Congestion Mitigation on an Urban Arterial through Infrastructure Intervention

BACHELORS OF

CIVIL ENGINEERING

NUST Institute of Civil Engineering (NICE)

School of Civil & Environmental Engineering (SCEE)

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This is to certify that the

Project report titled

Congestion Mitigation on an Urban Arterial through Infrastructure Intervention

has been accepted towards the partial fulfillments

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for

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Dr. Anwaar Ahmed

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Dedicated

To

OUR LOVING PARENTS AND INSTITUTE

WHO GAVE US INSPIRATION,

COURAGE,

MORAL AND FINANCIAL SUPPORT

FOR OUR STUDIES

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ABSTRACT

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 large scale 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. Aging transportation infrastructure of cities like Rawalpindi 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.

Our focus of study is to identify the traffic congestion problems of Rawalpindi Saddar (from Qasim Market Intersection to Pearl Continental Intersection) and coordinating the signals using advanced traffic simulation and coordination softwares. Longer delays at the intersection and slow traffic speed on links are damaging the environment of Rawalpindi. In addition, we have proposed different infrastructure interventions.

Present effort aims to investigate the traffic congestion problems of Rawalpindi and to suggest suitable cost effective solution for relieving traffic congestion and to reduce travel time, vehicle operating and environmental costs.

CHAPTER # 1
Introduction

1.1 Background:

Road transport is the most important transportation mean. A survey done by U.S Bureau of Transportation Statistics, shows that almost 88.79% of the passengers travel through roads and 28.50% of freight is carried by trucks [BTS, 2005]. The main conflicts arise when two or more roads meet at an intersection. A joint on road where two or more roads either unite or intersect at grade is termed as "intersection". Intersections continue to play an important role in the road network by providing a divergence links to the facilities where traffic flows in different directions converge. Intersections provide a lower capacity than the approach links. That is why they are supposed to be a bottleneck of any network, and special care has to be taken in designing the intersection as they are the popular source of traffic jam and other incidents. In U.S, approximately 39.7% of the accidents occur at intersections or are intersection related [FHWA, 2007]. Therefore in order to ensure smooth traffic flow and to provide safety at intersections signalization (round about) were introduced in 20th century.

The capacity of each roundabout varies depending upon number of roads intersecting and volume of traffic. However, a small roundabout should be able to serve an intersection with daily traffic entering volume of 15000 vehicles [FHWA, 2007]. When the volume exceed from specified volume for a roundabout we go for installation of traffic signal at that intersection. The installation of traffic signal at an intersection also causes a lot of problem. For example it increases the delay time, causes rear end accidents etc. Therefore, signal coordination is done in order to minimize the inconveniences at intersection due to traffic signal installation. In order to coordinate signals, the signals must have a maximum distance of 800m between them [MUTCD].

Traffic Signal operation is the radical factor in working of many signal networks. It is normally put into effect to amend the LOS of a road, where the spacing is such that isolated signals result into excessive delays and loss of capacity. Coordinated traffic signals are controlled from a master controller and set up in such a way that platoons of vehicles can pass through a series of green lights continuously. It is now possible for the drivers to travel long distances without having engaged with the red light. Most recently, methods are becoming so sophisticated that lights are centrally controlled by computers which allow them to work in real time coordination and they deal with the changing traffic patterns. In Pakistan, concerning about the poor state of intersections, coordination is becoming more and more necessary.

Coordination of signal is being emphasized to ensure minimum delays, optimal travel speeds, and reduce the number of stops. Signal Coordination provides the real time monitoring, improved mobility and access. It is necessary element for the betterment of road network. Regarding the traffic conditions in our state of Pakistan, a German organization conducted a survey in 108 different countries. Pakistan has one of the most unsophisticated traffic. The report said that the driving conditions in Pakistan are much worst. The survey deduced this result on the basis of following of rules, implication of rules, and the general behavior of drivers. Traffic in Pakistan is getting worse with each coming day especially in big cities like Karachi, Lahore, Rawalpindi and Islamabad.

After the decades of research, it has been established that the key to the traffic problems lies in a simple principle, which includes engineering, education and enforcement. Engineering deals with all the physical facilities that handles the traffic demand. Education comprises of the fact that all the drivers who are privileged to drive a vehicle must know the rules of the road. Traffic Enforcement involves majorly in traffic planning. Without enforcement, not a single facility would be helpful to counter the traffic problems. These elements help in the improvement of traffic conditions in Pakistan.

Urban Traffic Control System is applied to the Murree Road, Rawalpindi. Urban Traffic Controller (UTC) would be installed at Murree Road and Mall Road intersections. There are a total of 16 controllers. Loop detectors would be installed for real time data at each intersection. The main objective of this project is the physical road improvement for some intersection. It increases the efficiency of public transport and provides safety to the road users.

1.2 Problem Statement:

In this modern era, urbanization and traffic is increasing rapidly and the transportation trend of people is shifting from public transport to individual automobiles. Due to such reasons, the demand on roads has increased. Since such growth rates in traffic are not considered while designing the timings of the traffic signals and it results in an imbalance between demand and capacity. This imbalance results in increased traffic jams and congestion. Similarly, the traffic delays also increase. Long queues are seen along the major roads. Traffic delays due to uncoordinated signals results in poor environmental impacts due to increased energy and fuel consumption. Long queues of vehicles are formed due to traffic jams and the harmful gases are emitted by the cars which results in poor air quality and is a major source of air pollution. In addition to air pollution, it also has an impact on the environment through noise pollution.

According to the studies carried out in various countries, it has been concluded that the psychology of people is also affected by such effects. One of the main concerns of traffic engineer is to ensure the road safety. If logical and scientific techniques are applied in the field of traffic engineering, road accidents can be minimized and we can create a healthy environment. Due to imbalance in demand and capacity, roads are not being able to complete their designed Level of service as well as mobility along the major roads is also affected by the poor signal coordination.

In Pakistan, no considerable work is being done in the field of traffic engineering especially regarding the signal coordination.

1.3 Study Scope:

We have selected an urban arterial of Rawalpindi for this study. The selected arterial consists of the section of G.T road which leads from "Qasim market intersection" to "P.C Hotel intersection", having five traffic signals.

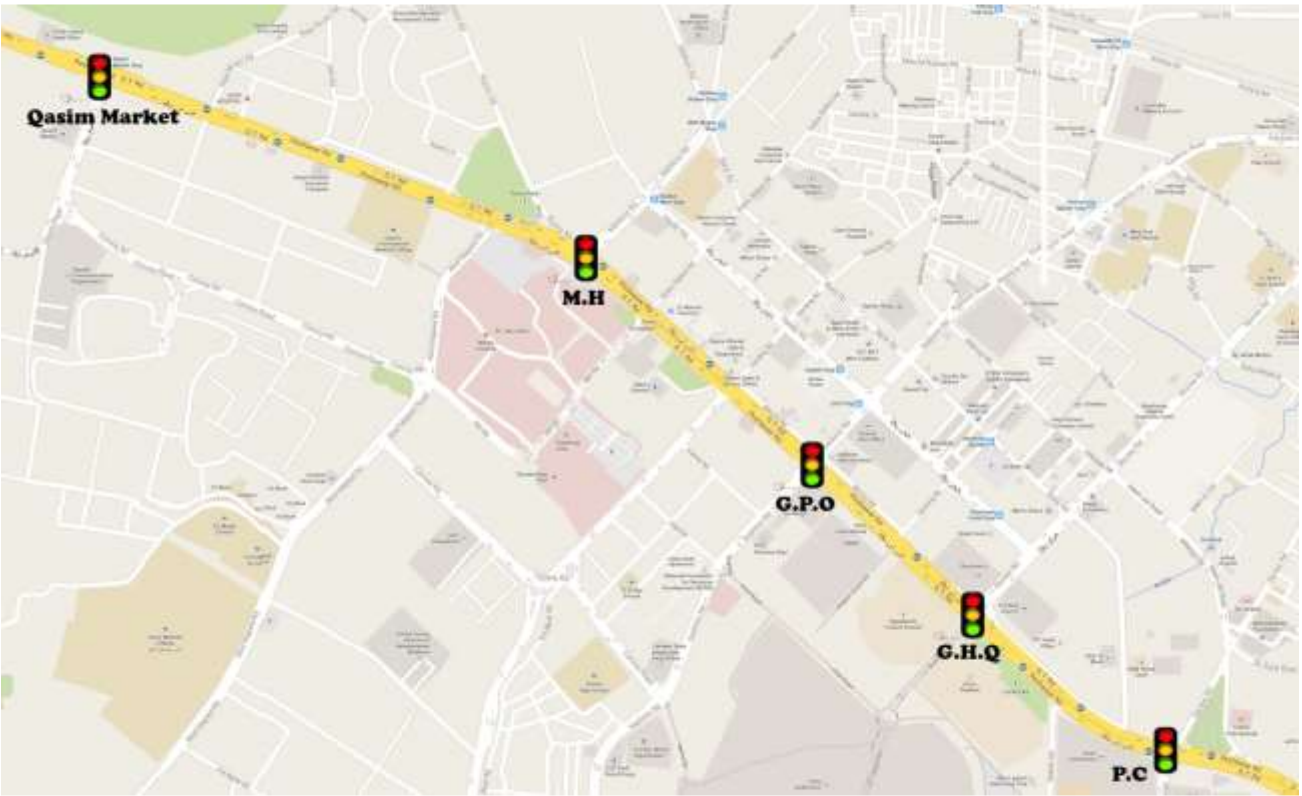
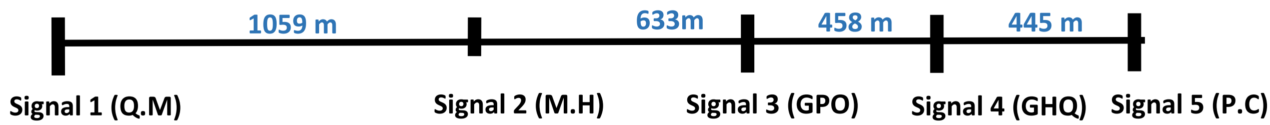


Figure 1.1 Map



During the initial survey of the field, we measured the travel lengths between the signals and the cycle lengths. The cycle timings and the phase lengths of these signals are also not fixed. These are changed by the traffic wardens according to the traffic volume fluctuations during the day as well as due to power issues. For signal coordination the appropriate distance between the signals should be within 800 m [MUTCD] or a maximum of 1 mile for major streets and highways. Since the measured distance between each two signals is less than 1 mile therefore these signals can be coordinated. The measured travel distances and the current cycle lengths of these signals are given in tables 1.1 and 1.2 respectively.

Table 1.1 Travel Distances

Travel Nodes	Travel Distance
Signal 1 to Signal 2	1059 m
Signal 2 to Signal 3	633 m
Signal 3 to Signal 4	458 m
Signal 4 to Signal 5	445 m

Table 1.2 Cycle lengths

Signal	Cycle Length
Signal 1 (Qasim Market)	1 min 40 sec
Signal 2 (M.H Signal)	1 min 15 sec
Signal 3 (G.P.O Signal)	2 min 15 sec
Signal 4 (GHQ Signal)	1 min 45 sec
Signal 5 (P.C Signal)	1 min 55 sec

1.4 Project Objectives:

- The research effort aims to improve the traffic operation on one of the busiest urban arterial. The main objectives of this study are:
- A detailed analysis of existing traffic conditions including physical corridor geometry, travel time and signal timings.
- To carry out traffic signal coordination using Synchro and to quantify results i.e. travel time, vehicle operating cost and environmental impact.
- To study different transportation interventions to provide the long term cost effective solutions for improving overall traffic operation.

These objectives will be achieved through following approaches:

- Identify different software which will be available for signal coordination.
- Identifying the methodology for signal coordination.
- Implementation of the methodology and techniques described in the report.
- Carry out cost and benefits analysis.

1.5 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

Literature Review

As discussed in Chapter 1, Traffic Signal Coordination is becoming popular in various countries to meet the traffic volume demands. Various methodologies and system are being implemented in various countries. Some of the implementations are discussed in this literature review.

2.1 Signal Coordination Projects:

The projects undertaken to coordinate signals in Pakistan and the world are discussed in this article(Pat Timbrook 2002).

2.1.1 Signal Coordination Worldwide:

1) SCATS:

The **Sydney Coordinated Adaptive Traffic System** (SCATS) has been employed in 263 cities around the world including Rawalpindi (Pakistan). It is an innovative computer based traffic management system. The basic purpose of the development of SCATS is to eliminate the problems which arise in fixed time signal operation system. In fixed time signal operation system, initial survey is done and the data about traffic volumes is collected, the signal timings are then calculated and fixed according to this data. It does not account for fluctuating traffic volumes over the time and thus it requires re-surveys and updates the timing plans according to the latest traffic conditions. To account for these problems, SCATS is developed and it is the fully responsive system. Logics and algorithms are developed on the system which serves as the on-line traffic controller, collects the real time traffic data using the detectors and then adjust the signal timing according to the prevailing conditions.

The traffic information is measured by the loop detectors. The information collected by the detectors is then pre-processed in the local controller and then it is transferred to the regional controller for strategic calculations. The cycle time, phase splits and offsets are then adjusted for effective coordination. This system is becoming popular nowadays and is being implemented in various countries.

2) Philadelphia (Pennsylvania):

The traffic signal unit of Philadelphia maintains 2860 signals. The unit uses Escort, which is a centralized distributed traffic control. The city has different agreements in order to provide signal coordination at different arterials. The three departments: the city of Philadelphia, Upper Darby Township and Springfield Township are involved in these agreements. In one of the agreements he township's traffic signals are coordinated to the city's system with the help of hardwire interconnect cable.

They provide a timing synchronization pulse through interconnect cable to provide coordination between signals. The city of Philadelphia controls the traffic signals on two major corridors with approximately 75 intersections on a single time of day plan. They change the progression pattern by changing the offset while keeping the cycle length same.

The prominent outcomes of traffic signal coordination in city includes consistent speed, less accidents, reduction in air pollution, reduction in congestion, lesser queue lengths and shortened delay time.

3) Tucson (Arizona):

Advanced Traffic Management System (ATMS), an integrated component of the ITS strategic deployment plan is used by department of transportation of Tucson. In the year of 1996 Tucson received some grant to study application and benefits of ITS. It was recognized that traffic signal coordination would benefit the region a lot. ATMS now controls 400 traffic signals for 7 departments. Each department maintains its own communication system. Each department shares its traffic system with others which makes it easier to coordinate its traffic signals with others. They share timing plans with each other and where possible they use common cycle length and adjust offset accordingly.

4) Monroe County (New York):

The department of transportation of county is maintaining over 735 traffic signals devices in county and city. Since 1970 the county has been coordinating traffic signals. In 1978, Sperry Systems Management designed and implemented a computerized traffic control system to improve the county's ability to provide coordination. The system currently controls 360 intersections.

5) City of Greenwood Village (Colorado):

In the city of Greenwood village, the signals on primary arterial Arapahoe Road were coordinated to reduce delay time caused by traffic signals. This project included coordination of 24 traffic signals with in an 8-mile road segment.

The Denver Regional Council of Governments (DRCOG) has been working with Colorado Department of Transportation (CDOT) since 1989 to coordinate traffic signals to reduce traffic congestion. One of the traffic Signal coordination projection sponsored by DRCOG included coordination of 49 traffic signals on 4 arterials in the city of Greenwood Village. The signal coordination resulted in a 13% reduction in travel time and a 17% improvement in travel speed.

6) Montgomery County (Maryland):

Due to high density land development in the area of Friendship heights the county decided to coordinate the traffic signals along two roadways, i.e. Wisconsin Avenue and Western Avenue.

The primary purpose was to eliminate unnecessary delays. The county and the city met and agreed upon common cycle lengths for the two roadways. Offsets were developed with the help of time-space diagrams.

The second signal coordination was done on two corridors, one of which is in Virginia and other in Maryland (Washington) region. The county, state and the city met to discuss coordination timings. They agreed upon using SYNCHRO (timing optimization software).

7) ACTS:

Adelaide Coordinated Traffic Signal System is developed by Department of Planning, Transport and Infrastructure, South Australia. It is all computer based traffic management system. This System provides Smooth traffic flow for over 580 traffic signals throughout the City. It is one of the most cultivated traffic systems of the world. ACTS manipulates the traffic lights, the turn arrows as well as the lane directions to promote easy and free flow of traffic. This system basically works at three levels.

- The Local Controllers.
- The Regional Computers.
- The Central Computer.

First, the traffic flow data is collected by the help of detectors which are placed on road intersection just behind the white stop line before the intersection. This is done by Local Controllers. Then this information is sent to the Regional Computers where they determine the timings of lights of signals. All regional computers are linked with a central computer from where staff monitors the operations of traffic lights in all the regions.

This system has surely helped as it has reduced the percentage of road crashes. Also it has reduced the travel time of users up to 20% and reduced the stops by 40%. And the fuel consumption is also reduced up to 12%.

2.1.2 Coordination Projects in Pakistan:

In Pakistan, no noticeable work has been done regarding the use of actuated signals and signal coordination. There are only two real time projects being implemented nowadays, one in **Lahore** and one in **Rawalpindi**.

Signal Priority for Metro bus system:

This system will be implemented in Lahore for smooth flow of Metro Bus by providing the priority signals for it. The length of Metro Bus corridor is 27 km from **Gajju Mata** to **Shahdara** and the route has 8 at-grade intersections. On all the 8 at-grade intersections, signal priority for metro buses will be provided. CCTV cameras will be installed at the intersections and the live video will be fed to the monitoring and controlling station installed at Arfa Karim IT Tower.

The signals will show green when the metro bus approach at the intersections and in the meantime, green signal will be indicated to the normal approaches. If this project remains successful, the Lahore Development Authority is planning to adapt the fifth generation signals on the rest of the roads of LAHORE city.

Integrated Traffic Management System for Murree Road:

Rawalpindi Development Authority (RDA) has launched Urban Traffic Control System on Murree Road to improve the Traffic signal system. Under this project, 16 UTC controllers (SCATS compatible) will be installed on Murree Road from Marrir Hassan Chowk to Faizabad. The expected life of traffic controller is 10 years. The total cost to execute this project is 36 million.

The traffic will be centrally controlled. Loop detectors and surveillance cameras will be installed at intersections for real time data collection and a room will be dedicated for centralized controlling and traffic monitoring and control in RDA office. Physical improvement of some intersections is also a part of this project and this project will result in 30 to 40 % accommodation in traffic congestion. RDA is also planning to link this system with more major roads of the city for centralized controlling and security purposes.

2.2 Theory of Signal Coordination:

2.2.1 Signal Coordination Concepts:

For traffic signal design and coordination, one must be aware of the various terminologies and concepts. These terminologies and concepts, which will also be used in the later stages of the project, are discussed under this article.

i. Coordination:

The synchronization of timings of traffic signals in a series so that continuous green light propagation to achieve smooth flow of traffic. The outcome of coordination is the reduction in traffic delays, travel times, energy and fuel consumption and enhancement of mobility.

ii. Cycle Length:

It is the time in seconds in which the signal indications complete one full cycle. It is the time between indications of red to one signal up to the same indication after completing one full cycle Fig 2.1.

iii. Split:

Split is the percentage of the cycle length or the time in seconds allocated for green time, yellow interval and red clearance time at individual leg Fig 2.1. The sum of all the splits should be equal to 100 in percentage or cycle time in seconds.

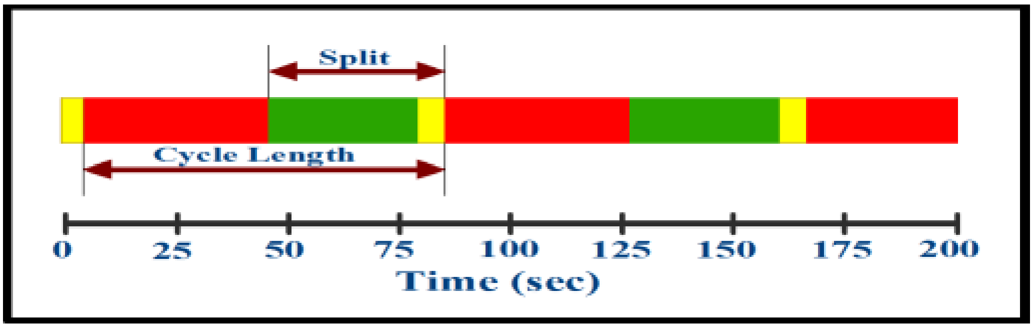


Figure 2.1 Split Length

iv. Offset:

It is time difference between the indication of green at upstream signal and indication of green at downstream signal.

v. Bandwidth:

It is the time difference between the first and the last vehicle which can pass through the entire coordinated system without stopping.

vi. Distance-time diagram:

It is a diagram which shows the relationship between signal locations (distance on y-axis) and signal timings (time on x-axis). It is a visual representation of coordination relationship among signals (fig 2.6 & 2.7). Traffic Signal Coordination is the mechanism by which the timing of two or more signals along a busy corridor is adjusted in a systematic manner so that the traffic signals work in efficient manner. Traffic Signal coordination is a multiple step process and is achieved by the application of theoretical knowledge, latest techniques and research works in traffic engineering to the signal timings and designs a logical sequencing of the signals under consideration, plus the systematic synchronization of the equipment involved in signal operation. For the evaluation of logical sequencing, required data (traffic volume and density, existing cycle lengths, signal offsets, green splits) is collected, complete analysis of the collected data and the corridor conditions is done and then the latest techniques are applied. After the designed timing has been implemented it is necessary to carry out the evaluation to check whether the desired results have been achieved. In addition to evaluation of the implemented results, the field visits must be carried out at monthly or yearly basis to update the coordinated and timing plans according to latest conditions.

vii. Level of Service (LOS):

Level of service is the measure used to relate the quality of traffic. It categorizes operational conditions within a traffic stream and their perception by facility users. Six level of service are defined for capacity analysis. They are allocated letters from A to F representing from Best to Worst respectively. LOS A describes the free flowing conditions in which individual vehicles of the traffic stream are not influenced by other vehicles. LOS F describes the breakdown operations and queues develop in such conditions. LOS defined in terms of average total vehicle delay of all movements through an intersection.

For signalized intersections, the Level of Service for the intersection is calculated by taking the total intersection delay and converting it to a level (A – F) using table 2.1.

Table 2.1 Signalized Intersection Level of Service (2010 HCM)

Control Delay Per Vehicles	LOS by Volume to Capacity Ratio	
	≤1	≥1
≤10	A	F
>10 and ≤20	B	F
>20 and ≤35	C	F
>35 and ≤55	D	F
>55 and ≤80	E	F
>80	F	F

viii. Intersection Capacity Utilization (ICU):

The ICU is shown for unsignalized intersections because it represents the potential capacity for the intersection if they were signalized. Level of Service gives the value of ICU. ICU LOS gives the concept of how efficient an intersection is working and how much capacity is available to handle traffic fluctuations.

Table 2.2 Level of Service analysis from ICU

Intersection Capacity Utilization (ICU)	Level Of Service LOS)
0-60%	A
60-70%	B
70-80%	C
80-90%	D
90-100%	E
100-110%	F
110-120%	G
>120%	H

ix. Intersection Delay:

The intersection delay study is used to evaluate the performance of intersections in allowing traffic to enter and pass through, or to enter and turn onto another route. It is defined in terms of the average stopped time per vehicle traversing the intersection.

x. Approach Delay:

It includes stopped time delay but adds the time which is lost due to deceleration from the approach speed to a stop and the time loss due to re-acceleration back to the desired speed. It is found by extending the velocity slope of the approaching vehicle as if no signal existed. It is basically the time difference between the hypothetical extension of the approaching velocity slope and the departure slope after full acceleration is achieved. Usually average approach delay is measured which is the average for all vehicles during a specific time period.

xi. Control Delay:

Control delay is the portion of the total delay attributed to the traffic signals operation for signalized intersections. It is measured by comparison with uncontrolled conditions. The signalized intersection capacity and LOS estimation procedure are built around the concept of average control delay per vehicle.

Control delays can be categorized into deceleration delay, stopped delay and acceleration delays. Stopped delay is easier to measure whereas overall control delay reflects better the efficiency of the signal. In 2000 version of the HCM, control delay is comprised of initial deceleration delays, queue move up time and final acceleration delay. Some vehicles have to stop at the intersection as a result of their arrival during red interval or that part of the green interval when the queue formed in the last red interval has not dissipated completely. Rest of the vehicles only suffer minor acceleration and deceleration delay as the vehicles present at the intersections have already started moving and incoming vehicles don’t need to come to a complete halt.

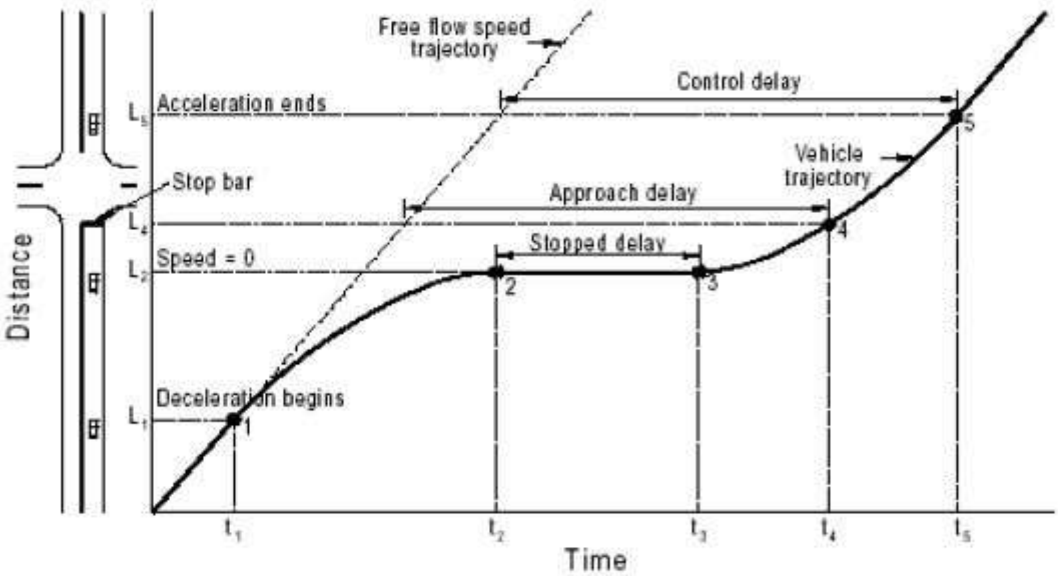


Figure 2.2 Control Delay

Average control delay per vehicle for a given lane group is given by the following equation:

$d=d_1(PF) + d_2 + d_3$

where,

d = control delay per vehicle

d_1 = uniform control delay assuming uniform arrival

d_2 = incremental delay to account for the effect of random arrival and oversaturation of queues

d_3 = initial queue delay

PF = uniform delay progression adjustment factor

Good signal progression will result in high proportion o vehicle arriving on the green. The progression adjustment factor PF applies to all coordinated lane groups, including both pre-timed control and non-actuated lane groups in semi-actuated control system.

xii. Weaving:

Weaving is defined as the movement of a vehicle from one lane to the adjacent lane. Presence of the other vehicles in the adjacent lanes complicates the process of weaving vehicles. HCM defines weaving as the crossing two or more traffic lines in the same direction along a significant length of the highway without the help of traffic control devices. The closure of the signalized intersection and rerouting of the traffic to mid-block U-turn openings results in free flow traffic conditions and also result in good progression of through vehicles on the road. But this causes problems for the traffic from side streets as they have to divert. Direct right turn movements now have to take a left turn plus U-turn to go to their destination. Through moment from the side streets is now replaced by a left turn, followed by a U-turn and another left turn. As a result of this, weaving sections are formed between intersection approach and the mid-block U-turns. Weaving sections have unique operational characteristics and require special design considerations.

