MANAGING DELAY ON CHAIN OF INTERSECTIONS ON A MAJOR URBAN CORRIDOR – AN ALTERNATIVE BASED ANALYSIS

FINAL YEAR PROJECT UG 2019

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This is to certify that the

Final Year Project, titled.

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DEDICATION

We would like to dedicate our works to our parents, our teachers, NUST and friends.

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"In the name of Almighty Allah, the Most Beneficent, the Most Merciful"

First and foremost, all thanks and praises to Allah Almighty for the strength, patience, knowledge, and His blessings to complete this project. We would like to acknowledge and give our warmest thanks to our supervisor, Assistant Professor Muhammad Asif Khan, who made this work possible. His guidance and advice carried us through all the stages of writing our report. He gave us his precious time and shared his lifelong hard-earned knowledge and experience.

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ABSTRACT

Traffic congestion has become one of the biggest problems in urban transportation systems and it worsens during the peak hours. The main reasons for traffic congestion are the increase in road traffic volume and inefficient infrastructure. This leads to delays and accidents and environmental problems, especially in rapidly growing urban areas. The common effects of traffic congestion are environmental, economic, health and social. The Peshawar Road or N-5 is one of the most important roads in Rawalpindi used by daily commuters of intercity and many businesses. Traditional signalized intersections on Peshawar Road serve the traffic volumes which have exceeded the road capacities. Therefore, the level of service of all the intersections for almost all approaches is “F”. This is concerning because the amount of people using this road are increasing day by day and the non-availability of public transport will eventually lead to the breakdown of the system. This study aims to provide better alternatives to traditional intersection designs, so that the road network can serve existing and future traffic efficiently. The combination of alternatives suggested in this study include single point urban interchange, Median U-turn intersection, and crossover displace left turn intersection. Synchro software was used to analyse traffic signal optimization and protected right turn phasing. Based on these short list designs the best performing were combined in a whole network at study area. These alternatives designs will reduce the delays and the user costs associated with these delays. The comparison of the existing and proposed designs was done using the PTV VISSIM software. Main criteria for the comparison of current and proposed designs were travel time delay and vehicle operating cost.

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$T_C = U_{TT} \times \frac{DT}{60} \times n$

Fuel cost = $F_C \times \frac{DT}{60} \times n$

$V = V_0 \times (1 + \text{G.F})^{n}$

Chapter 1 Introduction

1.1 General

Transportation is a dire need of our daily life. In core urban areas, whether developed or under developing countries, commuters face many traffic problems which include congestion, accidents, environmental problems etc. Many developed countries are using Intelligent Transport system (ITS) to tackle these traffic problems but in developing countries it is hard to deploy this system due to shortage of deployment strategy knowledge, the lack of a master plan, and stalled deployment due to financial constraints (Makino, Tamada, Sakai, & Kamijo, 2018). Among South Asian countries, Pakistan has the sixth-highest population density. This growing urbanization has had a tremendous impact on the Pakistani transportation infrastructure.

Traffic congestion has become one of the biggest problems in urban areas and it worsen during the peak hours (Babalik-sutcliffe, 2013). Increasing travel demand and increase in vehicle ownerships are the core factors of congestion in growing urban areas (Chow, Santacreu, Tsapakis, & Cheng, 2014). The primary causes of congestion identified by Federal Highway Administration (FHWA) are inadequate capacity of roads, improper maintenance of traffic control devices, variability of demand, special events (i.e., cricket match, political gatherings, religious events etc.), accidents, construction activities, and bad weather conditions (FHWA, 2008). The economy of the country suffers due to traffic congestion. Travel time delay is one of the major causes of traffic congestion, this adds to the congestion cost. Higher vehicle operating costs, which include fuel consumption cost, and maintenance cost etc., also add to the cost due to congestion. There is also an environmental implication resulting from greenhouse gases and emissions from the transport sector (Torok, 2008).

Just like other systems in the world the road transport system also modernizes to minimize the traffic congestion. Various methods have been developed and used to minimize road traffic congestion e.g., electronic toll collection, increasing physical capacity of roads, constructing interchanges and flyovers/underpasses etc. (Zhang, 2011). Traffic signals at the intersections also cause travel time delay, and the best way to reduce these trave time delays is by optimizing the signal timing for each approach or by removing the at-grade intersection by constructing fly overs, underpasses, and interchanges (Eom & Kim, 2020). Level of Service (LOS) is generally used to describe the traffic delays e.g., the LOS for an approach of intersection will be considered F if the waiting time for vehicles is greater than 60 seconds (Shafi, Chai, Qin, Chia, & Shaffie, 2020). By applying only traffic signal optimization, traffic delays can be reduced by 10-12% when vehicle delays are periodized over pedestrian delays (Farre, 2013).

Among the big cities of Pakistan, Rawalpindi and Islamabad are the twin cities with Islamabad being the capital of the country. The two cities are connected by different roads and of the important road that connects the twin cities is Peshawar Road, also called N-5. As there is no Rawalpindi bypass, all the Grand Trunk (GT) road traffic passes through it in addition to the local city traffic. So, the total traffic volume passing through N-5 to Rawalpindi is very high leading to severe traffic congestion. There is chain of intersections (Grouped Intersections) on Peshawar Road to regulate the traffic namely Kutchery, PC, GHQ/TM and GPO intersection. In this study different alternatives will be tested and analyzed to mitigate the intersection delay on N-5 corridor from Kutchery intersection to GPO intersection…. Using PTV VISSIM software.

1.2 Problem Statement

The Peshawar Road, also known as N-5, is a vital transportation route in Rawalpindi, serving as a major route for traffic from various cities like Peshawar, Attock, Jhelum, Gujrat and connecting to the M-2 motorway. In addition to serving as a major throughfare for intercity traffic, this road is also heavily used by local commuters in Rawalpindi-Islamabad twin cities leading to serious traffic congestion. There are many hospitals located in the vicinity of this route. The railway stations near this route also contribute to the congestion of road in the morning. The closer proximity of all these factors combined including hospitals, railway station, schools and shopping centres cause severe traffic congestion.

This study aims to remodel the section of the Peshawar Road known as Mall Road, from Kutchery to GPO Intersection, with the goal of making this road congestion free. The study considered four major intersections- Kutchery Intersection, PC Intersection, GHQ Intersection and GPO Intersection -to improve traffic flow and reduce travel time delay and user cost.

The approach used in this study include both feasibility and cost-effectiveness of each alternative considered by considering both agency and user costs. By implementing the proposed alternatives in this study will help to create a safer and more efficient transportation network that meets the needs of the growing population.

1.3 Study Objectives

Following are the objectives set for this study:

- To study the current situation of the intersections. The traffic problems users are facing like traffic congestion, travel time delay and high user cost.
- To suggest different alternatives for the intersections like flyover, underpass, and interchanges etc.
- To run VISSIM simulations of the new alternative intersection models and a detailed comparison between old and new models.

Following are the assumptions kept in mind when providing alternative intersection models:

1. The model must be economic.
2. The model must be safe for all the road users that include drivers and pedestrians.
3. The model must be efficient.

4. The model must be feasible.
5. The model must be environmentally friendly.

1.4 Scope of study

The scope of the study includes the analysis of intersection delays on N-5 corridor in Rawalpindi. The Intersections under study are GPO intersection, GHQ intersection, PC intersection and Kutchery intersection as shown in Figure 1. All the required data is collected which includes traffic volume data, queue length, vehicle composition data, PHF, Vehicle operating cost etc. With the help of this data delays due to intersections are calculated and the user cost associated with it is also calculated.

Feasibility studies for new alternatives like the availability of right of way, presence of underground pipelines etc. are also conducted. Based on the pervious results and the feasibility studies, anti-congestion alternatives to these intersections are suggested. The agency cost (construction cost), work zone user delay costs are also measured for each alternative to make sure they are economical. Overview of the study is shown in Figure 2.

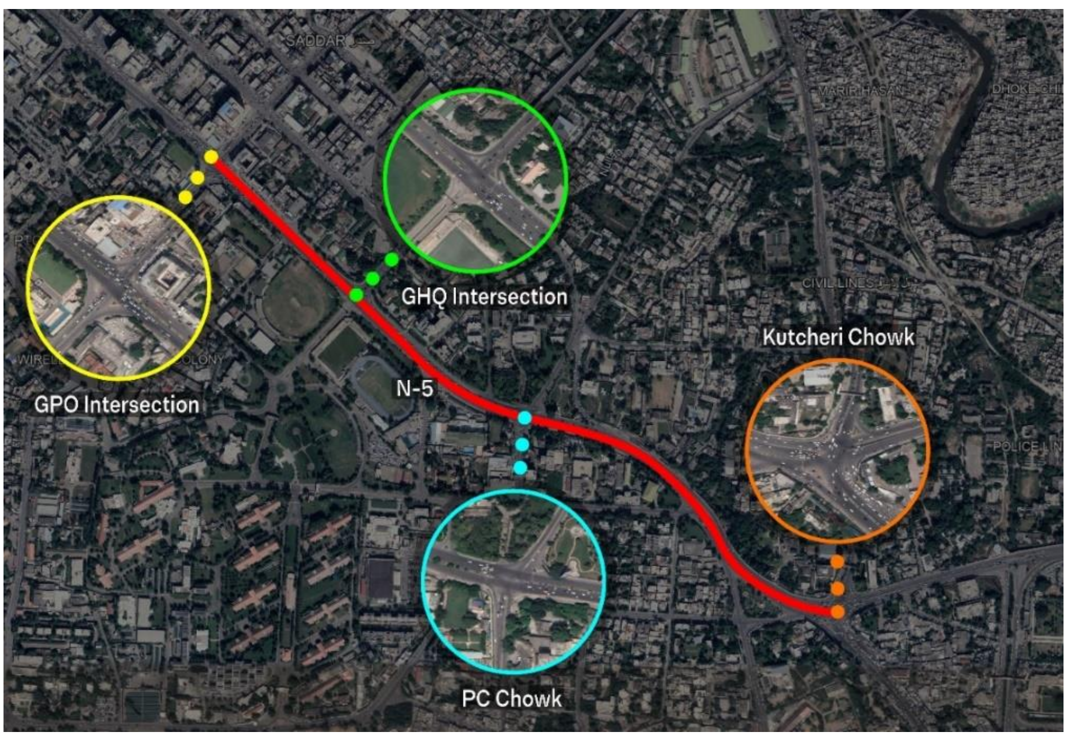


Figure 1 Intersections under study

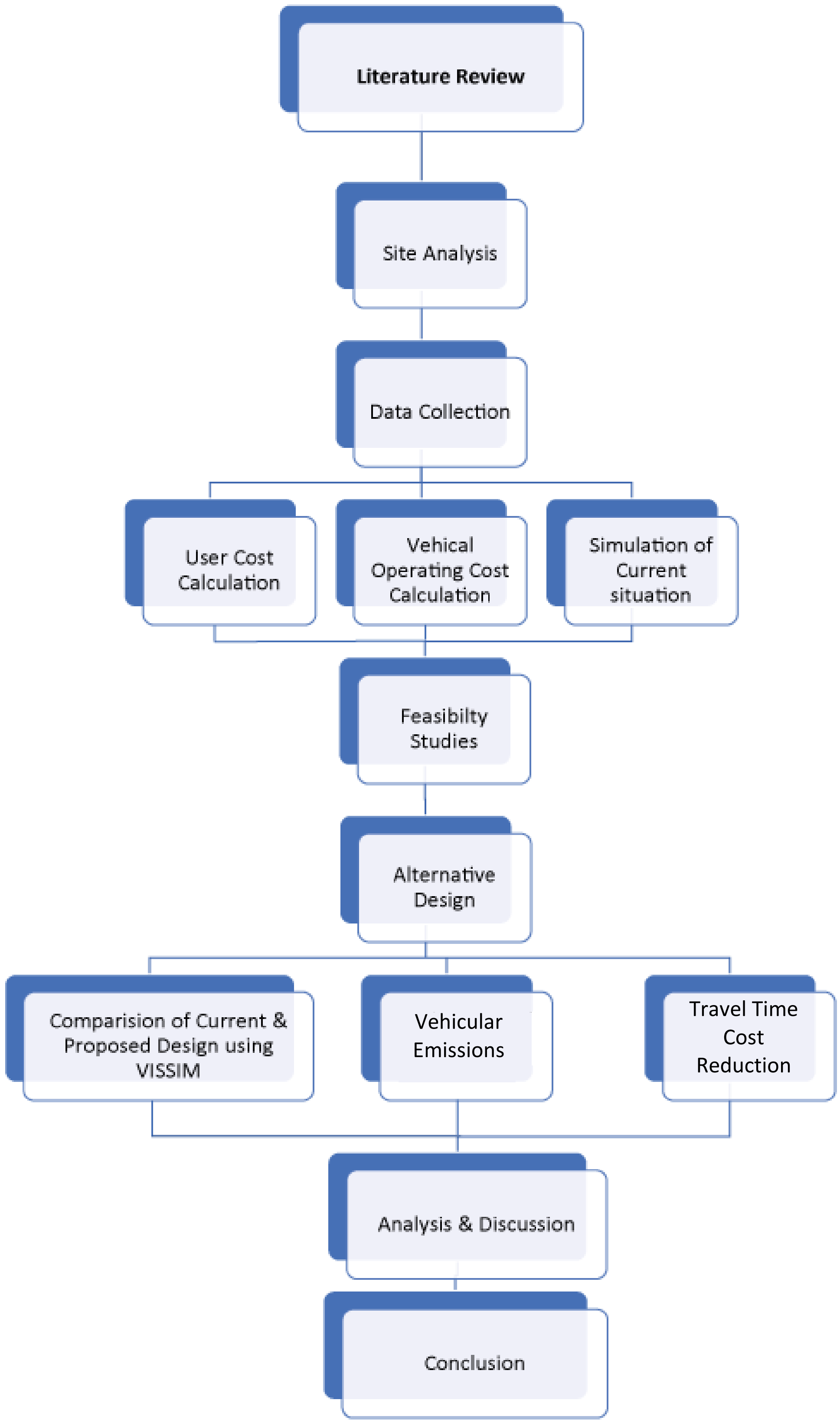


Figure 2 Overview of Study Approach

Chapter 2 Literature Review

2.1 General

This section presents the past research efforts related to traffic congestion in urban areas and its mitigation. The section starts by explaining different key terminologies used in traffic engineering. Intersection delay models were also studied to assist in intersection design and planning. The study will also explore the effects of traffic congestion on drivers' behavior and safety. Alternative intersection and interchange designs have been proposed as potential solutions to these issues. Finally, this section of the study examines the process of selecting alternative intersection designs and the factors that should be considered in this decision-making process.

