	11.5	1279.0	1556.1	1893.1	2303.3

Table 5.8: VISSIM results of fazizabad after intervention

Parameter	**2018**	**2023**	**2028**	**2033**
Delays(s/veh)	26.08	40.64	60.6	98.49
Density(pc/km/ln)	15.43	20.21	27.27	31.13
LOS	C	D	E	F
Stop Delays(s/veh)	75.6	85.5	115.02	117.72
Fuel consumption(gal/hr)	726.294	811.614	942.084	1009.602
Emission CO(grams/hr)	50768.15	56731.74	65851.72	70571.24
Emission NOX(grams/hr)	9877.638	11037.94	12812.35	13730.6
Emission VOC(grams/hr)	11766.01	13148.13	15261.77	16355.57

This table shows that even after 2018 a suitable intervention is required to reduce the traffic volume and keep the existing structure functional.

5.2.3 SYCHRO Analysis of Koral intersection

The analysis was performed using PHV in the form of PCU/hr and the results are;

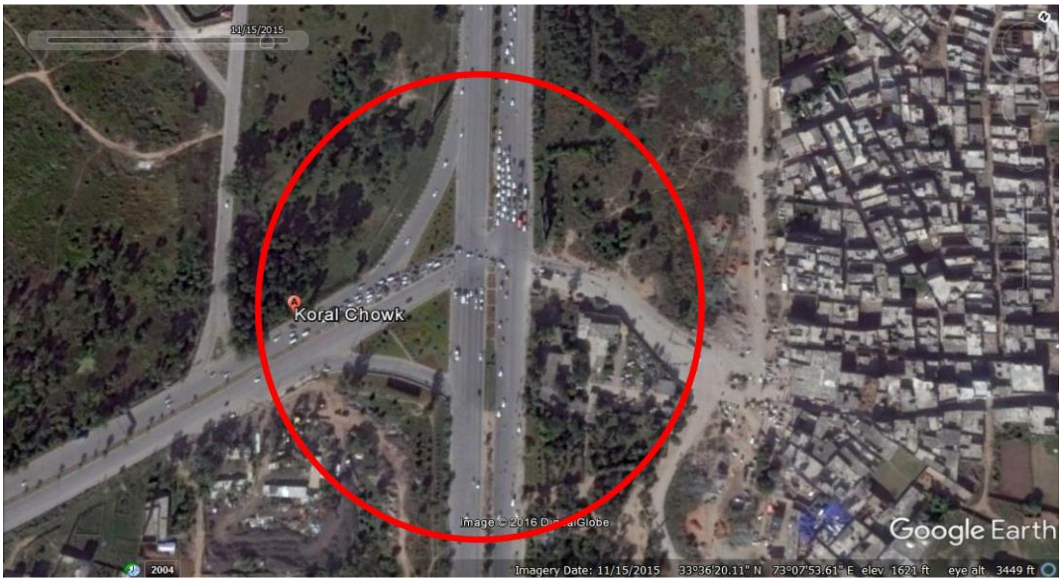


Figure 5.5: Koral

The result summary of intersection developed on SYNCHRO shows cycle length is 150 seconds, the intersection signal delay is 94 sec/vehicle, LOS is F and the intersection capacity utilization is 156.3 %.

5.2.3.1 Analysis of Koral Choke in VISSIM before intervention

The analysis was performed by using PHV in the form of Veh/hr. vehicle classes and composition is also used in this analysis. The following base data was used:

Table 5.9: Koral traffic count

Approach	No of lanes	Lane Width ft.	PHV
NBT	5	11.5	5986.3
NBL	1	11.5	427.6
NBR	1	11.5	136.1
SBT	5	11.5	7542.7
SBL	1	11.5	121.1
SBR	1	11.5	2329.7
EBL	2	11.5	45.9
EBR	2	11.5	121.1
WBR	2	11.5	127.4
WBL	1	11.5	526.4

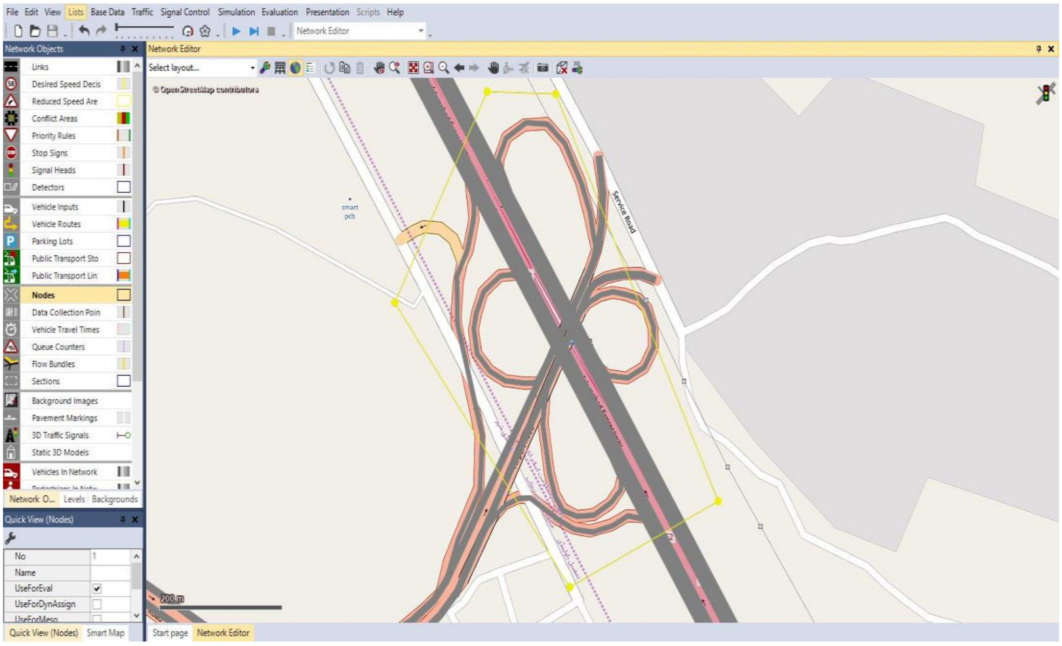


Figure 5.6: Koral VISSIM model

The results are shown in following table:

Table 5.10: VISSIM results of zero point before intervention

Delays(s/veh)	172.19
LOS	F
Stop Delays(s/veh)	140.39
Stops	4.93
Fuel consumption(gal/hr)	589.57
Emission CO(grams/hr)	41210.92
Emission NOX(grams/hr)	8018.148
Emission VOC(grams/hr)	9551.029

The above table is the result summary of intersection developed on **VISSIM.** According to this table delays are **172.19 s/veh.**, LOS is **F**, stop delays are **140.39 s/veh.** fuel consumption is 589.57 gal/hr. emissions of CO, NOX and VOC's are **41210.92, 8018 and 9551 grams/hr.** respectively.

5.2.3.2 Analysis of Koral Choke after intervention

Similarly, analysis was run after intervention for present year, next 5, 10 and 15 years using the following base data:

Table 5.11: Koral traffic count from 2018 to 2033

Approach	No of lanes	Lane Width ft.	PHV for current year	PHV for next 5 year	PHV for 10 years	PHV for 15 years
NBT	7	11.5	6389.2	7773.7	9457.3	11506.3
NBL	2	11.5	456.4	555.3	675.5	821.9
NBR	2	11.5	145.2	176.7	214.9	261.5
SBT	7	11.5	8050.4	9794.9	11916.2	14497.9
SBL	2	11.5	129.2	157.2	191.3	232.7
SBR	2	11.5	2486.5	3025.4	3680.6	4478.0
EBL	2	11.5	49.0	59.6	72.5	88.2
EBR	2	11.5	129.2	157.2	191.3	232.7
WBR	2	11.5	136.0	165.5	201.3	245.0
WBL	2	11.5	561.8	683.6	831.6	1011.8

Table 5.12: VISSIM results of Koral after intervention

Parameters	2018	2023	2028	2033
Delays(s/veh)	9.59	13.6	27.65	32.38
Density(pc/km/ln)	6.11	10.91	13.45	15.79
LOS	A	B	C	C
Stop Delays(s/veh)	13.56	26.82	58.08	82.14
Fuel consumption(gal/hr)	350.616	388.632	401.046	402.318
Emission CO(grams/hr)	24507.92	27165.18	28033.03	28122.17
Emission NOX(grams/hr)	4768.35	5285.358	5454.21	5471.55
Emission VOC(grams/hr)	5679.948	6295.794	6496.926	6517.584

5.2.4 VISSIM Analysis of PWD intersection

PWD intersection is a signalized intersection provide for the flow of traffic from north bound to U-Turn to south bound and then take left turn to PWD society.