The weaving vehicles have to execute all the required lane changes from the entry gore to exit gore, so the weaving length becomes an important parameter. Weaving vehicles have constraints of time and space, so shorter weaving length will result in complex weaving maneuvers causing more turbulence. There are three types of configurations for weaving sections namely Type A configuration, Type B configuration and Type C configuration.

In type A configuration, the auxiliary lane is almost completely occupied by the weaving vehicles. The shoulder lane of the road may be shared between the through and weaving traffic.

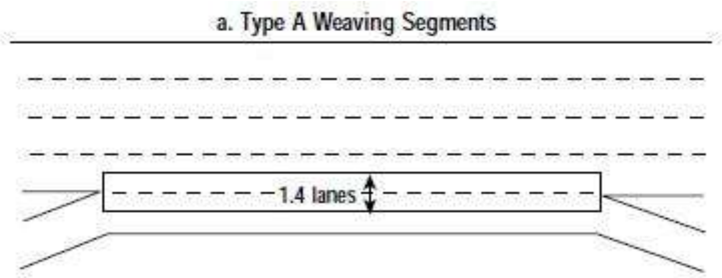


Figure 2.3 Type A Weaving Segment

Type B is more flexible than the type A configuration. Weaving vehicles have a complete lane which they can occupy. Along with that lane, they can also occupy the two adjacent lanes which mean those lanes are shared among through and weaving vehicles. Studies showed that the vehicles can occupy 3.5 lanes in type B configuration.

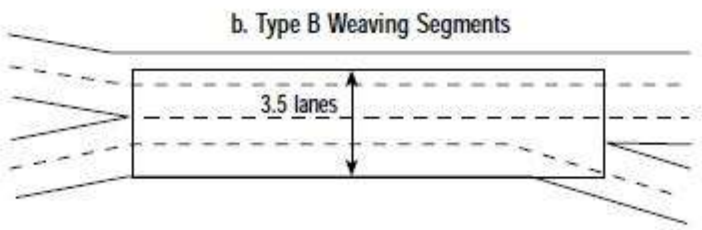


Figure 2.4 Type B Weaving Segment

Type C configurations are somewhat more restrictive than those of type B. in this case too, the weaving vehicles can occupy all through and subsequent portion of the lane adjacent through lanes but partial use of lanes as in type B is quite restricted. Vehicles in type C configuration can practically use three lanes.

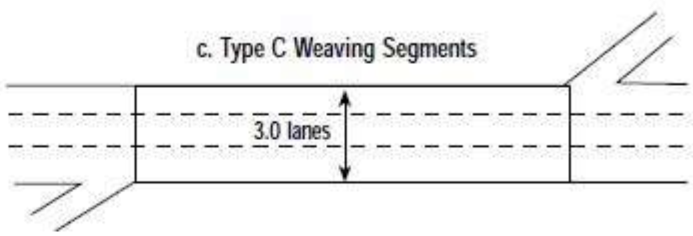


Figure 2.5 Type C Weaving Segment

2.2.2 Uncoordinated vs. Signals Coordinated:

Consider an uncoordinated signal, figure 2.6, distance of three signals has been plotted versus their time for a vehicle going from A to C. As the signals are not coordinated, every light of each signal will start at the same time. Thus a driver leaving intersection A at green signal will see green signals at both B and C intersections, but most probably would be unable to make it and therefore he would have to stop at intersection B and after leaving B he would be again stopped at intersection C. The time duration during which vehicle arrive at B till its leaving is called Delay time.

The same situation will occur if the signals are not synchronized or their cycle length is different. However the delay time of the vehicle will be affected.

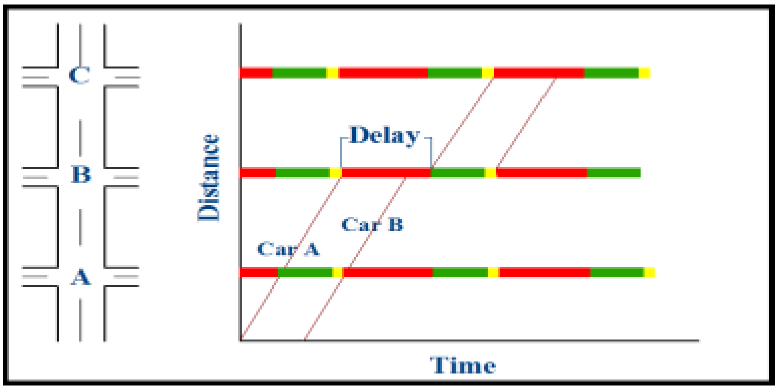


Figure 2.6 Unsynchronized Signals Time Space Diagram

Now in order to move the vehicle efficiently through all these signals without any delay we need the coordination of these signals. In order to do so the distance between the signals is calculated and an appropriate speed is selected taking in consideration the type of area and from distance and speed we can calculate the time which the vehicle will take in order to reach from one intersection to another. Thus the time at which the second signal must turn green with respect to the previous signal is obtained and we can coordinate the signals to regulate the thorough movement traffic without any delay. The same process is also done for the opposite side also i.e. for vehicle approaching from intersection C to A. One point must be kept in mind while coordinating the signals is that the cycle lengths of the signals to be coordinated must be same. If the cycle length is not same then coordination can be done. However the phase length for each signal can be different.

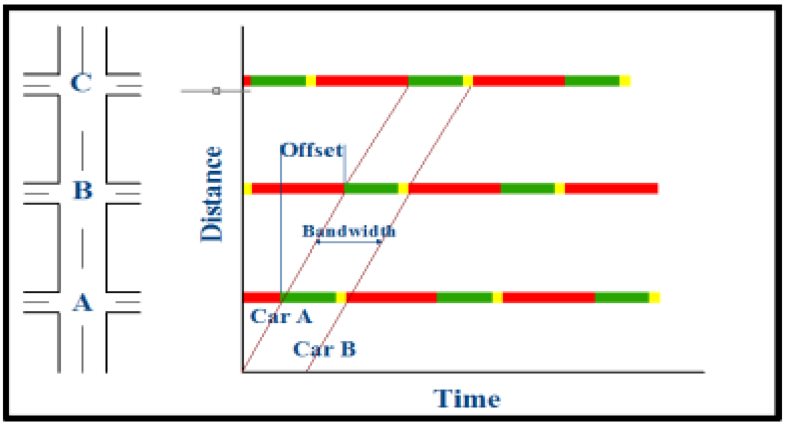


Figure 2.7 Synchronized Signals Time Space Diagram

2.3 Requirements for Signal Coordination:

There are three main requirements which must be fulfilled before starting the project of traffic signal coordination. These requirements are explained under this article.

1) Traffic Signal Spacing:

According to the **Manual of Uniform Traffic Control Devices (MUTCD)**, the signals with spacing of 800m or less along a major corridor or in a network of, should be considered for Coordination. As mentioned in table 1.2 the signals in the project undertaken are less than 800 m apart, so this requirement is fulfilled.

2) TRAFFIC FLOW CHARACTERISTICS:

Traffic flow characteristics like volume, time of the day, directionality of traffic, amount of traffic entering, leaving, or crossing the street, also affect the overall operation of traffic. For example, at any arterial, the traffic flow will be maximum in one direction at morning and it will be maximum in the other direction at evening. In such a condition, the traffic signal timings should be designed for the heavier flow.

3) TRAFFIC SIGNAL CYCLE LENGTHS:

Traffic Signal Cycle lengths are different for each intersection if the signals are not coordinated and these are determined using the volume at each intersection. If the difference in cycle length is larger, then it may not be appropriate to use signal coordination and the corridors be subdivided into multiple systems with their own cycle lengths.

If the signals are to be coordinated, their cycle length must be same or multiple of each other. The cycle lengths of the signals of project, as discussed in table 1.3, are not same neither multiple of each other, so the signals are to be redesigned.

2.4 SYNCHRO:

SYNCHRO is traffic signal timing software, developed by Trafficware Inc., is used to optimize or coordinate signal timing parameters for isolated intersections and also generate coordinated signal timings plans for arteries and networks. Most commonly used program to optimize the signal is SYNCHRO. We are using SYNCHRO for our project. SYNCHRO facilitates the design and analysis of an intersection or arterial. Primary objective of this program is to minimize the traffic delay by selecting the optimal timing.

It can also display time-space diagram which is a function of time for two or more signals. It is scaled with respect to distance and position of vehicle is easily identified. Time-space diagram usually determines the queues length, delays and speed of the moving vehicles.

Other features of SYNCHRO Studio comprises of following:

- Ease-of-use and measure of effectiveness, and it allows the engineer to observe traffic operations in minimum possible time.
- It supports Highway Capacity Manual (HCM) methodology for intersections and roundabouts.
- Implements the ICU (Intersection Capacity Utilization) standards.
- Measures the fuel consumption of vehicles which helps in selecting the best route.

SYNCHRO is basically designed to optimize cycle lengths, split times, intersection delays and phase orders. In coordinating signals, SYNCHRO determines which signal should have to run free and which to coordinate. It helps to decide what type of intersection should be constructed or modified. SYNCHRO has a unique visual display including a set of diagrams. User can change the offsets and delays and observe the impacts on delays, stops and LOS by those changes. User can compare those alternatives and select the best for their intersection or for the entire network. SYNCHRO allows user to quickly generate optimum timing plans. Thus, whenever user changes input values, it changes the result automatically.

2.4.1 Optimization Process:

Optimization process of SYNCHRO is composed of three steps.

- After testing all the possible cycle lengths for observed intersections, SYNCHRO determines the shortest cycle length that is suitable for critical percentile traffic for each phase. It is necessary to clear critical percentile traffic, if the splits for each phase does not able to do that, it will try a higher cycle time until the critical percentile is cleared.
- After setting up cycle time for each phase, SYNCHRO selects the cycle time with the best performance based on measures of effectiveness (MOEs).
- Finally, SYNCHRO optimized offsets and the phase sequence.

Delay is the key measure of effectiveness. Stopped delay is used to quantify the coordinated actuated traffic signal system. In comparison of measure of effectiveness, field measured travel times and stopping delays collected before (non-coordinated) and after (coordinated) are compared. Changes in the MOEs measured in the field and calculated by SYNCHRO are compared and the adaptive best alternative split features are implemented.

2.5 PTV VISSIM:

PTV Vissim is microscopic multi modal traffic flow simulation software package developed by PTV Planung Transport Verkher AG, A German based company. In this software micro simulation is done, Means that each entity (Car, Train, Person Etc.) of reality that is to be simulated is simulated individually, i.e. it is represented by a corresponding entity in the simulation, thereby considering all relevant properties.

A salient feature in this software is the multi-modality, means more than one kind of traffic can be simulated by this software. Such as:

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

The scope if this software expands over various 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.

2.5.1 Benefits of VISSIM:

Other Than multi modelling, there are some other features that make this software more effective.

Maximum Accuracy:

With the help of this software maximum accuracy can be achieved. In this software, we can map network and any desired geometry can be achieved, i.e. from a standard node to a complex intersection. Realistic behaviour of all road users within the existing and planned infrastructure is possible in this software.

Ease of Use and Productivity:

We can build our efficiently by using various inter-faces (Driver Model, Driving simulator etc.) to import existing networks. The interface with flexible dock able windows allows for efficiently creating and editing network objects and their attributes as well as gives results for numerous variables, which makes it more users friendly.

Flexibility and Integration Capacity:

The Generic COM interface allows interacting with external applications. It enables you to have manual settings for drivers and vehicle properties at different levels. For current studies it helps you to test the environment. Besides this, you can connect your work to any other PTV software.

Visualization in 2D and 3D:

Switch perspective helps you to display you analysis results in both 2D and 3D. This assists in public decision-making processes with the help of detailed reports. This salient feature makes the traffic simulations more appealing and understandable to all.

CHAPTER # 3
Research Methodology

3.1 Introduction:

This chapter explains the methodology used for this research. The data comprises of turning movement counts, geometric features and existing signal timings data. These measures are taken to determine capacity, LOS, approach delays, intersection delays, economic anylysis and environmental impact analysis.

Intersection capacity i.e. the maximum volume that an intersection allows is determined by Intersection Capacity Utilization (ICU) 2003 method. This method compares the current volume on the intersection to the ultimate capacity. The turning movement counts are also required to determine the Level of Service. Peak Hour Volume is first deduced and by that we find out the level of service of any intersection. Approach and Intersection delays are calculated using Synchro and we required queue move-up time, stopped delays and vehicular flow. Detailed economic and environmental impact analysis is done by analyzing the stopped delays and fuel consumption in existing conditions compared to the coordinated one. Also, economic measures are also taken for the proposed conditions. Recommended solutions are analyzed with respect to their cost.

3.2 Methods of Signal Coordination and Optimization:

Today the signal coordination is performed by many types of Software and also done manually. The methods are classified into two types:

1. Computer Simulation

2. Graphical Solutions

3.2.1 Computer Simulation

This method includes using of software for simulation. We have TSIS simulator which is used to simulate systems that are already been designed. Also we have Synchro for simulation and it gives the advantage of optimization as well. Vissim and SCAT are also used for Simulation.

Figure 3.1 Simulation Softwares

3.2.2 Graphical Solutions

Here we create a time space diagram. We can draw parallel broken lines on a computer Graphics program or we can draw these on a paper. These lines represent Red and Green intervals in traffic cycles. Everything is drawn according to a scale. We set some diagonal guides across the intersection representing the vehicle speed. Then we slide the intersection around till we get the best solution. Synchro is also subjected to give time-space diagram of the signal timings. And adjust it according to the best optimum conditions in which delays are minimum.

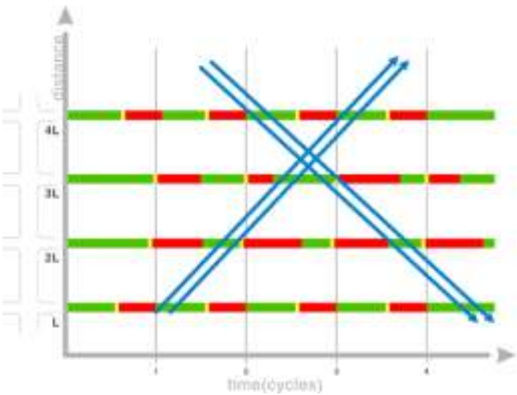


Figure 3.2 Signal Coordination using Graphs

Research Methodology Approach:

After the literature review, selection of site and finding the possible approach to the solutions, we have come to the methodology how we are going to achieve our results. Given below is the flow chart for our research methodology. It explains the procedure we have followed to reach to the results and conclusions.

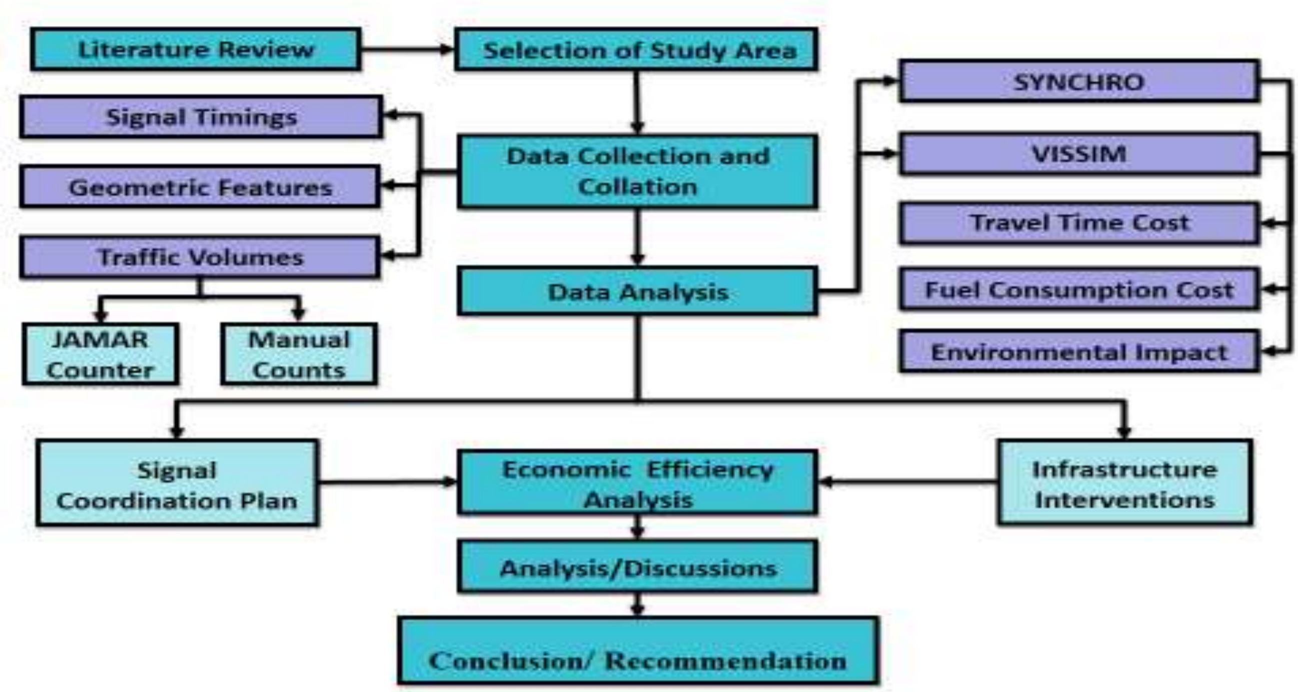


Figure 3.3 Flow Chart of Research Methodology

3.3 Data Collection

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

1. Traffic Volumes (Turning movements)

2. Signal Timings

3. Geometric Features (Lane usage, link distances)

3.3.1 Traffic Volumes

We collected traffic volumes during 7 am - 10 am (morning peak hours) and 4 pm – 7 pm (Evening peak hours) when the traffic is maximum. The volume collected was categorized in three types i.e. cars, bikes and heavy vehicles. For calculating the total volume, we used the following relation:

Total Volume=No. of cars + 0.4(No. of bikes) + 2(No. of H.V)

Where ‘0.4’ is the conversion factor for bikes and ‘2’ is the conversion factor for Heavy Vehicles.

The Traffic Volume was collected using two approaches:

1. Manual Count

2. Jamar Traffic Data Collector

3.3.1.1 Manual Count

Tally sheets are 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.

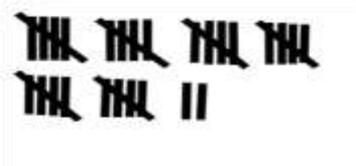


Figure 3.4 Manual Count (Tally Bar)

3.3.1.2 JAMAR Counter

This is an efficient way of counting traffic volume. JAMAR traffic data recorders are now used worldwide, by thousands of people because of its reliability, ease of use, and accuracy. It can save hundreds of hours of Data. PETRAPro is the software used for analyzing data gathered with the TDC Ultra hand-held data collectors. It can be used for ten different types of traffic studies. The study used in this project is Standard Turning Movement at signalized intersections.

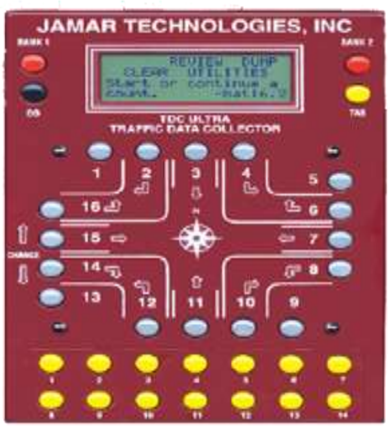


Figure 3.5 JAMAR Counter

3.3.1.3 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 4am – 7am(Morning Peak Hours) and 4pm – 7pm(Evening Peak Hours).

3.3.1.4 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.

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

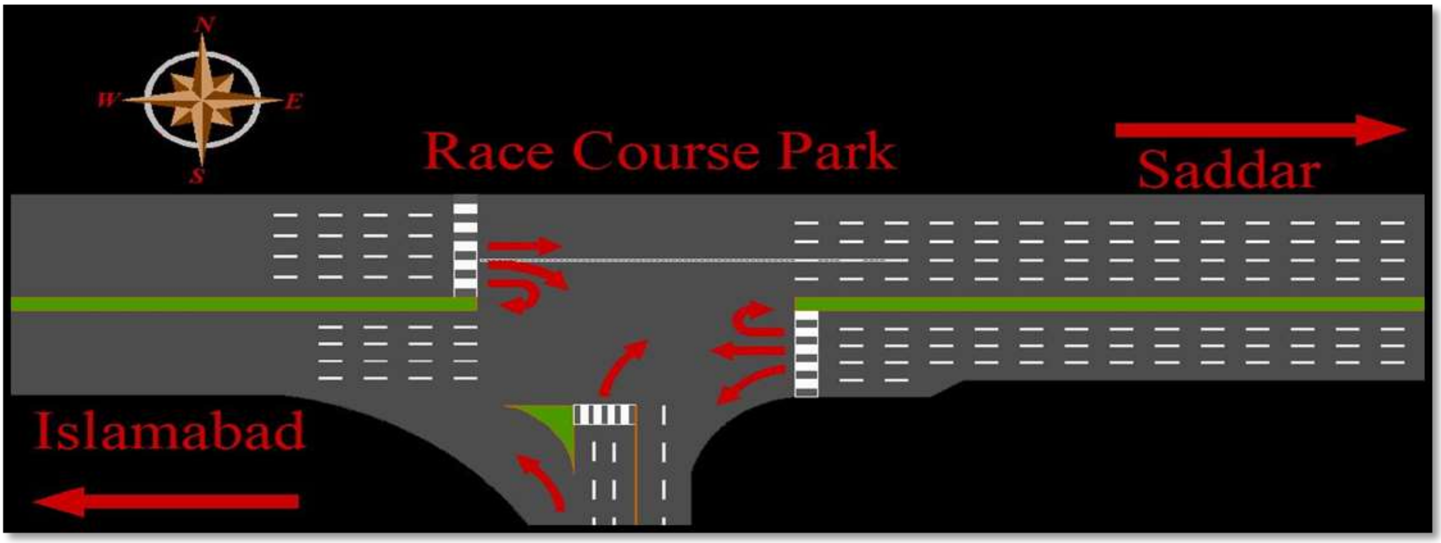
3.3.2 Signal timings

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 Table 3.1 to 3.10.