2.2 Traffic Engineering terms

2.2.1 Traffic congestions

Traffic congestion occurs when the number of vehicles exceeds the total capacity of the road and results in immense delays. The fundamental cause of congestion is friction/mutual interference between vehicles in traffic flow (Sorensen, et al., 2008).

In recent years, the increase in road traffic and aging infrastructure have led to serious congestion, delays and accidents and environmental problems, especially in rapidly growing urban cities (Kiunsi, 2013).

2.2.2 Passenger Car Unit

Passenger car unit (PCU)/Passenger car equivalent is a metric used in transportation engineering for expressing highway capacity. A Passenger Car Equivalent is basically the impact that a mode of transport has on traffic variables (such as headway, speed, density) compared to a single car. Highway capacity is usually measured in the units of PCU/hour. Different values of PCE are listed in Table 1 to convert different classes of vehicles into PCUs.

2.2.3 Heterogenous Traffic

Heterogenous traffic comprises of a wide variety of vehicles based on their physical dimensions, dynamic characteristics, and weight etc. The demarcation between homogenous and heterogenous traffic conditions is based on the percentage of dominant vehicle, if the percentage of dominant vehicle is greater the 85% then the traffic conditions can be treated as homogenous but if percentage of dominant vehicle is less the 85% then it lies in heterogenous range (Younas, Amir, & Khan, 2016).

To model a heterogenous traffic condition, along with traffic volume data, vehicle composition data is also required. Traffic characteristics such as size, speed, flow, headways, and densities are also of keen importance in heterogenous traffic flow conditions (Zhen, Jia, Xiaopeng, Michael, & Haizhong, 2017).

Table 1 Passenger Car Unit

No.	Vehicle Type	PCE
1	Animal Driven Cart	4
2	Motorcycle/Rickshaw	0.5
3	Bicycle	0.2
4	Passenger Car/Jeep	1
5	Large Bus	3.5
6	Hiace/Coaster	3
7	2-Axcel Truck	4
8	3-Axcel Truck	5
9	Long Vehicle	6
10	Truck Trolly	4

2.3 Signalized Intersection and Control delays

Signalized intersections assign right of way to different combinations of movements with the assistance of traffic signal. Combination of movements is assigned to minimize the number of conflict points. Traffic signals also induce a control delay at the intersection. Control delays is the portion of total delay associated with the traffic signal operation for signalized intersection (HCM 2010 : highway capacity manual, 2010). Total delay however comprises of many other types of delays including approach delay, travel time delay, control delay etc.

In signalized intersection, capacity and LOS are dependent on the average control delay per vehicle. Control delay is based on the deceleration delay, stopped time delay and acceleration delay. In recent years, researchers have explored various strategies for optimizing signal timing and control to reduce delays and improve traffic flow.

2.3.1 Traffic Signal Optimization

With the passage of time, the traffic flow pattern changes due to increase in traffic and economic growth. This change in traffic volume makes existing traffic signal timing less efficient (in the case of fixed signal time) and optimization is required. Traffic signal optimization is one the cheapest solutions to reduce stops, travel time and control delays at signalized intersections.

Several approaches and techniques have been developed to optimize traffic signal control; these methods include adaptive signal control systems (ASCS), coordinate signal systems, and optimize signal timing plans.

Adaptive signal control systems are designed to adjust signal timings in real-time based on traffic flow and demand. A study by Jing et al. (2017) evaluated the effectiveness of adaptive traffic signal control in connected vehicle environment. By implementation of ASCS, travel time was reduced by 15%, stopped delay by 20%, and queue length by 40% (Jing et al., 2017)

Coordinated signal systems aim to synchronize signal timings across multiple intersections to reduce stops and delays for vehicles travelling on a corridor. A study by Fan et al. (2019) evaluated the performance of a coordinated signal system and found that it reduced travel time and delay for vehicles by up to 30% to 40% (Fan et al., 2019).

Optimized signal timing aims to determine the most efficient signal timings based on traffic demand and other factors. A study by Wang et al. (2019) developed an optimized signal timing plan for a signalized intersection and found that it reduced overall delay by 32.5% compared to existing signal timing plan (Wang et al., 2020).

Overall, traffic signal optimization is a critical component of traffic engineering that can significantly improve safety and efficiency of signalized intersections. While different approaches have their pros and cons, optimized signal timings along with coordinated system yield best results and being cost effective (Cohen, Head, & Shelby, 2007).

2.4 Intersection delay Models

Intersection delay is a critical factor in traffic engineering that affects the overall traffic flow, safety, and efficiency of roadway networks. Intersection delay models have been deployed to aid in intersection design, planning as well as evaluation of existing intersections.

A commonly used intersection delay model is the HCM (Highway Capacity Manual) method, which is based on the concept of level of service (LOS). The HCM method considers various factors such as traffic volume, signal timing, and geometric design to calculate intersection delay and LOS (HCM, 2010).

The Webster method is another intersection delay model that considers the effects of queuing and signal timings on intersection delay. The webster method is useful in evaluating the performance of signalized intersection with heavy traffic volume (Webster, 1958).

The model proposed by Ghasemlou et al. (2015) performed better than the HCM and Webster models in predicting delay time under over saturated flow. The proposed model incorporates a new parameter called “jam density” which is not included in the HCM or Webster models (Ghasemlou et al., 2015).

2.4.1 Type of delays

The different forms of delays are defined below.

- Stopped time delay:

  It is defined as the time a vehicle is stopped in a queue while waiting to pass through an intersection. It begins when the vehicle is fully stopped and ends when it starts to accelerate.

- Approach delay:

  It the delay time plus time loss due to deceleration and acceleration to desired speed

- Travel time delay

  It is the difference between the expected travel time and the actual travel time.

- Time in queue delay

  It is total time from vehicle joining an intersection queue to its discharge across the STOP line on departure. Desired path and actual path are shown in Figure *3* with delay time.

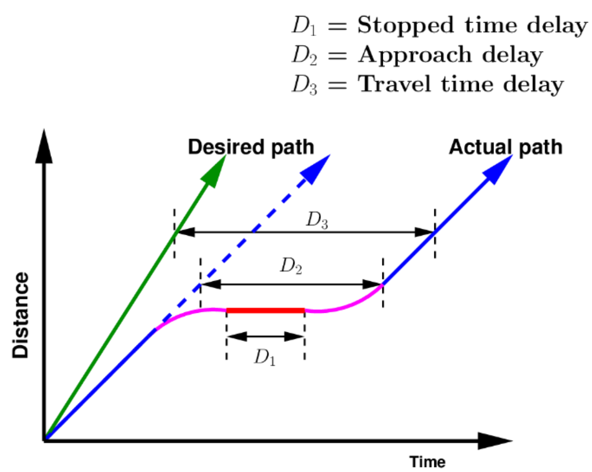


Figure 3 Type of delay measures

2.5 Effect of Traffic congestion

Traffic congestion is a significant issue in urban areas, and it has a wide range of negative effects on society, the economy, and the environment. The following literature review highlights some of the key findings on the effects of traffic congestion.

2.5.1 Economic Effects:

Traffic congestion has significant economic effects, both in terms of direct costs such as fuel consumption, and indirect costs such as loss of productivity due to traffic delays. According to a study on traffic congestion in Lahore, an estimated $3.3 billion is annually lost in productivity and increased fuel consumption (Ali et al., 2021).

- **Increased travel time and fuel cost**

  Along with the global implications of traffic congestion, individuals are also affected by traffic congestion as it leads to increased travel time and fuel costs. These are one of the most immediate consequences of traffic congestion. In Australia, traffic congestion was found to cost individuals an estimated $19 billion in 2015 in travel time and fuel cost (Australia, 2016). Another study by the Texas Transportation Institute found that traffic congestion in United States resulted in an estimated $166 billion in wasted time and fuel costs in 2019 (Schrank et al., 2009).

- **Reduced productivity and increased costs for businesses.**

  Traffic congestion has a significant impact on businesses, resulting in reduced productivity and increased costs. A study conducted by Texas Transportation Institution found that traffic congestion cost businesses in productivity an estimated $74.5 billion in 2016 (Schrank et al., 2009).The long commute time experienced by employees are more likely to experience stress, burnout, and reduced job satisfaction, which ultimately decreases the productivity and performance. Delay in transportation and delivery can result in increased inventory cost, lost sales, and reduced customer satisfaction (Harriet et al., 2013).

2.5.2 Environmental Effects:

Traffic congestion also has significant environmental effects, including increased air pollution and greenhouse gas emissions. According to a study by the European Environment Agency, road transport is responsible for around 20% of the European Union's total greenhouse gas emissions (Ortiz et al., 2019).

- **Air Pollution**

  The combustion of fossil fuels in vehicles releases harmful pollutants into the air, including nitrogen oxides (NOx), particulate matter (PM), and volatile organic compounds (VOCs). Studies have shown that exposure to high levels of air pollution can cause respiratory problems, cardiovascular disease, and premature death (Pope et al. 2002; Brook et al.,2010). Moreover, it can cause environmental degradation, such as acid rain and smog formation, which can lead to ecosystem damage.

- **Noise Pollution**

  Traffic congestion can also lead to noise pollution. The noise generated by traffic can be irritating, and it can cause high blood pressure, hearing loss, and sleep disturbance (Singh & Davar, 2004).

  The heavy vehicles are the largest contributors to noise pollution, about 70 to 80% of total vehicles other than the public transport also contributes to the noise pollution (Kamandang, Hendrata, & Casita, 2020).

- **Carbon Emissions**

  The transport sector is one of the major sources of carbon emissions, which contributes to global warming and climate change. Traffic congestion can lead to increased carbon emissions as vehicles spend more time on the road, idling or driving at low speeds, which results in inefficient fuel consumption (Litman, 2007).

  During traffic congestion, 51% increase in travel time contributes to about 53% increase in travel time, but more fuel in consumed during idle conditions(Bharadwaj et al., 2017).

2.5.3 Health Effects:

Traffic congestion has significant health effects, including increased exposure to air pollution, which can lead to respiratory problems and cardiovascular disease. According to a study by the World Health Organization, air pollution is responsible for an estimated 4.2 million premature deaths worldwide each year (WHO, 2018).

2.5.4 Social Effects

Traffic congestion has significant social effects, including reduced mobility for individuals and communities, increased stress, and reduced quality of life. According to a study by the American Psychological Association, traffic congestion is a significant source of stress for many people, and it can lead to negative health outcomes such as anxiety and depression (Stokols et al., 1978).

2.6 Alternative Intersection/interchange Designs

Many research papers were studied for alternative intersection/interchange design but the most prominent of them were FHWA's Informational Report(Alternative Intersections / Interchanges: Informational Report (AIIR), 2010) and Analysis of Unconventional Intersection designs (UAIDS) (El Esawey & Sayed, 2013). Unconventional Alternative intersection requires a lot of right of way as compared to conventional designs. Unconventional alternative intersection designs (UAID) are more suitable for rural areas in contrast to urban areas where theirs is little or no availability of right of way or it is too expensive. Unconventional alternative intersection designs (UAID) that is discussed in more detail is only unconventional MUT and J-Turn intersection since they require less ROW as compared to other options like Quadrant intersection etc. In FHWA's report there are four intersection designs and two interchange designs. Most relevant designs are discussed in detail. The intersection designs mentioned in these reports were based on right hand traffic, since our area of study has left hand traffic the names of intersections were also changed accordingly to avoid any type of confusion. Like Displaced Left-turns was renamed to displaced Right-turns.

2.6.1 Median U-turn Intersection

Median U-turn Intersection, as shown in Figure 4 re-routes the right-turning vehicles at primary intersection. This reduces the number of conflicts between right-turning vehicles and opposing through vehicles. Right-turn vehicle will take a U-turn from the crossover place in the median(figure). US has been using MUT as an alternative to signalized intersections in states namely Michigan, Florida, New Jersey, and Mary land (El Esawey & Sayed, 2013).

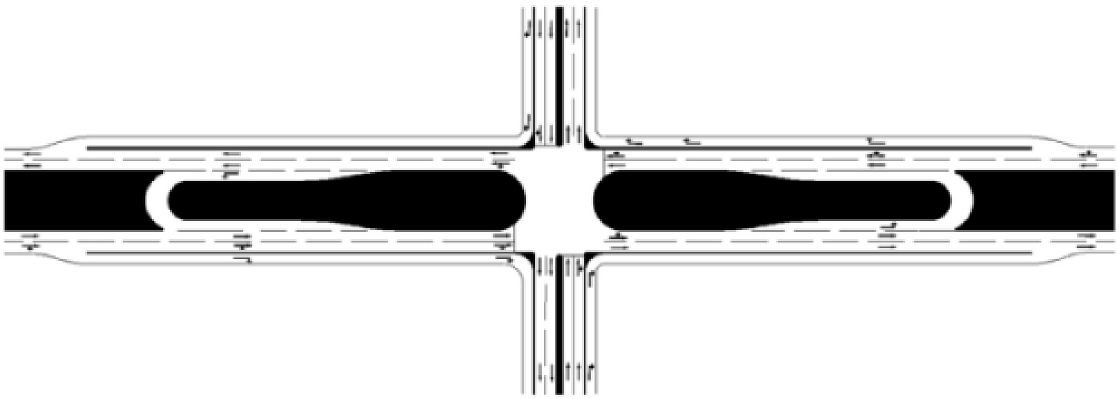


Figure 4 Median U-turn Intersection (Source: FHWA)

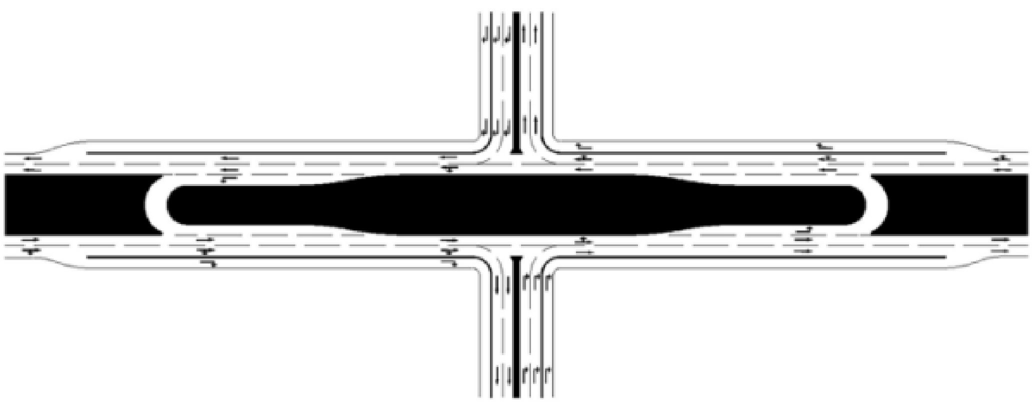


Figure 5 Unconventional Median U-turn Intersection (Source: FHWA)

With the increasing traffic demand, some variations to conventional MUTs, as shown in Figure 5 were made to cater for these changes. One of the unconventional models was proposed by Shai and Choupani which includes a non-traversable median. Both major and minor cross street's right turns were rerouted. Egypt has been using these unconventional MUTs for more than decade to cater delays at signalized intersections.