Figure 5.7: PWD

5.2.4.1 Analysis of PWD Signal before intervention

The analysis was performed by using PHV in the form of Veh/hr. vehicle classes and composition is also used in this analysis. The following base data was used:

Table 5.13: PWD traffic count

Approach	No of lanes	Lane Width ft.	PHV
NBT	2	11.5	3068.8
NBR	1	11.5	90.3
SBT	2	11.5	3866.7
SBR	1	11.5	1017.5

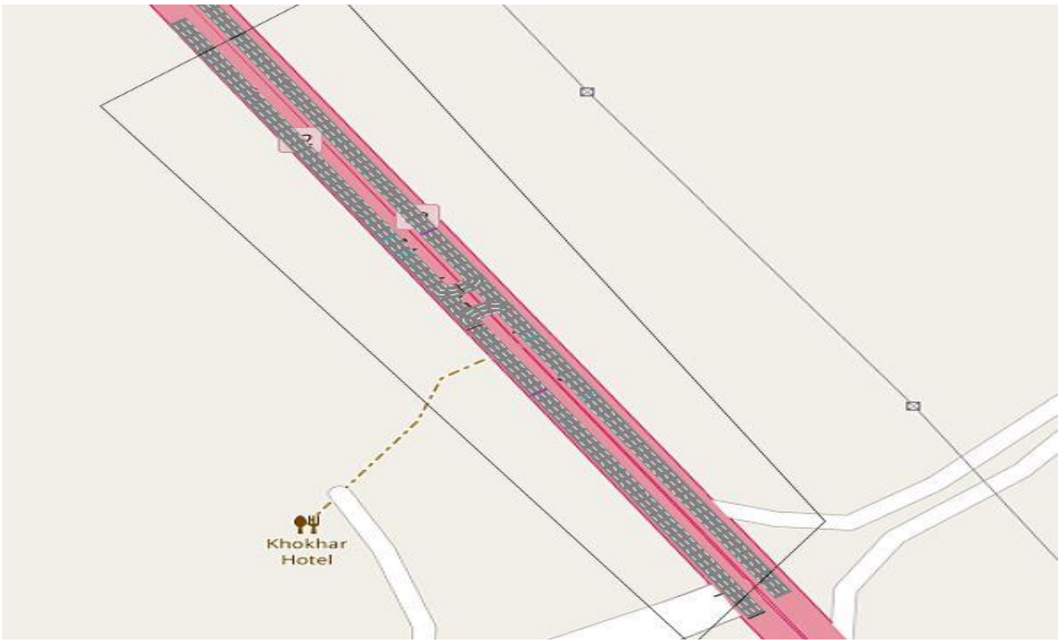


Figure 5.8: PWD VISSIM model

The results are shown in following table;

Table 5.14: VISSIM results of PWD before intervention

Delays(s/veh)	73.55
LOS	E
Stop Delays(s/veh)	57.09
Fuel consumption(gal/hr)	261.18
Emission CO(grams/hr)	18256.29
Emission NOX(grams/hr)	3552.012
Emission VOC(grams/hr)	4231.074

The above table is the result summary of intersection developed on **VISSIM.** According to this table delays are **73.55 s/veh.**, LOS is **E**, stop delays are **57.09 s/veh.** fuel consumption is **261.18 gal/hr.** emissions of CO, NOX and VOC's are **18256.29, 3552 and 4231 grams/hr.** respectively.

5.2.4.2 Analysis of PWD after intervention

Similarly, analysis was run after intervention for present year, next 5, 10 and 15 years using the following base data:

Table 5.15: PWD traffic count from 2018 to 2033

Approach	No of lanes	Lane Width ft.	PHV for current year	PHV for next 5 year	PHV for 10 years	PHV for 15 years
NBT	5	11.5	3406.3	4144.5	5042.1	6134.5
NBR	2	11.5	100.2	121.9	148.3	180.4
SBT	2	11.5	4292.0	5222.1	6353.0	7729.5
SBR	5	11.5	1129.5	1374.2	1671.8	2034.1

Figure 5.9: PWD VISSIM model after intervention

Table 5.16: VISSIM results of PWD after intervention

Parameter	**2018**	**2023**	**2028**	**2033**
Delays(s/veh)	1.39	2.19	6.63	15.47
Density(pc/km/ln)	5.40	6.72	9.57	13.31
LOS	A	A	B	C
Stop Delays(s/veh)	1.02	3.96	4.98	11.16
Fuel consumption(gal/hr)	157.764	195.138	237.63	341.418
Emission CO(grams/hr)	11027.8	13640.03	16610.44	23865.05
Emission NOX(grams/hr)	2145.606	2653.854	3231.786	4643.274
Emission VOC(grams/hr)	2555.796	3161.208	3849.63	5530.956

5.2.4.3 Analysis of PWD for proposed future strategy

No intervention required as the intersection is still at C by 2033

5.3 Summary of results

This includes comparison of the study area before intervention and after intervention and after proposed strategy in term of delays, fuel consumption and emissions. This chapter also include capital cost recovery of interchange in term of public benefits. The following tables and bar charts show comparison of VISSIM results of intersection and interchange; Delay and stop delay is in sec/veh., fuel consumption is in US gallon/hr. and emissions are in gram/hr.