Table 3.1 - Input Worksheet for Qasim Market Intersection (Morning)

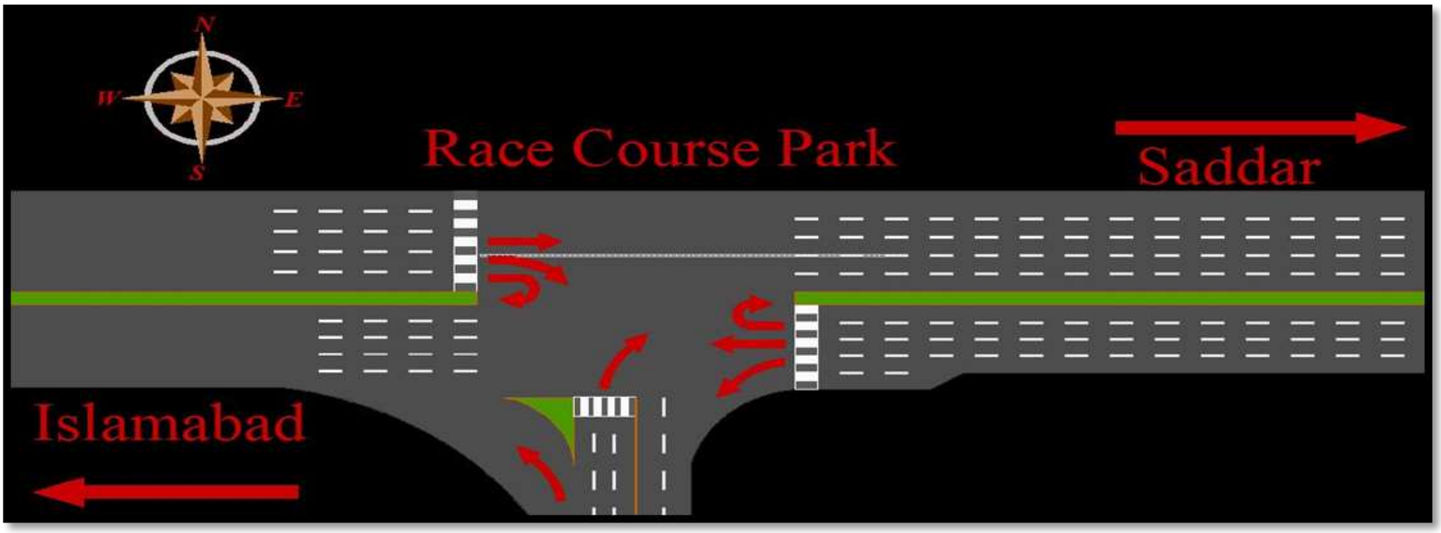
Intersection	Qasim Market	**Observer**	Attiq, Ali, Muneeb, Saad, Sohaib, Taimoor, Zain
Time Period	7:30-10:30 am	**Date Performed**	February 13, 2014
Weather Condition	Clear	**Intersection Type**	☐CBD ☑ Other



	East Bound		West Bound			North Bound		Total Volume	Cumulative Volume
Time (am)	**T**	**R**	**T**	**L**	**U**	**L**	**R**		
7:30-7:45	510	220	468	31	90	275	320	1914	
7:45-8:00	598	288	482	38	105	310	371	2192	
8:00-8:15	579	298	465	34	142	308	362	2188	
8:15-8:30	580	282	482	33	143	247	365	2132	8426
8:30-8:45	548	298	470	40	153	265	384	2158	8670
8:45-9:00	520	193	517	38	139	276	377	2060	8538
9:00-9:15	539	202	563	58	159	279	416	2216	8566
9:15-9:30	522	208	573	50	166	235	392	2146	8580
9:30-9:45	529	184	525	42	172	261	383	2096	8518
9:45-10:00	526	201	459	43	135	240	396	2000	8458
10:00-10:15	517	191	597	64	120	275	456	2220	8462
10:15-10:30	510	185	544	56	128	238	406	2067	8383
P.H.V (Approach)	2305	1166	1899	145	543	1130	1482	-	
Heavy vehicles %	1	2	1	1	1	4	1		
P.H.V (Intersection)	8670 (7:45-8:45)								
Max. 15min vol.	2192								
P.H.F	0.99								
Signal Timings and Phases									
Phases	-	1	2	-	1+2	-	3	-	
Green Time (s)	-	16	33	-	54	-	20		
Y+Ar Time (s)	-	3+2	3+2	-	3+2	-	3+2		
Cycle Length (s)	-	84							

Table 3.2 - Input Worksheet for Qasim Market Intersection (Evening)

Intersection	Qasim Market	**Observer**	Attiq, Ali, Muneeb, Saad, Sohaib, Taimoor, Zain
Time Period	4:00-7:00 pm	**Date Performed**	Dec 12, 2013
Weather Condition	Clear	**Intersection Type**	☐ CBD ☑ Other



	East Bound		**West Bound**			**North Bound**		**Total Volume**	**Cumulative Volume**
Time (pm)	**T**	**R**	**T**	**L**	**U**	**L**	**R**		
4:00-4:15	514	134	552	58	93	110	197	1658	-
4:15-4:30	532	148	563	59	110	122	182	1716	-
4:30-4:45	516	186	605	101	119	140	199	1866	-
4:45-5:00	545	230	615	118	107	122	215	1952	7192
5:00-5:15	546	197	620	82	102	101	189	1837	7371
5:15-5:30	581	230	542	100	94	113	181	1841	7496
5:30-5:45	519	127	548	95	115	83	163	1650	7280
5:45-6:00	522	276	647	77	72	88	204	1886	7214
6:00-6:15	516	239	619	97	94	99	181	1845	7222
6:15-6:30	505	212	594	101	84	93	185	1774	7155
6:30-6:45	550	211	577	79	79	76	191	1763	7268
6:45-7:00	546	178	569	69	81	96	192	1731	7113
P.H.V (Approach)	2188	843	2382	401	422	476	784	-	
Heavy vehicles %	3	4	2	0	1	5	0		
P.H.V (Intersection)	7496 (4:30-5:30)								
Max. 15min vol.	1952								
P.H.F	0.97								
Signal Timings and Phases									
Phases	-	1	2	-	1+2	-	3	-	
Green Time (s)	-	16	33	-	54	-	20		
Y+Ar Time (s)	-	3+2	3+2	-	3+2	-	3+2		
Cycle Length (s)	-	84							

Table 3.3 - Input Worksheet for Military Hospital Intersection (Morning)

Intersection	Military Hospital	Observer	Attiq, Ali, Muneeb, Saad, Sohaib, Taimoor, Zain
Time Period	7:30-10:30 am	Date Performed	Oct 30, 2013
Weather Condition	Cloudy	Intersection Type	☐ CBD ☑ Other

	East Bound			West Bound			South Bound		Total Volume	Cumulative Volume
Time (pm)	T	L	U	T	R	U	L	R		
7:30-7:45	620	226	148	408	102	70	35	197	1806	-
7:45-8:00	546	244	110	502	121	83	46	194	1846	-
8:00-8:15	546	240	93	503	96	99	41	178	1796	-
8:15-8:30	546	234	91	395	103	121	32	163	1685	7133
8:30-8:45	511	249	78	435	106	139	40	183	1741	7068
8:45-9:00	472	250	81	497	74	96	42	172	1684	6906
9:00-9:15	471	277	90	405	93	122	46	189	1693	6803
9:15-9:30	440	232	63	420	101	124	34	193	1607	6725
9:30-9:45	512	248	83	435	97	121	41	145	1682	6666
9:45-10:00	517	234	95	430	100	132	46	215	1769	6751
10:00-10:15	618	247	77	419	90	79	42	228	1800	6858
10:15-10:30	599	227	71	398	99	101	37	198	1730	6981
P.H.V (Approach)	2258	944	442	1808	422	373	154	732	-	
Heavy vehicles %	2	1	2	2	1	1	3	1		
P.H.V (Intersection)	7133 (7:30-8:30)									
Max. 15min vol.	1846									
P.H.F	0.97									
Signal Timings and Phases										
Phase	1	-	1+2	-	2	2+3	-	3	-	
Green Time (s)	22	-	42	-	15	15	-	15		
Y+Ar Time (s)	3+2	-	3+2	-	3+2	3+2	-	3+2		
Cycle Length (s)	67									

Table 3.4 - Input Worksheet for Military Hospital Intersection (Evening)

Intersection	Military Hospital	Observer	Attiq, Ali, Muneeb, Saad, Sohaib, Taimoor, Zain
Time Period	4:00-7:00 pm	Date Performed	Oct 30, 2013
Weather Condition	Cloudy	Intersection Type	☐ CBD ☑ Other

	East Bound			**West Bound**			**South Bound**		**Total Volume**	**Cumulative Volume**
Time (pm)	**T**	**L**	**U**	**T**	**R**	**U**	**L**	**R**		
4:00-4:15	529	189	126	584	97	107	65	164	1861	-
4:15-4:30	561	236	174	565	108	124	71	160	1999	-
4:30-4:45	510	173	200	587	95	106	51	96	1818	-
4:45-5:00	591	188	206	602	107	120	66	134	2014	7692
5:00-5:15	445	179	216	547	100	136	49	106	1778	7609
5:15-5:30	531	166	268	655	113	121	72	147	2073	7683
5:30-5:45	462	171	206	612	88	121	59	80	1799	7664
5:45-6:00	492	156	205	510	92	92	79	111	1737	7387
6:00-6:15	509	158	207	520	80	102	57	97	1730	7339
6:15-6:30	498	129	159	680	87	120	51	150	1874	7140
6:30-6:45	574	125	174	542	90	108	73	131	1817	7158
6:45-7:00	558	150	132	536	93	113	64	175	1821	7242
P.H.V (Approach)	2191	786	706	2338	407	457	253	554	-	
Heavy vehicles %	2	1	2	3	0	0	2	1		
P.H.V (Intersection)	7692 (4:00-5:00)									
Max. 15min vol.	2014									
P.H.F	0.96									
Signal Timings and Phases										
Phase	1	-	1+2	-	2	2	-	3	-	
Green Time (s)	22	-	42	-	15	15	-	15		
Y+Ar Time (s)	3+2	-	3+2	-	3+2	3+2	-	3+2		
Cycle Length (s)	67									

Table 3.5 - Input Worksheet for GPO Intersection (Morning)

Intersection	G.P.O	**Observer**	Attiq, Ali, Muneeb, Saad, Sohaib, Taimoor, Zain
Time Period	7:30-10:30 am	**Date Performed**	Feb 20, 2014
Weather Condition	Clear	**Intersection Type**	☑ CBD ☐ Other

	East Bound				West Bound				North Bound			South Bound				Total Vol.	Cum. Vol.
Time (am)	**T**	**L**	**R**	**U**	**T**	**L**	**R**	**U**	**T**	**L**	**R**	**T**	**L**	**R**	**U**		
7:30-7:45	476	52	26	41	524	156	10	14	166	24	115	96	30	47	7	1784	-
7:45-8:00	507	34	31	28	600	134	5	19	168	35	136	90	15	40	6	1848	-
8:00-8:15	451	30	38	31	544	123	16	11	153	44	127	67	13	33	10	1691	-
8:15-8:30	439	55	33	24	526	89	12	21	208	67	108	58	20	76	8	1744	7067
8:30-8:45	404	82	42	36	526	114	13	17	199	58	137	54	26	33	9	1750	7033
8:45-9:00	409	74	31	33	536	83	18	16	197	69	128	59	11	62	5	1731	6916
9:00-9:15	467	46	33	40	505	103	11	10	206	54	117	42	19	42	12	1707	6932
9:15-9:30	475	65	39	46	495	99	12	19	154	53	130	59	14	55	4	1719	6907
9:30-9:45	390	59	36	31	444	122	10	16	191	62	125	76	13	54	7	1636	6793
9:45-10:00	436	79	53	16	429	117	20	9	193	67	146	72	19	109	15	1780	6842
10:00-10:15	442	93	33	31	463	90	33	12	165	71	112	70	33	55	4	1707	6842
10:15-10:30	463	73	48	21	471	120	32	14	188	73	107	86	28	56	3	1783	6906
P.H.V (App.)	1873	171	128	124	2194	502	43	65	695	170	486	311	78	196	31	-	
Heavy veh. %	2	0	2	0	1	2	0	0	2	1	1	3	2	1	0		
P.H.V (Int.)	7067 (7:30-8:30)																
Max. 15 min Vol.	1848																
P.H.F	0.96																
Signal Timings and Phases																	
Phases	1	-	1	1	3	-	3	3	4	-	4	2	-	2	2	-	
Green Time (s)	43				41				20			20					
Y+Ar Time (s)	4+2				4+2				4+2			4+2					
Cycle Length (s)	148																

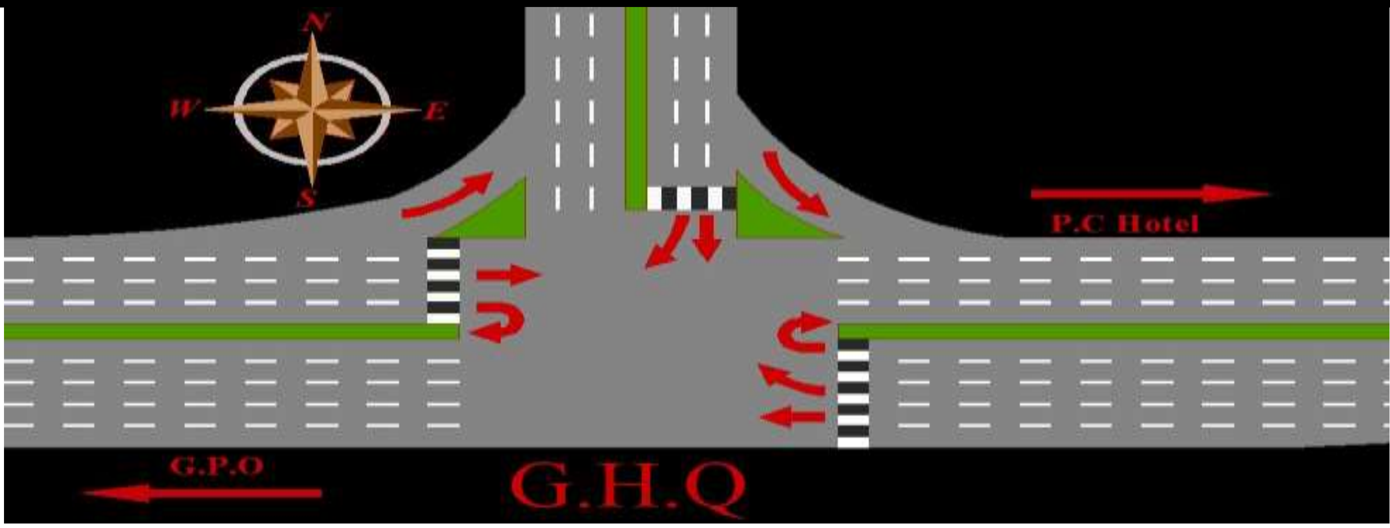
Table 3.6 - Input Worksheet for GPO Intersection (Evening)

Intersection	G.P.O	**Observer**	Attiq, Ali, Muneeb, Saad, Sohaib, Taimoor, Zain
Time Period	4:00-7:00 pm	**Date Performed**	Sep 19, 2013
Weather Condition	Clear	**Intersection Type**	☑ CBD ☐ Other

	East Bound				**West Bound**				**North Bound**			**South Bound**				**Total Vol.**	**Cum. Vol.**
Time (pm)	**T**	**L**	**R**	**U**	**T**	**L**	**R**	**U**	**T**	**L**	**R**	**T**	**L**	**R**	**U**		
4:00-4:15	627	87	54	47	310	144	89	19	149	46	66	136	69	47	9	1899	
4:15-4:30	467	110	44	30	679	148	113	14	75	20	66	115	67	72	10	2030	
4:30-4:45	586	134	53	28	524	145	97	17	135	41	75	104	83	91	8	2121	
4:45-5:00	534	88	71	30	699	161	121	13	133	28	77	104	87	71	8	2225	8275
5:00-5:15	480	112	62	49	480	155	147	14	114	38	80	112	70	44	9	1966	8342
5:15-5:30	535	128	81	38	504	155	114	20	127	36	66	122	96	69	13	2104	8416
5:30-5:45	560	120	66	45	468	166	119	23	116	28	52	106	70	62	12	2013	8308
5:45-6:00	524	125	65	44	537	152	139	16	114	30	69	129	62	65	9	2080	8163
6:00-6:15	496	124	55	34	589	152	118	18	117	25	76	139	68	74	9	2094	8291
6:15-6:30	619	123	73	34	486	144	79	16	97	33	56	125	61	56	10	2012	8199
6:30-6:45	535	115	43	30	523	128	113	12	144	28	82	121	64	42	8	1988	8174
6:45-7:00	454	106	48	22	561	142	132	14	182	21	79	80	75	48	11	1975	8069
P.H.V (App.)	2135	462	267	145	2207	616	479	64	509	143	298	442	336	275	38	-	
Heavy veh. %	3	0	3	0	4	7	2	0	1	7	1	0	0	4	0		
P.H.V (Int.)	8416 (4:30-5:30)																
Max. 15 min Vol.	2225																
P.H.F	0.95																
Signal Timings and Phases																	
Phases	1	-	1	1	3	-	3	3	4	-	4	2	-	2	2	-	
Green Time (s)	43				41				20			20					
Y+Ar Time (s)	4+2				4+2				4+2			4+2					
Cycle Length (s)	148																

Table 3.7 - Input Worksheet for GHQ Intersection (Morning)

Intersection	GHQ	**Observer**	Attiq, Ali, Muneeb, Saad, Sohaib, Taimoor, Zain
Time Period	7:30-10:30 am	**Date Performed**	Dec 3, 2013
Weather Condition	Clear	**Intersection Type**	☐ CBD ☑ Other



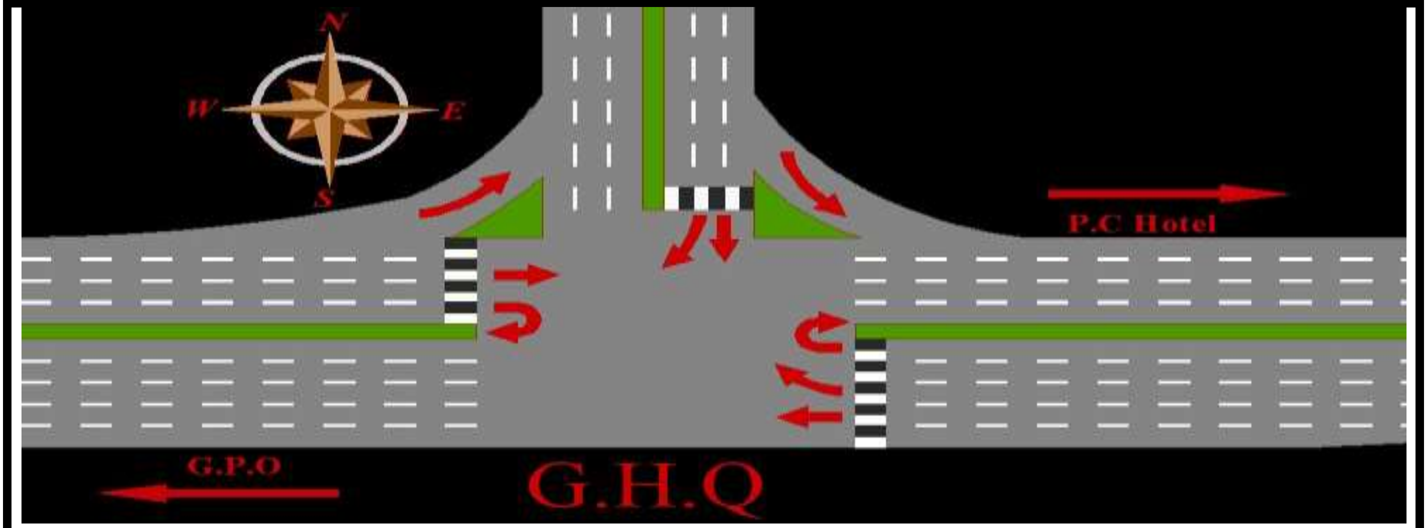
	East Bound			West Bound			South Bound		Total Volume	Cumulative Volume
Time (am)	**T**	**L**	**U**	**T**	**R**	**U**	**L**	**R**		
7:30-7:45	545	103	9	453	319	51	135	137	1752	
7:45-8:00	520	77	14	435	330	39	111	130	1656	
8:00-8:15	509	102	18	520	313	23	87	153	1725	
8:15-8:30	503	95	11	508	299	27	98	129	1670	6803
8:30-8:45	491	109	5	594	313	26	97	128	1763	6814
8:45-9:00	553	105	7	569	299	11	95	141	1780	6938
9:00-9:15	477	110	13	558	336	13	104	113	1724	6937
9:15-9:30	470	120	17	604	305	17	96	134	1763	7030
9:30-9:45	474	94	7	585	279	9	84	116	1648	6915
9:45-10:00	434	116	20	481	321	15	103	127	1617	6752
10:00-10:15	479	111	20	520	291	14	115	117	1667	6695
10:15-10:30	503	112	15	540	288	12	107	125	1702	6634
P.H.V (Approach)	1991	444	42	2325	1253	67	392	516	-	
Heavy vehicles %	1	1	0	3	1	2	1	3		
P.H.V (Intersection)	7030 (8:30-9:30)									
Max. 15min vol.	1780									
P.H.F	0.99									

Signal Timings and Phases

Phases	1	-	1	3	3	3	-	2	-
Green Time (s)	36			30			18		
Y+Ar Time (s)	4+2			4+2			4+2		
Cycle Length (s)	100								

Table 3.8 - Input Worksheet for GHQ Intersection (Evening)

Intersection	GHQ	**Observer**	Attiq, Ali, Muneeb, Saad, Sohaib, Taimoor, Zain
Time Period	4:00-7:00 pm	**Date Performed**	Sep 20, 2013
Weather Condition	Clear	**Intersection Type**	☐ CBD ☑ Other



	East Bound			West Bound			South Bound		Total Volume	Cumulative Volume
Time (pm)	**T**	**L**	**U**	**T**	**R**	**U**	**L**	**R**		
4:00-4:15	549	145	10	441	246	14	103	150	1658	
4:15-4:30	562	161	16	416	257	11	166	203	1792	
4:30-4:45	505	136	11	544	259	13	189	214	1871	
4:45-5:00	534	153	28	492	245	15	184	223	1874	7195
5:00-5:15	576	129	27	559	276	15	132	223	1937	7474
5:15-5:30	527	149	32	570	262	14	194	208	1956	7638
5:30-5:45	605	161	24	493	270	15	217	222	2007	7774
5:45-6:00	601	144	20	602	286	14	186	225	2078	7978
6:00-6:15	559	159	27	524	261	19	189	184	1922	7963
6:15-6:30	503	120	18	483	270	10	166	259	1829	7836
6:30-6:45	523	171	19	530	266	12	204	196	1921	7750
6:45-7:00	539	146	35	504	256	11	167	228	1886	7558
P.H.V (Approach)	2309	583	103	2224	1094	58	729	878	-	
Heavy vehicles %	2	2	0	3	1	9	1	2		
P.H.V (Intersection)	7978 (5:00-6:00)									
Max. 15min vol.	2078									
P.H.F	0.96									
Signal Timings and Phases										
Phases	1	-	1	3	3	3	-	2	-	
Green Time (s)	36			30			18			
Y+Ar Time (s)	4+2			4+2			4+2			
Cycle Length (s)	102									

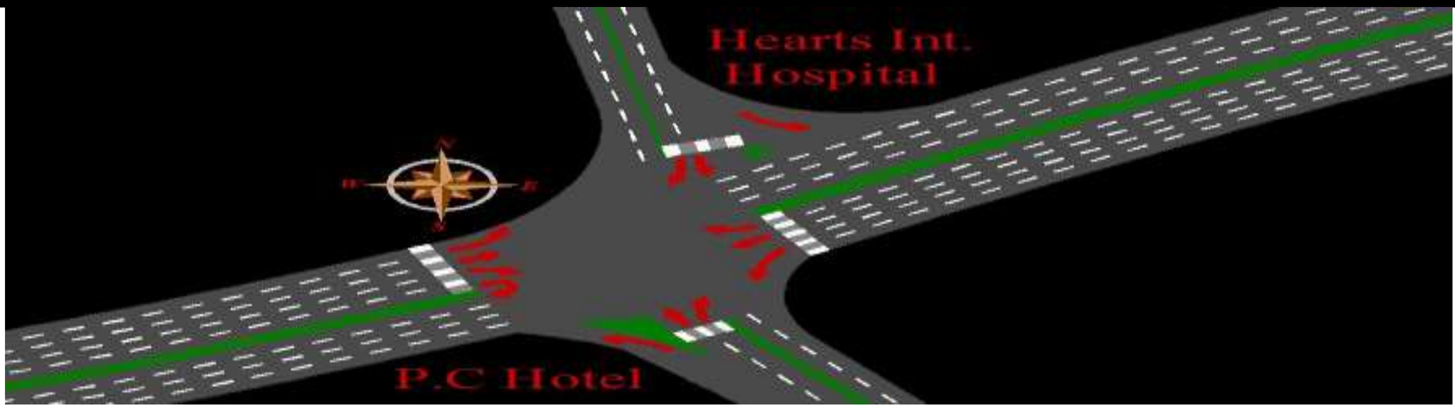
Table 3.9 - Input Worksheet for P.C Hotel Intersection (Morning)

Intersection	P.C Hotel	**Observer**	Attiq, Ali, Muneeb, Saad, Sohaib, Taimoor, Zain
Time Period	7:30-10:30 am	**Date Performed**	Feb 13, 2014
Weather Condition	Clear	**Intersection Type**	☐ CBD ☑ Other

	East Bound			**West Bound**			**North Bound**			**South Bound**			**Total Volume**	**Cumulative Volume**
Time (am)	**T**	**L**	**R**	**T**	**L**	**R**	**T**	**L**	**R**	**T**	**L**	**R**		
7:30-7:45	579	70	210	445	14	51	142	21	36	79	54	76	1777	
7:45-8:00	526	60	231	506	11	52	160	16	37	66	59	96	1820	
8:00-8:15	452	57	188	637	21	48	149	21	22	59	61	69	1784	
8:15-8:30	458	71	202	565	10	39	173	11	18	41	60	66	1714	7095
8:30-8:45	500	73	137	651	9	60	133	9	16	44	47	49	1728	7046
8:45-9:00	439	82	169	652	14	52	144	16	6	28	56	65	1723	6949
9:00-9:15	432	72	133	617	7	38	106	15	13	40	60	45	1578	6743
9:15-9:30	454	54	144	563	13	42	116	11	9	35	64	53	1558	6587
9:30-9:45	513	56	128	510	10	42	75	7	10	22	61	53	1487	6346
9:45-10:00	428	56	129	586	9	54	64	20	8	35	70	49	1508	6131
10:00-10:15	430	67	120	611	11	44	70	13	11	21	50	54	1502	6055
10:15-10:30	458	73	135	595	10	45	75	9	7	24	62	41	1534	6031
P.H.V (App.)	2015	258	831	2153	56	190	624	69	113	245	234	307	-	
Heavy vehicles %	2	2	3	1	5	2	1	2	0	1	3	3		
P.H.V (Int.)	7095 (4:00-5:00)													
Max. 15min vol.	1820													
P.H.F	0.98													
Signal Timings and Phases														
Phases	1	-	1	3	-	3	4	-	4	2	-	2	-	
Green Time(s)	44			43			10			22				
Y+Ar Time(s)	4+2			4+2			2+2			2+2				
Cycle Length(s)	139													

Table 3.10 - Input Worksheet for P.C Hotel Intersection (Evening)

Intersection	P.C Hotel	**Observer**	Attiq, Ali, Muneeb, Saad, Sohaib, Taimoor, Zain
Time Period	4:00-7:00 pm	**Date Performed**	Oct 25, 2013
Weather Condition	Clear	**Intersection Type**	☐ CBD ☑ Other



	East Bound			**West Bound**			**North Bound**			**South Bound**			**Total Volume**	**Cumulative Volume**
Time (pm)	**T**	**L**	**R**	**T**	**L**	**R**	**T**	**L**	**R**	**T**	**L**	**R**		
4:00-4:15	610	75	154	590	13	40	72	49	9	61	8	56	1737	-
4:15-4:30	489	72	169	561	9	42	70	69	13	66	10	91	1661	-
4:30-4:45	568	64	170	559	18	40	64	53	9	49	6	63	1663	-
4:45-5:00	591	83	183	612	3	41	66	49	11	40	4	45	1728	6789
5:00-5:15	614	76	180	627	8	29	58	43	11	35	10	38	1729	6781
5:15-5:30	604	91	186	588	5	18	55	52	5	37	8	50	1699	6819
5:30-5:45	619	90	158	611	3	28	62	41	7	48	9	47	1723	6879
5:45-6:00	638	81	169	614	6	27	51	55	7	36	12	43	1739	6890
6:00-6:15	680	80	229	654	2	36	65	55	6	33	8	31	1879	7040
6:15-6:30	621	71	198	594	4	18	66	61	7	54	5	58	1757	7098
6:30-6:45	597	50	186	588	7	30	62	47	8	40	7	38	1660	7035
6:45-7:00	612	71	189	622	9	20	51	37	4	51	1	29	1696	6992
P.H.V (App.)	2558	322	754	2473	15	109	244	212	27	171	34	179	-	
Heavy vehicles %	1	1	1	1	3	0	0	6	0	1	4	3		
P.H.V (Int.)	7098 (5:30-6:30)													
Max. 15min vol.	1879													
P.H.F	0.95													
Signal Timings and Phases														
Phases	1	-	1	3	-	3	4	-	4	2	-	2	-	
Green Time(s)	44			43			10			22				
Y+Ar Time(s)	4+2			4+2			2+2			2+2				
Cycle Length(s)	139													

3.3.3 Geometric Features

The intersection geometry is presented visually in diagrammatic form. It includes all the relevant information including approach, number and width of lanes. The existence of exclusive left and right-turn lanes is noted along with the storage lengths of these lanes. This helps to recreate the signalized intersection, the connecting links and external links on Synchro. The geometric features are measured using Hodometer and measuring tape. Following features have been measured:

- Lane Widths
- Median Widths
- Storage and Taper Lengths
- Curb Radii
- Intersection-to-intersection Distance
- Island Dimensions

3.3.3.1 Curb radii specifies the horizontal curvature of the street intersection and is measured in feet from the back of the curb to the center point of the radius. Curb radius controls the graphics and layout is SimTraffic.