2.6.2 Restricted Crossing U-turn Intersection

A RCUT is really like unconventional MUT, except the primary intersection and crossovers of RCUTs are controlled by signals. Unsignalized RCUTs are also known as J-turn intersections (El Esawey & Sayed, 2013). Figure *6* shows the traffic movement in RCUT.

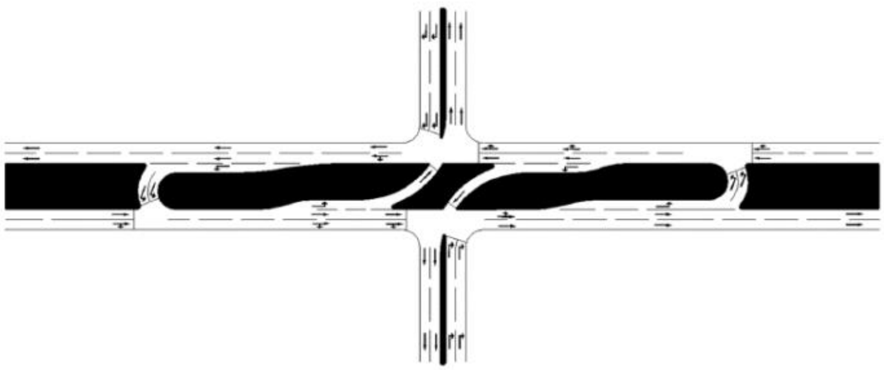


Figure 6 Restricted Crossing U-turn Intersection (Source: FHWA)

2.6.3 Displaced Right-turn Intersection

Displaced Right-turn intersection is also known as Continuous Flow Intersection (Goldblatt et al., 1994) and Crossover Displaced Right-turn Intersection (El Esawey & Sayed, 2013). DRT intersection has one primary intersection and four secondary intersections. It allows both through and right turn movements at same time, so the primary intersection can be operated using two phase signals (Reid & Hummer, 2001). It reduces the traffic delay and vehicular accident rate at the same time. Figure *7* shows the traffic movement in displace right-turn intersection.

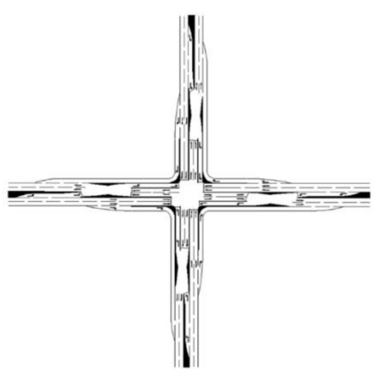


Figure 7 Displaced right-turn Intersection (Source: FHWA)

2.6.4 Synchronized Split phase Intersection.

In synchronized split phase intersection, there is a crossover between through and right-turn movements prior to the main intersection. This configuration helps with the concurrent movement of both through and opposing right-turn movement in single signal phase. In contrast to Displace Right-turns where only right-turns were cross overed, both through and right-turn were cross-overed in synchronized split-phase intersection. Figure *8* shows the traffic movement in Synchronized Split phase Intersection.

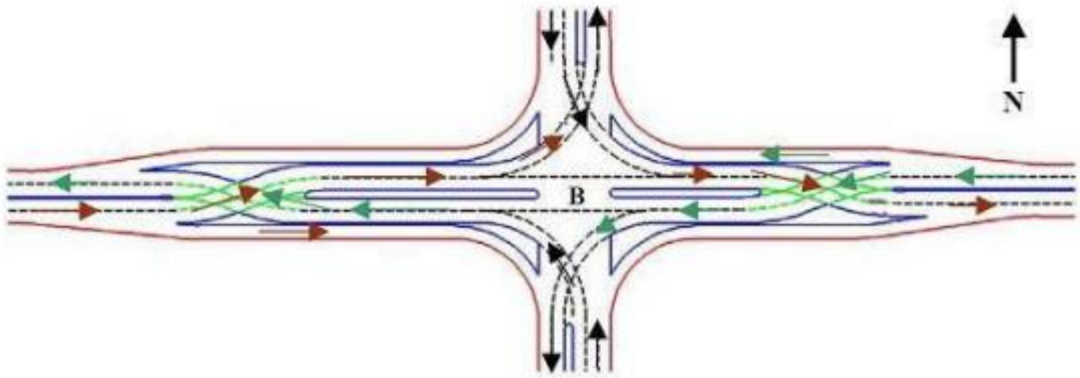


Figure 8 Synchronized Split phase Intersection (Source: FHWA)

2.6.5 Continuous Green T-intersection

As opposed to conventional T-intersection, the continuous Green T-intersection has channelized right turn. This channelization helps the through movement in one direction to continuously flow in one direction. Figure *9* shows the drawing of continuous green T-intersection.

Figure 9 Continuous Green T-Intersection

2.6.6 Tight Urban Diamond Interchange

Tight Urban Diamond Interchange is favorable for urban and suburban areas because the right-of-way is limited in these areas. The conventional diamond interchange is not feasible in urban/suburban areas. Detailed traffic movement is shown in the Figure 10.

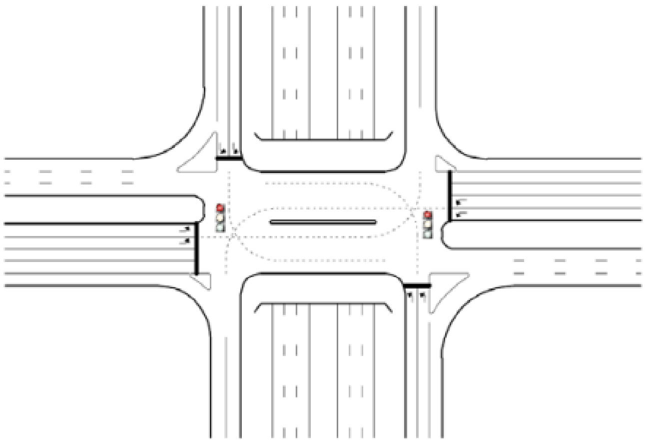


Figure 10 Tight Urban Diamond Interchange

2.6.7 Single Point Urban Interchange

Single Point Urban Interchange is another variation of compressed diamond interchange(Alternative Intersections / Interchanges: Informational Report (AIIR), 2010). It reduced the traffic congestion and requires less right of way as compared to diamond interchange. All turning movements take place in one single point whether it is on the overpass or underpass. Detailed traffic movement is shown in the Figure *11*.

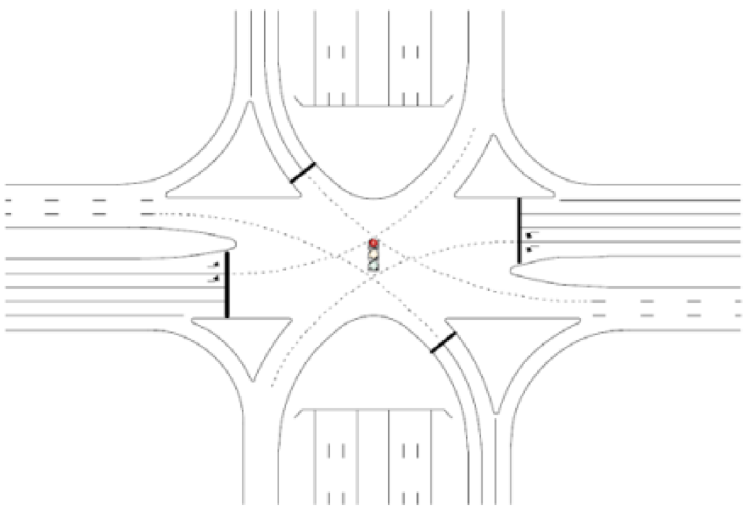


Figure 11 Single Point Urban Interchange

2.7 Selection of Alternative Intersection Design

With the countless options of alternative intersection designs, simulation analysis is the most preferred methodology for the selection of alternatives. But it is very time consuming so there is need for the preliminary studies to filter out the non-feasible alternative design before performing the simulation analysis. Selection parameters should account for mobility as well as safety at the selected intersection.

Many studies have been performed on selection of alternative intersections. In this report, we have selected the selection procedure proposed by Warren Hughes. In his report, the author organized the selection procedure into six steps.

1. Establish objectives for projects and relative importance of factors.
2. Assess the level of expected pedestrian conflicts.
3. Assess availability of right of way.
4. Assess local site needs.
5. Determine level of services at sketch planning level.
6. Conduct simulation analysis of viable alternatives.

2.7.1 Establish objectives for projects and relative importance of factors.

The first step involves the establishment of specific objectives for the site, which will allow the prioritization and weighting of factors for different projects. If an intersection is judged to be poor with respect to the primary objectives, then that intersection could be eliminated for further consideration. This screening process increases the efficiency in selection for alternative as more detailed traffic analysis part can be skipped.

2.7.2 Assess the level of expected pedestrian conflicts.

The second step is to examine the alternatives with respect to pedestrians and conflicts. While pedestrian mobility needs can be met by all the alternative intersections, they are better suited to different degrees, depending on the design. If the pedestrian activity in the immediate vicinity of the subject intersection is low or non-existent, then all alternative intersections and roundabout designs are viable. However, if pedestrian activity is high on all four legs, some alternatives might not be viable.

2.7.3 Assess availability of right of way

The third step in the assessment methodology is to evaluate alternatives in terms of the availability of the right-of-way to accommodate the alternative and the cost of additional right-of-way. There are greater challenges to implement intersection alternatives if the median width is insufficient to accommodate U-turns and if additional and costly right-of-way is needed.

2.7.4 Assess local site needs.

The fourth step is to assess alternatives in terms of access, particularly for trucks and buses. All alternative intersections have constraints that limit their ability to accommodate truck and bus turning movements.

2.7.5 Determine LOS at sketch planning level.

The fifth is to assess alternatives in terms of capacity and vehicular throughput. Capacity is defined as the maximum number of vehicles that can pass through an intersection each time, and vehicular throughput is the actual number of vehicles that do pass through the intersection each time. Alternative intersections have different capacities and vehicular throughputs, and these differences are due to differences in geometric design and signal timings.

2.7.6 Simulation analysis of viable intersection.

The final step is to conduct the simulation analysis of selected alternative intersection designs. Based on the results of these analysis, the best intersection is selected.

Chapter 3 Methodology

3.1 General

This chapter summarizes the methodologies used for the selection of alternatives, user cost of current scenario and the impact of alternatives on the user cost. In the first section, we have included the location of the study area based on the existing traffic behavior and transport framework. Then the data collection procedures are explained. Based on available data, the current scenario was simulated. After this the chapter identifies the criteria for the selection of alternatives in the details. Selection of alternatives are mainly based on the available right of way. Then the simulation of the alternative designs is discussed in detail.

Lastly the chapter includes the formulations for the cost estimation for cost-benefit analysis. The cost-benefit analysis helps us validate our selected alternative intersection design. Benefits of the reduced user and vehicle operating cost. They are also included in this chapter.

3.2 Location of Study area

Location of Study area of N-5 Rawalpindi. The selection of its intersections is based on the existing traffic behavior and transportation framework. Instead of selection an isolated intersection series of intersection are selected. Four intersections were selected as they would portray the more realistic image of the existing situation.

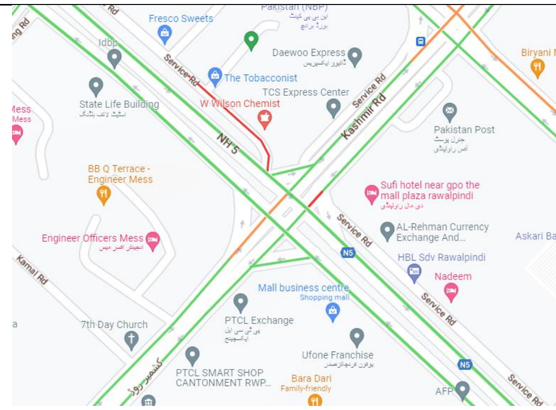
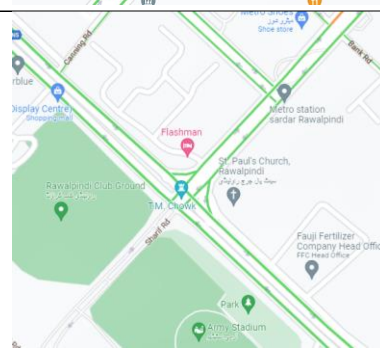
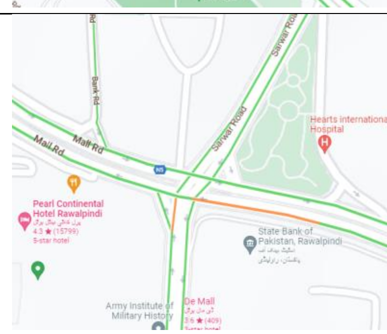
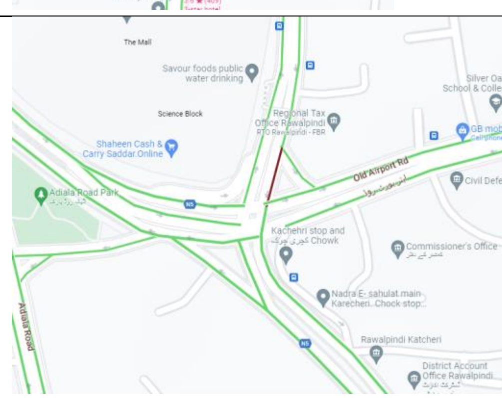
The Intersections under study are GPO intersection, GHQ intersection, PC Intersection and Kutchery Intersection. Their salient features and location details are mentioned in the Table *2*.

3.3 Data Collection

When collecting data for remodeling an intersection there are several key aspects to consider. Identify the goals and objectives of the intersection remodeling project. This includes improving traffic flow, enhancing pedestrian safety, and improving the level of service. For this purpose, a site survey is conducted. Measurements of the intersection, including the dimensions of the roads, the layout of the sidewalks, bike lanes and existing traffic control devices are considered.