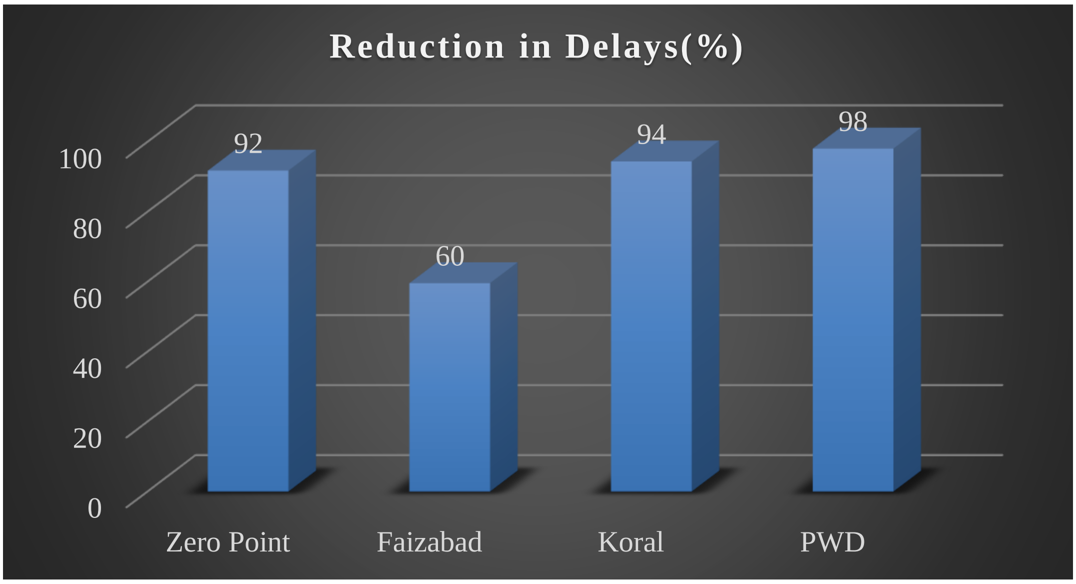


Figure 5.10: Reduction in delays

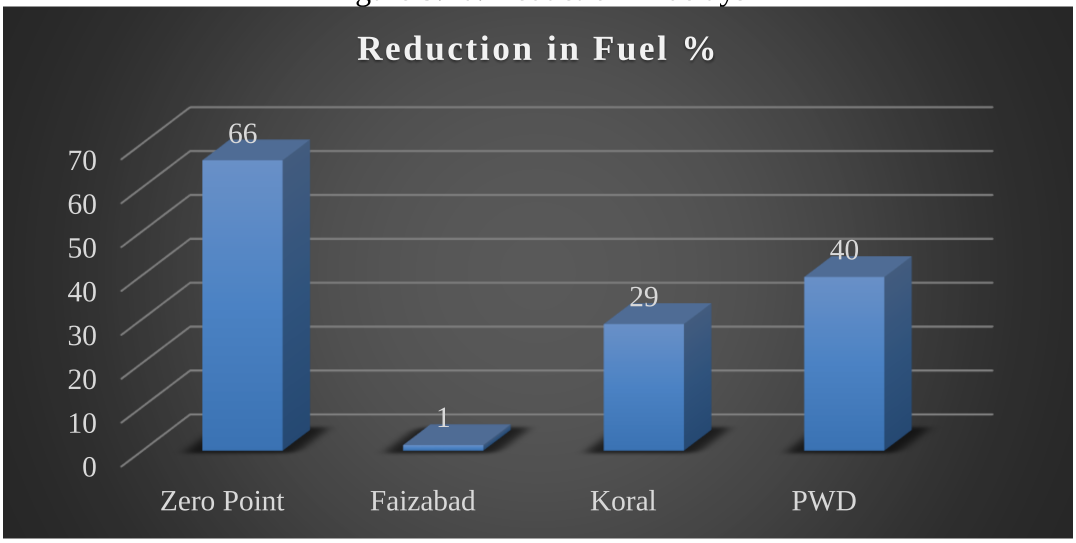


Figure 5.11: Reduction in fuel consumption

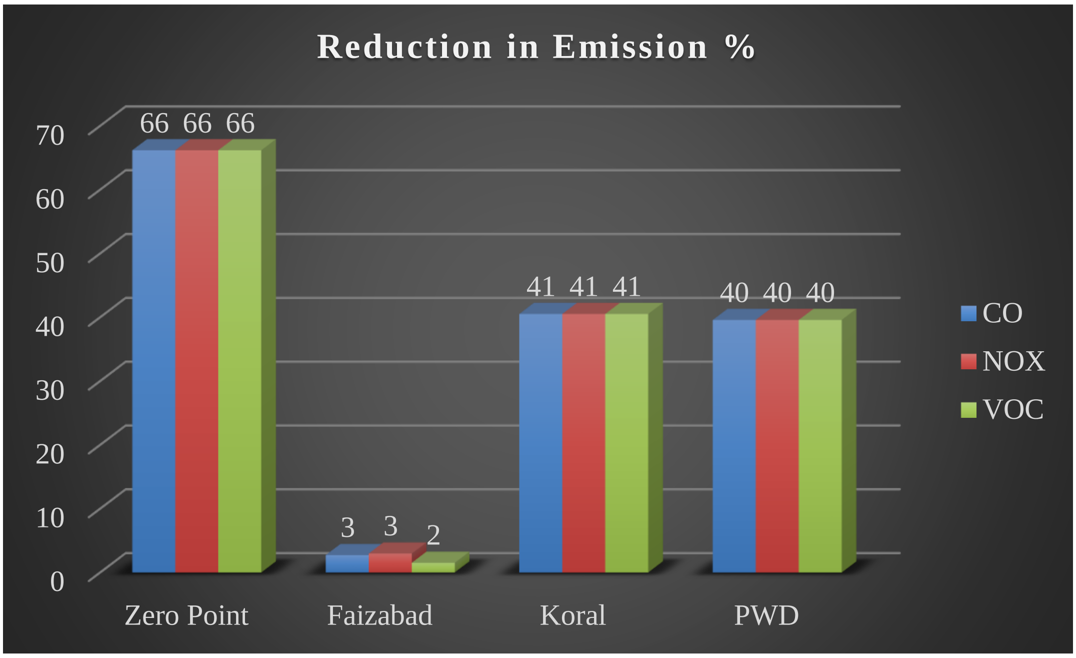


Figure 5.12: Reduction in emissions

5.3.1 Zero Point Results

Table 5.17: Zero-point result summary

Zero Point					
	Before Intervention	**After Intervention**			
Parameters	2014	2018	2023	2028	2033
Delays(s/veh)	36.38	9.13	11.59	15.15	21.78
Density(pc/km/ln)	20.76	2.98	9.56	18.82	28.67
LOS	D	B	C	C	D
Stop Delays(s/veh)	117.18	5.34	16.2	13.74	27.3
Fuel consumption(gal/hr)	640.926	216.726	272.49	373.152	593.796
Emission CO(grams/hr)	44800.64	15149.09	19047.02	26083.15	41506.14
Emission NOX(grams/hr)	8716.578	2947.464	3705.858	5074.836	8075.586
Emission VOC(grams/hr)	10382.98	3510.948	4414.332	6045.024	9619.446

5.3.2 Faizabad Results

Table 5.18: Faizabad result summary

Faizabad					
	Before Intervention	**After Intervention**			
Parameters	2014	2018	2023	2028	2033
Delays(s/veh)	64.58	26.08	40.64	60.6	98.49
Density(pc/km/ln)		15.43	20.21	27.27	31.13
LOS	E	C	D	E	F
Stop Delays(s/veh)	84.96	75.6	85.5	115.02	117.72
Fuel consumption(gal/hr)	775.932	726.294	811.614	942.084	1009.602
Emission CO(grams/hr)	54237.49	50768.15	56731.74	65851.72	70571.24
Emission NOX(grams/hr)	10552.64	9877.638	11037.94	12812.35	13730.6
Emission VOC(grams/hr)	12570.06	11766.01	13148.13	15261.77	16355.57

5.3.3 KoralChoke Results

Table 5.19: Koral result summary

Koral Choke					
	Before Intervention	**After Intervention**			
Parameters	2014	2018	2023	2028	2033
Delays(s/veh)	172.19	9.59	13.6	27.65	32.38
Density(pc/km/ln)	-	6.11	10.91	13.45	15.79
LOS	F	A	B	C	C
Stop Delays(s/veh)	140.39	13.56	26.82	58.08	82.14
Fuel consumption(gal/hr)	589.57	350.616	388.632	401.046	402.318
Emission CO(grams/hr)	41210.92	24507.92	27165.18	28033.03	28122.17
Emission NOX(grams/hr)	8018.148	4768.35	5285.358	5454.21	5471.55
Emission VOC(grams/hr)	9551.029	5679.948	6295.794	6496.926	6517.584

5.3.4 PWD Results

Table 5.20: PWD result summary

PWD					
	Before Intervention	**After Intervention**			
Parameters	2014	**2018**	**2023**	**2028**	**2033**
Delays(s/veh)	73.55	1.39	2.19	6.63	15.47
Density(pc/km/ln)	-	5.40	6.72	9.57	13.31
LOS	E	A	A	B	C
Stop Delays(s/veh)	57.09	1.02	3.96	4.98	11.16
Fuel consumption(gal/hr)	261.18	157.764	195.138	237.63	341.418
Emission CO(grams/hr)	18256.29	11027.8	13640.03	16610.44	23865.05
Emission NOX(grams/hr)	3552.012	2145.606	2653.854	3231.786	4643.274
Emission VOC(grams/hr)	4231.074	2555.796	3161.208	3849.63	5530.956

5.4 Cost Recovery Analysis in Terms of Public Benefits

Cost recovery in term of public benefits calculation are discussed in the analysis chapter. Here only results are represented:

5.4.1 Savings due to Fuel Consumption Reduction

Table 5.21: Savings (In million RS.) due to fuel consumption reduction

Location	**Year**	**Fuel cost before Intervention**	**Fuel cost After Intervention**	**Savings**
Zero Point	2018	1910.1	645.9	1264.2
	2023	2067.5	812.1	1255.4
	2028	2282.7	1112.0	1170.6
	2033	2520.3	1769.6	750.7
Faizabad	2018	2312.4	2164.5	147.9
	2023	2418.7	2342.9	75.8
	2028	2807.5	2586.7	220.8