3.3.3.2 Storage Length is the length of the turning bay. Sometimes, at turnings a lane is added which is called storage lane and its length is storage length. If there are two or more storage lanes, then the average length is used rather than the sum.

Storage length data is used for analyzing potential blocking problems, such as through traffic blocking right turn traffic and right turn traffic blocking through traffic. If there are no storage lanes then no blocking analysis is performed.

3.3.3.3 Taper Length defines the length of taper at the end of storage lane. It impacts when vehicles can start entering the storage lanes.

Geometry of each intersection is illustrated from Figure 3.5 to 3.9.

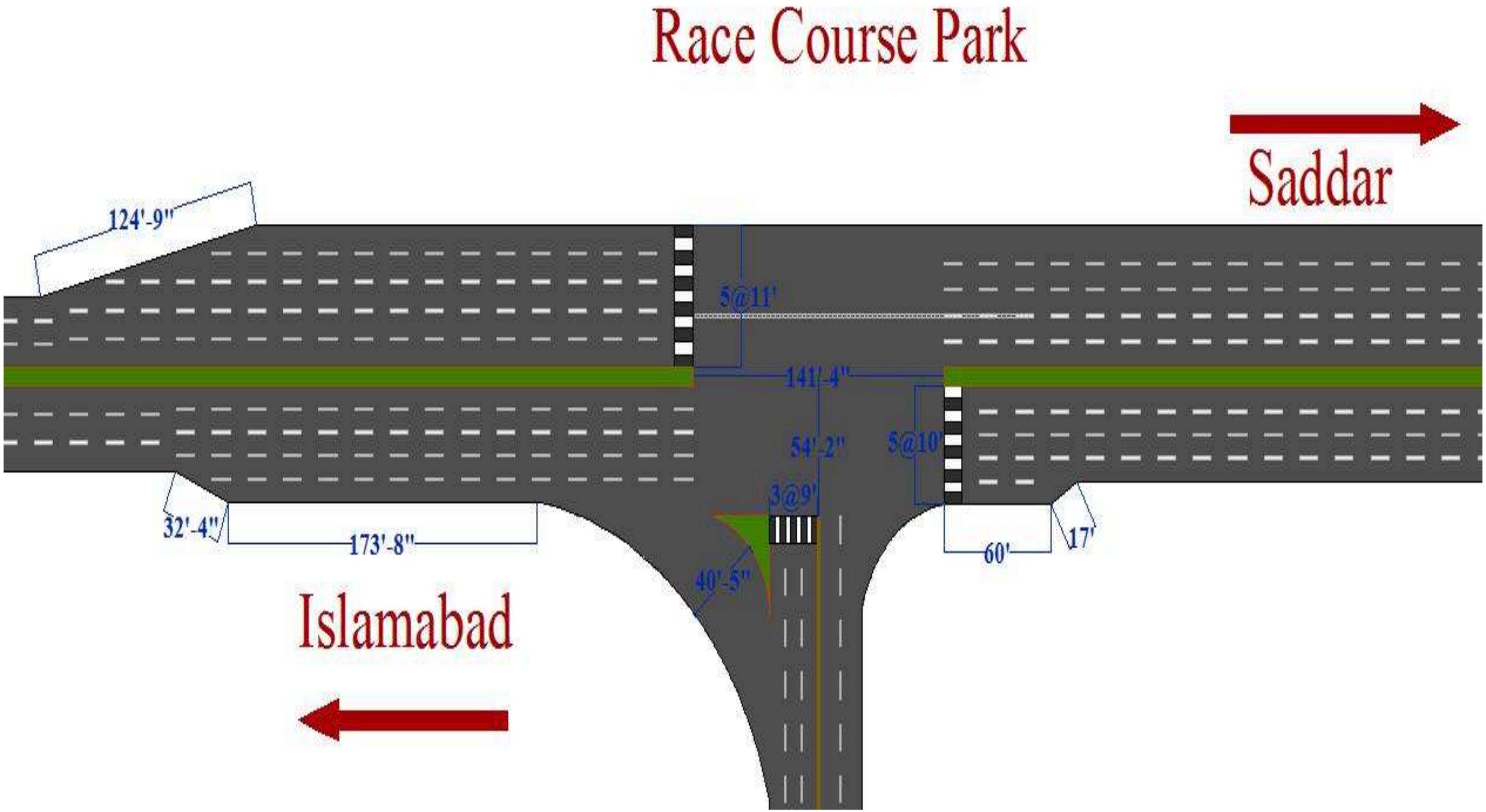


Figure 3.6 Layout of Qasim Market Intersection

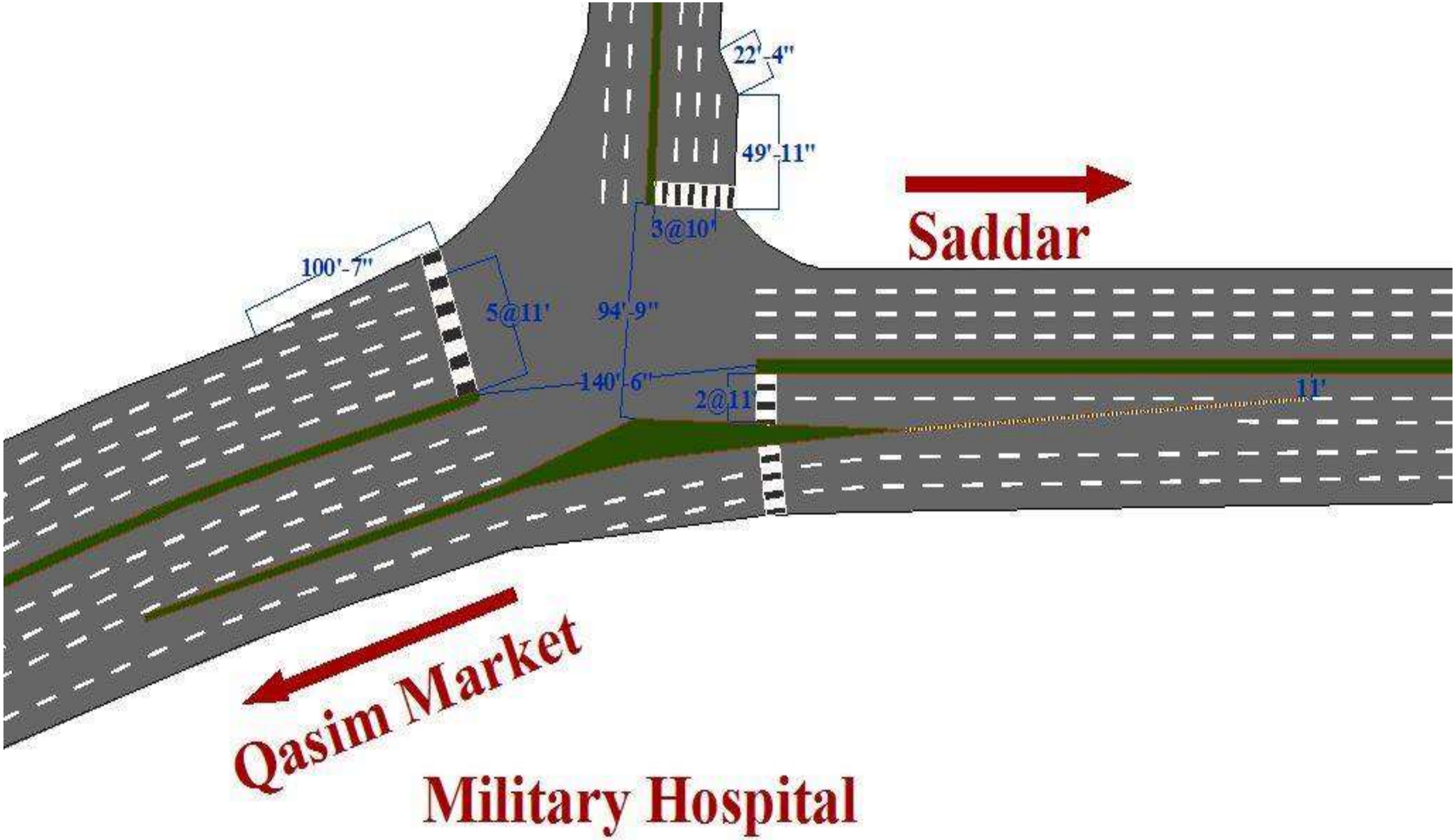


Figure 3.7 Layout of Military Hospital Intersection

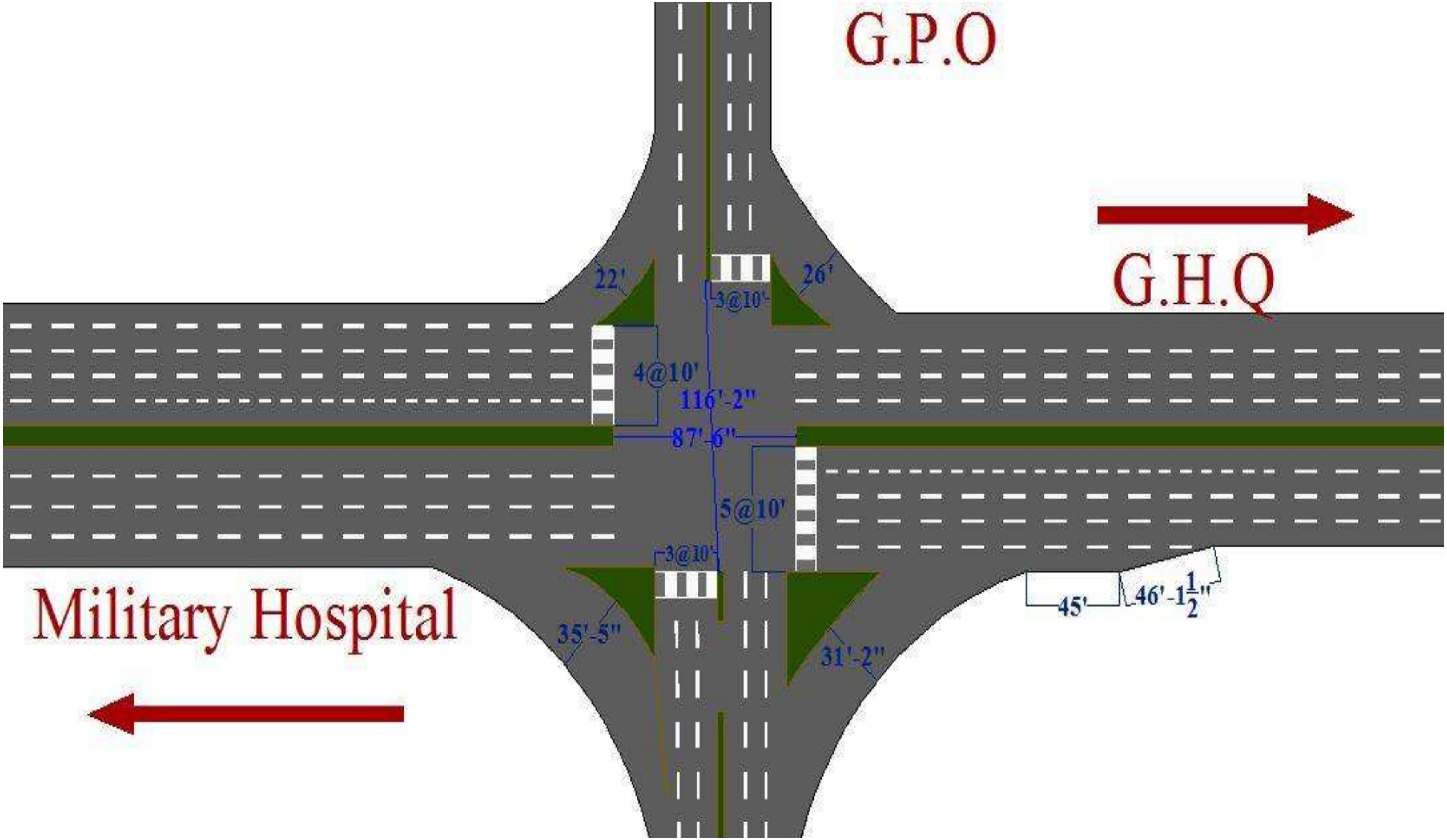


Figure 3.8 Layout of GPO Intersection

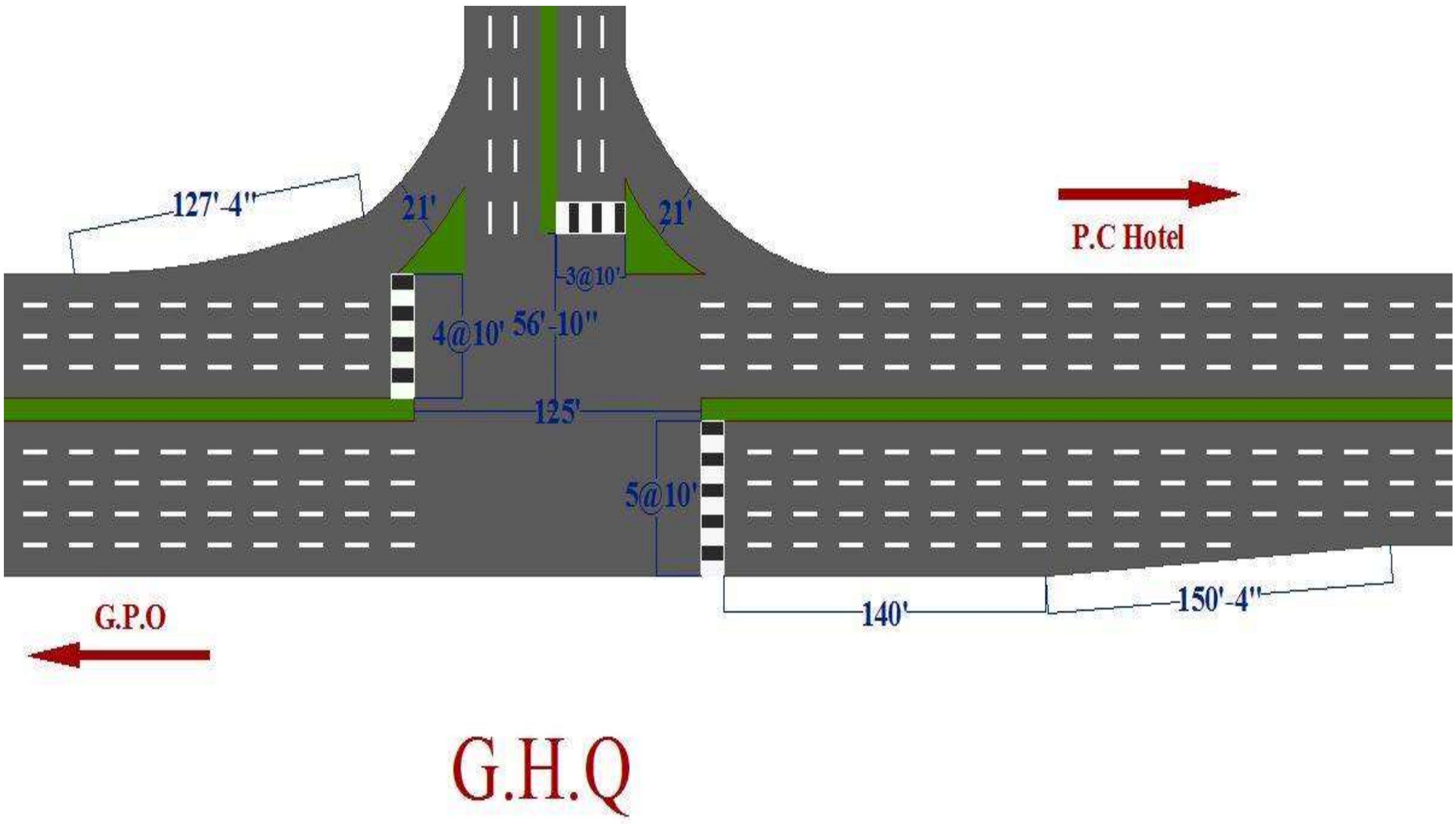


Figure 3.9 Layout of GHQ Intersection

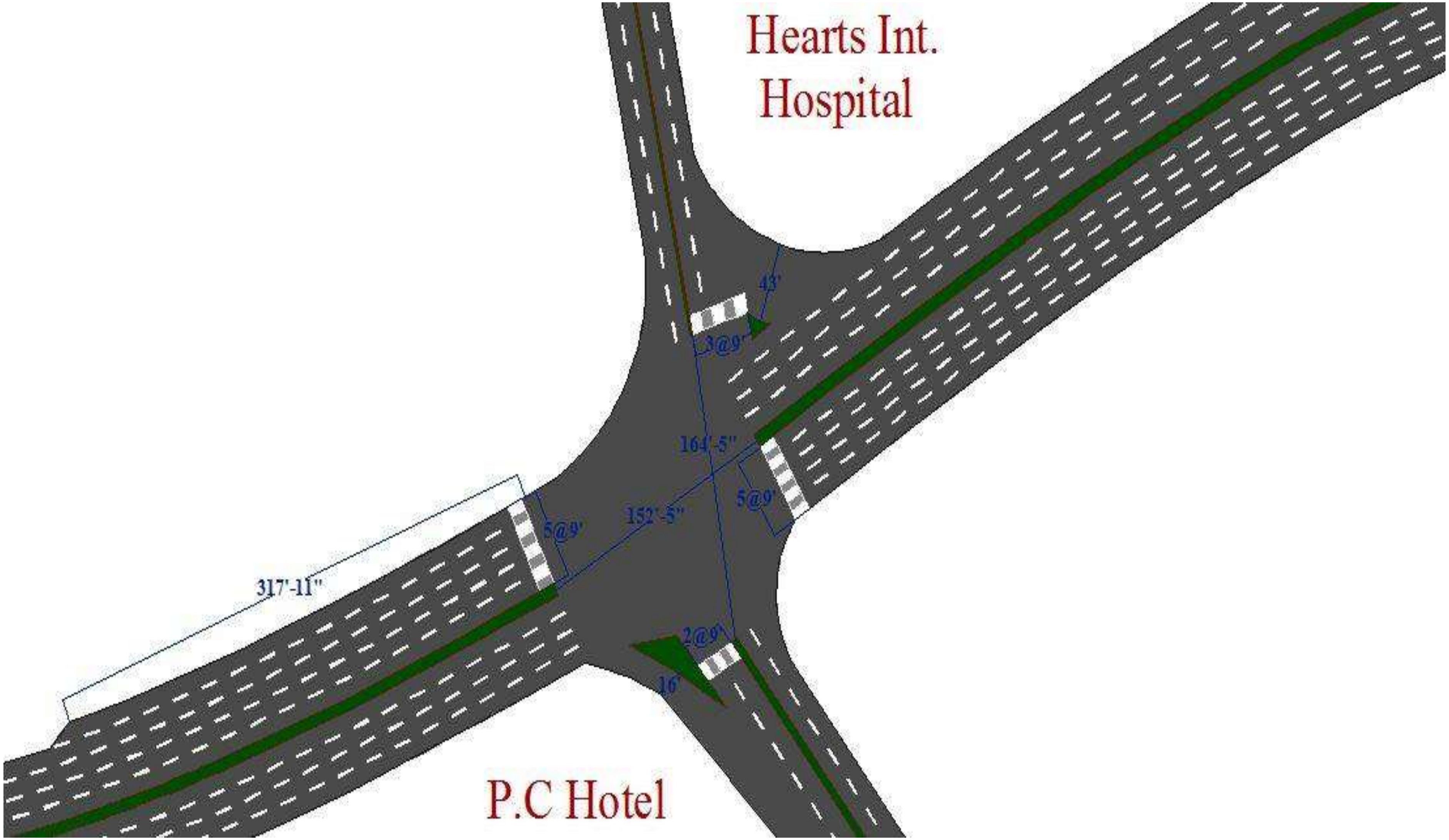


Figure 3.10 Layout of PC Intersection

CHAPTER # 4

Analysis and Results

4.1 Introduction

This chapter includes the results before and after optimization of the intersections. The software used for the analysis is Synchro 8. The data which is collated as discussed in chapter 3, is used as input parameters in Synchro. The Synchro then processes the data and provides analysis results. These results include LOS, intersection capacity utilization and approach delays. Synchro also provides the optimize solutions for the existing traffic and congestion problems by suggesting optimize signal timings and choosing the best offsets between the intersections in a network to achieve best coordination plan. The results for existing conditions and the coordinated signals are then compared with each other to finalize the solution.

4.2 Analysis Methodology

This section describes the methodology used to handle the data in Synchro and then comparison of results among different alternatives. First of all, data for existing traffic conditions was fed in the Synchro to determine LOS, ICU and approach delays. Then the intersection timings were optimized based on the turning movements and the 5 intersections were coordinated same results for these timings are obtained and compared. Synchro has windows for different types of data including lane, volume, timing, phasing and simulation settings. These windows are discussed in this section in detail.

4.2.1 Mapping out the network

Intersection to intersection distance was measured during the data collection in field. This distance is used to model the network in Synchro. Google map of our site was downloaded and flipped for the right side traffic provision of Synchro. On ground distance was used as a reference to set the scale of the image in Synchro. This further set the pixels of the image and other link distances are automatically calculated. This helps in determining the travel distance and time based on speed and also optimized timings are calculated from it. The links and intersections are drawn on this map on scale.

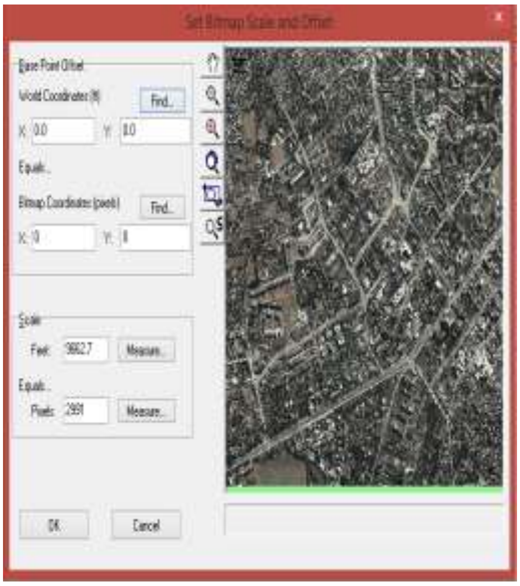


Figure 4.1 Scaling the Map

4.2.2 Lane Window

The selected corridor consists of five intersections out of which three are T-intersections and other two are 4-legged intersections. All the intersections are signalized. The turning and through lanes for each intersection are shown in the geometric features section in chapter 3 (Fig 3.5-3.9).

- The lane configuration for each turning movement were selected in lanes and sharing (#RL) row.
- The street name for entire corridor was fed as Peshawar Road#1 so that Synchro treats it as one network.
- Link distance and Link speed is automatically set by Synchro based on mapping of network. However they can be overridden.
- Ideal saturation flow is by default taken as 1900 veh/hr/ln. This is in accordance with the HCM 2000. Synchro automatically adjusts it for turning lanes and heavy vehicles.
- Default lane width in Synchro is 12ft. We selected 9ft lane width based on field conditions.
- Grade for these at grade intersections is 0.
- Area type can either be Central Business District (CBD) or other. We selected GPO intersection as CBD and remaining four intersections as others.

- Storage length and storage lanes for each approach if provided were measured in field and each value was fed for approaches.
- Right turn channelization option was selected for the left turns with islands and curb radii of these islands were measured in field and fed in Synchro.
- Lane Utilization factor is automatically calculated by Synchro whenever the traffic is shared between two or more lanes as traffic is not equally shared between them. Synchro has built in default values of lane utilization factor for shared lanes.
- Right Turn factor (for right side drive traffic) for exclusive right turning lane is taken by default as 0.85 in accordance with HCM 2000. For shared lanes and single lanes, the values are adjusted as mentioned below

  Shared lane: $f_{RT=}$ 1-(0.15 x Proportion of right turning traffic)

  Single lane: $f_{RT=}$ 1-(0.135 x Proportion of right turning traffic)

  Left turn factor for exclusive lanes has default value of 0.95. For shared lanes

  $F_{LT=}$1/(1+0.05 x Proportion of left turning traffic)

4.2.3 Volume Window

Traffic volume data was collected in the field with help of Jamar counter and manual counts and the tables turning movements are provided in chapter 3. Peak hour volumes and peak hour factor for each turning movement was calculated. These are the input parameters in this window.

- Lanes and sharing (#RL) are the same as provided in the lane window.
- Traffic volumes of the peak hour (vph) for each turning movement were fed in the traffic volume section.
- Growth factor was kept as 1 as we did this analysis for the existing conditions.
- Heavy vehicles were counted separately in the field and their percentage was fed in the Heavy Vehicles % section.
- Adjusted flow is calculated by Synchro by dividing the provide traffic volume by peak hour factor.
- Lane group flow is automatically calculated by Synchro where there is a shared lane.

- Both the input parameters in lane window as well as volume window are used in calculating intersection capacity utilization and v/c ratio of the intersection.

4.2.4 Timing Window

Signal timings of each intersection were measured in the field and the phase sequence was also determined. In the Options->Phase templates tab, the phase sequence was set before using the timing the window. The data we fed in the software is provided in tables in chapter 3. The input parameters in this window are explained below.

- Lanes and Sharing as well as Traffic volume are the same as they were fed in the lane and volume window respectively.
- Controller type was selected as pre-timed controller according to the existing condition.
- Protected and Permitted phases as well as the phase sequence of each approach were determined in the field and they were fed as existing.
- The detector options were left as no signal is actuated.
- Total split, Yellow time and all red time for each approach were fed in their sections.
- Volume to Capacity ratios, Total Delay, Control Delay and Approach Delay are automatically calculated by Synchro based on the input values.
- Level of Service is calculated by Synchro based on control delay per vehicle.
- Fuel used as gallons per hour is calculated by using total travel, total delays and total stops. Fuel emissions in terms of carbon monoxide, nitrogen oxides and volatile oxygen compounds are calculated by Synchro automatically for environmental impact analysis of traffic conditions.

4.2.5 Simulation Settings

Taper lengths before the storage lanes, median widths were measured in field and they were used as input parameters in this window. They are further explained here:

- Lanes and Sharing, Traffic Volumes, Storage lanes and storage lengths are the same as they were fed in the previous windows.
- Taper length is the length which is required for addition of storage lane. Taper length as measured in field is fed in this section.