Properly analyze the traffic volumes and patterns to understand the current usage of the intersection. This is done through various methods such as manual or automated traffic controls counts or using traffic data from transport agencies. As in our case the traffic data was provided by the Rawalpindi Development Authority (RDA). Peak hours, turning movements etc are provided in this data. Data like traffic signal timings, vehicle compositions and the geometric data of the intersections were recorded manually by visiting the site by the group members respectively.

Table 2 Salient Features and Location map of Intersections

Intersection	Salient Features	Location Map
GPO Intersection	• Four-legged intersection • GPO, Saddar market, and CMH hospital nearby • Heavy traffic • Pedestrian crossing at each approach	
GHQ/TM Intersection	• Three-legged intersection • GHQ nearby with VIP movements • Moderate traffic • Pedestrian crossing at 2 approaches	
PC Intersection	• Four-legged intersection • Pedestrian crossing at each approach • PC hotel nearby • Heavy traffic	
Kutchery Intersection	• Four-legged intersection • Pedestrian crossing at each arm • Heavy traffic flow • Local bus stand nearby • District courts and DC office nearby	

As the name suggests, geometric data includes lane width, No. of lanes, median width, and footpath width if any. Traffic data includes the vehicle composition data, traffic signal timings, and traffic volume data.

Traffic composition data and traffic signal timing was recorded during peak time.

3.4 Selection of Alternatives

For the selection of alternatives, the methodology proposed by Liran Chen in *Planning Methodology for Alternative Intersection Design and Selection* is used (Chen, 2022). This selection of alternatives is based on a three-stage selection model. Firstly stage 1, as known as initial stage, is developed to identify the project objectives, budget and right of way restrictions and other constraints. Stage 2, the filtering stage, helps in filtering the selected alternative designs based on the selected criteria in stage 1. Then the final stage 3, the detailed analysis stage, where a detailed analysis is performed. This stage includes the simulation analysis, user cost and cost-benefit analysis. These stages are shown in Figure *12*.

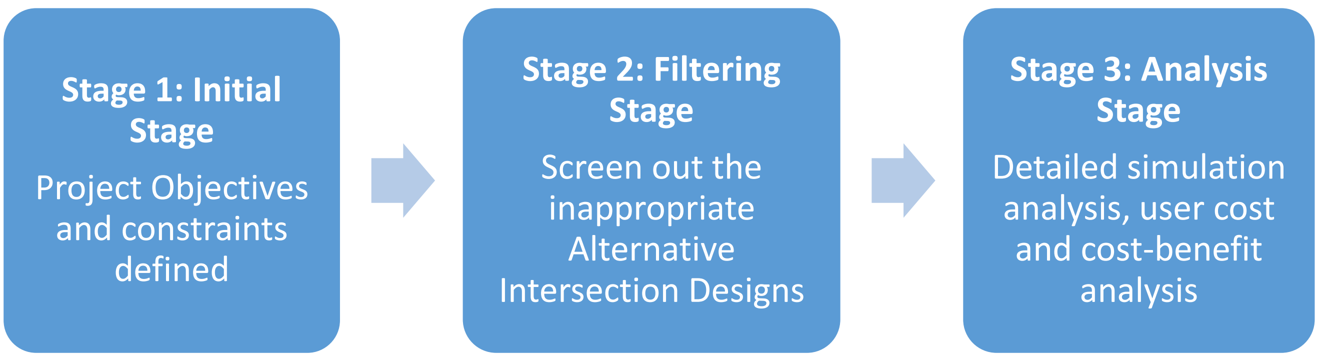


Figure 12 Screening Process of Alternative Designs

3.4.1 Stage 1: Defining Project Objectives and Constraints

This stage is divided into two parts. Firstly, the project objectives are defined. The project objectives can be classified into the following categories: safety, mobility, economic feasibility, environmental sustainability, and community livability. In this study our focus is on three objectives: transportation mobility, economic feasibility, and environmental sustainability. Along with these objectives as our main priority, it is also made sure that the safety of the system isn't compromised. Since there is more than one project objective, specific weight must be assigned to each objective. Table *3* shows the project objectives with weighted average.

Table 3 Project Objectives with weighted averages

Project Objectives	Objective Weight
Reduce Delays	0.6
Economic Feasibility	0.3
Environmental Sustainability	0.1

The second part of stage 1 is defining the project constraints. Since our study area is an urban area, one of main constraints for the alternative intersection designs is availability of right of way (ROW). Along with this the other constraints present are desired intersection LOS, current intersection geometries etc.

3.4.2 Stage 2: Filtering Stage

Before performing the detailed analysis on all alternative intersection designs, this stage helps filter out all the non-feasible alternative designs. Therefore, it will save a lot of time, effort, and money.

For this initial screening process two constraints would be used: ROW and Intersection capacity. The Alternative Intersections/ Interchanges: Information Report (AIIR), by Hughes (Hughes et al, 2010) proposed a way to analyze the ROW by qualitatively method show in table. Viable alternative intersection design is selected based on two parameters adequacy of median width and Affordability of additional Right of way. For the median to accommodate U-turns the term “Sufficient” and “Insufficient” are used and for the ROW, “Affordable” and “Very costly” terms are used. However, the limits of these terms are not defined clearly so it should be based on our empirical judgement and may vary from person to person.Viable alternatives based on right of way are shown in Table *4*

Secondly, for the intersection capacity, LOS of the intersection is determined with the help of simulations. Based on LOS the break-down point of each alternative intersection is determined.

3.4.3 Stage 3: Detailed Analysis stage

In the last stage for the selection of alternative intersection design, detailed mobility and cost analysis will be performed. Based on result of these analysis most appropriate Intersection design will be selected.

Control delay is used for the estimation of mobility at a signalized intersection. Average speed and capacity can also be used for the mobility analysis, but they don’t provide better, and more accurate results as compared to control delay.

Table 4 Viable Alternatives Based on ROW

Adequacy of Median width to Accommodate U-Turns	Affordability of Additional Right-of-way Required	Viable Alternative Intersection Design to Consider Further
Sufficient	Affordable	MUT
		RCUT
		DLT
		Roundabout
		QR
Sufficient	Very costly	MUT
		RCUT
		DLT
Insufficient	Affordable	MUT
		RCUT
		DLT
		Roundabout
		QR
Insufficient	Very costly	MUT with loons
		RCUT with loons

Source: (Hughes et al., 2010)

The second step of this stage is cost-benefit analysis. Cost-benefit ratio is the primary indicator to evaluate potential alternative intersection design in terms of monetary value. A lower cost-benefit ratio indicates a more attractive alternative intersection design. The calculation of the cost benefit ratio involves dividing the total benefits expressed in Rupees by the construction cost also expressed in Rupees. The equations for the estimation were taken from research initiated by USDOT for estimation of Value of travel time. The annual delay reduction can be estimated using equation.

$$Annual\ delay\ reduction\ benifit = \frac{Delay\ Reduction}{C}\ x\ VTT\ x\ Persons\ Volume\ x\ 8760$$

$$Persons\ Volume = Vehical\ volumes\ X\ Occupation\ rate$$

Where:

Delay reduction = delay reduced by UAID in a circle length (s),

C = circle time (s),

Person’s volume= total number of drivers and passengers entering the intersection per hour,

Vehicles volume = the average total number of vehicles entering the intersection per hour during the designed service life of alternative design,

Occupation rate = average number of persons in a vehicle, and

8760 = number of hours in a year.

The construction cost is onetime expense, but it is annualized for comparison purpose equation shows how the annual construction cost is calculated.

$$Annual\ Construction\ Cost = construction\ cost \text{ x}[\frac{i}{1-(1+i)^{-n}}] + annual\ maintenance\ cost$$

Where:

Construction cost= the present value of the cost to construct alternative.

i = interest rate

n = designed service life of alternative

$$Cost - Benifit\ Ratio = \frac{Annual\ Construction\ Cost}{Annual\ delay\ reduction\ benefit}$$

Once all costs and benefits are calculated the candidates are ranked in ascending order based on their cost benefit ratio with the lowest ratio being the most desirable option.

3.5 Simulation

VISSIM and Synchro are the two software tools used for simulation and analysis purposes.

Synchro is a traffic analysis and signal optimization that will be used to design, optimize, and analyze traffic signals. It will also be used to get the optimum traffic signal timing for our new alternative design.

VISSIM on the other hand will be used for detailed analysis. It is a microsimulation software that is used to model and simulate traffic operations for various transportation modes, which includes cars, buses, motorcycles etc.

3.6 User costs calculation

Vehicle cost is comprised of ownership cost (fixed) and transportation cost (variable). Transportation costs consist of vehicle operating cost (VOC), safety cost, environmental cost, maintenance cost. The most important costs among these are travel time and vehicle operating costs. Travel time cost is the cost incurred in moving from one place to another while vehicle operating cost is related with the operations of the vehicle.

3.6.1 Travel time cost

Components of travel time may be divided in the form of a trip phase, i.e., time spent inside and outside an automotive vehicle. But for the sake of this study, we will only consider the time spent inside the vehicle. Inside vehicle travel time (IVTT) is the ratio between the distance travelled and the average operational speed can be determined as IVTT. The operational speed, on the other hand, is highly influenced by traffic conditions. IVTT calculated using the help of VISSIM model.

3.6.2 Vehicle operating Cost (VOC)

Traffic vehicle operating cost calculation is a crucial aspect of transport management enabling policymakers to evaluate financial implications of a project. VOC depends upon the following factors.

- Fuel consumption
- Maintenance and repairs
- Vehicle depreciation
- Tolls and taxes
- Fluids

Fuel consumption cost comprises of 80% of vehicle operating cost. Thereover, only fuel cost will be used for the calculation VOC. Fuel consumption value will be obtained from the VISSIM model.

Note these values will be calculated for both individual intersections and the whole network.

Chapter 4 Data Collection

Field Data were collected at four intersections located successively in N-5 Rawalpindi. Traffic signal timings, vehicle composition and the geometric data were collected at the field. For traffic volume data, usage of video cameras for data collection because of security reasons as General Headquarters is nearby. So, previously collected data by Rawalpindi Development Authority (RDA) was used.

Traffic signal timings collected in field is shown in Figure *13*.

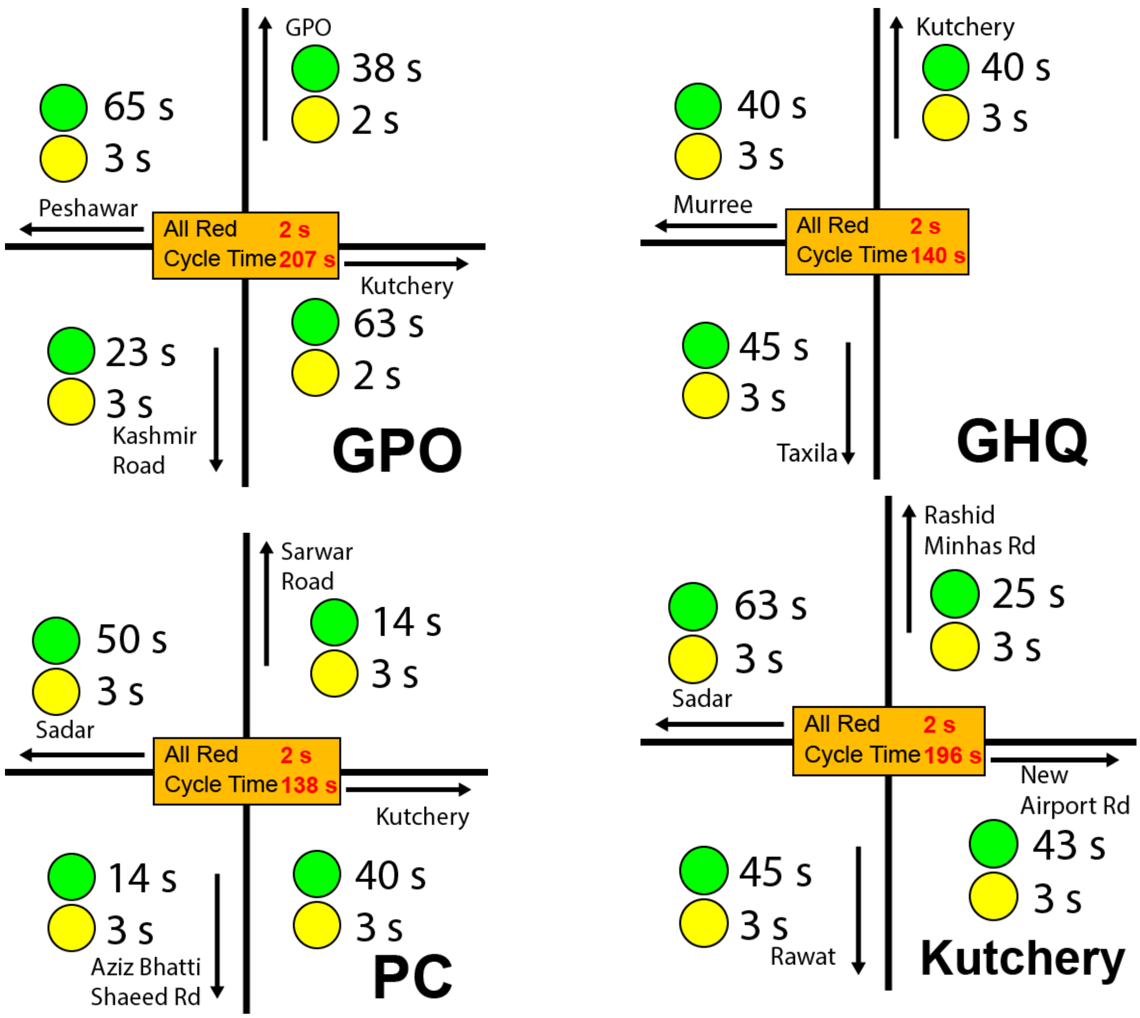


Figure 13 Traffic Signal Timings of Intersections

Vehicle composition data was estimated by collection vehicular data for 15 mins at each approach of intersections. This data was collected during the peak hour, so it gives a good estimation of overall composition. Vehicle composition data of GPO, GHQ, PC and Kutchery intersection is shown in Figure *14*, Figure *15*, Figure *16* and Figure *17* respectively.