	2033	3008.8	2856.0	152.8
Koral	2018	1757.0	1044.9	712.1
	2023	1901.8	1158.2	743.7
	2028	2099.8	1195.2	904.6
	2033	2318.3	1199.0	1119.4
PWD	2018	778.4	470.2	308.2
	2023	842.5	581.5	261.0
	2028	930.2	708.2	222.0
	2033	1027.0	1017.5	9.5

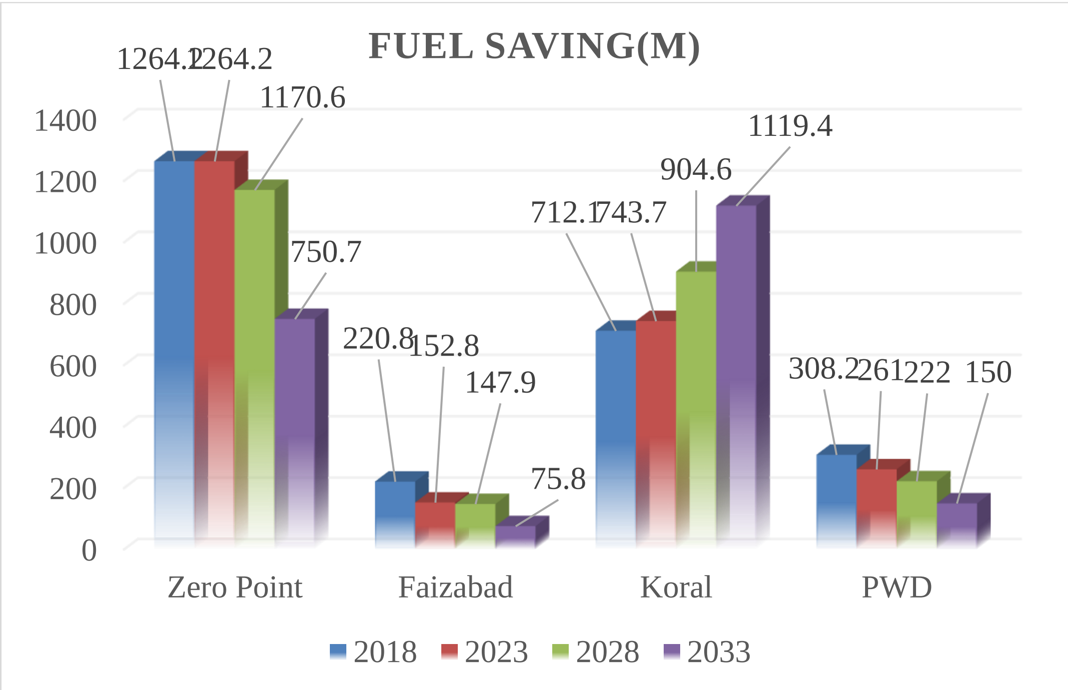


Figure 5.13: Savings due to reduction in fuel

The above table shows savings in million Rs. /year due to reduction of fuel consumption because of conversion of the interventions.

5.4.2 Savings due to Emissions

Table 5.22: Savings (In million RS.) due to CO emissions

Location	Year	CO cost before Intervention	CO cost After Intervention	Savings
Zero Point	2018	4.7	1.6	3.1
	2023	5.1	2.0	3.1
	2028	5.6	2.7	2.9
	2033	6.2	4.3	1.8
Faizabad	2018	5.7	5.3	0.4
	2023	5.9	5.7	0.2
	2028	6.9	6.3	0.5
	2033	7.4	7.40	0.4
Koral	2018	4.3	2.6	1.7
	2023	4.7	2.8	1.8
	2028	5.1	2.9	2.2
	2033	5.7	2.9	2.7
PWD	2018	1.9	1.1	0.8
	2023	2.1	1.4	0.6
	2028	2.3	1.7	0.5
	2033	2.5	2.5	0.0

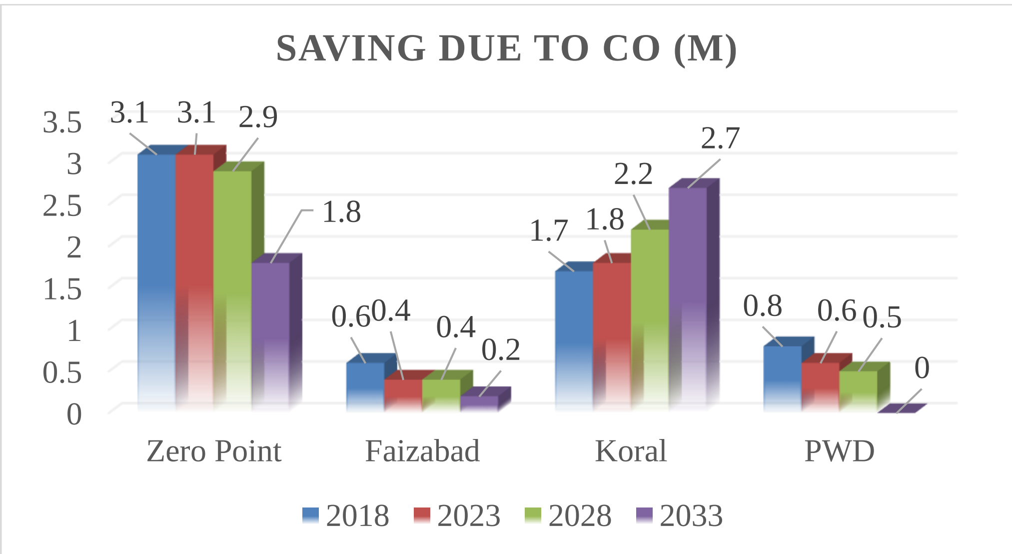


Figure 5.14: Saving due to reduction in CO

The above table shows savings in million Rs. /year due to reduction of vehicular CO emissions because of intervention.

Table 5.23: Savings (In million RS.) due to NOX emissions

Location	Year	NOX cost before Intervention	NOX cost After Intervention	Savings
Zero Point	2018	32.9	11.1	21.8
	2023	35.7	14.0	21.6
	2028	39.4	19.2	20.2
	2033	43.5	30.5	12.9
Faizabad	2018	39.9	37.33	2.5
	2023	41.7	40.44	1.3
	2028	48.4	44.648	3.8
	2033	51.9	49.35	2.6
Koral	2018	30.3	18.0	12.3
	2023	32.8	20.0	12.8
	2028	36.2	20.6	15.6
	2033	40.0	20.7	19.3
PWD	2018	69.0	41.7	27.3
	2023	74.7	51.5	23.1
	2028	82.4	62.8	19.7
	2033	91.0	90.2	0.8

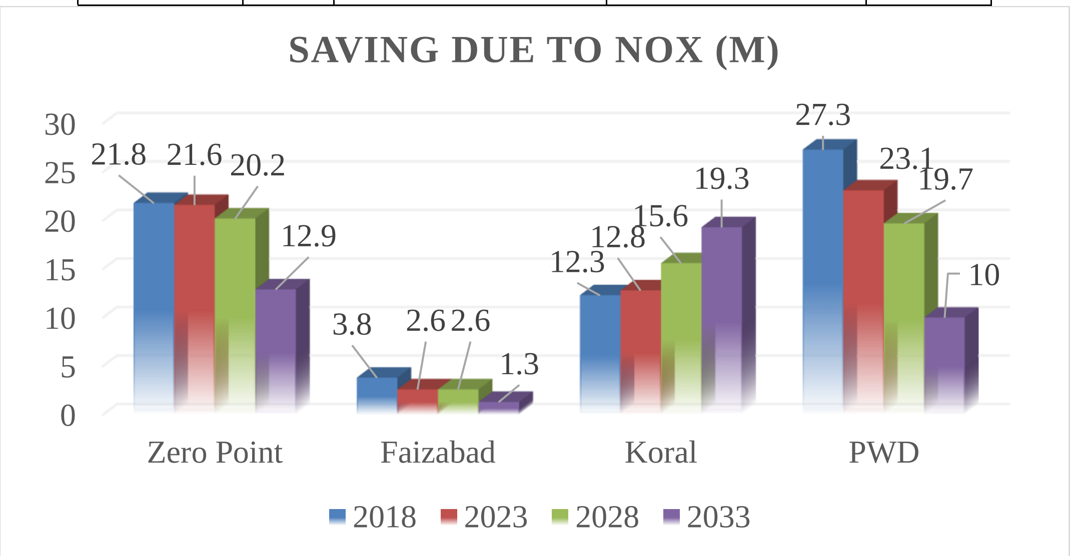


Figure 5.15: Saving due to reduction in NOX

The above table shows savings in million Rs. /year due to reduction of vehicular NOX emissions because of intervention.