- Lane alignment affects the SimTraffic simulation. It aligns the movement of vehicles from different approaches to one approach by specifying the lanes for them.
- Median Width was fed as measured in field.
- Headway factor is automatically calculated by Synchro based on saturation flow, lane widths and area type.
- Mandatory distance and positioning distance affect the simulation. These are the distances beyond which a vehicle can change its lane. These are the default values calculated by Synchro and can be overridden. For the intersections e.g. GPO intersection, where drivers change their lanes just before the intersections, these values were overridden.

4.3 Results of Existing Conditions

Analysis of the traffic flow based on the existing condition was done using Synchro to obtain the results about following parameters.

- Intersection capacity utilization.
- Intersection Level of service and v/c ratio.
- Travel Times.
- Fuel Consumption Costs.
- Environmental Impact Assessment.

4.3.1 Intersection Capacity Utilization

Intersection Capacity utilization gives an idea about the capacity of the intersection. It is the comparison of existing volumes at the intersection with the ultimate capacity of intersection. It is an important tool for analyzing the congestion problems and to facilitate the traffic impact studies.

Intersection Capacity Utilization is calculated by Synchro using the HCM 2010 Manual. Calculation of ICU requires some specific data like no. of lanes, traffic volumes, signal timings, saturated flow rates and delay times. Based on the intersection capacity utilization, intersections are given a LOS from A to H.

Letter A for and intersection shows that there are no congestion problems. To move the traffic efficiently, cycle length of 80s is sufficient. It also indicates that the intersection can handle 40% more traffic than existing volumes.

Letter B indicates that there congestion is very little. To move the traffic efficiently, cycle length of 90s is sufficient. It also indicates that the intersection can handle 30% more traffic than existing volumes.

Letter C indicates that there is no major congestion. To move the traffic efficiently, cycle length of 100s is sufficient. It also indicates that the intersection can handle 20% more traffic than existing volumes.

Letter D indicates that normally there is no congestion. To move the traffic efficiently, cycle length of 110s is sufficient. It also indicates that the intersection can handle 10% more traffic than existing volumes.

Letter E indicates that the intersection is on the verge of congestion. To move the traffic efficiently, cycle length of 120s is required. It also indicates that the available reserve capacity of intersection is less than 10%.

Letter F shows that demand has exceeded capacity. Intersection requires a cycle length of more than 120s to move the traffic efficiently. At the end of green, there may be residual queues of vehicles. The intersection may observe 15 to 60 minutes of congestion periods per day. Signal timings optimizations are necessary at this phase of ICU.

Letter G shows that the demand has exceeded 10 to 20% in capacity. Congestion periods from 60 to 120 minutes per day are common in this case. Signal timing optimizations are necessary to cater for the exceeded demand.

Letter H indicates that intersection is experiencing 20% more demand than its capacity. Congestion periods are more than 120 minutes per day. There are long queues of vehicles in this case. Signal timings must be optimized.

Signal timings for existing conditions are shown in tables 4.1 and 4 .2. The values indicate that all the signal except Military Hospital intersection has an ICU LOS of F.

All these intersections are operating at the demand higher than their capacity. It indicates that signal timings need to optimized to move the through traffic techniques. In addition to signal timings, additional traffic management plans are required.

4.3.2 Intersection Level of Service and v/c ratio

Intersection Level of service is then determined from ICU, intersection delays and saturation flows. Based on the ICU values, LOS is given a letter from A to H.

Based on Control Delay/vehicle, LOS is given a letter from A to F, with A showing that intersection has minimum delays and the traffic is flowing with minimum hindrance and F showing that the traffic flow is in worse condition. Level of service criteria is stated in the terms of average delay per vehicle during a specified time period. We do not measure delays in the field as well as they cannot be measured for future situations, therefore analytical models are used. Delay varies with the following:

- Quality of progression
- Cycle length
- Green time
- v/c ratio

For every given situation there will be a cycle length that will produce minimum delays for any given lane group. If the cycle time is kept too short, it will result in higher v/c ratio hence increasing delays. On the other hand if the cycle length is too large, it means there will be too much wasted green time so the delays will start increasing. Existing LOS on the intersections under study is really low. Except MH intersection, which has LOS D, all the remaining intersections have LOS F during morning and evening peak hours.

The **v/c** ratio, which is the ratio between flow rate and capacity of the intersection, is often termed as the “degree of saturation”. It is the principal output from the analysis of signalized intersections. It shows the proportion of the capacity of the intersection which is being used by the existing traffic. it is the measure of existing or proposed capacity.

For an intersection to work efficiently, its v/c ratio should be less than or equal to 1. Cases in which v/c is greater than 1.00, it shows that the intersection is unable t handle the traffic demand. v/c value higher than 1.00 for future projections shows that the intersection will operationally fail. Capacity is difficult to measure in the field so equations are used to estimate it. Analysis of existing conditions of intersections shows high value of v/c which means there is much higher flow rate than the capacity of the intersections. At Qasim Market intersection during morning peak hours, maximum v/c ratio was 2.14 which shows that the demand is more than 200% of the capacity provided. Highest value of v/c recorded during morning peak hours was for PC Hotel intersection which was 3.77. During evening peak hours, v/c ratio was comparatively less as compared to morning peak hours.

Following tables show the existing LOS, v/c ratio and ICU for all the intersections:

Table 4.1 Intersection Report for Morning Peak Hours

Morning Peak Hours					
Intersection	**v/c ratio**	**Intersection signal delay**	**Intersection LOS**	**ICU**	**ICU LOS**
QM	2.14	133.1	F	117.0 %	H
MH	1.22	46.3	D	81.3%	D
GPO	2.59	323.8	F	122.1%	H
GHQ	1.73	202.2	F	115.4%	H
PC Hotel	3.77	289.4	F	126.8%	H

Table 4.2 Intersection Report for Evening Peak Hours

Evening Peak Hours					
Intersection	**v/c ratio**	**Intersection signal delay**	**Intersection LOS**	**ICU**	**ICU LOS**
QM	1.61	107.4	F	100.0 %	F
MH	1.20	39	D	86.8%	E
GPO	2.00	299.7	F	134.2%	H
GHQ	1.70	227.0	F	137.6%	H
PC Hotel	1.84	257.6	F	112.7%	H

4.3.3 Travel Time

To comapre results obtained from sychro and the actual existing conditions of the intersections, we did a trial drive on a car during a peak hour. We noted down the time to reach the intersection from the reference pint. This time is mentioned as time before stop in the tables. After that,stopped delay for intersection was noted. It is the time for which a vehicle has to stop at the stop line before it gets the green light . After getting green light, vehicle takes some time to clear the intersection. Sum of these three times is the section travel time section. At times, vehicle gets the green light but cannot make it through the intersection due to large number of vehicles ahead of it. So it has to stop at the intersection more than once. Using these travel times and the dictances between the intersection , we plot a time space diagram. Time space diagrams shows travel times and delays for each length of travel. The graph below is time sapce diagram for our live feed east-bound during a peak hour. We chose Traffic Police Centre as reference point. Distance betwwen traffic police centre and our first intersection i.e Qasim Market intersection is 100 m. This distance was travelled in 10 second. This intersection is channelized for east-bound through traffic, so there were no delays. Next intersection is 1059 meter away from the first intersection. Steep slope shows quick approach to the intersection. Horizontal line shows that there were stop delays at the intersection before the vehicle was given the green light. Dstance to the next intersections is 633 meter. A reativly mild slope of the graph shows that more time was needed to travel this section length due to congestion. Next two intersections are 458 and 445 meters apart. So there was delay at each of the intersection except Qasim market intersection

Silmilarly, travel time was obtained for different peak hours and also in opposite direction i.e west-bound. Just as we did in eastbound travel , we established a reference point and started travelling westbound. In west bound travel, MH ntersection is channelized and does not have any delay from throgh traffic. Rest of the intersections have their delay times as shown in the graph.

4.3.3.1 Field Calculations:

For field calculations, we started from our reference point, that is, the traffic police station and calculated our cumulative travel time for all the intersections. In this travel time all the delays have been incurred including the number of stops encountered during the trial runs. The spread sheets models are made accordingly. These trials were run in the peak hours to estimate to closest possible results. These spreadsheet models explain the existing delays and total travel time for both individual section and the whole study area. These delays could be for any reason like traffic congestion during peak hours or any crash.

For **Live feed Travel Time** calculations, Four trial runs are done for each east bound and west bound. These trial runs are elaborated in Table 4.3 to 4.6. Time space diagrams using live feed travel time are shown in figure 4.2 and 4.3.

Table 4.1 East Bound Travel Time (Live Feed)

Site Location: Peshawar Road (Saddar)		Recorder: Sohaib Ishaq		Start Location: Traffic Police Centre → Hearts International Hospital		
Run No. 1				Start Time: 4:07 PM		
Check Point	**Cumulative Distance (m)**	**Cumulative Travel Time**	**Per Section**			
			Time Before Stop	**Stopped Delay**	**No of Stops**	**Section Travel Time**
C.P 1	100	0:00:10	0:00:10	0:00:00	0	0:00:10
C.P 2	1059	0:01:57	0:01:06	0:00:24	1	0:01:47
C.P 3	633	0:04:46	0:01:24	0:01:18	1	0:02:49
C.P 4	458	0:05:42	0:00:27	0:00:06	1	0:00:56
C.P 5	445	0:07:44	0:00:49	0:00:49	1	0:02:02
Section Totals	**2695**			**0:02:37**	**4**	**0:07:44**

Table 4.2 East Bound Travel Time (Live Feed)

Site Location: Peshawar Road (Saddar)		Recorder: Ali Qumain	Start Location: Qasim Market Plaza→Hearts Int. Hospital			
Run No. 3			Start Time: 4:29 PM			
Check Point	**Cumulative Distance**	**Cumulative Travel Time**	**Per Section**			
			Time Before Stop	**Stopped Delay**	**No of. Stops**	**Section Travel Time**
C.P 1	100	0:00:45	0:00:19	0:00:15	1	0:00:45
C.P 2	1059	0:02:02	0:01:14	0:00:00	0	0:01:17
C.P 3	633	0:05:12	0:01:10	0:01:42	1	0:03:10
C.P 4	458	0:06:54	0:00:51	0:00:37	1	0:01:42
C.P 5	445	0:07:56	0:00:37	0:00:09	1	0:01:02
Section Totals	**2695**			**0:02:43**	**4**	**0:07:56**

Table 4.3 East Bound Travel Time (Live Feed)

Site Location: Peshawar Road (Saddar)		Recorder: Taimoor Abbas	Start Location: Traffic Police Station			
Run No. 5			Start Time: 05:42PM			
Check Point	**Cumulative Distance**	**Cumulative Travel Time**	**Per Section**			
			Time Before Stop	**Stopped Delay**	**No of. Stops**	**Section Travel Time**
C.P 1	100	0:00:25	0:00:25	0:00:00	0	0:00:25
C.P 2	1059	0:02:38	0:01:21	0:00:44	1	0:02:13
C.P 3	633	0:05:12	0:00:52	0:01:21	1	0:02:34
C.P 4	458	0:06:12	0:00:37	0:00:07	1	0:01:00
C.P 5	445	0:09:34	0:00:30	0:02:39	2	0:03:22
Section Totals	**2695**			**0:04:51**	**5**	**0:09:34**

Table 4.4 East Bound Travel Time (Live Feed)

Site Location: Peshawar Road (Saddar)		Recorder: Taimoor Abbass		Start Location: Traffic Police Station		
Run No. 7				Start Time: 06:30		
Check Point	**Cumulative Distance**	**Cumulative Travel Time**	**Per Section**			
			Time Before Stop	**Stopped Delay**	**No of. Stops**	**Section Travel Time**
C.P 1	100	0:00:23	0:00:23	0:00:00	0	0:00:23
C.P 2	1059	0:02:17	0:01:10	0:00:29	1	0:01:54
C.P 3	633	0:06:56	0:00:43	0:03:48	2	0:04:39
C.P 4	458	0:08:48	0:01:01	0:00:42	1	0:01:52
C.P 5	445	0:10:38	0:00:41	0:00:53	0	0:01:50
Section Totals	**2695**			**0:05:52**	**4**	**0:10:38**

Table 4.5 West Bound Travel Time (Live Feed)

Site Location: Peshawar Road (Saddar)		Recorder: Zain Riaz	Start Location: Heart International Hospital			
Run No. 2			Start Time: 4:15 PM			
Check Point	**Cumulative Distance**	**Cumulative Travel Time**	**Per Section**			
			Time Before Stop	**Stopped Delay**	**No of. Stops**	**Section Travel Time**
C.P 1	270	0:01:51	0:00:28	0:01:10	1	0:01:51
C.P 2	445	0:03:25	0:00:39	0:00:35	1	0:01:34
C.P 3	458	0:06:00	0:00:40	0:01:36	1	0:02:35
C.P 4	633	0:07:07	0:01:07	0:00:00	0	0:01:07
C.P 5	1059	0:10:00	0:01:40	0:01:03	1	0:02:53
Section Totals	**2865**			**0:04:24**	**5**	**0:10:00**

Table 4.6 West Bound Travel Time (Live Feed)

Site Location: Peshawar Road (Saddar)		Recorder: Attiq-ur-Rehman	Start Location: Hearts International Hospital			
Run No. 4			Start Time:4:40 PM			
Check Point	**Cumulative Distance**	**Cumulative Travel Time**	**Per Section**			
			Time Before Stop	**Stopped Delay**	**No of. Stops**	**Section Travel Time**
C.P 1	270	0:02:44	0:00:15	0:02:21	2	0:02:44
C.P 2	445	0:05:21	0:00:36	0:01:54	1	0:02:37
C.P 3	458	0:09:44	0:00:31	0:03:05	2	0:04:23
C.P 4	633	0:11:13	0:01:29	0:00:00	0	0:01:29
C.P 5	1059	0:14:28	0:01:32	0:01:35	1	0:03:15
Section Totals	**2865**			**0:08:55**	**6**	**0:14:28**

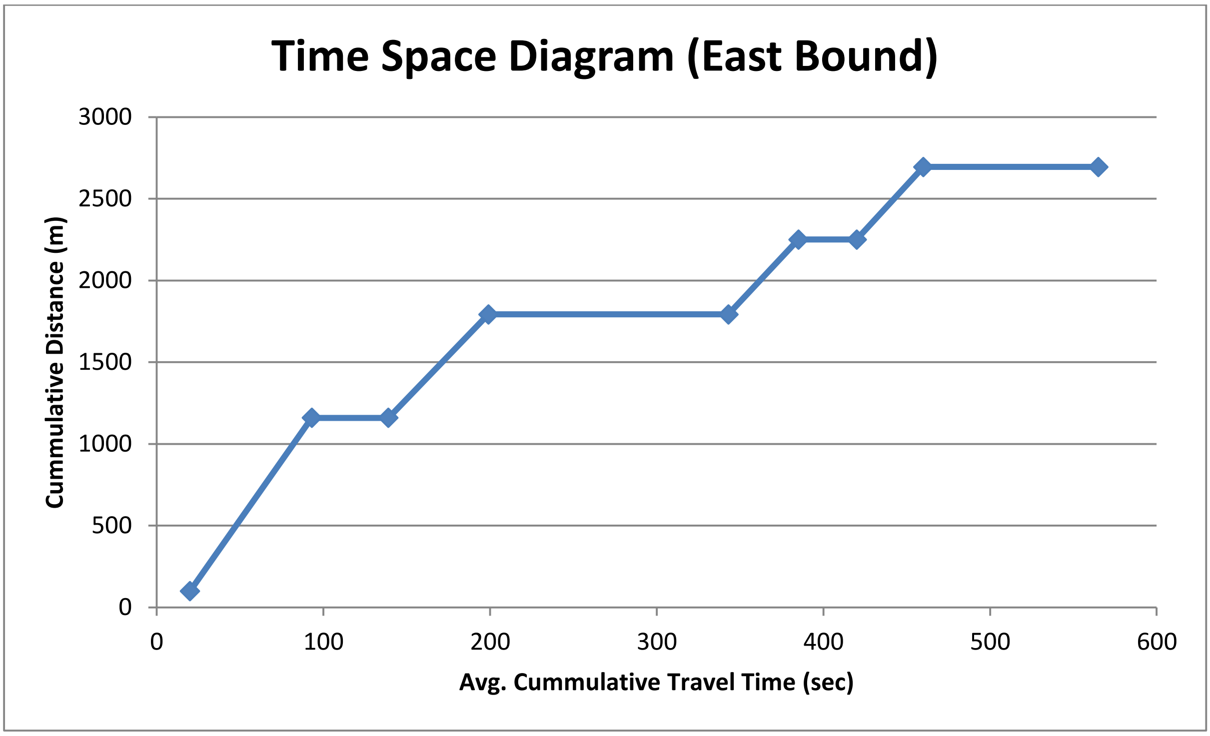


Figure 4.2 Time space diagram (East Bound)

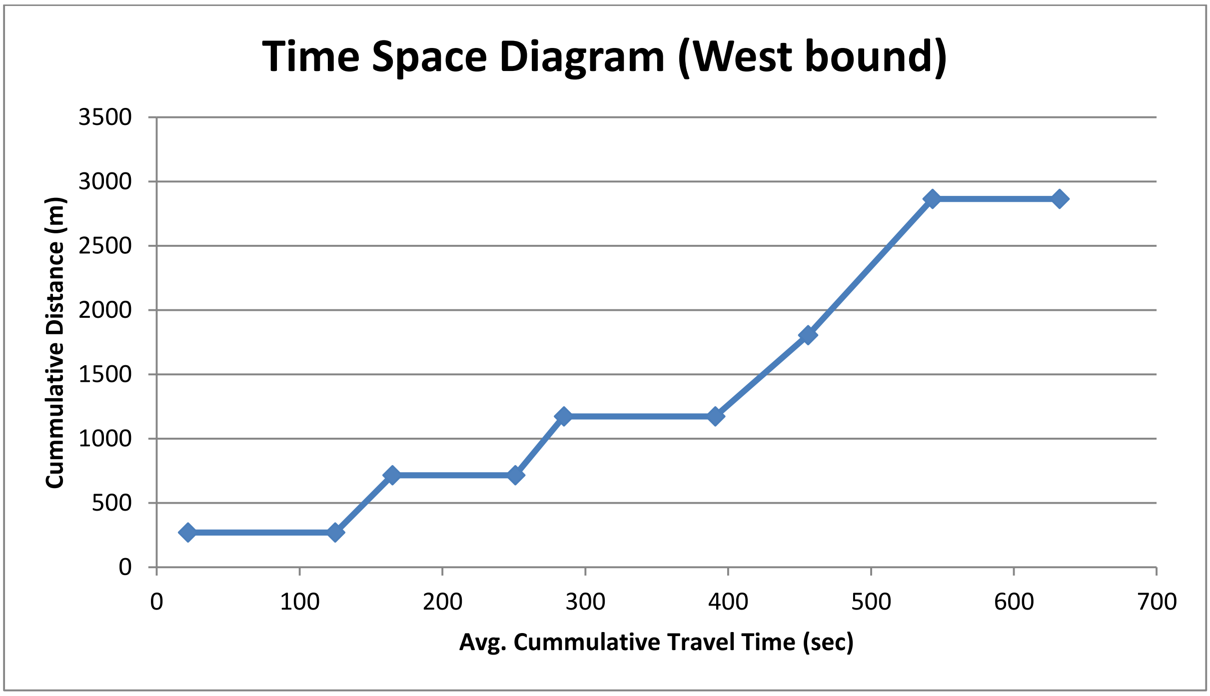


Figure 4.3 Time space diagram (West Bound)

Limitations of Synchro:

One of the lead problems we are facing in Synchro 8 is the calculation of delays; that varies greatly from the original delays timing. We have tested trial car run by moving it along the section in peak hours at average vehicle speed and the time taken by this sample car is less than the delays shown on Synchro. We calculated different values from our trial runs and compared the results accordingly. Analysis shows that following are some reasons for which the total delay of Synchro is greater than that of actual timing.

One of the main reasons for this difference is the lane sharing in Synchro. When a through lane is shared with the right or left turn, then the Synchro automatically increases its delay. And the vehicles get slow before turning, while this doesn't happen in the real time situation. Vehicles don't wait and there is no such delay.

Another reason for this delay is that vehicles maneuver carefully and utilize the free space in lanes while in Synchro, only one vehicle fits in a lane at a time. Lengthy queues form due to this reason in Synchro.

Bikes are converted into car volume with a certain conversion factor as Synchro doesn't include bike volume. In real life scenario, bikes usually go first in seconds and they don't indulge in the queue while Synchro makes queue of cars.

In some cases, the delays cause a change in LOS value. Though it's rare but in some cases, it may happen in Synchro.

4.3.3.2 Travel time calculation using PTV VISSIM 6.0:

The problems we encountered in calculating travel time from Synchro are somehow resolved by using software named PTV VISSIM. In this software a different approach is used to resolve this dilemma. This software not only gives us the travel time for all type of vehicles we have on our study area but also gives a collective estimated travel time for the whole platoon. These values are proposed to be more accurate as in this approach the volumes for each type of vehicle is utilized without any conversion i.e. Bikes are not converted into equivalent car volumes as we did for the Synchro. The values obtained from this software are considered more closed to reality as in this system if bikes found enough space they utilize that space so that there will no long queues or any unwanted congestions. In this software we can introduce volume for any type of vehicle we have on our field. The reports generated from VISSIM depend entirely on the volume of individual Vehicle type.

The travel time by Vissim is shown in Table 4.7 and 4.8. Time space diagrams using Vissim travel time are shown in figure 4.4 and 4.5.

Table 4.7 East Bound Travel Time (Vissim)

VEHICLE TRAVEL TIME MEASURE MENTEVALUATION	TIME INTERVAL	VEHICLE TRAVEL TIME MEASUREMENT	VEHS (ALL)	VEHS (Bikes)	VEHS (H.V)	VEHS (Cars)	TRAVEL TIME (ALL)	TRAVEL TIME (Bikes)	TRAVEL TIME (H.V)	TRAVEL TIME (Cars)
	1800-5400	Q.M.	2995	1017	63	1915	19.49	18.8	23.42	19.73
	1800-5400	MH	1331	515	4	812	95.94	91.52	112.94	98.66
	1800-5400	GPO	1569	537	10	1022	91.64	89.33	107.15	92.7
	1800-5400	GHQ	1243	469	10	764	57.08	54.13	68.72	58.74
	1800-5400	PC	960	350	9	601	94.87	95.92	93.17	94.28

Table 4.8 West Bound Travel Time (Vissim)

VEHICLE TRAVEL TIME MEASURE MENTEVALUATION	TIME INTERVAL	VEHICLE TRAVEL TIME MEASUREMENT	VEHS (ALL)	VEHS (Bikes)	VEHS (H.V)	VEHS (Cars)	TRAVEL TIME (ALL)	TRAVEL TIME (Bikes)	TRAVEL TIME (H.V)	TRAVEL TIME (Cars)
	1800-5400	P.C	2911	1032	35	1844	185.86	184.04	198.25	186.64
	1800-5400	G.H.Q	1431	582	18	831	76.18	75.54	87.78	76.39
	1800-5400	G.P.O	1180	524	14	642	73.19	72.78	89.97	73.15
	1800-5400	M.H	1053	489	11	553	45.92	44.1	58.78	47.28
	1800-5400	Q.M	318	241	6	77	87.19	84.6	112.23	95.31

4.3.4 Fuel Consumption Cost

Fuel Consumption Cost is the main parameter for determining the traffic flow efficiency on an urban arterial. Congestion and poorly designed signal times and traffic management plans results in delays due to which the commuters experience extra travel time due to which fuel consumption of the vehicles increase. The rate at which vehicles consume fuel differ according to the type and horse power of vehicle. Traffic on the urban arterial comprises of cars, motorcycles and heavy vehicles. Volume of each type of vehicle was collected on the arterial and the fuel consumption rate of each type was calculated as discussed further in this section. Using the inputs of volume, travel time delay and fuel consumption rate, annual fuel consumption was calculated.

A particular concern in this section was to clear that how the numbers should be adjusted to account for existing conditions. However, these fuel costs may tend to change depending upon the economic trends. There are two issues in calculating fuel costs: the expected consumption of fuel by a given vehicle (Fuel consumption rate) and the price of the fuel. Our concern in this section is the marginal cost of usage of vehicle i.e. we focus on costs that would increase as if the vehicle is running for a longer time on this section. The specific cost that we address in this section is the Fuel consumption cost. The information for our assumptions is available from the current fuel rates, existing speed limits and it entirely focuses in the loads taken from point A to point B in between the intersections. These cost estimations are entirely dependent on the present fuel rates and speed limits. However, these variables can be changed in our formulas accordingly for the future projections.

There are a few innovations in this research:

- Considering 24 hours traffic volume and accordingly developed fuel costs.
- These costs are then projected for Annual consumption.
- Considering full life-cycle costs.
- Providing explicit guidance on how to adjust the costs in the future.

Under existing conditions, during the peak hours the congestion causes the extended delays because of which the fuel consumption in these hours increases. In our models we have considered this factor and made calculations accordingly. The purpose of this report is to describe the methodology we have adopted to estimate the fuel consumptions during the delays, and to explain how to use and update a spreadsheet program that we have developed for calculating total fuel consumption costs for a project given counts of different type of vehicles. This is done in following order:

- Collect the existing Traffic volume from the site.
- Collect it separately for different type of vehicles.
- Calculate the speed limit and travel distance between two points.
- Studies and engineering approach for determining the adjustment factors.

The main reason to collect separate traffic volume for every type of vehicle is that the fuel consumption depends inseparably on the type of vehicle. For example, the fuel efficiency of motor bike is generally higher than the cars and the efficiency for trucks is less as compare to cars or motor bikes. The impact of these facts is that it is difficult to generate estimates of fuel costs that will remain valid for any length of time, especially for longer spans. The information that this report will add will be the estimates of cost of driving a kilometre in any type of vehicle.

4.3.4.1 Methodology:

For our spread sheet model, we have separate counts for every type of vehicle for through movement in both east bound and west bound. For each type of count we multiply it with our adjustment factor 'K' and with the difference between congested travel time and uncongested travel time. The above mentioned statement can be expressed as:

$$FCC = K \times (TTC - TTUC) \times \text{Traffic Count} \qquad \text{…….. Equation 4.1}$$

Where

FCC = Fuel consumption cost

K = Fuel Consumption rate (Rs/min)

TTc = Congested Travel time (min)

TTuc = Uncongested Travel time (min)

Uncongested travel time: It's the time required by a vehicle to reach from point A to point B without any delay or obstruction. It is expressed in sec, min or hours.

Congested Travel time: It's the reverse of uncongested travel time. It is also expressed in sec, min or hours.