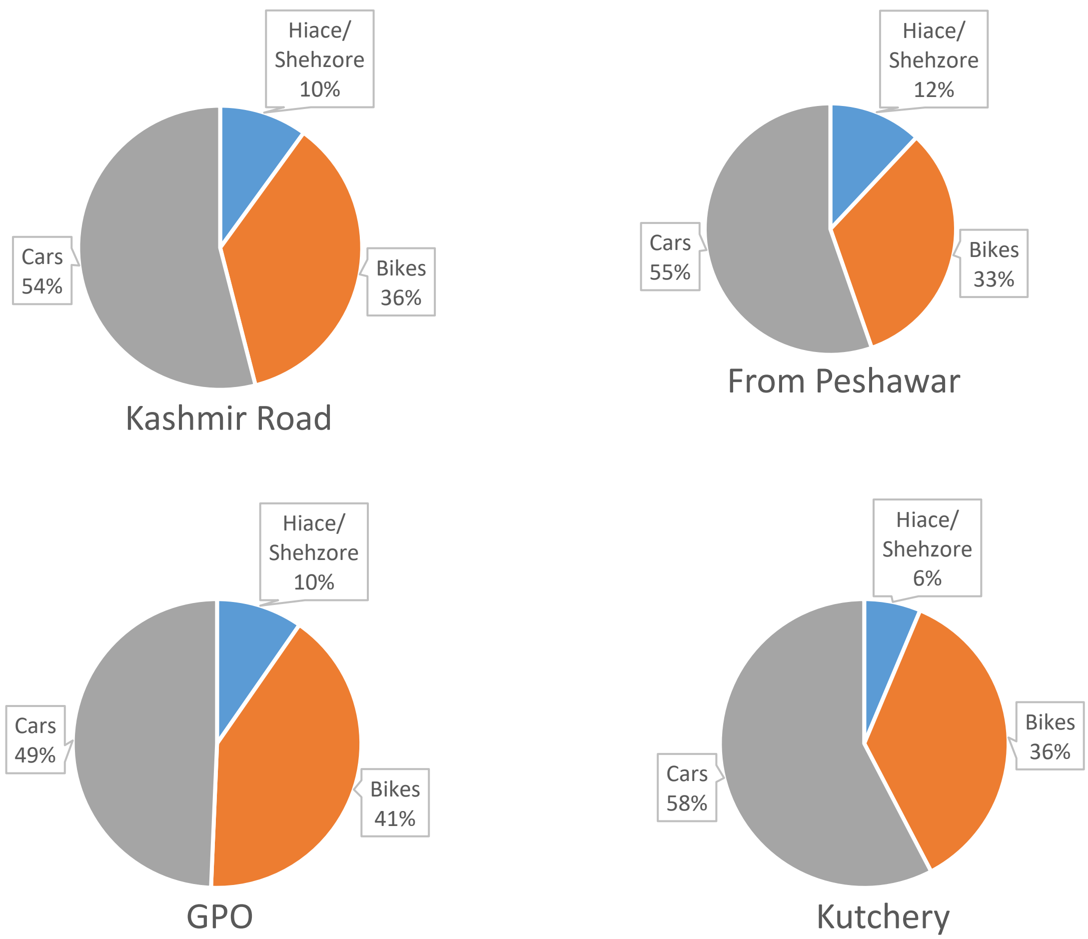


Figure 14 Vehicle Composition Data for all Approaches (GPO Intersection)

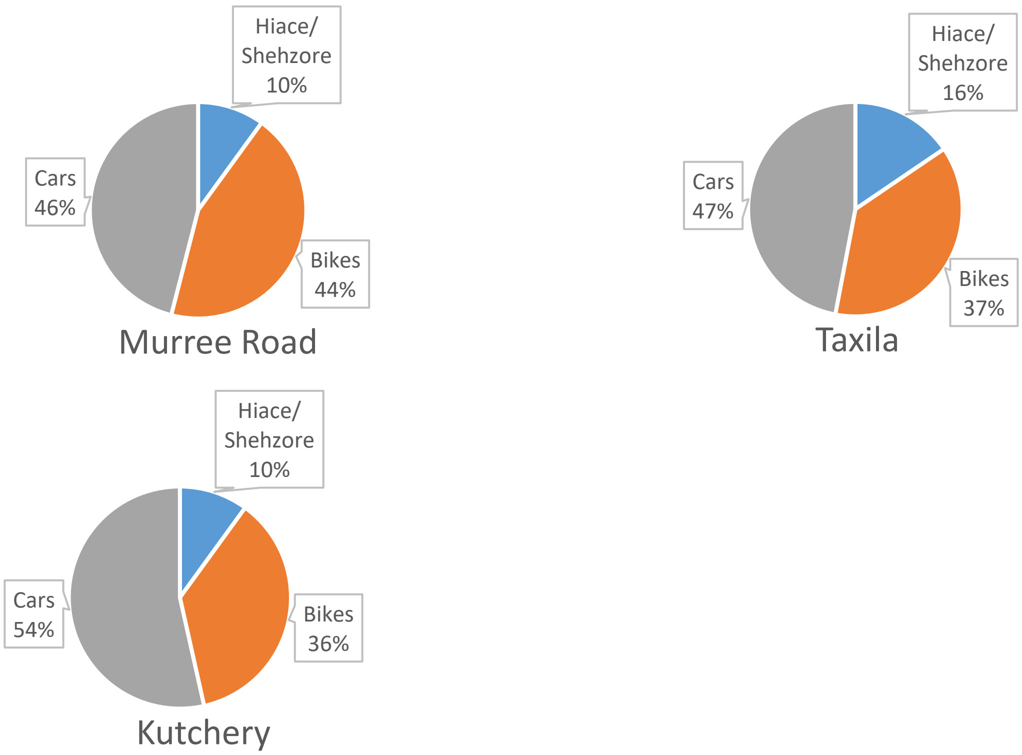


Figure 15 Vehicle Composition Data for all Approaches (GHQ Intersection)

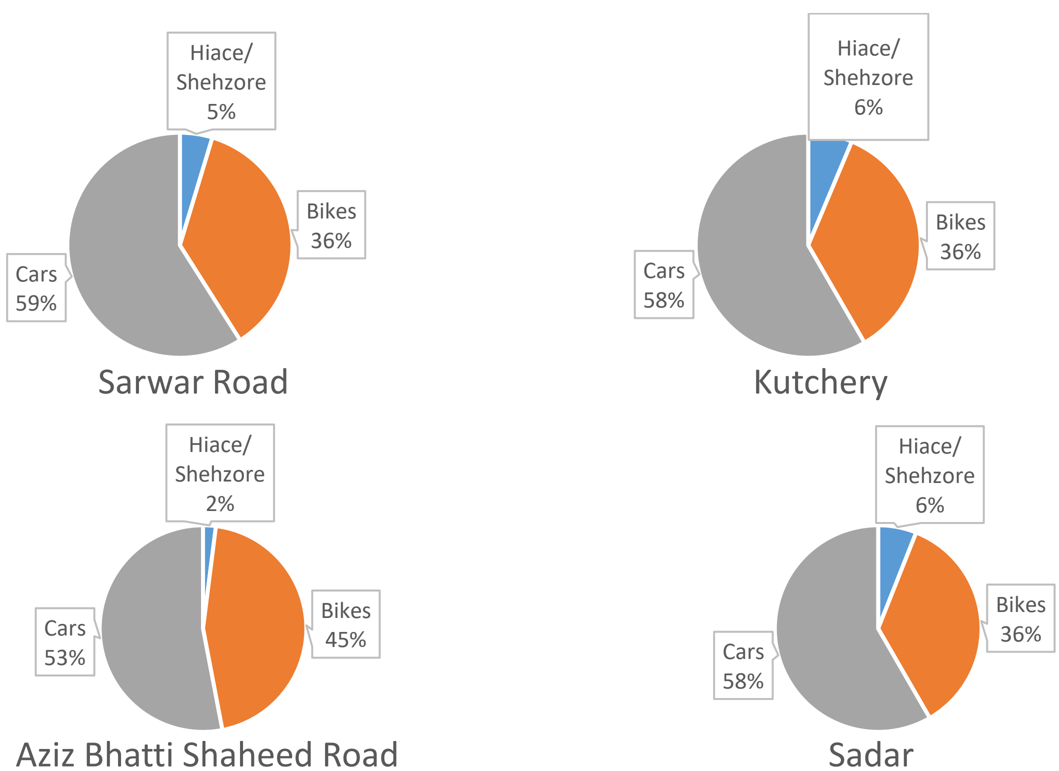


Figure 16 Vehicle Composition Data for all Approaches (PC Intersection)

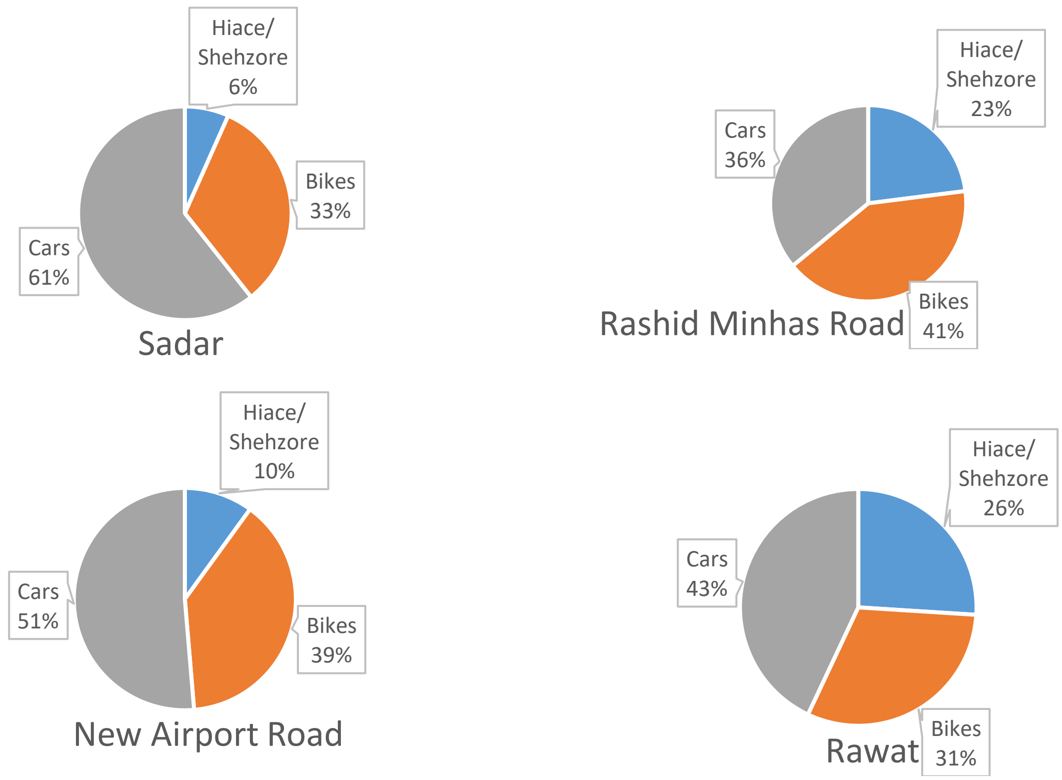


Figure 17 Vehicle Composition Data for all Approaches (Kutchery Intersection)

Vehicles were divided into 3 groups. The passenger car is our first group with the Passenger Car Unit (PCU) value equal to 1. Motorcycles and rikshaw are included in the same group with passenger car units (PCU) value equal to 0.5. All other vehicle classes were included in the third group with PCU value equal to 3. PCU values used in the analysis are shown in Table *5*.

Table 5 Passenger Car Unit (PCU)

No.	**Vehicle Type**	**PCU**
1	Passenger Car/Jeep	1
2	Motorcycle/Rickshaw	0.5
3	Shehzore/Hiace/Coaster	3

Traffic volume data acquired by RDA was peak hourly volume and this data was collected in year 2022. To use this data for simulation and analysis growth factor was first applied.

$V = V_0 \text{x} \ (1 + \text{G.F})^{\ n}$

Here,

V= Future traffic volume

V_0 = Present traffic volume and n = number of years

Traffic volume data of GPO, GHQ, PC and Kutchery intersection is shown in Table *6*, Figure *15*, Table *8*, and Table *9* respectively.

Table 6 Traffic Volume Data (GPO Intersection)

GPO Intersection	**Movement**	**Cars**	**Bikes**	**Hiace/ Shehzore**	**Total Volume**	**P.C.U**	**10-year Forecast**
Kashmir Road	Right	287	1072	52	1410	**978**	**1379**
	Through	680	1155	90	1925	**1527**	**2154**
	Left	138	600	13	750	**475**	**670**
From Peshawar	Right	379	644	50	1074	**852**	**1202**
	Through	1544	2872	216	4632	**3628**	**5118**
	Left	428	1359	49	1836	**1255**	**1770**
GPO	Right	109	475	10	594	**376**	**531**
	Through	43	891	56	990	**657**	**926**
	Left	87	306	9	402	**268**	**378**
Towards Kutchery	Right	383	1670	35	2088	**1322**	**1865**
	Through	2233	4204	131	6569	**4685**	**6609**
	Left	540	1534	57	2131	**1477**	**2084**

Table 7 Traffic Volume Data (GHQ Intersection)

GHQ Intersection	Movement	Cars	Bikes	Hiace/ Shehzore	Total Volume	P.C.U	10-year Forecast
Murree Road	Right	178	1918	36	2131	**1243**	**1753**
	Left	109	1046	61	1216	**815**	**1149**
Kutchery	Right	167	932	66	1165	**831**	**1172**
	Through	1508	4166	278	5951	**4424**	**6240**
Taxila	Through	1301	3904	217	5423	**3706**	**5227**
	Left	730	2317	83	3130	**2254**	**3179**

Table 8 Traffic Volume Data (PC Intersection)

PC Intersection	Movement	Cars	Bikes	Hiace/ Shehzore	Volume	P.C.U	10-year Forecast
Sarwar Road	Right	232	553	5	791	**524**	**740**
	Through	116	1055	28	1199	**727**	**1026**
	Left	69	108	3	180	**132**	**187**
Kutchery	Right	596	2468	21	3085	**1892**	**2669**
	Through	1297	2162	144	3603	**2811**	**3965**
	Left	321	878	20	1219	**821**	**1158**
Aziz Bhatti Shaheed	Right	364	1953	8	2325	**1364**	**1924**
	Through	96	3061	32	3188	**1722**	**2429**
	Left	274	2641	20	2934	**1653**	**2332**
Sadar	Right	603	1170	55	1828	**1353**	**1909**
	Through	946	2918	79	3944	**2642**	**3727**
	Left	547	1806	24	2376	**1521**	**2145**

Table 9 Traffic Volume Data (Kutchery Intersection)

Kutchery Intersection	**Movement**	**Cars**	**Bikes**	**Hiace/ Shehzore**	**Volume**	**P.C.U**	**10-year Forecast**
Rashid Minhas Road	Right	301	1124	54	1479	**1025**	**1447**
	Through	272	2162	202	2637	**1960**	**2765**
	Left	140	1675	89	1903	**1243**	**1754**
Airport	Right	229	1558	68	1854	**1212**	**1709**
	Through	1023	2763	51	3837	**2558**	**3608**
	Left	278	1113	73	1464	**1054**	**1487**
Rawat	Right	142	794	56	992	**708**	**999**
	Through	1934	840	1043	3817	**5483**	**7735**
	Left	253	2275	181	2709	**1932**	**2725**
Sadar	Right	1613	1864	108	3584	**2867**	**4045**
	Through	1005	1911	70	2986	**2170**	**3061**
	Left	199	854	14	1067	**669**	**943**

Chapter 5 Traffic Simulations

In this section, the creation of traffic simulation is discussed in detail. The software tools used for the creation of models are Synchro and VISSIM. Synchro is used for traffic signal timings and their optimization. VISSIM is used for the detailed analysis of the whole network.