Table 5.24: Savings (In million RS.) due to VOC emissions

Location	**Year**	**VOC cost before Intervention**	**VOC cost After Intervention**	**Savings**
Zero Point	2018	29.8	10.1	19.7
	2023	32.2	12.7	19.6
	2028	35.6	17.3	18.2
	2033	39.3	27.6	11.7
Faizabad	2018	36.0	33.7	2.3
	2023	37.7	36.5	1.2
	2028	43.8	40.3	3.5
	2033	446.9	44.5	2.4
Koral	2018	27.4	16.3	11.1
	2023	29.6	18.0	11.6
	2028	32.7	18.6	14.1
	2033	36.1	18.7	17.4
PWD	2018	12.1	7.3	4.8
	2023	13.1	9.1	4.1
	2028	14.5	11.0	3.5
	2033	16.0	15.9	0.1

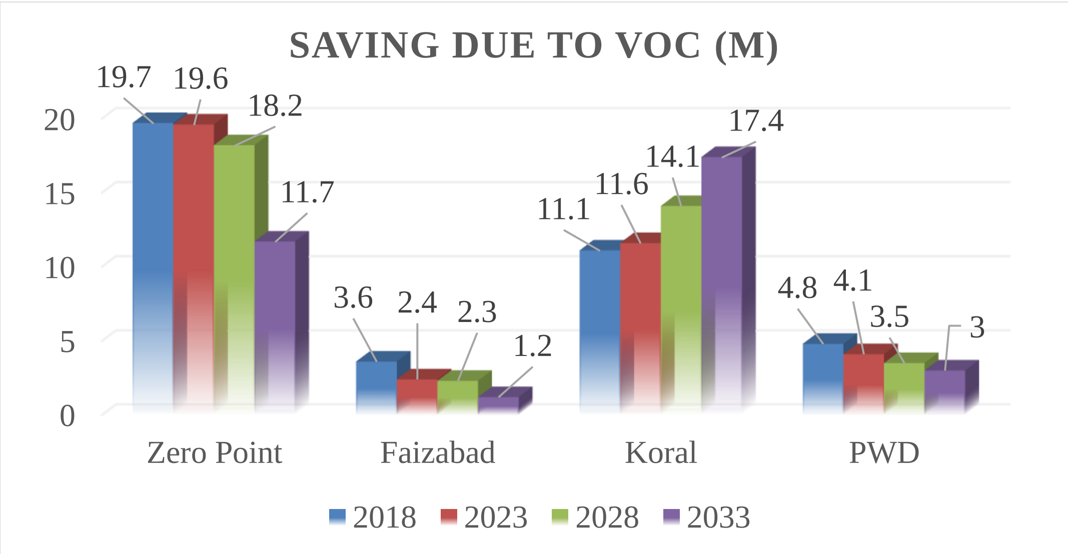


Figure 5.16: Saving due to reduction in VOC

The above table shows savings in million Rs. /year due to reduction of vehicular VOC emissions because of intervention.

From the above tables the total saving from the four intersections can be calculated which is Rs 8465.1 million. The cost recovery per Km will be RS 830 million. Therefore, the total cost recovery for 25 Km is 20.75 billion. Whereas the total cost of the project is 21.814 billion. This cost is recovered after 15 years. However, a successful project should recover the cost in 5 years.

5.5 Causes of Congestion

After conducting field visits again and again the following causes of congestion were identified in the second portion of the study area i.e. between Faizabad and Koral Choke.

- Inadequate distance between the ramps.
- Improper location and geometry of bus stops.
- Time headway between the vehicle is not according the National Safety Council of United States.
- Presence of heavy vehicles.
- Presence of pedestrians.

Therefore, ramp analysis and time headway analysis are conducted in the coming section with the aim to mitigate these problems in next section.

5.6 Ramp Analysis

Ramp analysis was performed for the already constructed interchanges by the method as discussed in the above chapter.

5.6.1 Zero Point Ramp Analysis

The below figure shows the main configuration of Zero Point with lengths between the ramps.

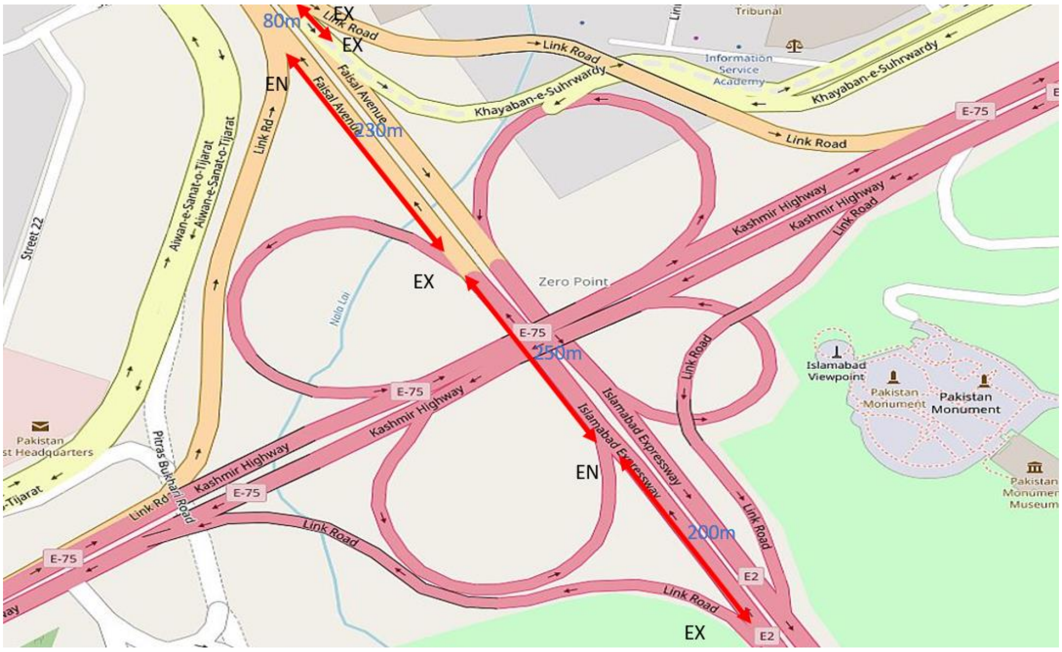


Figure 5.17: Zero-point distance between ramps

5.6.2 I-8 Interchange Ramp Analysis

The below figure shows the main configuration of I-8 interchange with lengths between the ramps.

Figure 5.18: I-8 distance between ramps

5.6.3 Faizabad Interchange Ramp Analysis

The below figure shows the main configuration of Faizabad interchange with lengths between the ramps.