Fuel Consumption rate: The main hurdle for calculating these estimated was to calculate an appropriate adjustment factor. For this, divide the existing speed limit on that particular section with the fuel efficiency of the vehicle which will give the values in Lit/hr. Now, after multiplying this value with 1/60 we will have our value in Lit/min. Then, finally multiplying the above value with the current fuel rates will give value of adjustment factor in our desired units i.e. Rs/min. For Example, if the speed limit on a given road link is 60 km/hr and the mileage for a given car is 13 km/lit, then

Step 1

$$\frac{60\ \mathrm{km/hr}}{13\ \mathrm{km/lit}} = 4.6154\ lit/hr$$

Step 2

$$\frac{4.6154\ \mathrm{lit/hr}}{60} = 0.0769\ lit/min$$

Step 3

For a given fuel rate of 108 Rs/ltr.

$$108\ \mathrm{Rs/ltr} \times 0.0769\ \mathrm{lit/min} = 8.462\ \mathrm{Rs/min}$$

Now, but substituting all the values in equation (A). We get fuel consumption cost for a given vehicle for a given interval of time.

Then, after calculating FCC for all the vehicles for 24 hours, add all the values to get Average Daily cost for weekdays. As far for Weekends calculation, using engineering approach we assume it to be 60% of the Average Daily cost for weekdays. For estimating the annual cost under the given conditions it'll be as:

Annual Cost = (261×ADCWEEKDAYS) + (104ADCWEEKENDS) … Equation 4.2

where 261 and 104 are the number of days that we have during the week and at the weekends respectively in a year.

Fuel consumption costs in east bound direction and west bound direction are shown in Table 4.9 and 4.10.

Table 4.9 Fuel Consumption Cost (East Bound)

Time	Volume	Volume Composition			Uncongested Travel Time (min)	Congested Travel Time (min)			DELAY (min)			Fuel Consumption Cost		
		Cars	Bikes	Trucks		Cars	Bikes	HV	Cars	Bikes	HV	Cars	Bikes	Trucks
1am-5am	167	114	47	7	2.48	4.90	4.70	5.70	2.42	2.22	3.22	2326	220	1639
5am-8am	1253	827	413	25	2.48	4.95	4.70	5.80	2.47	2.22	3.32	17282	1946	6335
8am-11am	8352	5128	3165	59	2.48	5.72	5.51	6.43	3.24	3.03	3.95	140594	20331	17749
11am-2pm	7099	4756	2272	71	2.48	5.73	5.53	6.60	3.25	3.05	4.12	130810	14689	22276
2pm-4pm	5357	3603	1674	80	2.48	5.82	5.57	6.23	3.34	3.09	3.75	101828	10967	22951
4pm-7pm	8929	6167	2678	84	2.48	5.77	5.53	6.33	3.29	3.05	3.85	171689	17316	24630
7pm-10pm	6250	4250	1938	63	2.48	5.70	5.36	6.21	3.22	2.88	3.73	115808	11830	17756
10pm-1am	2232	1462	681	89	2.48	4.93	4.95	5.15	2.45	2.47	2.67	30313	3565	18157
Total Cost (Rs. Million)												710649	80864	131493

Table 4.10 Fuel Consumption Cost (West Bound)

Time	Volume	Volume Composition			Uncongested Travel Time (min)	Congested Travel Time (min)			DELAY (min)			Fuel Consumption Cost		
		Cars	Bikes	Trucks		Cars	Bikes	HV	Cars	Bikes	HV	Cars	Bikes	Trucks
1am-5am	166	113	46	7	2.48	4.63	4.60	5.90	2.15	2.12	3.42	2054	209	1730
5am-8am	1245	822	374	25	2.48	5.00	4.83	6.55	2.52	2.12	4.07	17524	1679	7719
8am-11am	8301	6060	2184	57	2.48	6.72	6.50	7.50	4.24	4.02	5.02	217426	18613	21792
11am-2pm	7056	4727	2258	71	2.48	6.37	6.00	6.96	3.89	3.52	4.48	155613	16849	24074
2pm-4pm	5348	3597	1671	80	2.48	6.78	6.52	7.10	4.30	4.04	4.62	130875	14315	28228
4pm-7pm	8914	6128	2721	65	2.48	7.05	6.88	7.53	4.57	4.40	5.05	236978	25381	25000
7pm-10pm	6240	4243	1934	62	2.48	6.13	5.88	6.47	3.65	3.40	3.99	131053	13943	18961
10pm-1am	2229	1460	680	89	2.48	5.03	5.01	5.38	2.55	2.53	2.90	31497	3646	19688
Total Cost (Rs.)												923020	94635	147193

Average Daily Cost (weekdays) = 2.08 Million PKR

Average Daily Cost (weekends) = 1.25 Million PKR

Average Annual Cost = 675.2 Million PKR

4.3.5 Environmental Impact Assessment

Environment Impact Assessment is a formal process of predicting the impacts of any activity, plan or policy on the environment. It is used to analyze whether the effects of the project or plan are within the acceptable limits. Coordination of the signal on an urban arterial reduces delays and improves travel time as well as the LOS of the corridor. Along with these benefits, another justification for coordination is its impact on the environment. So another important aspect of the study is Environmental Impact Analysis of coordination. Signal coordination focuses upon creation of green waves on arterials having large travel demand. Poorly optimized signal cause congestion on the arterial which result in sub-optimal speed and acceleration of the vehicles. This causes incomplete combustion of fuel and increased emission of CO, VOCs and NO_X. Air present in our atmosphere has different compounds in it in different proportions. Any increase or decrease in their concentration may cause severe environmental impacts.

Emission of CO, which is emitted in huge quantity by daily traffic, increases the amount of carbon in the air. Increased carbon contents in the atmosphere are causing greenhouse effect. Greenhouse effect raises the temperature of the earth resulting in climate changes. NO_X emitted by the vehicles are another source of environmental pollution. They are the compounds of Nitrogen and Oxygen combine together in different proportions to form a series of compound. They are the main source of acid rain which is causing both environmental and infrastructure damage. VOCs are also having adverse effect on the environment. US Environment Protection Agency gave the following estimates for the vehicular emissions:

Component	Emission Rate	Annual pollution emitted
Hydrocarbons	2.80 grams/mile (1.75 g/Km)	77.1 pounds (35.0 kg)
Carbon monoxide	20.9 grams/mile (13.06 g/Km)	575 pounds (261 kg)
NO_x	1.39 grams/mile (0.87 g/Km)	38.2 pounds (17.3 kg)
Carbon dioxide - greenhouse gas	0.916 pounds per mile (258 g/km)	11,450 pounds (5,190 kg)

In order to find out the daily emissions, we have used following formula:

Total Emissions= (Emission Rate)*(Travel Speed)*(No. of vehicles)*(Delays)

These emissions are calculated for the dealays only. The daily vehicular emissions are shown in Table 4.11 and 4.12.

Table 4.11 Daily Vehicular Emissions (East Bound)

Time	Volume	Volume Composition			Uncongested Travel Time (min)	Congested Travel Time (min)	Delays	Emissions (g-veh)			
		Cars	Bikes	Trucks				Hydrocarbons	CO2	CO	NOx
1am-5am	167	114	47	7	2.48	5.10	2.62	893.52	131731.085	6668.25	444.21
5am-8am	1253	827	413	25	2.48	5.15	2.67	6829.33	1006837.78	50966.28	3395.15
8am-11am	8352	5128	3165	59	2.48	5.88	3.40	57976.80	8547436.8	432672.58	28822.75
11am-2pm	7099	4756	2272	71	2.48	5.95	3.47	50294.87	7414901.42	375343.46	25003.74
2pm-4pm	5357	3603	1674	80	2.48	5.87	3.39	37079.90	5466637.39	276722.03	18434.01
4pm-7pm	8929	6167	2678	84	2.48	5.87	3.39	61799.84	9111062.31	461203.39	30723.35
7pm-10pm	6250	4250	1938	63	2.48	5.75	3.27	41728.57	6151982.78	311414.32	20745.06
10pm-1am	2232	1462	681	89	2.48	5.01	2.53	11530.50	1699925.34	86050.48	5732.31
Total (Rs.)								268133.34	39530514.90	2001040.79	133300.57

Table 4.12 Daily Vehicular Emissions (West Bound)

Time	Volume	Volume Composition			Uncongested Travel Time (min)	Congested Travel Time (min)	Delays	Emissions (g-veh)			
		Cars	Bikes	Trucks				Hydrocarbons	CO2	CO	NOx
1am-5am	166	113	46	7	2.48	5.04	2.56	868.86	128094.945	6484.19	431.95
5am-8am	1245	822	374	25	2.48	5.46	2.98	7575.70	1116874.65	56536.37	3766.21
8am-11am	8301	6060	2184	57	2.48	6.91	4.43	75022.59	11060473.8	559882.90	37296.95
11am-2pm	7056	4727	2258	71	2.48	6.44	3.96	57094.57	8417370.34	426088.59	28384.16
2pm-4pm	5348	3597	1671	80	2.48	6.80	4.32	47172.89	6954631.49	352044.52	23451.66
4pm-7pm	8914	6128	2721	65	2.48	7.15	4.67	85051.94	12539086.1	634730.48	42282.96
7pm-10pm	6240	4243	1934	62	2.48	6.16	3.68	46881.70	6911701.66	349871.41	23306.90
10pm-1am	2229	1460	680	89	2.48	5.14	2.66	12102.61	1784270.81	90320.07	6016.73
Total (Rs.)								331770.86	48912503.74	2475958.52	164937.51

CHAPTER # 5
Conclusion and Recommendations

The analysis on the Arterial segment suggests that the existing condition is not satisfactory in providing efficient movement and with the increasing traffic; the situation is becoming even worst. The level of service in the existing condition is not adequate.

5.1 Conclusion

The existing condition of this corridor does not facilitate the traffic flow and it needs some improvements. Level of service on these conditions is not satisfactory and if these conditions persist then it will cause major traffic congestion problem in the next few years. We have made some recommendations and alterations to the existing design and the possible solutions which can make the flow efficient and smooth. It also improves the intersection capacity utilization (ICU) and Level of service. The study and analysis of the result concludes that the current geometry is not suitable while the results obtained from our recommendations have reduced the traffic delays and it is also beneficial economically with the less fuel consumption.

On the basis of demographical conditions of Rawalpindi and increasing urbanization, traffic volume is increasing abruptly. If certain solution will not be considered, it will be disastrous. With the growth factor to be 3.5, traffic volume would be increased in next ten years in the following manner:

Table 5.1 AM Peak Hour Projection

AM PEAK Hour		
Intersection	**Present Volume (2013)**	**Projected Volume (2023)**
Qasim Market	8670	12230
MH	7133	10062
GPO	7067	9969
GHQ	7030	9917
PC	7095	10008

Table 5.2 PM Peak Hour Projection

PM PEAK Hour		
Intersection	**Present Volume (2013)**	**Projected Volume (2023)**
Qasim Market	7496	10574
MH	7692	10850
GPO	8416	11872
GHQ	7978	11254
PC	7098	10012

On the basis of the above given data, we can clearly see the potential problem that the facility will be facing in the upcoming years. This will cause more congestion, more delays and ultimately more fuel consumption and emission. So we need to provide a solution for the existing condition that will satisfy the traffic demand and improve traffic operations as well as reduce fuel consumption and emission.

5.2 Recommendations:

After analyzing existing corridor conditions, we need to provide recommendations for improvement of traffic operation. The facility under study is the busiest corridor of Rawalpindi and there are many sensitive places on both sides of the road such as GHQ, Army messes etc. So special considerations are needed while planning any remedial measures for the facility. Taking these factors into account, we came up with the following recommendations:

- Signal coordination
- Intervention # 01 (Flyover at GPO intersection)
- Intervention # 02 (T-section at GPO)
- Intervention # 03 (Closing minor approaches of GPO and channelizing GHQ intersection)

5.2.1 Signal Coordination:

Signal coordination is the first recommendation for improving operations of facility. In signal coordination we optimize the timings of signals using Synchro. Basic concept of coordination is that timings of signals are adjusted in such a way that continuous progression of green wave is achieved. Healthy progression results in smooth traffic flows. Coordination helps to reduce travel times, delays, fuel consumptions and emissions. It also improves the mobility of vehicles.

Table 5.3 and 5.4 show comparison of existing and coordinated conditions:

Table 5.3 Comparison of Existing and Coordinated Condition (Morning)

Intersections	Existing conditions					Coordinated conditions				
	v/c	Signal delays	LOS	ICU	ICU LOS	v/c	Signal delays	LOS	ICU	ICU LOS
QM	2.14	133.1	F	117.0 %	H	1.3	95.8	F	117%	H
MH	1.22	46.3	D	81.3%	D	0.97	21.4	C	81.3%	D
GPO	2.59	323.8	F	122.1%	H	2.62	321.7	F	122.1%	H
GHQ	1.73	202.2	F	115.4%	H	1.19	80.0	E	100%	G
PC	3.77	289.4	F	126.8%	H	2.91	245.8	F	126.8%	H

Table 5.4 Comparison of Existing and Coordinated Condition (Evening)

Intersections	Existing conditions					Coordinated conditions				
	v/c	Signal delays	LOS	ICU	ICU LOS	v/c	Signal delays	LOS	ICU	ICU LOS
QM	1.61	107.4	F	100.0 %	F	1.2	62.0	E	100%	F
MH	1.20	39	D	86.8%	E	0.92	18.7	B	86.8%	E
GPO	2.00	299.7	F	134.2%	H	2.03	295.8	F	134.2%	H
GHQ	1.70	227.0	F	137.6%	H	1.72	125.0	F	137.6%	H
PC	1.84	257.6	F	112.7%	H	1.65	228.5	F	112.7%	H

Comparison of the data shows that coordination improves signal delays significantly. Lower delay time means vehicles will be able to traverse the distance quickly resulting in lower fuel consumption as well as emission.

Fuel Consumption costs are given in table 5.5 and 5.6. The vehicular emissions of coordinated signals are given in the table 5.7 and 5.8.

Table 5.5 Fuel Consumption Cost in Coordinated Condition (East Bound)

Time	Volume	Volume Composition			Uncongested Travel Time (min)	Congested Travel Time (min)			DELAY (min)			Fuel Consumption Cost		
		Cars	Bikes	Trucks		Cars	Bikes	HV	Cars	Bikes	HV	Cars	Bikes	Trucks
1am-5am	167	114	47	7	2.48	4.03	3.88	4.27	1.55	1.40	1.79	1493	139	909
5am-8am	1253	827	413	50	2.48	4.68	4.27	4.80	2.20	1.40	2.32	15416	1230	8854
8am-11am	8352	5128	3165	59	2.48	5.67	5.38	6.33	3.19	2.90	3.85	138279	19481	17315
11am-2pm	7099	4756	2272	71	2.48	5.67	5.38	6.33	3.19	2.90	3.85	128261	13983	20834
2pm-4pm	5357	3603	1674	80	2.48	6.02	5.67	5.87	3.54	3.19	3.39	107824	11310	20727
4pm-7pm	8929	6167	2678	84	2.48	6.38	6.05	7.03	3.90	3.57	4.55	203696	20268	29130
7pm-10pm	6250	4250	1938	63	2.48	5.48	5.35	6.18	3.00	2.87	3.70	108016	11789	17629
10pm-1am	2232	1462	681	89	2.48	4.85	4.80	5.05	2.37	2.32	2.57	29323	3349	17477
Total Cost (Rs.)												732307	81549	132875

Table 5.6 Fuel Consumption Cost in Coordinated Condition (West Bound)

Time	Volume	Volume Composition			Uncongested Travel Time (min)	Congested Travel Time (min)			DELAY (min)			Fuel Consumption Cost		
		Cars	Bikes	Trucks		Cars	Bikes	HV	Cars	Bikes	HV	Cars	Bikes	Trucks
1am-5am	166	113	46	7	2.48	3.43	3.40	3.83	0.95	0.92	1.35	911	91	684
5am-8am	1245	822	374	50	2.48	3.77	3.57	4.02	1.29	0.92	1.54	8948	729	5829
8am-11am	8301	6060	2184	57	2.48	5.15	4.78	5.87	2.67	2.30	3.39	136917	10665	14702
11am-2pm	7056	4727	2258	71	2.48	5.15	4.78	5.87	2.67	2.30	3.39	106809	11025	18199
2pm-4pm	5348	3597	1671	80	2.48	5.42	4.87	5.57	2.94	2.39	3.09	89381	8457	18860
4pm-7pm	8914	6128	2721	65	2.48	7.13	6.62	7.37	4.65	4.14	4.89	241299	23862	24191
7pm-10pm	6240	4243	1934	62	2.48	5.22	4.73	7.62	2.74	2.25	5.14	98259	9240	24411
10pm-1am	2229	1460	680	89	2.48	3.75	3.57	4.00	1.27	1.09	1.52	15687	1566	10319
Total Cost (Rs.)												698210	65635	117195

Average Daily Cost (Weekdays) = 1.82 million PKR

Average Daily Cost (Weekends) = 0.10 million PKR

Average Annual Cost = 591.10 million PKR

Table 5.7 Vehicular Emissions in Coordinated Condition (East Bound)

Time	Volume	Volume Composition			Uncongested Travel Time (min)	Congested Travel Time (min)	Delays	Emissions (g-veh)			
		Cars	Bikes	Trucks				Hydrocarbons	CO2	CO	NOx
1am-5am	167	114	47	7	2.48	4.06	1.58	538.84	79440.8832	4021.31	267.88
5am-8am	1253	827	413	25	2.48	4.58	2.10	5371.38	791894.88	40085.84	2670.34
8am-11am	8352	5128	3165	59	2.48	5.79	3.31	56442.12	8321181.12	421219.48	28059.80
11am-2pm	7099	4756	2272	71	2.48	5.79	3.31	47975.80	7073003.95	358036.56	23850.83
2pm-4pm	5357	3603	1674	80	2.48	5.85	3.37	36861.14	5434385.84	275089.45	18325.25
4pm-7pm	8929	6167	2678	84	2.48	6.49	4.01	65102.47	10776392.3	545553.27	36342.37
7pm-10pm	6250	4250	1938	63	2.48	5.67	3.19	40707.68	6001475.56	303795.62	20237.53
10pm-1am	2232	1462	681	89	2.48	4.90	2.42	11029.18	1626015.55	82309.16	5483.08
Total Cost (Rs.)								264028.61	40104790.07	2030110.69	135237.08

Table 5.8 Vehicular Emissions in Coordinated Condition (West Bound)

Time	Volume	Volume Composition			Uncongested Travel Time (min)	Congested Travel Time (min)	Delays	Emissions (g-veh)			
		Cars	Bikes	Trucks				Hydrocarbons	CO2	CO	NOx
1am-5am	166	113	46	7	2.48	3.56	1.08	366.07	53969.7816	2731.96	181.99
5am-8am	1245	822	374	25	2.48	3.78	1.30	3304.84	487227.195	24663.52	1642.98
8am-11am	8301	6060	2184	57	2.48	5.27	2.79	47284.57	6971096.79	352878.00	23507.19
11am-2pm	7056	4727	2258	71	2.48	5.27	2.79	40191.89	5925432.27	299946.30	19981.11
2pm-4pm	5348	3597	1671	80	2.48	5.28	2.80	30575.02	4507631.52	228177.01	15200.15
4pm-7pm	8914	6128	2721	65	2.48	7.04	4.56	82989.34	12234999.8	619337.59	41257.56
7pm-10pm	6240	4243	1934	62	2.48	5.86	3.38	43059.82	6348247.72	321349.28	21406.88
10pm-1am	2229	1460	680	89	2.48	3.77	1.29	5869.31	865304.265	43801.84	2917.89
Total Cost (Rs.)								253640.86	37393909.39	1892885.49	126095.74

Table 5.9 Travel Time Comparison (East Bound)

Time interval	Travel time for existing Cond.	Travel time for Co-ordinated Cond.
1am-5am	5.1	4.06
5am-8am	5.15	4.58
8am-11am	5.88	5.79
11am-2pm	5.95	5.79
2pm-4pm	5.87	5.85
4pm-7pm	5.87	6.48
7pm-10pm	5.75	5.67
10pm-1am	5.01	4.9

Table 5.10 Travel Time Comparison (West Bound)

Time interval	Travel time for existing Cond.	Travel time for Co-ordinated Cond.
1am-5am	5.04	3.55
5am-8am	5.46	3.78
8am-11am	6.91	5.26
11am-2pm	6.44	5.26
2pm-4pm	6.8	5.28
4pm-7pm	7.15	7.04
7pm-10pm	6.16	5.85
10pm-1am	5.14	3.77

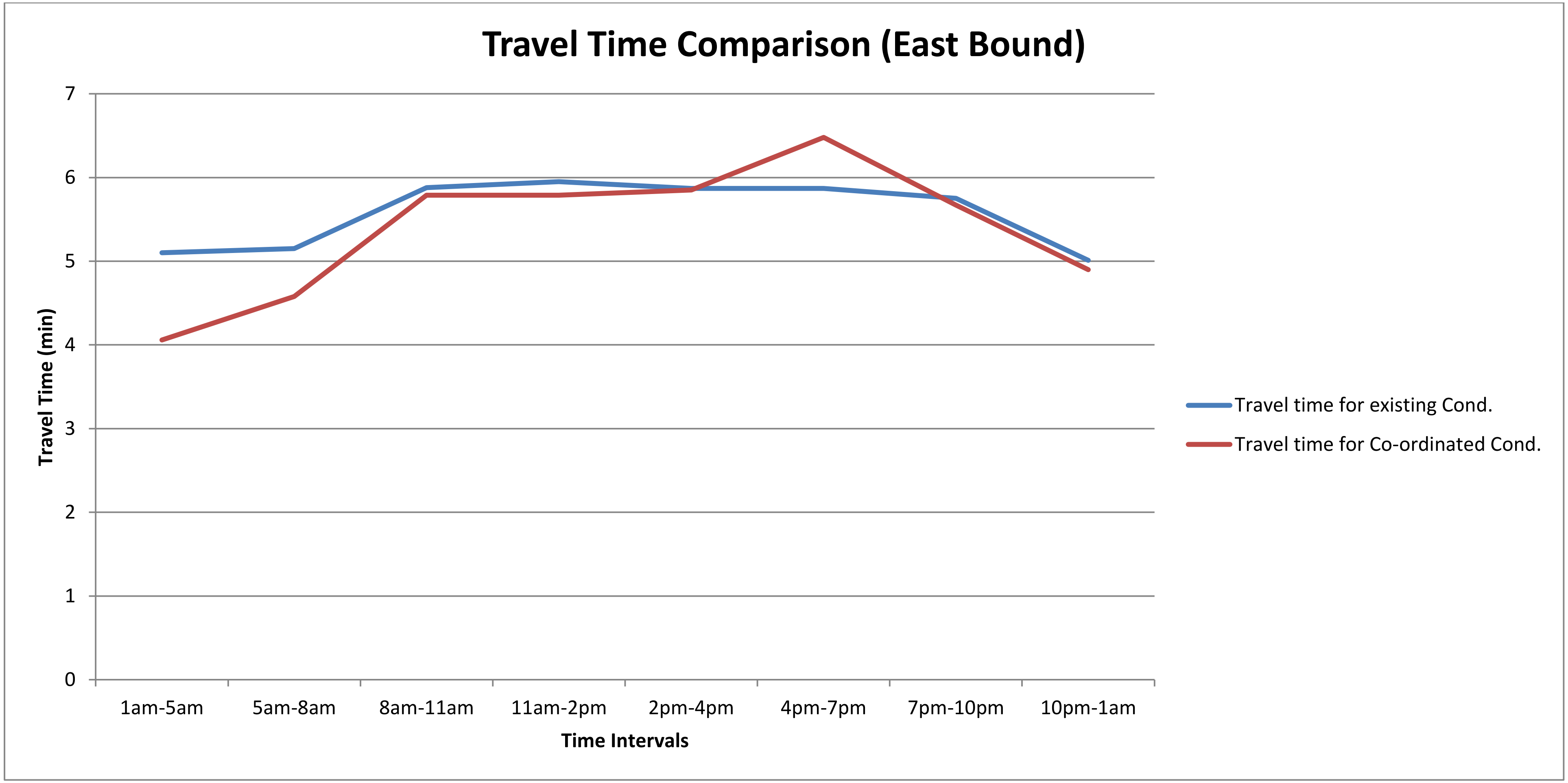


Figure 5.1 Travel Time Comparison (East Bound)

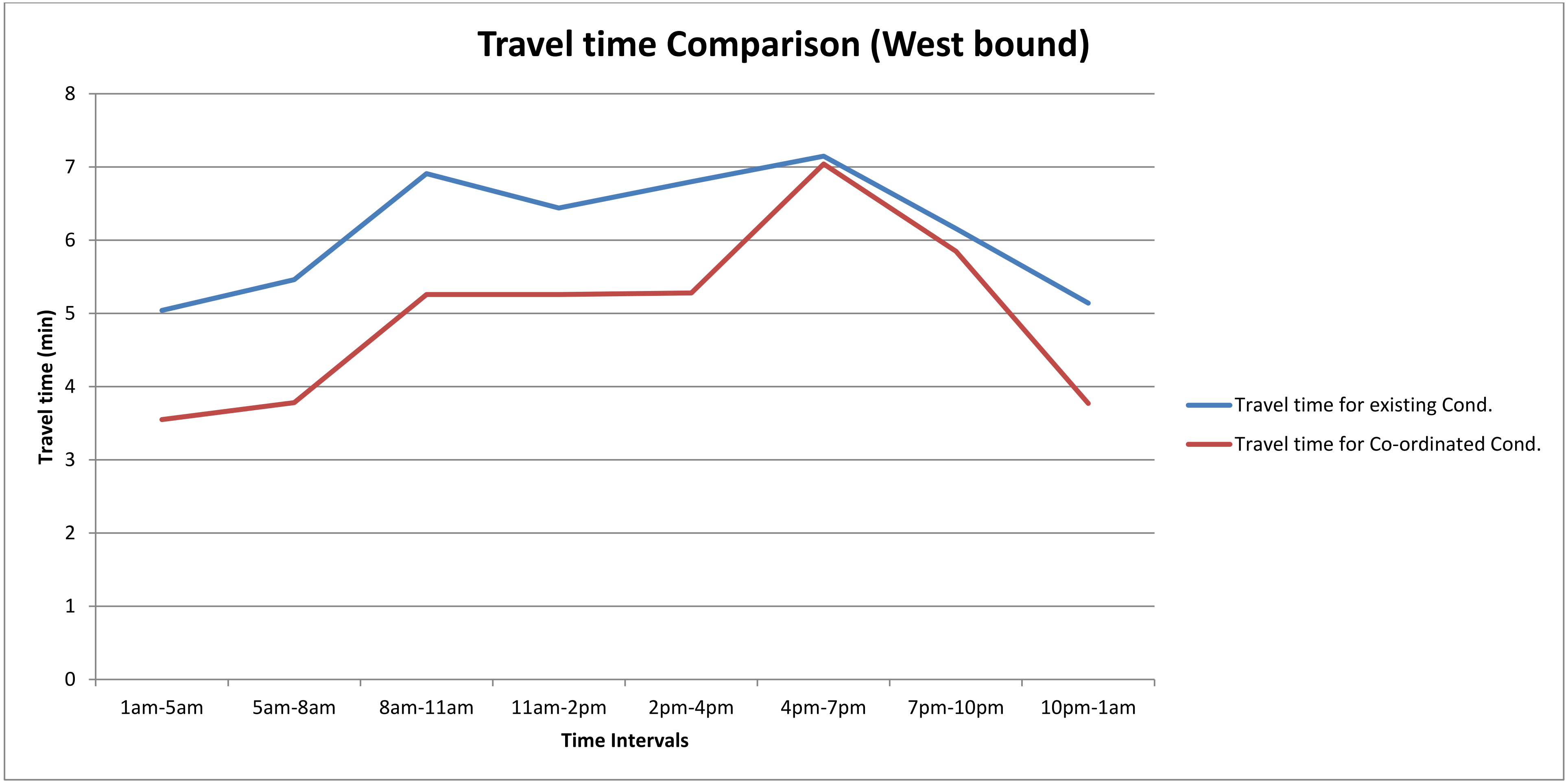


Figure 5.2 Travel Time Comparison (West Bound)

5.2.2 Intervention # 01:

Providing flyover at GPO intersection is another intervention. GPO is the busiest intersection of the corridor. The flyover will allow the through traffic to cross the intersection without any hindrance. Traffic from minor streets can be adjusted accordingly.