5.1 Creation of intersection model using Synchro

The Synchro software is used for the creation of intersection models to optimize the traffic signal timing of whole network. Moreover, it was also used to generate the traffic signal timings for alternative intersection design.

Synchro is an American based software, so it only model right-hand traffic. Therefore, for modelling the left-hand traffic the background image needs to be flipped. Vehicle inputs of model were entered accordingly. Comparison between left hand and right-hand drive is shown in Figure 18

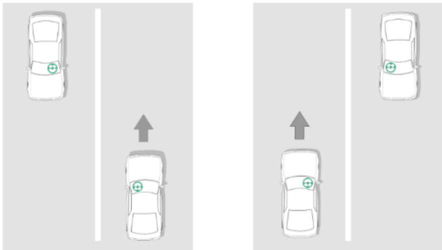


Figure 18 Left hand Vs Right Hand Drive

For traffic signal optimization and protected right-turn phasing Kutchery Intersection wasn't modeled as its PC-1 is already approved. Since the approved design would be used. The current

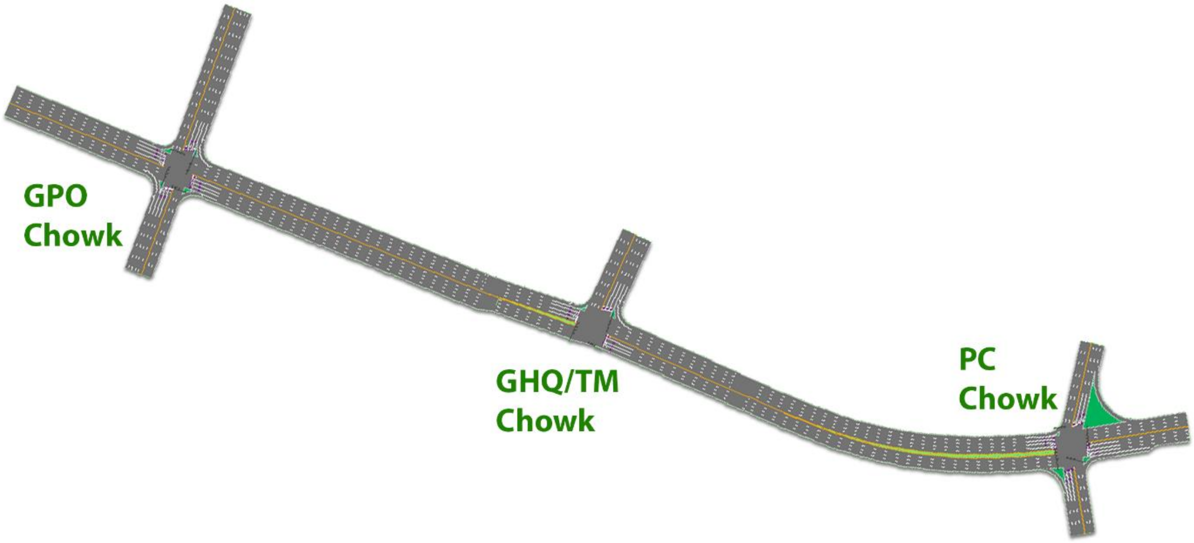


Figure 19 Synchro Model of three intersections

scenario is first modeled, show in Figure *19*, based on this model second scenario with optimized traffic signal timing is modeled.

In the third scenario, protected right-turn traffic signal phasing was included. Protected right-turn can help in reducing congestion thus improving the overall traffic flow. Not only that, but it also provides a designated crossing period for pedestrians, thus lowering the possibility of collisions with turning vehicles.

5.2 Creation of intersection model using VISSIM

VISSIM was used for the modeling and simulation of unconventional intersection designs. It is a micro-simulation software in which models can develop from scratch by lane-by-lane development.

Everything in VISSIM was kept same as default except few settings related to driver behavior. These settings include Observe adjacent lane, Diamond queuing, consider next turn and overtake left and right. This setting will help in depicting the real time traffic of Pakistan in better way compared to default setting. Figure *20* shows the snapshot of VISSIM window with changed settings.

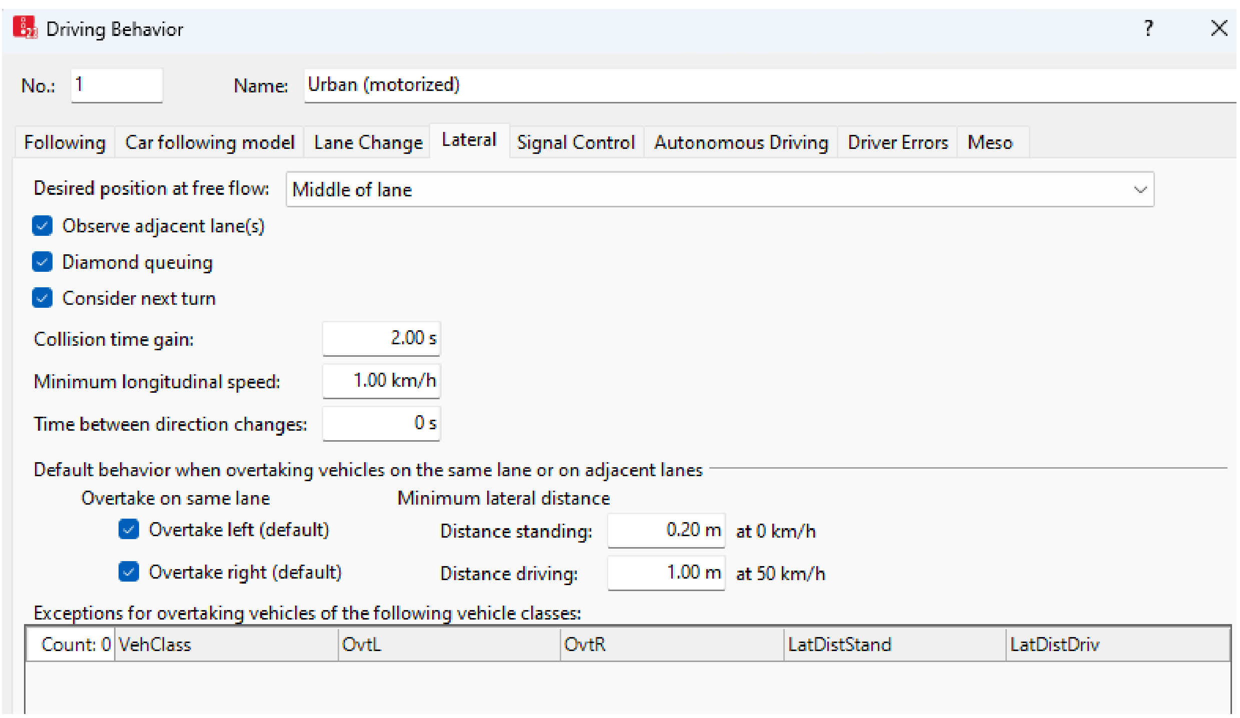


Figure 20 Vissim Changed Settings

Total Simulation time is changed to 7200s or 2 hours and for analysis purpose first hour isn't use. The first hour is used as a warmup for the traffic to reach its maximum. The travel time detectors were placed to face upstream and downstream of the main intersection for the better capture of delays.

The alternative intersection designs that were shortlisted for the detailed analysis are median U-turn intersection, Crossover Displace Right-turns, and Single Point Urban Interchange. For the GHQ/TM Intersection, a three-legged intersection, only one flyover was added for the traffic coming for Taxila. However, for Kutchery Intersection, the approved design by Rawalpindi Development Authority (RDA) was used.

Firstly, only intersections were modelled with alternative designs. Then the best performing alternative designs were modelled in the whole network. The newly designed network was compared to the current scenario. According to Highway Capacity Manual (HCM), control delay is the parameter used to measure LOS of signalized intersection (HCM 2010 : highway capacity manual, 2010). For the comparison of different scenarios, we will use the average delay per vehicle. VISSIM assesses this by contrasting the real and ideal travel time between two chosen places. As a result, this delay cannot by directly compared with HCM control delays. They do, however, offer a reliable indicator of intersection efficiency.

Traffic signal timing for the alternative designs were calculated with the help of Synchro. Whole model cannot by created in simple because of its limitations so simplified model was made in synchro for the calculation.

Figure *21* shows the model of single point urban interchange in Synchro for traffic signal timings and on right hand side Figure *22* shows the model of single point urban interchange in VISSIM.

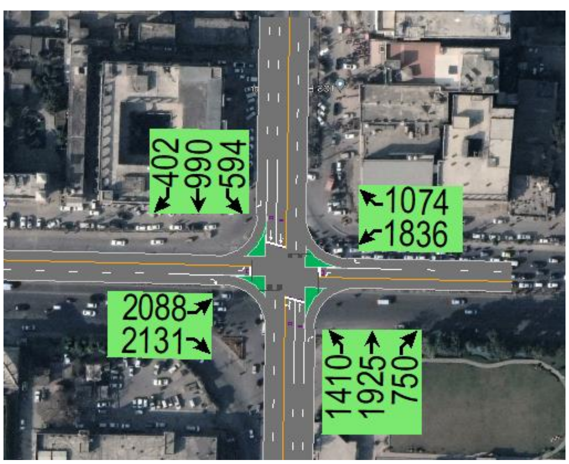


Figure 21 Synchro Model of SPUI for Traffic Signal Timings

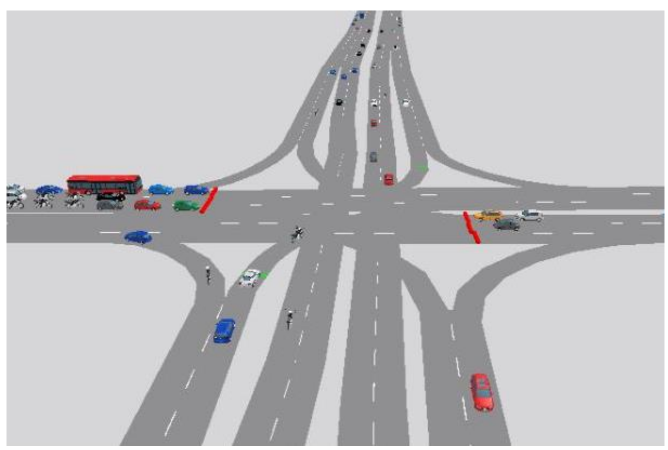


Figure 22 Vissim model of SPUI

Chapter 6 Analysis and Discussion

In this chapter, the results obtained from simulations are analyzed and discussed in detail.

6.1 Traffic signal Optimization and Protected Right-turn Phasing.

Firstly, traffic signal optimization was performed using Synchro, just by performing that a slight decrease in control delay was observed. Then with protect turn phasing a quite noticeable decrease in control delay was observed. Results of comparison of these three scenarios is shown in Table *10* and control delay comparison is shown in Figure *23*.

Table 10 Comparison of Three scenarios using Synchro.

	Current Scenario	Optimized Signals	Protected Right-Turns
Control Delay / Veh (s/v)	2996	2081	**1379**
Total Delay (hr)	58016	40721	**27118**
Stops/Veh	1	0.97	**0.57**
Stops (#)	69806	67929	**39461**
Total Travel Time	58441	40721	**27118**
Fuel Consumed (l)	164308	115175	**76852**
Fuel Economy (km/l)	0.1	0.2	**0.3**
Performance Index	58209.8	40484.7	**26802.6**

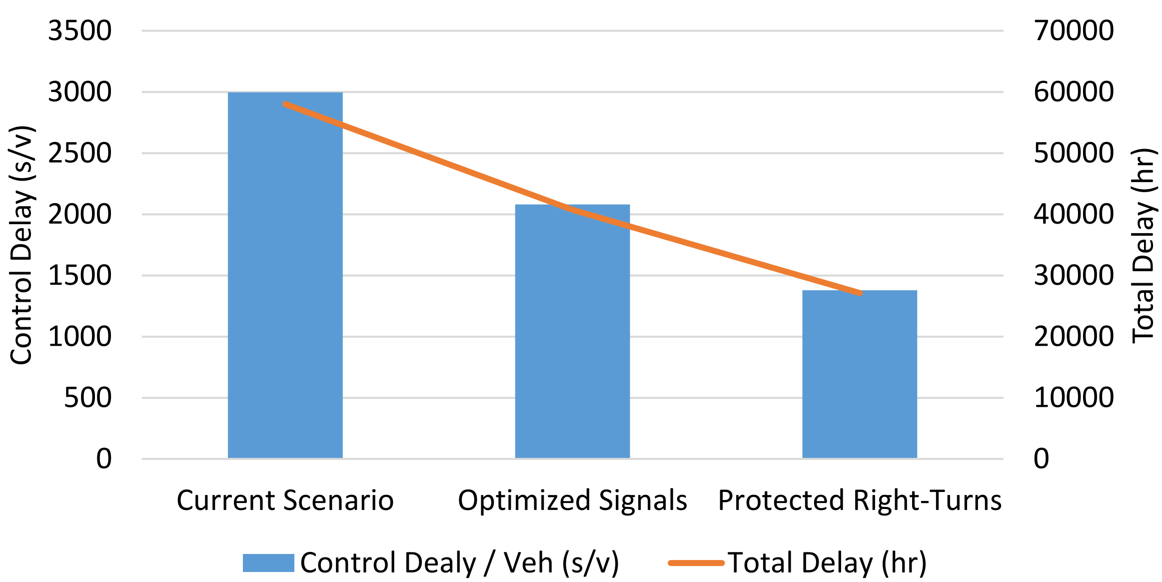


Figure 23 Control Delay Per Vehicle (Synchro)

With protected turn phasing, there was 43% reduction in stops per vehicle. There the total travel time was reduced from 58441 hours to 27118 hours. This significant reduction in travel time led to a reduction in fuel consumption and increased the fuel economy shown in Figure *24*. From the environmental aspect, there was significant reduction in the emission of harmful gases like CO2, NOx, and VOCs shown in Figure *25*.