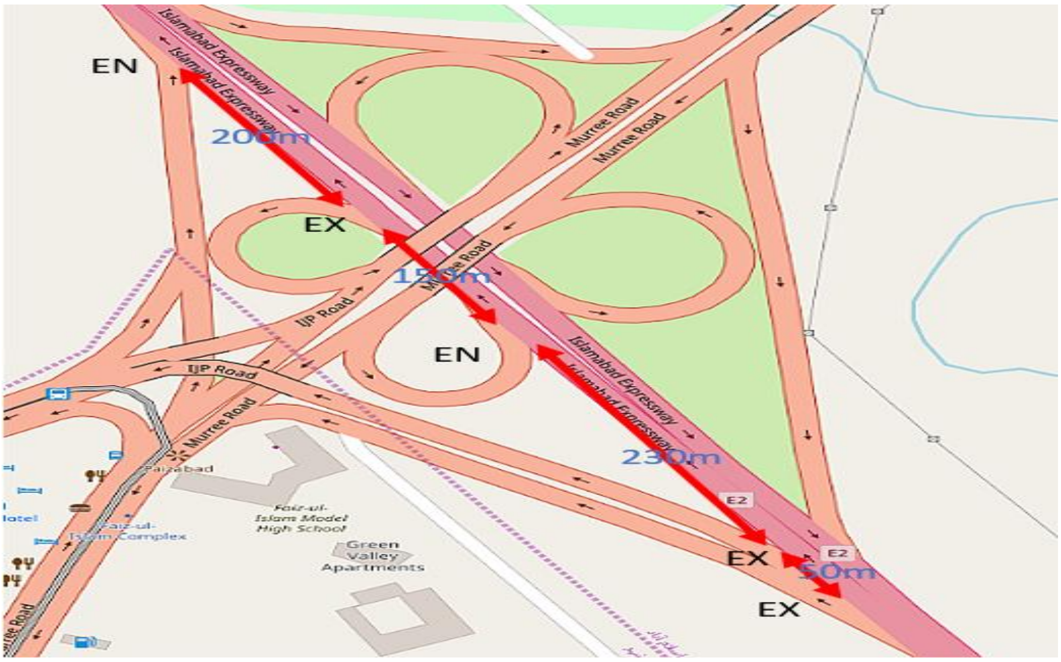


Figure 5.19: Faizabad distance between ramps

5.6.4 Koral Interchange Ramp Analysis

The below figure shows the main configuration of Koral interchange with lengths between the ramps.

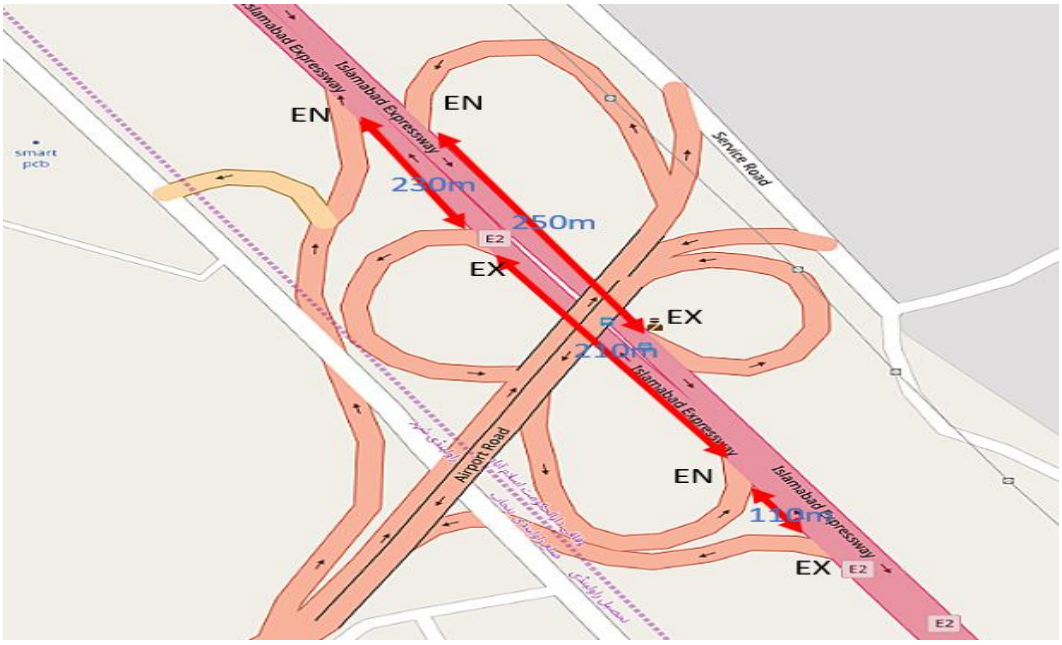


Figure 5.20: Koral distance between ramps

5.6.5 Gulberg Interchange Ramp Analysis

The below figure shows the main configuration of Gulberg interchange with lengths between the ramps.

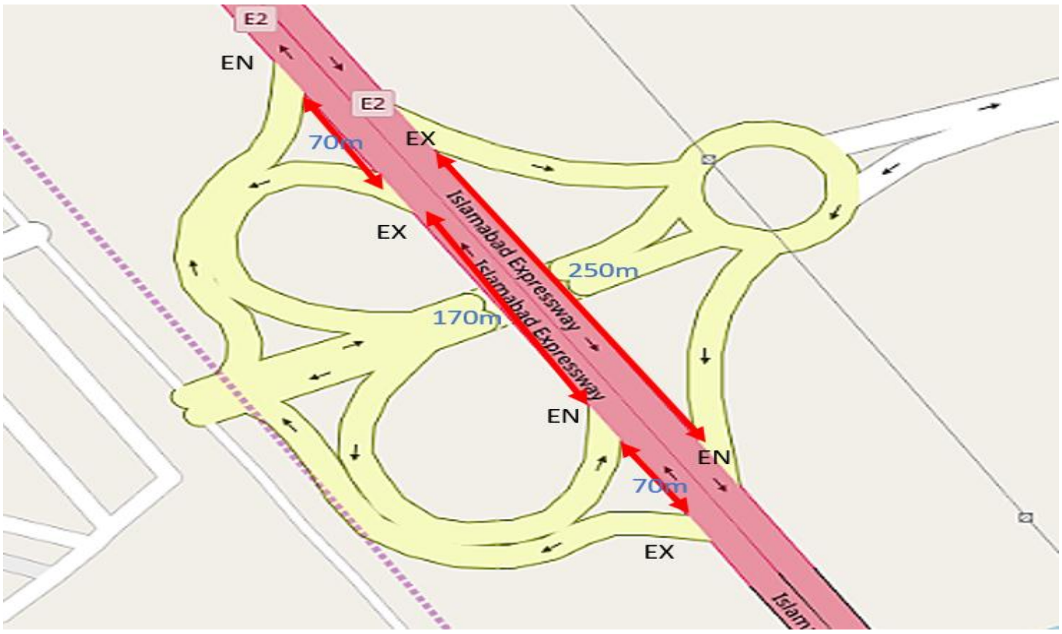


Figure 5.21: Gulberg distance between ramps

5.6.6 Navel Anchorage Interchange Ramp Analysis

The below figure shows the main configuration of Navel Anchorage interchange with lengths between the ramps.

Figure 5.22: Navel distance between ramps

5.6.7 Summary of Results

Table 5.25: Ramp analysis summary

Location	Zero Point	I-8	Faizabad	Koral	Gulberg	Navel	Required
EX-EN	200	170	230	110	70	100	150
EN-EX	250	180	150	250	250	-	600
EX-EN	230	100	200	230	70	60	150
EX-EX	80	-	50	-	-	-	300

As It can be seen that almost all the interchanges failed in EX-EN Ramp area which is very critical and contributing to turbulence in traffic streams and causing congestion.

5.7 Time Headway Analysis

Time headway is the difference between the time the front of a vehicle arrives at a point on the highway and the time the front of the next vehicle arrives at that same point. Time headway is usually expressed in seconds. In the study area time headway of the vehicles were determined from videos recorded at that intersection. The speed of the video was reduced to about 80% to find the time headway between different vehicles. As shown in the picture:

Figure 5.23: Time headway image

It was found that on average cars have 1 second time headway. Whereas, The United States Nation Safety Council suggests that a three- second rule-with increase in one second per factor of driving difficulty-is more appropriate of reduction in accidents and reductions. Factors that make driving more difficult include poor lighting condition, adverse traffic mix, personal condition. In our study area therefore, the time headway should be between 4 to 5 seconds.

5.8 Analysis of Other Mitigation Strategies

Considering Faizabad interchange which is the most inefficient and at lowest LOS as our base interchange on which we will apply the following four alternatives for congestion mitigation.

- Increasing number of lanes
- Providing alternative routes for heavy vehicles.
- Providing alternative and efficient public transport.
- Providing distances between the ramps and bus stops as per AASHTO Guidelines.
- Providing adequate time headway between the vehicles.
- Using tollways as a congestion mitigation solution.

5.8.1 Increasing Number of Lanes

The increase in number of lanes is impossible at this stage at the interchanges. However, the number of lanes can be increased by two before and after the interchanges. So, currently the number of lanes is five, two lanes will be added before and after the interchange will be analyzed for the traffic volume of 2023 and for the next 15 years using the 4 percent growth rate. The results are as shown.