In this intervention, PC intersection will be closed as the traffic from minor streets is not significantly large, so there will be no v/c, signal delays or LOS for this intersection. Flyover will significantly reduce vehicular delays and improve traffic operations.

Table 5.11 Intervention 1 Data (Morning)

Intersections	Existing conditions					Coordinated conditions				
	v/c	Signal delays	LOS	ICU	ICU LOS	v/c	Signal delays	LOS	ICU	ICU LOS
QM	2.14	133.1	F	117.0 %	H	1.32	99.1	F	117%	H
MH	1.22	46.3	D	81.3%	D	0.97	17.8	B	81.3%	D
GPO	2.59	323.8	F	122.1%	H	0.88	18.8	B	59.2%	B
GHQ	1.73	202.2	F	115.4%	H	1.10	64.4	E	94.2%	F
PC	3.77	289.4	F	126.8%	H	-	-	-	77.0%	D

Table 5.12 Intervention 1 Data (Evening)

Intersections	Existing conditions					Coordinated conditions				
	v/c	Signal delays	LOS	ICU	ICU LOS	v/c	Signal delays	LOS	ICU	ICU LOS
QM	1.61	107.4	F	100.0 %	F	1.2	65	E	100%	F
MH	1.20	39	D	86.8%	E	1.21	38.7	D	86.8%	E
GPO	2.00	299.7	F	134.2%	H	0.79	15.1	B	56.2%	B
GHQ	1.70	227.0	F	137.6%	H	1.25	98.1	F	104.2%	G
PC	1.84	257.6	F	112.7%	H	-	-	-	63.5%	B

By comparing values given in the table, we can see that the flyover will significantly improve traffic conditions of the corridor. LOS of the GPO intersection will improve significantly from

F to B. v/c value and signal delays have been reduced for all of the intersection. This results in smooth traffic operations. Due to lower travel time, the fuel consumption and emission will also improve.

5.2.3 Intervention # 02:

In this intervention, we closed the southern minor approach of GPO. Traffic volume on this approach is not significantly large. U-turn will be provided at distance according to HCM. This U-turn allows turning vehicles of southern approach to maneuver onto the eastbound road. PC intersection will be closed in this intervention too and there will be no v/c, delays or LOS for it.

Table 5.13 Intervention 2 Data (Morning)

Intersections	Existing conditions					Coordinated conditions				
	v/c	Signal delays	LOS	ICU	ICU LOS	v/c	Signal delays	LOS	ICU	ICU LOS
QM	2.14	133.1	F	117.0 %	H	1.27	92	F	114.5%	H
MH	1.22	46.3	D	81.3%	D	0.97	17.8	B	81.3%	D
GPO	2.59	323.8	F	122.1%	H	1.49	145.3	F	88.0%	E
GHQ	1.73	202.2	F	115.4%	H	1.13	50.9	D	99.3%	F
PC	3.77	289.4	F	126.8%	H	-	-	-	77.0%	D

Table 5.14 Intervention 2 Data (Evening)

Intersections	Existing conditions					Coordinated conditions				
	v/c	Signal delays	LOS	ICU	ICU LOS	v/c	Signal delays	LOS	ICU	ICU LOS
QM	1.61	107.4	F	100.0 %	F	1.15	58.5	E	97.5%	F
MH	1.20	39	D	86.8%	E	0.92	16.6	B	86.8%	E
GPO	2.00	299.7	F	134.2%	H	1.46	135.9	F	105.7%	G
GHQ	1.70	227.0	F	137.6%	H	1.31	92.1	F	107.5%	G
PC	1.84	257.6	F	112.7%	H	-	-	-	63.5%	B

By comparing the values in the above tables, it is concluded that closing the southern approach at GPO will provide beneficial conditions to the traffic flow. There is considerable improvement in the v/c ratios and signal delays. Also, LOS and ICU will also be improved at intersections. These conditions will result in the efficient flow with lower fuel consumption and gas emissions.

Similarly, travel times of the whole corridor will also reduce resulting into the smooth and continuous progression throughout.

5.2.4 Intervention # 03:

In this plan, we have closed both the minor approaches of GPO. Both southern and northern approaches will be closed. PC intersection is closed in this case too. In this intervention, the westbound traffic of the GPO intersection is channelized allowing them to move freely without stopping at the intersection. Free travel will ensure economical fuel consumption and lesser emission. U-turn will be provided for turning movements of northern and southern approaches of PC intersection to allow them to maneuver in desired direction of travel.

Table 5.15 Intervention 3 Data (Morning)

Intersection	Existing conditions					Coordinated conditions				
	v/c	Signal delays	LOS	ICU	ICU LOS	v/c	Signal delays	LOS	ICU	ICU LOS
QM	2.14	133.1	F	117.0 %	H	1.32	99.1	F	117.0%	H
MH	1.22	46.3	D	81.3%	D	0.97	16.9	B	81.3%	D
GPO	2.59	323.8	F	122.1%	H	1.25	62.1	E	68.5%	C
GHQ	1.73	202.2	F	115.4%	H	1.15	61.5	E	99.3%	F
PC	3.77	289.4	F	126.8%	H	-	-	-	77.0%	D

Table 5.16 Intervention 3 Data (Evening)

Intersections	Existing conditions					Coordinated conditions				
	v/c	Signal delays	LOS	ICU	ICU LOS	v/c	Signal delays	LOS	ICU	ICU LOS
QM	2.14	133.1	F	117.0 %	H	1.2	63.6	E	100%	F
MH	1.22	46.3	D	81.3%	D	0.92	13.1	B	86.8%	E
GPO	2.59	323.8	F	122.1%	H	1.33	78.0	E	85.4%	E
GHQ	1.73	202.2	F	115.4%	H	1.33	100	F	107.5	G
PC	3.77	289.4	F	126.8%	H	-	-	-	63.5%	B

Closing minor approaches of GPO has improved the overall performance of the corridor. V/c and signal delays have been significantly improved. These have also improved the LOS of intersections.

5.3 Economic Efficiency Analysis

Economic analysis is the technique that determines the best and suitable option. It sympathizes on cost and benefits of the project whether the benefits outweighs the cost and by how much. In our study, costs are initial construction cost used for the implementation of that intervention and operational/maintenance cost used per year while benefits are the savings that come from the reduced fuel consumption and travel times.

5.3.1 Overview

- Study period of 20 years (2014-2034)
- Annual worth analysis technique
- Weighted average cost of capital (WACC) is 4%

5.3.3 Recommendations

Considering all the possible solutions and analyzing the results. We have come to the solution that intervention 01 is the best possible option for this corridor as it provides the minimum delays, reduced fuel consumption and ensures the efficient flow with minimum travel time. Also, the economic efficiency analysis results that intervention 01 has greater benefits than the other options so intervention 01 is most suitable option.

Intervention 01 suggests the following infrastructural improvements

- Grade Separation at GPO for through traffic (east-west)
- Channelization on GHQ (west through traffic)
- Closing of minor approaches of PC intersection (north-south)

Table 5.17 Annual economic benefits

Details	Signal Coordination	Improvement 1	Improvement 2	Improvement 3
Initial (Construction) Cost (Million)	5	1000	30	40
Operation & Maintenance Cost (Million)	0.5	1	0.6	0.8
Travel Time Benefits (Million)	48.4	269.46	213.6	223
Fuel Consumption Benefits (Million)	83.9	478.8	377.3	390.8
Net benefit (Travel Time) (Million)	47.99	198.46	210.9	219.4
Net Benefit (Fuel Consumption) – (Million)	83.49	407.8	374.6	387.2

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ANNEX-1

Synchro reports for existing conditions

PC Hotel Intersection
Existing Condition

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL2	NBL	NBR	SEL	SER	SER2
Lane Configurations												
Volume (vph)	831	2015	258	190	2153	56	307	245	234	113	624	69
Satd. Flow (prot)	1577	4577	1425	0	6797	0	1577	1787	1568	1497	1367	1425
Flt Permitted	0.950				0.996		0.950	0.950		0.985		
Satd. Flow (perm)	1577	4577	1425	0	6797	0	1577	1787	1568	1497	1367	1425
Satd. Flow (RTOR)			179		4				162			133
Confl. Peds. (#/hr)												
Confl. Bikes (#/hr)												
Peak Hour Factor	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	3%	2%	2%	2%	1%	5%	3%	1%	3%	0%	1%	2%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%		0%		
Shared Lane Traffic (%)											42%	
Lane Group Flow (vph)	848	2056	263	0	2448	0	313	250	239	383	369	70
Turn Type	Split	NA	Perm	Split	NA		Prot	Prot	Perm	Prot	Prot	Free
Protected Phases	4	4		8	8		2	2		6	6	
Permitted Phases			4						2			Free
Total Split (s)	50.0	50.0	50.0	49.0	49.0		26.0	26.0	26.0	14.0	14.0	
Total Lost Time (s)	6.0	6.0	6.0		6.0		4.0	4.0	4.0	4.0	4.0	
Act Effct Green (s)	44.0	44.0	44.0		43.0		22.0	22.0	22.0	10.0	10.0	139.0
Actuated g/C Ratio	0.32	0.32	0.32		0.31		0.16	0.16	0.16	0.07	0.07	1.00
v/c Ratio	1.70	1.42	0.46		1.16		1.26	0.89	0.62	3.58	3.77	0.05
Control Delay	354.2	229.1	14.9		121.6		190.6	88.3	26.0	1200.8	1285.2	0.1
Queue Delay	0.0	0.0	0.0		0.0		0.0	0.0	0.0	0.0	0.0	0.0
Total Delay	354.2	229.1	14.9		121.6		190.6	88.3	26.0	1200.8	1285.2	0.1
LOS	F	F	B		F		F	F	C	F	F	A
Approach Delay		244.8			121.6			109.7		1136.4		
Approach LOS		F			F			F		F		

Intersection Summary	
Cycle Length: 139	
Actuated Cycle Length: 139	
Offset: 40 (29%), Referenced to phase 4:EBTL, Start of Green	
Control Type: Pretimed	
Maximum v/c Ratio: 3.77	
Intersection Signal Delay: 289.4	Intersection LOS: F
Intersection Capacity Utilization 126.8%	ICU Level of Service H
Analysis Period (min) 15	

Splits and Phases: 5: PeshawarRd.#1

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL2	NBL	NBR	SEL	SER	SER2
Lane Configurations												
Volume (vph)	754	2558	322	109	2473	15	179	171	34	27	244	212
Satd. Flow (prot)	1608	4622	1439	0	6838	0	1577	1787	1553	1488	1381	1371
Flt Permitted	0.950				0.998		0.950	0.950		0.990		
Satd. Flow (perm)	1608	4622	1439	0	6838	0	1577	1787	1553	1488	1381	1371
Satd. Flow (RTOR)			176		1				102			223
Confl. Peds. (#/hr)												
Confl. Bikes (#/hr)												
Peak Hour Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	1%	1%	1%	0%	1%	3%	3%	1%	4%	0%	0%	6%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%			0%			0%		0%		
Shared Lane Traffic (%)											45%	
Lane Group Flow (vph)	794	2693	339	0	2734	0	188	180	36	144	141	223
Turn Type	Split	NA	Perm	Split	NA		Prot	Prot	Perm	Prot	Prot	Free
Protected Phases	4	4		8	8		2	2		6	6	
Permitted Phases			4						2			Free
Total Split (s)	50.0	50.0	50.0	49.0	49.0		26.0	26.0	26.0	14.0	14.0	
Total Lost Time (s)	6.0	6.0	6.0		6.0		4.0	4.0	4.0	4.0	4.0	
Act Effct Green (s)	44.0	44.0	44.0		43.0		22.0	22.0	22.0	10.0	10.0	139.0
Actuated g/C Ratio	0.32	0.32	0.32		0.31		0.16	0.16	0.16	0.07	0.07	1.00
v/c Ratio	1.56	1.84	0.59		1.29		0.76	0.64	0.11	1.35	1.42	0.16
Control Delay	294.8	409.9	23.1		174.3		75.5	66.1	0.7	252.0	283.6	0.3
Queue Delay	0.0	0.0	0.0		0.0		0.0	0.0	0.0	0.0	0.0	0.0
Total Delay	294.8	409.9	23.1		174.3		75.5	66.1	0.7	252.0	283.6	0.3
LOS	F	F	C		F		E	E	A	F	F	A
Approach Delay		351.7			174.3			64.6		150.3		
Approach LOS		F			F			E		F		

Intersection Summary	
Cycle Length: 139	
Actuated Cycle Length: 139	
Offset: 40 (29%), Referenced to phase 4:EBTL, Start of Green	
Control Type: Pretimed	
Maximum v/c Ratio: 1.84	
Intersection Signal Delay: 257.6	Intersection LOS: F
Intersection Capacity Utilization 112.7%	ICU Level of Service H
Analysis Period (min) 15	

Splits and Phases: 5: PeshawarRd.#1

GHQ Intersection
Existing Condition

Lane Group	NWL	NWR	NEU	NET	NER	SWU	SWL	SWT
Lane Configurations								
Volume (vph)	516	392	42	1991	444	67	1253	2325
Satd. Flow (prot)	4448	1439	1624	4622	1439	0	3119	4532
Flt Permitted	0.950		0.950				0.950	
Satd. Flow (perm)	4448	1439	1624	4622	1439	0	3119	4532
Satd. Flow (RTOR)		372			77			
Confl. Peds. (#/hr)								
Confl. Bikes (#/hr)								
Peak Hour Factor	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	3%	1%	0%	1%	1%	2%	1%	3%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0
Parking (#/hr)								
Mid-Block Traffic (%)	0%			0%				0%
Shared Lane Traffic (%)								
Lane Group Flow (vph)	521	396	42	2011	448	0	1334	2348
Turn Type	Prot	Perm	Split	NA	Free	Split	Split	NA
Protected Phases	2		4	4		8	8	8
Permitted Phases		2			Free			
Total Split (s)	22.0	22.0	42.0	42.0		36.0	36.0	36.0
Total Lost Time (s)	6.0	6.0	6.0	6.0			6.0	6.0
Act Effct Green (s)	16.0	16.0	36.0	36.0	100.0		30.0	30.0
Actuated g/C Ratio	0.16	0.16	0.36	0.36	1.00		0.30	0.30
v/c Ratio	0.73	0.73	0.07	1.21	0.31		1.43	1.73
Control Delay	46.9	14.4	21.6	130.5	0.6		228.0	356.9
Queue Delay	0.0	0.0	0.0	0.0	0.0		0.0	0.0
Total Delay	46.9	14.4	21.6	130.5	0.6		228.0	356.9
LOS	D	B	C	F	A		F	F
Approach Delay	32.8			105.4				310.2
Approach LOS	C			F				F

Intersection Summary	
Cycle Length: 100	
Actuated Cycle Length: 100	
Offset: 35 (35%), Referenced to phase 4:NETU, Start of Green	
Control Type: Pretimed	
Maximum v/c Ratio: 1.73	
Intersection Signal Delay: 202.2	Intersection LOS: F
Intersection Capacity Utilization 115.4%	ICU Level of Service H
Analysis Period (min) 15	

Splits and Phases: 4: PeshawarRd.#1

GHQ Intersection
Existing Conditions
Evening

Lane Group	NWL	NWR	NEU	NET	NER	SWU	SWL	SWT
Lane Configurations								
Volume (vph)	878	729	103	2309	583	58	1094	2224
Satd. Flow (prot)	4536	1425	1624	4577	1425	0	3108	4532
Flt Permitted	0.950		0.950				0.950	
Satd. Flow (perm)	4536	1425	1624	4577	1425	0	3108	4532
Satd. Flow (RTOR)		385			87			
Confl. Peds. (#/hr)								
Confl. Bikes (#/hr)								
Peak Hour Factor	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	1%	2%	0%	2%	2%	9%	1%	3%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0
Parking (#/hr)								
Mid-Block Traffic (%)	0%			0%				0%
Shared Lane Traffic (%)								
Lane Group Flow (vph)	915	759	107	2405	607	0	1200	2317
Turn Type	Prot	Perm	Split	NA	Free	Split	Split	NA
Protected Phases	2		4	4		8	8	8
Permitted Phases		2			Free			
Total Split (s)	22.0	22.0	42.0	42.0		36.0	36.0	36.0
Total Lost Time (s)	6.0	6.0	6.0	6.0			6.0	6.0
Act Effct Green (s)	16.0	16.0	36.0	36.0	100.0		30.0	30.0
Actuated g/C Ratio	0.16	0.16	0.36	0.36	1.00		0.30	0.30
v/c Ratio	1.26	1.38	0.18	1.46	0.43		1.29	1.70
Control Delay	165.2	199.7	23.0	238.5	0.9		169.0	347.0
Queue Delay	0.0	0.0	0.0	0.0	0.0		0.0	0.0
Total Delay	165.2	199.7	23.0	238.5	0.9		169.0	347.0
LOS	F	F	C	F	A		F	F
Approach Delay	180.8			184.8				286.3
Approach LOS	F			F				F

Intersection Summary

Cycle Length: 100
Actuated Cycle Length: 100
Offset: 35 (35%), Referenced to phase 4:NETU, Start of Green
Control Type: Pretimed
Maximum v/c Ratio: 1.70
Intersection Signal Delay: 227.0 Intersection LOS: F
Intersection Capacity Utilization 137.6% ICU Level of Service H
Analysis Period (min) 15

Splits and Phases: 4: PeshawarRd.#1

GPO Intersection
Existing Condition

Lane Group	SEL	SET	SER	NWU	NWL	NWT	NWR	NEU	NEL	NET	NER	SWU
Lane Configurations												
Volume (vph)	486	695	170	31	196	311	78	124	128	1873	171	65
Satd. Flow (prot)	1448	2867	1295	0	1396	2734	1235	0	1501	4272	1308	0
Flt Permitted	0.950				0.950				0.950			
Satd. Flow (perm)	1448	2867	1295	0	1396	2734	1235	0	1501	4272	1308	0
Satd. Flow (RTOR)			155				155				178	
Confl. Peds. (#/hr)												
Confl. Bikes (#/hr)												
Peak Hour Factor	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	1%	2%	1%	0%	1%	3%	2%	0%	2%	2%	0%	0%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%				0%				0%		
Shared Lane Traffic (%)												
Lane Group Flow (vph)	506	724	177	0	236	324	81	0	262	1951	178	0
Turn Type	Split	NA	Free	Split	Split	NA	Free	Split	Split	NA	Free	Split
Protected Phases	6	6		2	2	2		4	4	4		8
Permitted Phases			Free				Free				Free	
Total Split (s)	26.0	26.0		26.0	26.0	26.0		49.0	49.0	49.0		47.0
Total Lost Time (s)	6.0	6.0			6.0	6.0			6.0	6.0		
Act Effct Green (s)	20.0	20.0	148.0		20.0	20.0	148.0		43.0	43.0	148.0	
Actuated g/C Ratio	0.14	0.14	1.00		0.14	0.14	1.00		0.29	0.29	1.00	
v/c Ratio	2.59	1.87	0.14		1.26	0.88	0.07		0.60	1.57	0.14	
Control Delay	756.1	434.8	0.2		200.7	87.0	0.1		52.0	296.5	0.2	
Queue Delay	0.0	0.0	0.0		0.0	0.0	0.0		0.0	0.0	0.0	
Total Delay	756.1	434.8	0.2		200.7	87.0	0.1		52.0	296.5	0.2	
LOS	F	F	A		F	F	A		D	F	A	
Approach Delay		495.7				117.9				247.6		
Approach LOS		F				F				F		

Intersection Summary	
Cycle Length: 148	
Actuated Cycle Length: 148	
Offset: 52 (35%), Referenced to phase 4:NETL, Start of Green	
Control Type: Pretimed	
Maximum v/c Ratio: 2.59	
Intersection Signal Delay: 323.8	Intersection LOS: F
Intersection Capacity Utilization 122.1%	ICU Level of Service H
Analysis Period (min) 15	

Splits and Phases: 3: PeshawarRd.#1

Lane Group	SWL	SWT	SWR
Lane Configurations			
Volume (vph)	43	2194	502
Satd. Flow (prot)	1516	4314	1330
Flt Permitted	0.950		
Satd. Flow (perm)	1516	4314	1330
Satd. Flow (RTOR)			155
Confl. Peds. (#/hr)			
Confl. Bikes (#/hr)			
Peak Hour Factor	0.96	0.96	0.96
Growth Factor	100%	100%	100%
Heavy Vehicles (%)	0%	1%	2%
Bus Blockages (#/hr)	0	0	0
Parking (#/hr)			
Mid-Block Traffic (%)		0%	
Shared Lane Traffic (%)			
Lane Group Flow (vph)	113	2285	523
Turn Type	Split	NA	Free
Protected Phases	8	8	
Permitted Phases			Free
Total Split (s)	47.0	47.0	
Total Lost Time (s)	6.0	6.0	
Act Effct Green (s)	41.0	41.0	148.0
Actuated g/C Ratio	0.28	0.28	1.00
v/c Ratio	0.27	1.91	0.39
Control Delay	44.0	443.2	0.9
Queue Delay	0.0	0.0	0.0
Total Delay	44.0	443.2	0.9
LOS	D	F	A
Approach Delay		348.5	
Approach LOS		F	

Intersection Summary

Lane Group	SEL	SET	SER	NWU	NWL	NWT	NWR	NEU	NEL	NET	NER	SWU
Lane Configurations												
Volume (vph)	298	509	143	38	275	442	336	145	267	2135	462	64
Satd. Flow (prot)	1448	2895	1223	0	1360	2816	1260	0	1487	4230	1308	0
Flt Permitted	0.950				0.950				0.950			
Satd. Flow (perm)	1448	2895	1223	0	1360	2816	1260	0	1487	4230	1308	0
Satd. Flow (RTOR)			155				155				486	
Confl. Peds. (#/hr)												
Confl. Bikes (#/hr)												
Peak Hour Factor	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	1%	1%	7%	0%	4%	0%	0%	0%	3%	3%	0%	0%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0
Parking (#/hr)												
Mid-Block Traffic (%)		0%				0%				0%		
Shared Lane Traffic (%)												
Lane Group Flow (vph)	314	536	151	0	329	465	354	0	434	2247	486	0
Turn Type	Split	NA	Free	Split	Split	NA	Free	Split	Split	NA	Free	Split
Protected Phases	6	6		2	2	2		4	4	4		8
Permitted Phases			Free				Free				Free	
Total Split (s)	26.0	26.0		26.0	26.0	26.0		49.0	49.0	49.0		47.0
Total Lost Time (s)	6.0	6.0			6.0	6.0			6.0	6.0		
Act Effct Green (s)	20.0	20.0	148.0		20.0	20.0	148.0		43.0	43.0	148.0	
Actuated g/C Ratio	0.14	0.14	1.00		0.14	0.14	1.00		0.29	0.29	1.00	
v/c Ratio	1.61	1.37	0.12		1.80	1.22	0.28		1.00	1.83	0.37	
Control Delay	335.9	228.3	0.2		414.6	173.5	0.6		96.1	407.2	0.8	
Queue Delay	0.0	0.0	0.0		0.0	0.0	0.0		0.0	0.0	0.0	
Total Delay	335.9	228.3	0.2		414.6	173.5	0.6		96.1	407.2	0.8	
LOS	F	F	A		F	F	A		F	F	A	
Approach Delay		227.7				189.2				302.2		
Approach LOS		F				F				F		

Intersection Summary	
Cycle Length: 148	
Actuated Cycle Length: 148	
Offset: 52 (35%), Referenced to phase 4:NETL, Start of Green	
Control Type: Pretimed	
Maximum v/c Ratio: 2.00	
Intersection Signal Delay: 299.7	Intersection LOS: F
Intersection Capacity Utilization 134.2%	ICU Level of Service H
Analysis Period (min) 15	

Splits and Phases: 3: PeshawarRd.#1

Lane Group	SWL	SWT	SWR
Lane Configurations			
Volume (vph)	479	2207	616
Satd. Flow (prot)	1490	4190	1268
Flt Permitted	0.950		
Satd. Flow (perm)	1490	4190	1268
Satd. Flow (RTOR)			155
Confl. Peds. (#/hr)			
Confl. Bikes (#/hr)			
Peak Hour Factor	0.95	0.95	0.95
Growth Factor	100%	100%	100%
Heavy Vehicles (%)	2%	4%	7%
Bus Blockages (#/hr)	0	0	0
Parking (#/hr)			
Mid-Block Traffic (%)		0%	
Shared Lane Traffic (%)			
Lane Group Flow (vph)	571	2323	648
Turn Type	Split	NA	Free
Protected Phases	8	8	
Permitted Phases			Free
Total Split (s)	47.0	47.0	
Total Lost Time (s)	6.0	6.0	
Act Effct Green (s)	41.0	41.0	148.0
Actuated g/C Ratio	0.28	0.28	1.00
v/c Ratio	1.39	2.00	0.51
Control Delay	228.0	482.6	1.5
Queue Delay	0.0	0.0	0.0
Total Delay	228.0	482.6	1.5
LOS	F	F	A
Approach Delay		353.5	
Approach LOS		F	