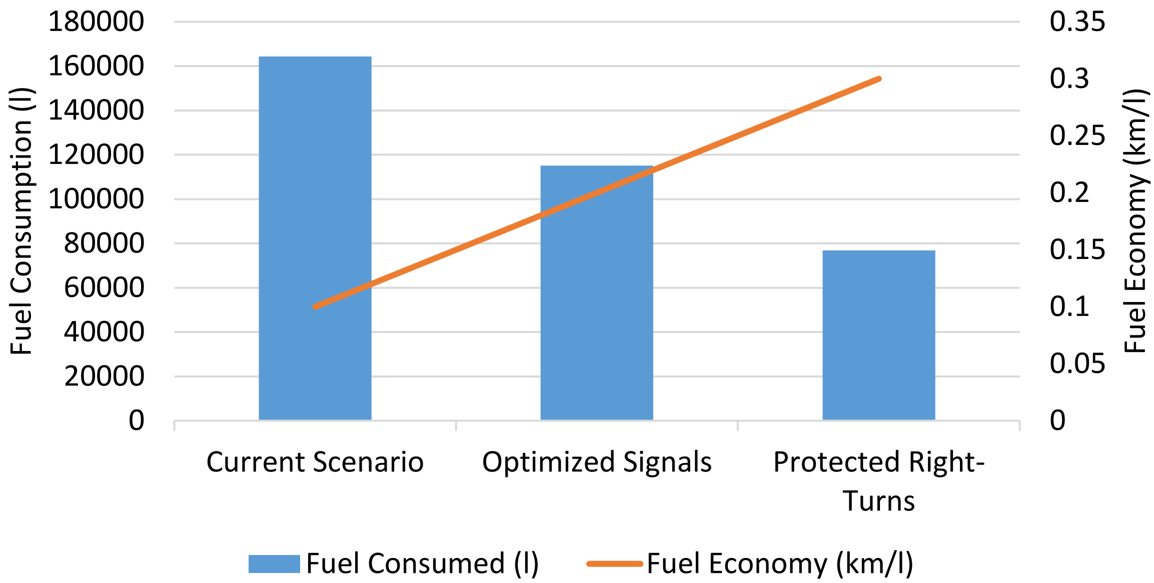


Figure 24 Three Scenarios - Fuel Consumed & Fuel Economy (Synchro)

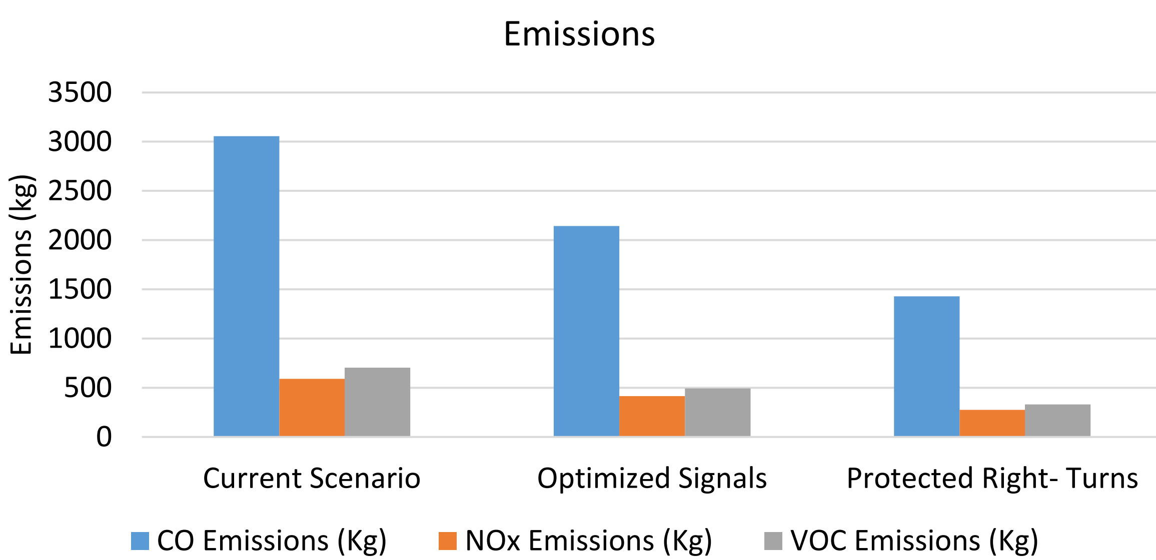


Figure 25 Three Scenarios - Emissions (Synchro)

Although these results suggest that the protected right-turn signal phasing is the best option but note that the control delay of protected right turn phasing is 1379 seconds, which is a lot. According to HCM, for an average control delay greater than 80 sec/veh LOS of intersection is “F”. With this alternative we are still far ahead of the limit. So, until a suitable alternative is constructed, we can implement this model as it would cost less and improves the efficiency of the system, so its cost to benefit ratio is greater than 1.

6.2 Median U-turn Intersection

Median U-turn intersection (MUT) was modelled for both GPO Intersection and PC Intersection, and its optimized signal timings were obtained from the synchro model. Based on the results from the VISSIM, due to high turning movement, design caused spill back blocking the entire network. This indicates the limitations of MUT with handling high turning movements.

Figure *26* shows the model of Median U-turn intersection in Synchro for traffic signal timings and on right hand side Figure *27* shows the model of Median U-turn intersection in VISSIM.

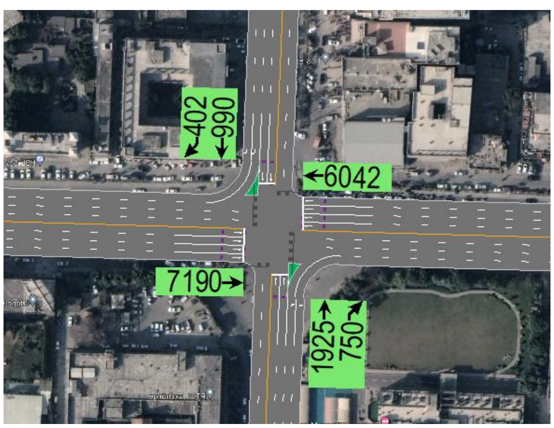


Figure 26 Synchro Model of MUT for Traffic Signal Timings

Figure 27 Vissim Model of MUT

Comparison of average vehicle delay between current scenario and Median U-turn Intersection on GPO intersection is shown in Figure *28*.

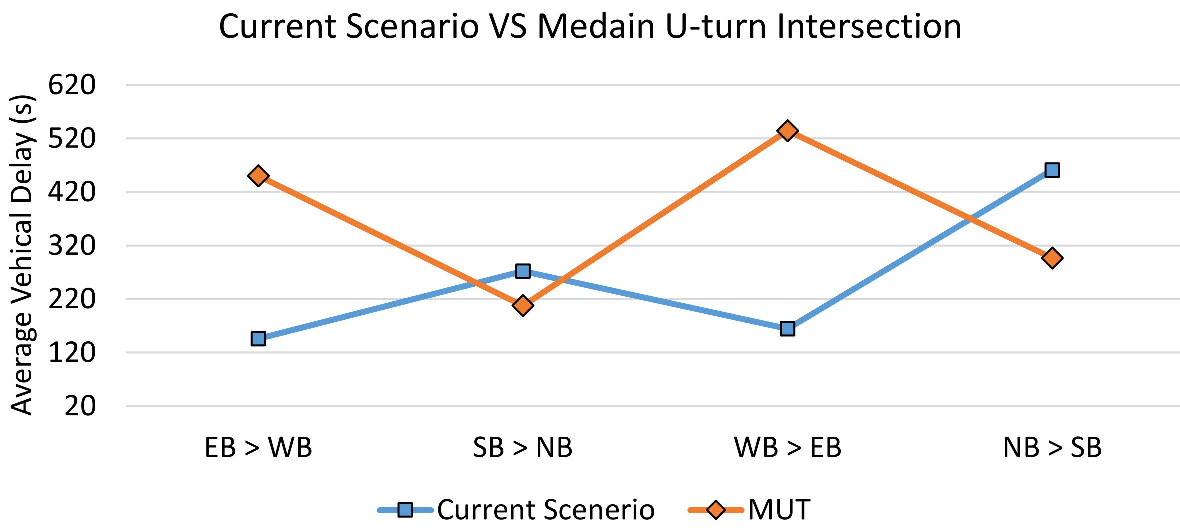


Figure 28 Average Vehicle Delay (MUT) – GPO Intersection

6.3 Crossover Displace Right-turns.

Crossover Displace Right-turns, known as Continuous Flow intersection, was modeled for the analysis. But due to unavailability of right of way, the original design was modified. On GPO and Kashmir Road, right of way wasn't available for the crossover. So, these roads were treated as conventional intersections. Roads toward Kutchery and Peshawar were cross-over. This modification led to a non-competitive result. And the full potential of this design wasn't utilized.

Comparison of average vehicle delay between current scenario and partial crossover displace right-turn intersection on GPO intersection is shown in Figure *29* and Vissim model of partial crossover displace right-turn intersection is shown in Figure *30*.

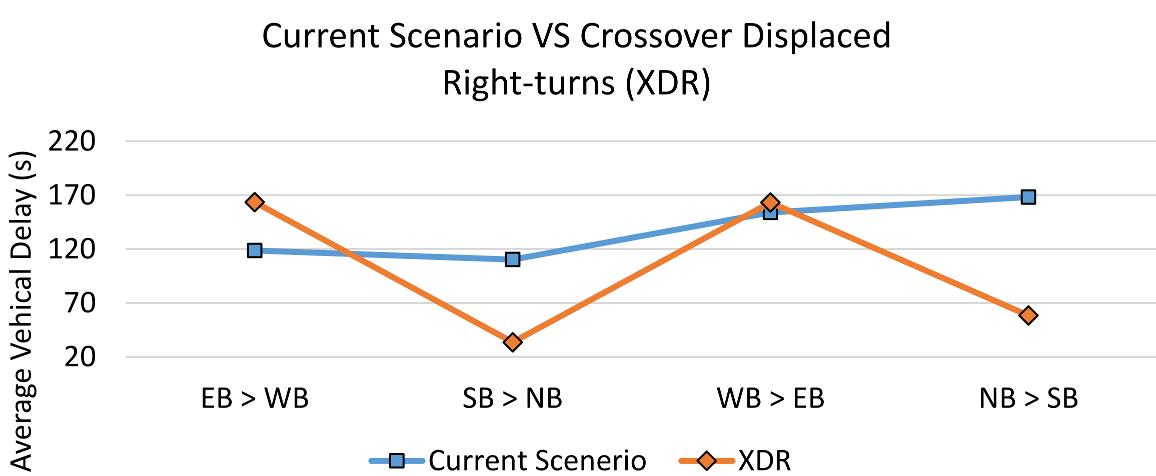


Figure 29 Average Vehicle Delay (XDR) - GPO Intersection

Figure 30 Vissim Model of XDR

6.4 Single Point Urban Interchange

Between tight urban diamond interchange (TUDI) and single point urban interchange design (SPUI), SPUI was selected for detailed analysis because it requires less right of way as compared to tight urban diamond interchange (TUDI). All the minor road movements and the turning motions of the major road ramps are carried out in one central location, which is either on the underpass or flyover, in our case it was in underpass.

Result of average vehicle delay at GPO and PC intersection are shown in Figure *31* and Figure *32* respectively.

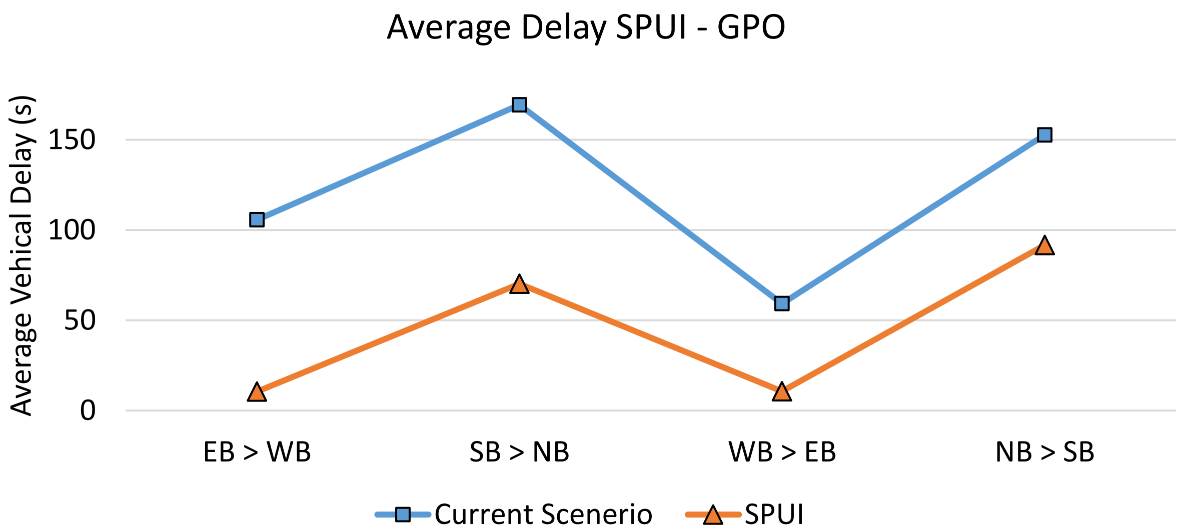


Figure 31 Average Vehicle Delay (SPUI) – GPO Intersection

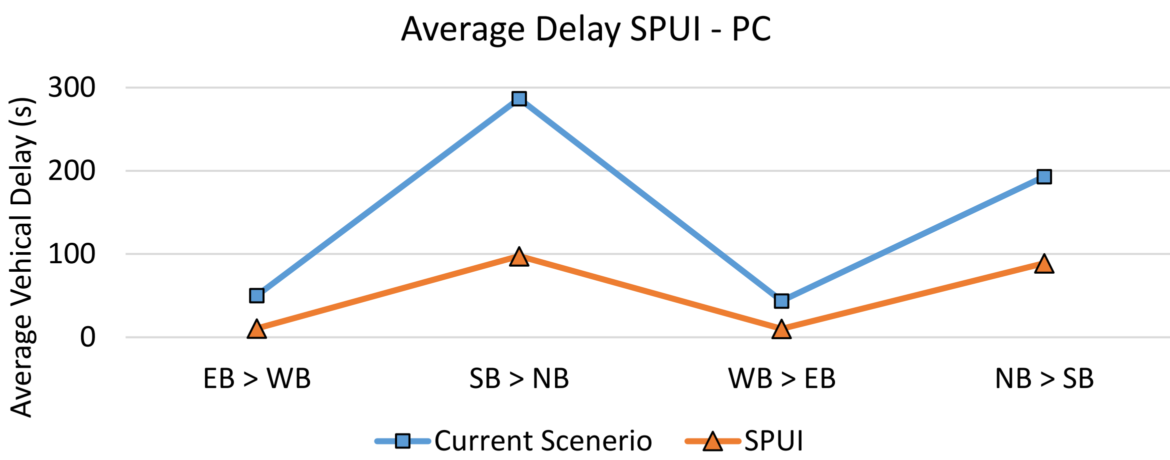


Figure 32 Average Vehicle Delay (XDR) – PC Intersection

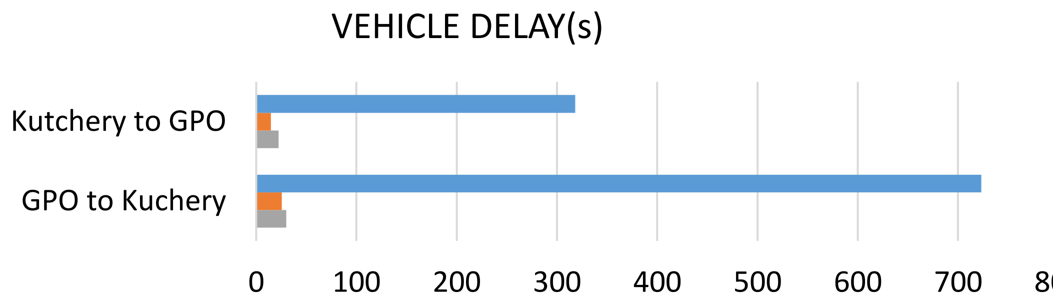
6.5 Simulation of whole Network

After selecting the best alternative design, the next step was to model them as a network. Network of intersections in the current scenario were also modeled for the comparison. The new network of intersections has a signal free route for the vehicles entering the GPO Intersection from Peshawar Road to the exit at Kutchery Intersection towards Rawat and Airport Road.