Table 5.26: Summary of analysis increasing number of lanes

Increasing Number of lanes				
Parameters	**2023**	**2028**	**2033**	**2038**
Delays (s/Veh.)	27.97	43.77	56.38	84.41
Density (pc/km/ln)	15.20	20.08	27.68	31.11
LOS	C	D	E	F
Stop Delays (s/Veh.)	53	56	61	68
Fuel consumption (gal/hr.)	468	484	500	526
Emission CO (grams/hr.)	32729	33836	34924	36794
Emission NOX (grams/hr.)	6368	6583	6795	7159
Emission VOC (grams/hr.)	7585	7842	8094	8527

As compared to the current situation:

Table 5.27: VISSIM results of fazizabad after intervention

Parameter	**2018**	**2023**	**2028**	**2033**
Delays(s/veh)	26.08	40.64	60.6	98.49
Density(pc/km/ln)	15.43	20.21	27.27	31.13
LOS	C	D	E	F
Stop Delays(s/veh)	75.6	85.5	115.02	117.72
Fuel consumption(gal/hr)	726.294	811.614	942.084	1009.602
Emission CO(grams/hr)	50768.15	56731.74	65851.72	70571.24
Emission NOX(grams/hr)	9877.638	11037.94	12812.35	13730.6
Emission VOC(grams/hr)	11766.01	13148.13	15261.77	16355.57

It can be seen that increasing number of lanes only effective for the next five years. This analysis excludes a very important factor i.e. whenever an infrastructure is improved in terms of increasing its capacity its attractiveness is increased. Traffic from other routes is also attracted towards the new improved facility. Which further worsen the condition due to increased traffic volume.

5.8.2 Providing Alternative Route to Heavy Vehicles

Another mitigation solution that can be provided for the section between Faizabad and Koral is to divert the heavy vehicles and passing by vehicles to an alternate route. Previously a lot of studies have also been conducted on Rawalpindi bypass. The same route can be utilized by the heavy vehicles on Islamabad Expressway and other passing by vehicles. So, the traffic composition shows that on average we have 6 percent heavy vehicles on this route. It is further assumed that we have 4 percent passing by vehicles. Analysis was conducted for reduced traffic of 10 percent under the current number of lanes and ramps configuration.

Table 5.28: Summary of analysis alternative route

Alternative Route				
Parameters	**2023**	**2028**	**2033**	**2038**
Delays (s/Veh.)	21.13	24.95	26.82	44.48
Density(pc/km/ln)	12.52	13.54	16.33	20.67
LOS	C	C	C	D
Stop Delays (s/Veh.)	47	49	49	54
Fuel consumption (gal/hr.)	408	438	460	640
Emission CO (grams/hr.)	28527	30623	32188	44737
Emission NOX (grams/hr.)	5550	5958	6263	8704
Emission VOC (grams/hr.)	6611	7097	7460	10368

Table 5.29: VISSIM results of fazizabad after intervention

Parameter	**2018**	**2023**	**2028**	**2033**
Delays(s/veh)	26.08	40.64	60.6	98.49
Density(pc/km/ln)	15.43	20.21	27.27	31.13
LOS	C	D	E	F
Stop Delays(s/veh)	75.6	85.5	115.02	117.72
Fuel consumption(gal/hr)	726.294	811.614	942.084	1009.602
Emission CO(grams/hr)	50768.15	56731.74	65851.72	70571.24
Emission NOX(grams/hr)	9877.638	11037.94	12812.35	13730.6
Emission VOC(grams/hr)	11766.01	13148.13	15261.77	16355.57

It can be seen that divergence of traffic and heavy vehicle is very effective in reducing the traffic congestion. We can have obtained LOS up till 2038 by this intervention. However, it will be very expensive. Previous studies have shown that the Rawalpindi bypass will be cost about Rs. 45 Billion.

5.8.3 Providing Efficient Public Transport

Providing public transport in the form of Bus Rapid Transit (BRT) is a common mitigation solution in different cities of Pakistan. However, they are very expensive and as effective in reducing congestion. If a BRT is provided on this route and it reduce the traffic volume by 10 percent then the following results can be obtained.

Table 5.30: Summary of analysis of BRT

BRT				
Parameters	**2023**	**2028**	**2033**	**2038**
Delays (s/Veh.)	32.98	41.3	43.28	49.93
Density(pc/km/ln)	15.15	18.96	20.74	21.58
LOS	C	D	D	D
Stop Delays (s/Veh.)	39	50	60	62
Fuel consumption (gal/hr.)	344	400	425	481
Emission CO (grams/hr.)	24048	27942	29698	33603
Emission NOX (grams/hr.)	4679	5437	5778	6538
Emission VOC (grams/hr.)	5573	6476	6883	7788

Table 5.31: VISSIM results of fazizabad after intervention

Parameter	**2018**	**2023**	**2028**	**2033**
Delays(s/veh)	26.08	40.64	60.6	98.49
Density(pc/km/ln)	15.43	20.21	27.27	31.13
LOS	C	D	E	F
Stop Delays(s/veh)	75.6	85.5	115.02	117.72
Fuel consumption(gal/hr)	726.294	811.614	942.084	1009.602
Emission CO(grams/hr)	50768.15	56731.74	65851.72	70571.24
Emission NOX(grams/hr)	9877.638	11037.94	12812.35	13730.6
Emission VOC(grams/hr)	11766.01	13148.13	15261.77	16355.57

It can be seen that BRT is also very effective in reducing the traffic congestion. However, it will be very expensive. As previously build BRT in the form of Metro have Rs. 5 Billion per KM.

5.8.4 Providing Adequate Distance Between Ramps

As previously discussed that none of the interchange has adequate distance between the ramps as per the guild lines of AASHTO. Which contributes to the increase in delays as causing congestion. Therefore, the provision of adequate ramps distances was provided and analyzed under same traffic and number of lanes. Following results were obtained.

Table 5.32: Summary of analysis of ramps distances

Distance Between Ramps				
Parameters	**2023**	**2028**	**2033**	**2038**
Delays (s/Veh.)	34.57	35.88	44.95	56.82
Density(pc/km/ln)	15.72	17.72	21.85	23.68
LOS	C	D	D	E
Stop Delays (s/Veh.)	52	58	65	69
Fuel consumption (gal/hr.)	523	541	668	807
Emission CO (grams/hr.)	36537	37799	46706	56435
Emission NOX (grams/hr.)	7109	7354	9087	10980
Emission VOC (grams/hr.)	8468	8760	10825	13079

Table 5.33: VISSIM results of fazizabad after intervention

Parameter	**2018**	**2023**	**2028**	**2033**
Delays(s/veh)	26.08	40.64	60.6	98.49
Density(pc/km/ln)	15.43	20.21	27.27	31.13
LOS	C	D	E	F
Stop Delays(s/veh)	75.6	85.5	115.02	117.72
Fuel consumption(gal/hr)	726.294	811.614	942.084	1009.602
Emission CO(grams/hr)	50768.15	56731.74	65851.72	70571.24
Emission NOX(grams/hr)	9877.638	11037.94	12812.35	13730.6
Emission VOC(grams/hr)	11766.01	13148.13	15261.77	16355.57

It can be seen that providing distances between the ramps can also be good solution for reducing traffic congestion. As it will be the most cost effective and can accommodate the same traffic volumes.