Simulation results include the comparison of current situation and updated network with alternative intersection designs. Not only that, vehicle volume was forecasted for ten years, and our new network was also tested on those volumes to estimate the performance of our network in future.

Vehicle delay was measured for a vehicle entering the first intersection GPO Intersection to exiting the last intersection in network, Kutchery Intersection and vice versa. Results from all three scenarios compiled in a graph are given below. The route distance was 2.35 km.

Average vehicle delay comparison results of current scenario, remodeled network, and remodeled network with 10-year forecast volume is shown in Figure *33*.



	GPO to Kuchery	Kutchery to GPO
Current Scenario	723.08	318.32
Remodeled	25.47	14.62
Remodeled (10 yr forecast)	30.12	22.45

Figure 33 Average Vehicle Delay - Current Vs Remodeled

Other details like fuel consumption and emissions were extracted from the model with the help of Nodes in VISSIM. Due to this immense reduction in traffic delay fuel consumption and emissions were also reduced. Making the whole network environmentally friendly. For comparison the no. of vehicles was kept at 100 and based on these vehicles, emission and fuel consumption were calculated. Graphical results of emissions and fuel consumption are shown in Figure *34* and Figure *35* respectively.

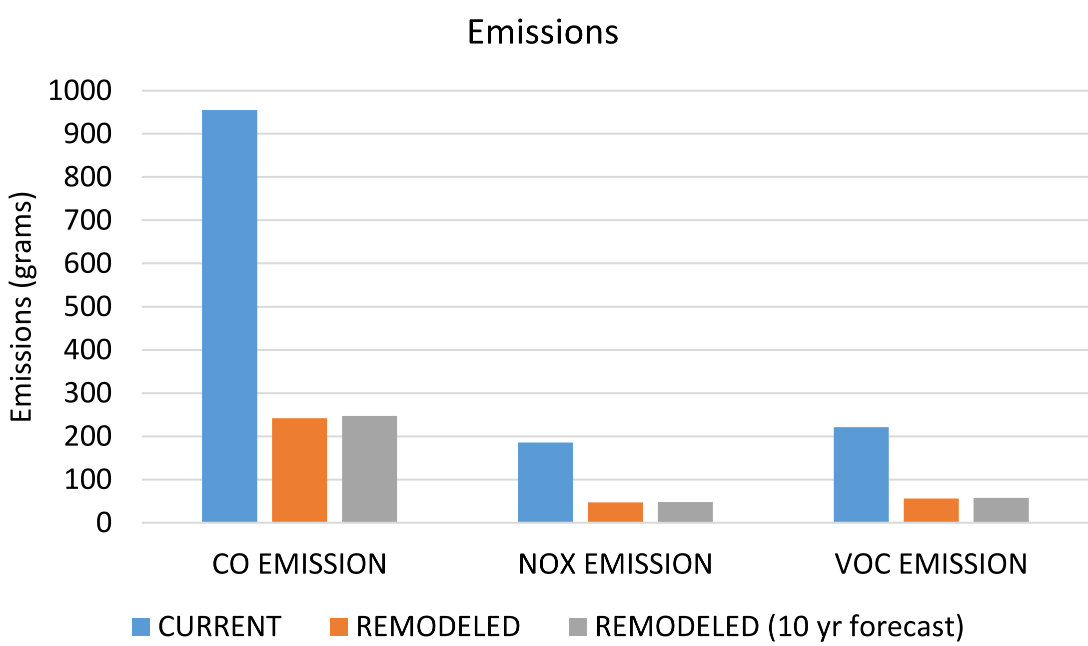


Figure 34 Emissions - Current Vs Remodeled

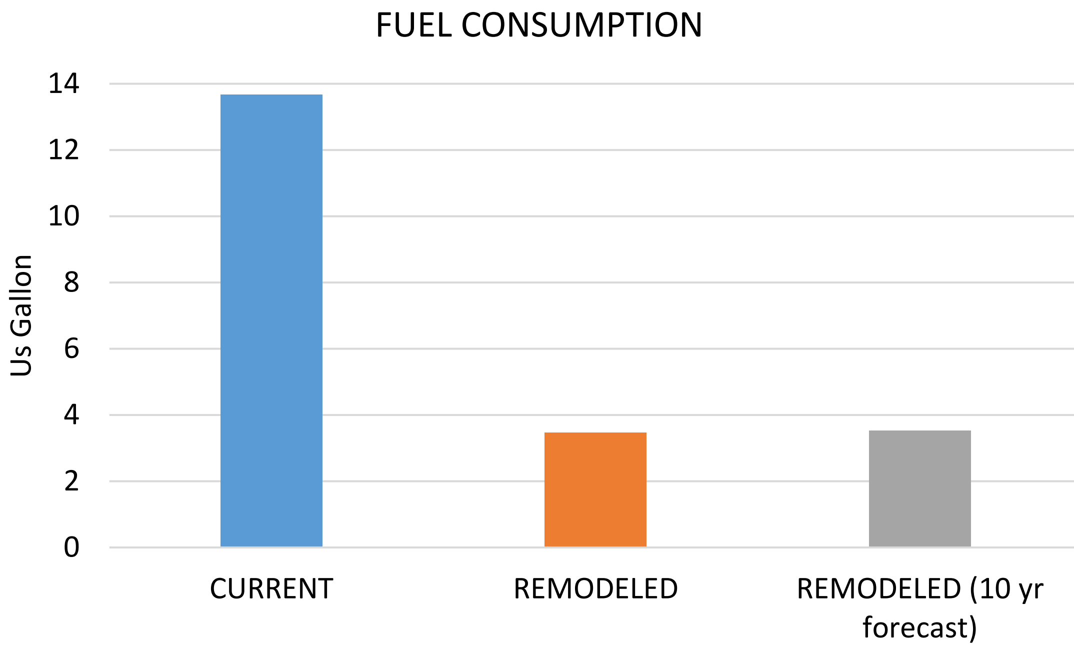


Figure 35 Fuel Consumption - Current Vs Remodeled

6.6 User Cost

Travel time delay cost and vehicle operating costs were calculated to get an estimate of user cost in both current and proposed scenarios. Two routes, GPO to Kutchery and Kutchery to GPO were selected for the calculation of user cost.

Travel time cost and fuel consumption cost were calculated using the congested travel time. Formula used for the calculation of travel time costs following formula was used:

$$\text{Travel time cost} = T_C = U_{TT} \text{ x } \frac{DT}{60} \text{ x n}$$

Here

U_{TT} = Unit travel time cost per hour of delay

D_T = delay time (minutes)

n_i = Number of "i" type of vehicles

The unit trave time cost per hour was obtained from the study by Arslan Jamil et al. (A. J., et al., 2014). They converted the rates to dollars to equivalent PKR in 2014. Same values were converted to equivalent PKR in 2023 Since this study was conducted in 2017 its equivalent cost was calculated in PKR is shown in Table *11*.

Table 11 Unit Travel Time Cost (Pkr/hr)

Vehicle type	**Cost / hour**
CARS	1022.1258
BIKES	473.9466
BUSES	1219.1277

Trave time cost of both current and remodeled scenarios is shown in Table *12* and Table *13* respectively.

Table 12 Travel Time Cost (PKR) (Current Scenario)

DELAY TIME (s)		**TRAVEL TIME COST (PKR)**					
GPO to Kutchery	**Kutchery to GPO**	**CARS - 3472**		**BIKES - 1215**		**Hiace/Shehzore - 134**	
		TTC(G2K)	**TTC(K2G)**	**TTC(G2K)**	**TTC(K2G)**	**TTC(G2K)**	**TTC(K2G)**
723.08	318.32	712730.6	313763.9	214202	94297.96	173168.61	76233.65
						TOTAL	**1584397**

Table 13 Travel Time Cost (PKR) (Remodeled)

DELAY TIME (s)		**TRAVEL TIME COST (PKR)**					
GPO to Kutchery	**Kutchery to GPO**	**CARS - 7765**		**BIKES - 2718**		**Hiace/Shehzore - 299**	
		TTC(G2K)	**TTC(K2G)**	**TTC(G2K)**	**TTC(K2G)**	**TTC(G2K)**	**TTC(K2G)**
25.47	14.62	56154.355	32233.08	16876.52	9687.266	13643.545	7831.512
						TOTAL	**136426**

Formula used for the calculation of travel time costs following formula was used:

$$\text{Fuel cost} = F_C \times \frac{DT}{60} \times n$$

Here

Fc = Fuel consumption cost per hours of delay(liters)

DT = Delay time (minutes)

n_i = Number of "i" type of vehicles

Unit fuel consumption was calculated based on experimentation and it's value for all type of vehicles is shown in Table 14.

Table 14 Unit Fuel Consumption (PKR/hr)

VEHICLE TYPE	UFC(Gallon/m)	UFC (liters/m)	COST (pkr/m)	COST (pkr/h)
CARS	0.021	0.079	23.068	1384.08
BIKES	0.0042	0.016	4.672	280.32
BUSES	0.177	0.67	195.64	11738.4

Fuel consumption cost of both current and remodeled scenarios is shown in Table 15 and Table *16* respectively.

Table 15 Vehicle Operating Cost (PKR) (Current Scenario)

DELAY TIME (s)		**VEHICLE OPERATING COST (PKR)**					
GPO to Kutchery	**Kutchery to GPO**	**CARS - 3472**		**BIKES - 1215**		**Hiace/Shehzore - 134**	
		TTC(G2K)	**TTC(K2G)**	**TTC(G2K)**	**VOC(K2G)**	**VOC(G2K)**	**TTC(G2K)**
723.08	318.32	965122.03	424873.7	68413.71	30117.63	315130.67	138729.3
						TOTAL	**1942387**

Table 16 Vehicle Operating Cost (PKR) (Remodeled)

DELAY TIME (s)		**VEHICLE OPERATING COST (PKR)**					
GPO to Kutchery	**Kutchery to GPO**	**CARS - 7765**		**BIKES - 2718**		**Hiace/Shehzore - 299**	
		TTC(G2K)	**TTC(K2G)**	**TTC(G2K)**	**VOC(K2G)**	**VOC(G2K)**	**TTC(G2K)**
25.47	14.62	76039.68	43647.43	5390.155	3093.995	24828.399	14251.72
						TOTAL	**167251**

For the total user cost we will add Travel time cost and vehicle operating cost for both scenarios. Summary of total user cost is shown in Table *17*.

Table 17 Summary of Total User Cost

TOTAL USER COST(TUC)	
CURRENT	3,526,784
REMODELLED	303,678
COST REDUCTION	**PKR 3,223,107**

The cost reduction of PKR 3,223,107 is per hour cost reduction during the peak hour.

Chapter 7 Conclusions

7.1 Conclusions

In this study we provide better alternatives to traditional intersection designs, so that our road network can serve existing and future traffic efficiently. The comparison of the existing and proposed designs was done using the Synchro and PTV VISSIM software.

The potential benefits of intersection remodelling make it a useful strategy for improving efficiency and sustainability of transportation system in urban areas. In conclusion remodelling of a chain of intersections in our case had a significant impact on travel time delay, emissions, and fuel consumptions. Travel time delay of whole network was reduced to 0s from 12 mins because of signal free corridor.

The final design of the network has a much better, smoother, and faster driving experience. In turn this reduces the amount the fuel consumption, vehicle emissions thus reducing the environmental impact. The main benefit of the remodelling is to the daily users of the route as it significantly reduces the user cost.

7.2 Recommendations

In our study, detailed analysis of alternatives and their potential impact on the traffic congestion were considered. In future, we recommend detailed feasibility of proposed alternatives, comparison between user vs agency cost and the potential impact of well-designed public transit on the traffic congestion of proposed route.

Detailed feasibility study in must to determine the viability and practicality of proposed alternatives prior to their deployment. This should cover a range of topics, such as social acceptability, economic viability, and environmental impact. Based on results, it is decided whether the suggested alternative is in line with our long-term transportation goals and whether it can be successfully incorporated into our current infrastructure by carefully considering these elements. The feasibility analysis will also assist in identifying any potential implementation-related risks or barriers, enabling the development of effective mitigation solutions.

It is crucial to consider both the costs carried by the users and the costs incurred by the construction company, in its installation and operation, while evaluating the suggested alternative. From the viewpoint of the user, elements like cost, practicality, and accessibility are crucial. The agency's costs must be evaluated, which includes the investment needed for infrastructure expansion. A sustainable and fair solution that satisfies the needs of both parties requires balancing the financial burden between users and the agency.

A well-designed public transit should also be incorporated into the system to check the impact on traffic congestion. By diverting private vehicle users to public transit, a potential reduction in the number of vehicles on the road during peak hours can be achieved, thus easing traffic congestion in congested areas. Additionally, a well-designed public transit system can encourage a modal shift from private vehicles to public transportation, promoting sustainable transportation choices and reducing overall traffic volume.

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