5.8.5 Providing Adequate Time Headway Between the Vehicles

As already discussed that in our study area between Faizabad and Koral choke the time headway is one second which further contribute to congestion. Therefore, the time headway was increased to 4 seconds and analyzed in VISSIM. The results are as follows:

Table 5.34: Summary of analysis of time headway

Time Headway				
Parameters	**2023**	**2028**	**2033**	**2038**
Delays (s/Veh.)	14.27	16.71	18.27	19.83
Density(pc/km/ln)	8.44	10.38	12.31	15.20
LOS	B	B	C	C
Stop Delays (s/Veh.)	4	6	7	10
Fuel consumption (gal/hr.)	117	124	129	136
Emission CO (grams/hr.)	8182	8680	8983	9830
Emission NOX (grams/hr.)	1592	1689	1748	2344
Emission VOC (grams/hr.)	1896	2012	2082	3021

Table 5.35: VISSIM results of fazizabad after intervention

Parameter	**2018**	**2023**	**2028**	**2033**
Delays(s/veh)	26.08	40.64	60.6	98.49
Density(pc/km/ln)	15.43	20.21	27.27	31.13
LOS	C	D	E	F
Stop Delays(s/veh)	75.6	85.5	115.02	117.72
Fuel consumption(gal/hr)	726.294	811.614	942.084	1009.602
Emission CO(grams/hr)	50768.15	56731.74	65851.72	70571.24
Emission NOX(grams/hr)	9877.638	11037.94	12812.35	13730.6
Emission VOC(grams/hr)	11766.01	13148.13	15261.77	16355.57

5.8.6 Using Toll ways as a Congestion Mitigation Solution

It can be seen from the average occupancy data in previous chapter that the average occupancy of cars is 1.37. Which implies that 63 percent cars are having only one passenger and 37 percent cars are having two passengers. Therefore, if tollways are used and only those vehicles are allowed use the selected route for free which are having two passengers and the rest are subjected to adequate tex. The it is very easily possible to reduce the traffic volume by 20 percent. If 20 percent reduction is obtained in traffic volume then the following results can be obtained.

Table 5.36: Summary of analysis of Toll ways

Toll ways				
Parameters	**2023**	**2028**	**2033**	**2038**
Delays (s/Veh.)	27.86	37.13	41.44	46.97
Density(pc/km/ln)	10.67	13.19	16.08	18.42
LOS	B	C	D	D
Stop Delays (s/Veh.)	47	48	49	50
Fuel consumption (gal/hr.)	312	382	445	457
Emission CO (grams/hr.)	21806	26729	31113	31945
Emission NOX (grams/hr.)	4243	5201	6053	6215
Emission VOC (grams/hr.)	5054	6195	7211	7404

Table 5.37: VISSIM results of fazizabad after intervention

Parameter	**2018**	**2023**	**2028**	**2033**
Delays(s/veh)	26.08	40.64	60.6	98.49
Density(pc/km/ln)	15.43	20.21	27.27	31.13
LOS	C	D	E	F
Stop Delays(s/veh)	75.6	85.5	115.02	117.72
Fuel consumption(gal/hr)	726.294	811.614	942.084	1009.602
Emission CO(grams/hr)	50768.15	56731.74	65851.72	70571.24
Emission NOX(grams/hr)	9877.638	11037.94	12812.35	13730.6
Emission VOC(grams/hr)	11766.01	13148.13	15261.77	16355.57

It can be seen that toll ways are effective in providing LOS up to D till 2038. It can be seen that the results of are better than all the other above interventions.

5.8.7 Summary of Alternative Congestion Mitigation Solutions

If we consider the improvement in LOS then the best solution is to educate the commuters about keeping distance between the vehicles followed by alternative route for heavy traffic followed by BRT and Toll ways then providing adequate distance between ramps having same results and the least effective is addition of lanes.

However, it should be noted that provision of efficient public transport is very important to make other congestion mitigation solutions effective and more sustainable. Therefore, it is recommended to provide efficient public transport on this route with addition of providing adequate distance between the ramps and proper location and designing the bus stops along with educating the commuters to keep proper distance between the vehicles.

CHAPTER 6

6. Conclusions and Recommendations

6.1 Synopsis of the Research

The research study focused on analysis of Islamabad Expressway which is under upgradation to Signal Free Corridor. The study began with extensive literature review that covered state of the art and practice regarding LOS analysis of multilane highways, calculation of transportation user benefits, analysis of environment impact of the vehicular traffic using VISSIM. An analytical framework was developed for the research design. Analysis of Islamabad Expressway after conversion to signal free corridor was conducted and compared to the situation before conversion to signal free corridor. User benefit or cost recovery analysis was also conducted to calculate saving due to reduction in fuel consumption and reduction in emissions. The most congested section along the Expressway was identified and causes of congestion were also identified. Mitigation strategies for these causes were proposed and their effectiveness in reducing congestion were also computed and compared to the current intervention of conversion to signal free corridor.

6.2 Research Findings and Conclusions

6.2.1 Major Conclusions and Findings from the Literature Review

- From literature review it was found that the mitigation strategies are broadly classified in to two categories: supply strategies and demand strategies.
- Supply strategies which tends to increase the capacity of the transportation network that can be achieved by expanding roadway capacity and expanding transit capacity.
- In literature review it was found that expanding roadway capacity lead to short term reduction in traffic congestion. Whereas increasing transit capacity can reduce the severity of traffic congestion in the area.
- Demand based strategies tends to reduce the demand that can be achieved by

use of toll ways, use of ramp metering, and increasing residential densities.

- Case studies conducted by different researchers have shown that toll ways also result in short term reduction in travel time and delay. However, several case studies have found if toll prices are maintained and changed according to demand then the efficiency of toll ways can be increased.
- Similarly, the literature on ramp metering have found that in the absence of ramp metering travel times increased and travel speeds fell.
- In contrast, the literature on increasing residential densities reported mixed findings regarding the effect of this action on traffic congestion. Some studies have found that increasing residential densities reduces traffic congestion, while others have found that the opposite occurs.

6.2.2 LOS Analysis and Public Benefit Analysis

- It is concluded that the conversion of Islamabad Expressway to Signal Free corridor is very effective and will remain effective until 2033 for the last section starting from Koral Choke and ending at Rawat Choke in terms of improving LOS. It will remain at B even after 2033.
- The first portion of the expressway between Zero Point and Faizabad Choke will operate under LOS C till 2033 after which it will require some interventions to reduce the traffic volume or increase the capacity to keep the LOS at C.
- The second portion between Faizabad and Koral Choke will operate under LOS D till 2023 and after that it will require a considerable intervention.
- It is also concluded that the project is not cost effective as cost recovery in term of public benefits has very long payback period i.e. more than 15.

6.2.3 Causes of Congestion and their Mitigation

- It can be concluded from ramp analysis that all the constructed interchanges have inadequate ramp distances. Which further contribute to congestion by creating turbulence in through traffic and turning movements.
- Time headway is also inadequate causing generation of waves in traffic stream due to braking and causing difficulties for traffic merging to and from

the ramps.

- Presence of heavy vehicles and inefficient public transport and bus stops also contributes to congestion.
- It is also concluded that if we consider the improvement in LOS then the best solution is to educate the commuters about keeping proper distance between the vehicles having at least 3 second time headway.
- Educating the commuters was followed by alternative route for heavy traffic as a best solution followed by BRT and Toll ways and then providing adequate distance between ramps having same results and the least effective is addition of lanes.

6.3 Recommendations

Recommendations and direction for future research are appended below:

- The last portion from Koral choke to Rawat is still under construction and the commuters are facing excessive delays and fuel costs due to bottlenecks and inefficient traffic signals. Therefore, immediate finishing of this portion is required.
- The first portion from Zero Point to Faizabad will be at LOS D after 2033. Increase in number of lanes will be ineffective at that point. It is proposed to educate the commuters to keep safe distance between the vehicles.
- For the portion between Faizabad and Koral it is proposed to educate the commuters regarding keeping safe distance between the vehicles and to improve the interchanges by providing proper distances between the ramps before 2023.
- It is also recommended to provide efficient public transport in the form of BRT or Metro on this route from Rawat to Zero Point with park and ride facility. Presence of efficient public transport is necessary for a sustainable transportation road network and to increase the efficiency of other mitigation strategies.
- Permanent traffic counters should be installed by the Government to keep track of the traffic volumes, for proper calculation of traffic growth rates as

well as for proper calibration in VISSIM.

- Further research is also required to study the behavior and psychology of the drivers as it was observed that the behavior of the driver was the main influencing factor in reducing the traffic congestion.
- In future a transportation system should planned keeping balance between the physics of jamming and psychology of driving, balance between rush hour and middle of the night and balance between ideal city for traffic and ideal city for humans.
- For drivers it should also be a balance between what they thick make their trip faster and what actually will make them faster and a balance between their vindictive instincts and empathy for others.

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