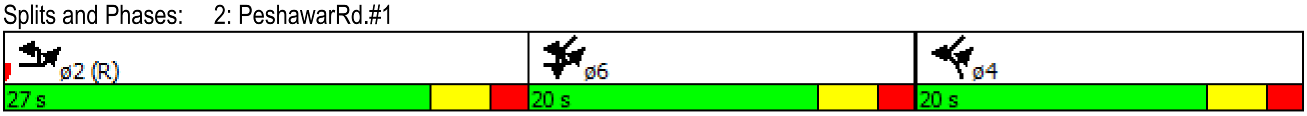
Intersection Summary

Millitary Hospital Intersection
Existing Condition

Lane Group	EBU	EBL	EBR	NBL	NBR	SWU	SWL	SWR
Lane Configurations								
Volume (vph)	442	2258	944	732	154	373	422	1808
Satd. Flow (prot)	1652	5797	1439	4536	1411	0	3236	3249
Flt Permitted	0.950	0.950		0.950			0.950	
Satd. Flow (perm)	1652	5797	1439	4536	1411	0	3236	3249
Satd. Flow (RTOR)			470		143			699
Confl. Peds. (#/hr)								
Confl. Bikes (#/hr)								
Peak Hour Factor	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	2%	2%	1%	1%	3%	1%	1%	2%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0
Parking (#/hr)								
Mid-Block Traffic (%)		0%		0%			0%	
Shared Lane Traffic (%)								
Lane Group Flow (vph)	456	2328	973	755	159	0	820	1864
Turn Type	Prot	Prot	Free	Prot	Free	Prot	Prot	Free
Protected Phases	2 6	2		4		4 6	6	
Permitted Phases			Free		Free			Free
Total Split (s)		27.0		20.0			20.0	
Total Lost Time (s)		5.0		5.0			5.0	
Act Effct Green (s)	42.0	22.0	67.0	15.0	67.0		35.0	67.0
Actuated g/C Ratio	0.63	0.33	1.00	0.22	1.00		0.52	1.00
v/c Ratio	0.44	1.22	0.68	0.74	0.11		0.49	0.57
Control Delay	8.1	129.5	2.6	29.4	0.2		11.5	0.7
Queue Delay	0.0	0.0	0.0	0.0	0.0		0.0	0.0
Total Delay	8.1	129.5	2.6	29.4	0.2		11.5	0.7
LOS	A	F	A	C	A		B	A
Approach Delay		81.9		24.3			4.0	
Approach LOS		F		C			A	

Intersection Summary	
Cycle Length: 67	
Actuated Cycle Length: 67	
Offset: 39 (58%), Referenced to phase 2:EBL, Start of Green	
Control Type: Pretimed	
Maximum v/c Ratio: 1.22	
Intersection Signal Delay: 46.3	Intersection LOS: D
Intersection Capacity Utilization 81.3%	ICU Level of Service D
Analysis Period (min) 15	

Splits and Phases: 2: PeshawarRd.#1

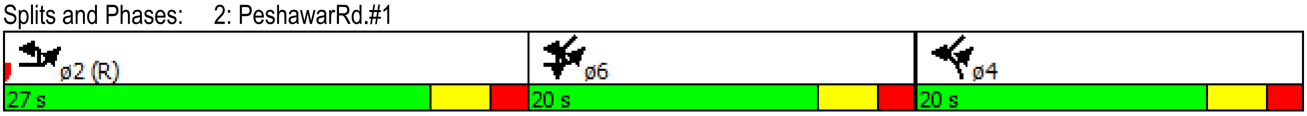


Lane Group	EBU	EBL	EBR	NBL	NBR	SWU	SWL	SWR
Lane Configurations								
Volume (vph)	706	2191	786	554	253	407	457	2338
Satd. Flow (prot)	1652	5797	1439	4536	1425	0	3268	3217
Flt Permitted	0.950	0.950		0.950			0.950	
Satd. Flow (perm)	1652	5797	1439	4536	1425	0	3268	3217
Satd. Flow (RTOR)			404		220			405
Confl. Peds. (#/hr)								
Confl. Bikes (#/hr)								
Peak Hour Factor	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96
Growth Factor	100%	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	2%	2%	1%	1%	2%	0%	0%	3%
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0
Parking (#/hr)								
Mid-Block Traffic (%)		0%		0%			0%	
Shared Lane Traffic (%)								
Lane Group Flow (vph)	735	2282	819	577	264	0	900	2435
Turn Type	Prot	Prot	Free	Prot	Free	Prot	Prot	Free
Protected Phases	2 6	2		4		4 6	6	
Permitted Phases			Free		Free			Free
Total Split (s)		27.0		20.0			20.0	
Total Lost Time (s)		5.0		5.0			5.0	
Act Effct Green (s)	42.0	22.0	67.0	15.0	67.0		35.0	67.0
Actuated g/C Ratio	0.63	0.33	1.00	0.22	1.00		0.52	1.00
v/c Ratio	0.71	1.20	0.57	0.57	0.19		0.53	0.76
Control Delay	13.3	119.1	1.6	25.7	0.3		12.0	1.7
Queue Delay	0.0	0.0	0.0	0.0	0.0		0.0	0.0
Total Delay	13.3	119.1	1.6	25.7	0.3		12.0	1.7
LOS	B	F	A	C	A		B	A
Approach Delay		73.7		17.7			4.5	
Approach LOS		E		B			A	

Intersection Summary

Cycle Length: 67
Actuated Cycle Length: 67
Offset: 39 (58%), Referenced to phase 2:EBL, Start of Green
Control Type: Pretimed
Maximum v/c Ratio: 1.20
Intersection Signal Delay: 39.0 — Intersection LOS: D
Intersection Capacity Utilization 86.8% — ICU Level of Service E
Analysis Period (min) 15

Splits and Phases: 2: PeshawarRd.#1

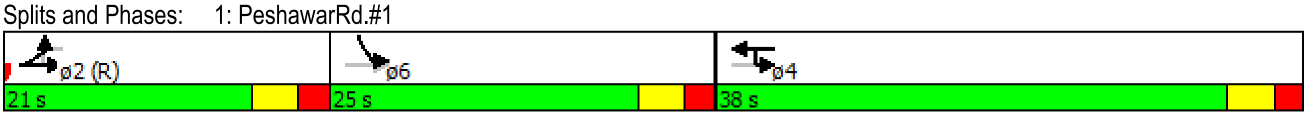


Lane Group	EBL	EBT	WBU	WBT	WBR	SBL	SBR
Lane Configurations							
Volume (vph)	843	2188	422	2382	401	784	476
Satd. Flow (prot)	3030	4532	1608	4577	1454	4581	1384
Flt Permitted	0.950		0.267			0.950	
Satd. Flow (perm)	3030	4532	452	4577	1454	4581	1384
Satd. Flow (RTOR)					79		330
Confl. Peds. (#/hr)							
Confl. Bikes (#/hr)							
Peak Hour Factor	0.97	0.97	0.97	0.97	0.97	0.97	0.97
Growth Factor	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	4%	3%	1%	2%	0%	0%	5%
Bus Blockages (#/hr)	0	0	0	0	0	0	0
Parking (#/hr)							
Mid-Block Traffic (%)		0%		0%		0%	
Shared Lane Traffic (%)							
Lane Group Flow (vph)	869	2256	435	2456	413	808	491
Turn Type	Split	NA	D.P+P	NA	Free	Prot	Free
Protected Phases	2	2	4	4		6	
Permitted Phases		4 6	2		Free		Free
Total Split (s)	21.0	21.0	38.0	38.0		25.0	
Total Lost Time (s)	6.0	5.0	6.0	6.0		6.0	
Act Effct Green (s)	15.0	84.0	47.0	32.0	84.0	19.0	84.0
Actuated g/C Ratio	0.18	1.00	0.56	0.38	1.00	0.23	1.00
v/c Ratio	1.61	0.50	0.63	1.41	0.28	0.78	0.35
Control Delay	308.8	0.4	17.2	213.0	0.5	36.7	0.7
Queue Delay	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Delay	308.8	0.4	17.2	213.0	0.5	36.7	0.7
LOS	F	A	B	F	A	D	A
Approach Delay		86.2		160.7		23.1	
Approach LOS		F		F		C	

Intersection Summary

Cycle Length: 84
Actuated Cycle Length: 84
Offset: 25 (30%), Referenced to phase 2:EBWB, Start of Green
Control Type: Pretimed
Maximum v/c Ratio: 1.61
Intersection Signal Delay: 107.4 Intersection LOS: F
Intersection Capacity Utilization 100.0% ICU Level of Service F
Analysis Period (min) 15
Description: Qasim Market Intersection

Splits and Phases: 1: PeshawarRd.#1



Lane Group	EBL	EBT	WBU	WBT	WBR	SBL	SBR
Lane Configurations							
Volume (vph)	1166	2305	543	1899	145	1482	1130
Satd. Flow (prot)	3090	4622	1608	4622	1439	4536	1398
Flt Permitted	0.950		0.267			0.950	
Satd. Flow (perm)	3090	4622	452	4622	1439	4536	1398
Satd. Flow (RTOR)					36		414
Confl. Peds. (#/hr)							
Confl. Bikes (#/hr)							
Peak Hour Factor	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Growth Factor	100%	100%	100%	100%	100%	100%	100%
Heavy Vehicles (%)	2%	1%	1%	1%	1%	1%	4%
Bus Blockages (#/hr)	0	0	0	0	0	0	0
Parking (#/hr)							
Mid-Block Traffic (%)		0%		0%		0%	
Shared Lane Traffic (%)							
Lane Group Flow (vph)	1178	2328	548	1918	146	1497	1141
Turn Type	Split	NA	D.P+P	NA	Free	Prot	Free
Protected Phases	2	2	4	4		6	
Permitted Phases		4 6	2		Free		Free
Total Split (s)	21.0	21.0	38.0	38.0		25.0	
Total Lost Time (s)	6.0	5.0	6.0	6.0		6.0	
Act Effct Green (s)	15.0	84.0	47.0	32.0	84.0	19.0	84.0
Actuated g/C Ratio	0.18	1.00	0.56	0.38	1.00	0.23	1.00
v/c Ratio	2.14	0.50	0.79	1.09	0.10	1.46	0.82
Control Delay	540.6	0.4	25.5	77.2	0.1	240.2	5.6
Queue Delay	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Delay	540.6	0.4	25.5	77.2	0.1	240.2	5.6
LOS	F	A	C	E	A	F	A
Approach Delay		181.9		62.0		138.8	
Approach LOS		F		E		F	

Intersection Summary	
Cycle Length: 84	
Actuated Cycle Length: 84	
Offset: 25 (30%), Referenced to phase 2:EBWB, Start of Green	
Control Type: Pretimed	
Maximum v/c Ratio: 2.14	
Intersection Signal Delay: 133.1	Intersection LOS: F
Intersection Capacity Utilization 117.0%	ICU Level of Service H
Analysis Period (min) 15	
Description: Qasim Market Intersection	

Splits and Phases: 1: PeshawarRd.#1

1: PeshawarRd.#1

Direction	All
Volume (vph)	8670
Total Delay / Veh (s/v)	133
Stops / Veh	0.46
Fuel Consumed (gal)	370
Fuel Economy (mpg)	7.3

2: PeshawarRd.#1

Direction	All
Volume (vph)	7133
Total Delay / Veh (s/v)	46
Stops / Veh	0.45
Fuel Consumed (gal)	223
Fuel Economy (mpg)	15.6

3: PeshawarRd.#1

Direction	All
Volume (vph)	7067
Total Delay / Veh (s/v)	324
Stops / Veh	0.60
Fuel Consumed (gal)	571
Fuel Economy (mpg)	3.5

4: PeshawarRd.#1

Direction	All
Volume (vph)	7031
Total Delay / Veh (s/v)	202
Stops / Veh	0.70
Fuel Consumed (gal)	402
Fuel Economy (mpg)	4.8

5: PeshawarRd.#1

Direction	All
Volume (vph)	7095
Total Delay / Veh (s/v)	289
Stops / Veh	0.74
Fuel Consumed (gal)	519
Fuel Economy (mpg)	3.1

1: PeshawarRd.#1

Direction	All
Volume (vph)	7496
Total Delay / Veh (s/v)	107
Stops / Veh	0.46
Fuel Consumed (gal)	294
Fuel Economy (mpg)	9.3

2: PeshawarRd.#1

Direction	All
Volume (vph)	7692
Total Delay / Veh (s/v)	39
Stops / Veh	0.43
Fuel Consumed (gal)	226
Fuel Economy (mpg)	16.4

3: PeshawarRd.#1

Direction	All
Volume (vph)	8415
Total Delay / Veh (s/v)	300
Stops / Veh	0.56
Fuel Consumed (gal)	644
Fuel Economy (mpg)	3.8

4: PeshawarRd.#1

Direction	All
Volume (vph)	7978
Total Delay / Veh (s/v)	227
Stops / Veh	0.66
Fuel Consumed (gal)	492
Fuel Economy (mpg)	4.2

5: PeshawarRd.#1

Direction	All
Volume (vph)	7098
Total Delay / Veh (s/v)	258
Stops / Veh	0.69
Fuel Consumed (gal)	477
Fuel Economy (mpg)	3.5

ANNEX-2

Synchro reports for Infrastructural Intervention 1

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	SEL	SET	SER	NWL	NWT	NWR
Lane Configurations												
Volume (vph)	0	2959	1072	0	2650	1132	0	0	806	0	0	786
Satd. Flow (prot)	0	5767	1439	0	5824	1425	0	0	2533	0	0	2508
Flt Permitted												
Satd. Flow (perm)	0	5767	1439	0	5824	1425	0	0	2533	0	0	2508
Lane Group Flow (vph)	0	3019	1094	0	2704	1155	0	0	822	0	0	802
Sign Control		Free			Free			Free			Free	

Intersection Summary	
Control Type: Unsignalized	
Intersection Capacity Utilization 77.0%	ICU Level of Service D
Analysis Period (min) 15	

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	SEL	SET	SER	NWL	NWT	NWR
Lane Configurations												
Volume (vph)	0	3312	675	0	2753	769	0	0	483	0	0	205
Satd. Flow (prot)	0	5824	1439	0	5824	1439	0	0	2484	0	0	2533
Flt Permitted												
Satd. Flow (perm)	0	5824	1439	0	5824	1439	0	0	2484	0	0	2533
Lane Group Flow (vph)	0	3380	689	0	2809	785	0	0	493	0	0	209
Sign Control		Free			Free			Free			Free	

Intersection Summary	
Control Type: Unsignalized	
Intersection Capacity Utilization 63.5%	ICU Level of Service B
Analysis Period (min) 15	

Lane Group	NWL	NWR	NEU	NET	NER	SWU	SWL	SWT	ø8
Lane Configurations									
Volume (vph)	516	392	42	1991	444	67	1253	2325	
Satd. Flow (prot)	4448	1439	0	5820	1439	0	3119	4532	
Flt Permitted	0.950			0.885			0.950		
Satd. Flow (perm)	4448	1439	0	5155	1439	0	3119	4532	
Satd. Flow (RTOR)		195			54				
Lane Group Flow (vph)	521	396	0	2053	448	0	1334	2348	
Turn Type	NA	Free	Prot	NA	Free	Prot	Prot	NA	
Protected Phases	2		7	7 8		4	4	4 8	8
Permitted Phases		Free			Free				
Detector Phase	2		7	7 8		4	4	4 8	
Switch Phase									
Minimum Initial (s)	4.0		4.0			4.0	4.0		4.0
Minimum Split (s)	20.0		20.0			20.0	20.0		20.0
Total Split (s)	21.0		43.0			66.0	66.0		20.0
Total Split (%)	14.0%		28.7%			44.0%	44.0%		13%
Yellow Time (s)	3.5		3.5			3.5	3.5		3.5
All-Red Time (s)	0.5		0.5			0.5	0.5		0.5
Lost Time Adjust (s)	0.0						0.0		
Total Lost Time (s)	4.0						4.0		
Lead/Lag			Lag						Lead
Lead-Lag Optimize?			Yes						Yes
Recall Mode	C-Max		None			None	None		None
Act Effct Green (s)	17.0	150.0		55.0	150.0		62.0	82.0	
Actuated g/C Ratio	0.11	1.00		0.37	1.00		0.41	0.55	
v/c Ratio	1.03	0.28		1.10	0.31		1.03	0.95	
Control Delay	112.3	0.5		96.0	0.6		77.2	41.6	
Queue Delay	0.0	0.0		0.0	0.0		0.0	0.0	
Total Delay	112.3	0.5		96.0	0.6		77.2	41.6	
LOS	F	A		F	A		E	D	
Approach Delay	64.0			78.9				54.5	
Approach LOS	E			E				D	

Intersection Summary	
Cycle Length: 150	
Actuated Cycle Length: 150	
Offset: 92 (61%), Referenced to phase 2:NWL, Start of Green	
Natural Cycle: 150	
Control Type: Actuated-Coordinated	
Maximum v/c Ratio: 1.10	
Intersection Signal Delay: 64.4	Intersection LOS: E
Intersection Capacity Utilization 94.2%	ICU Level of Service F
Analysis Period (min) 15	

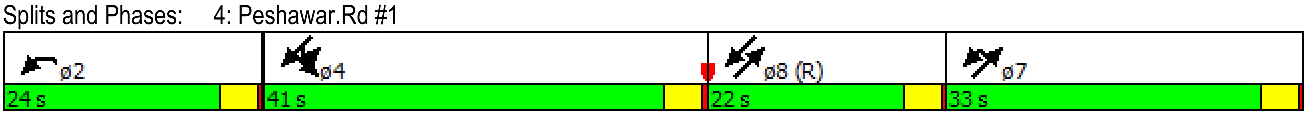
Splits and Phases: 4: PeshawarRd.#1

Lane Group	NWL	NWR	NEU	NET	NER	SWU	SWL	SWT	ø8
Lane Configurations									
Volume (vph)	878	729	103	2309	583	58	1094	2224	
Satd. Flow (prot)	4536	1425	1624	4577	1425	0	3108	4532	
Flt Permitted	0.950		0.950				0.950		
Satd. Flow (perm)	4536	1425	1624	4577	1425	0	3108	4532	
Satd. Flow (RTOR)		267			62				
Lane Group Flow (vph)	915	759	107	2405	607	0	1200	2317	
Turn Type	NA	Free	Prot	NA	Free	Prot	Prot	NA	
Protected Phases	2		7	7 8		4	4	4 8	8
Permitted Phases		Free			Free				
Detector Phase	2		7	7 8		4	4	4 8	
Switch Phase									
Minimum Initial (s)	4.0		4.0			4.0	4.0		4.0
Minimum Split (s)	20.0		20.0			20.0	20.0		20.0
Total Split (s)	24.0		33.0			41.0	41.0		22.0
Total Split (%)	20.0%		27.5%			34.2%	34.2%		18%
Yellow Time (s)	3.5		3.5			3.5	3.5		3.5
All-Red Time (s)	0.5		0.5			0.5	0.5		0.5
Lost Time Adjust (s)	0.0		0.0				0.0		
Total Lost Time (s)	4.0		4.0				4.0		
Lead/Lag			Lag						Lead
Lead-Lag Optimize?			Yes						Yes
Recall Mode	Max		None			None	None		C-Max
Act Effct Green (s)	20.0	120.0	29.0	51.0	120.0		37.0	59.0	
Actuated g/C Ratio	0.17	1.00	0.24	0.42	1.00		0.31	0.49	
v/c Ratio	1.21	0.53	0.27	1.24	0.43		1.25	1.04	
Control Delay	149.5	1.4	38.2	142.0	0.9		158.4	60.9	
Queue Delay	0.0	0.0	0.0	0.0	0.0		0.0	0.0	
Total Delay	149.5	1.4	38.2	142.0	0.9		158.4	60.9	
LOS	F	A	D	F	A		F	E	
Approach Delay	82.4			111.0				94.2	
Approach LOS	F			F				F	

Intersection Summary

Cycle Length: 120
Actuated Cycle Length: 120
Offset: 0 (0%), Referenced to phase 8:NESW, Start of Green
Natural Cycle: 110
Control Type: Actuated-Coordinated
Maximum v/c Ratio: 1.25
Intersection Signal Delay: 98.1 Intersection LOS: F
Intersection Capacity Utilization 104.2% ICU Level of Service G
Analysis Period (min) 15

Splits and Phases: 4: Peshawar.Rd #1



Lane Group	SEL	SET	SER	NWU	NWL	NWT	NWR	NEU	NEL	NET	NER	SWU
Lane Configurations												
Volume (vph)	486	695	170	31	196	311	78	124	128	0	171	65
Satd. Flow (prot)	1448	2867	1295	0	1320	2708	1283	0	2808	0	1308	0
Flt Permitted	0.950				0.950	0.993			0.950			
Satd. Flow (perm)	1448	2867	1295	0	1320	2708	1283	0	2808	0	1308	0
Satd. Flow (RTOR)			177				131				178	
Lane Group Flow (vph)	506	724	177	0	181	379	81	0	262	0	178	0
Turn Type	Split	NA	Free	Split	Split	NA	Free	custom	custom		Free	custom
Protected Phases	6	6		2	2	2						
Permitted Phases			Free				Free	4	4		Free	8
Detector Phase	6	6		2	2	2		4	4			8
Switch Phase												
Minimum Initial (s)	4.0	4.0		4.0	4.0	4.0		4.0	4.0			4.0
Minimum Split (s)	20.0	20.0		20.0	20.0	20.0		20.0	20.0			20.0
Total Split (s)	35.0	35.0		20.0	20.0	20.0		20.0	20.0			20.0
Total Split (%)	46.7%	46.7%		26.7%	26.7%	26.7%		26.7%	26.7%			26.7%
Yellow Time (s)	3.5	3.5		3.5	3.5	3.5		3.5	3.5			3.5
All-Red Time (s)	0.5	0.5		0.5	0.5	0.5		0.5	0.5			0.5
Lost Time Adjust (s)	0.0	0.0			0.0	0.0			0.0			
Total Lost Time (s)	4.0	4.0			4.0	4.0			4.0			
Lead/Lag												
Lead-Lag Optimize?												
Recall Mode	None	None		C-Max	C-Max	C-Max		None	None			None
Act Effct Green (s)	29.7	29.7	75.0		21.1	21.1	75.0		12.2		75.0	
Actuated g/C Ratio	0.40	0.40	1.00		0.28	0.28	1.00		0.16		1.00	
v/c Ratio	0.88	0.64	0.14		0.49	0.50	0.06		0.57		0.14	
Control Delay	40.3	21.1	0.2		30.2	26.7	0.1		17.2		0.1	
Queue Delay	0.0	0.0	0.0		0.0	0.0	0.0		0.0		0.0	
Total Delay	40.3	21.1	0.2		30.2	26.7	0.1		17.2		0.1	
LOS	D	C	A		C	C	A		B		A	
Approach Delay		25.3				24.3						
Approach LOS		C				C						

Intersection Summary	
Cycle Length: 75	
Actuated Cycle Length: 75	
Offset: 74 (99%), Referenced to phase 2:NWTL, Start of Green	
Natural Cycle: 70	
Control Type: Actuated-Coordinated	
Maximum v/c Ratio: 0.88	
Intersection Signal Delay: 18.8	Intersection LOS: B
Intersection Capacity Utilization 59.2%	ICU Level of Service B
Analysis Period (min) 15	

Splits and Phases: 3:

Lane Group	SWL	SWT	SWR
Lane Configurations			
Volume (vph)	43	0	502
Satd. Flow (prot)	2836	0	1283
Flt Permitted	0.950		
Satd. Flow (perm)	2836	0	1283
Satd. Flow (RTOR)			523
Lane Group Flow (vph)	113	0	523
Turn Type	custom		Free
Protected Phases			
Permitted Phases	8		Free
Detector Phase	8		
Switch Phase			
Minimum Initial (s)	4.0		
Minimum Split (s)	20.0		
Total Split (s)	20.0		
Total Split (%)	26.7%		
Yellow Time (s)	3.5		
All-Red Time (s)	0.5		
Lost Time Adjust (s)	0.0		
Total Lost Time (s)	4.0		
Lead/Lag			
Lead-Lag Optimize?			
Recall Mode	None		
Act Effct Green (s)	12.2		75.0
Actuated g/C Ratio	0.16		1.00
v/c Ratio	0.25		0.41
Control Delay	24.2		0.3
Queue Delay	0.0		0.0
Total Delay	24.2		0.3
LOS	C		A
Approach Delay			
Approach LOS			

Intersection Summary

Lane Group	SEL	SET	SER	NWU	NWL	NWT	NWR	NEU	NEL	NET	NER	SWU
Lane Configurations												
Volume (vph)	298	509	143	38	275	442	336	145	267	0	462	64
Satd. Flow (prot)	1608	3217	1358	0	1466	3008	1425	0	3091	0	1454	0
Flt Permitted	0.950				0.950	0.993			0.950			
Satd. Flow (perm)	1608	3217	1358	0	1466	3008	1425	0	3091	0	1454	0
Satd. Flow (RTOR)			164				164				355	
Lane Group Flow (vph)	314	536	151	0	257	537	354	0	434	0	486	0
Turn Type	Split	NA	Free	Split	Split	NA	Free	custom	custom		Free	custom
Protected Phases	6	6		2	2	2						
Permitted Phases			Free				Free	4	4		Free	8
Detector Phase	6	6		2	2	2		4	4			8
Switch Phase												
Minimum Initial (s)	4.0	4.0		4.0	4.0	4.0		4.0	4.0			4.0
Minimum Split (s)	20.0	20.0		20.0	20.0	20.0		20.0	20.0			20.0
Total Split (s)	20.0	20.0		20.0	20.0	20.0		20.0	20.0			20.0
Total Split (%)	33.3%	33.3%		33.3%	33.3%	33.3%		33.3%	33.3%			33.3%
Yellow Time (s)	3.5	3.5		3.5	3.5	3.5		3.5	3.5			3.5
All-Red Time (s)	0.5	0.5		0.5	0.5	0.5		0.5	0.5			0.5
Lost Time Adjust (s)	0.0	0.0			0.0	0.0			0.0			
Total Lost Time (s)	4.0	4.0			4.0	4.0			4.0			
Lead/Lag												
Lead-Lag Optimize?												
Recall Mode	None	None		C-Max	C-Max	C-Max		None	None			None
Act Effct Green (s)	14.9	14.9	60.0		18.3	18.3	60.0		14.8		60.0	
Actuated g/C Ratio	0.25	0.25	1.00		0.30	0.30	1.00		0.25		1.00	
v/c Ratio	0.79	0.67	0.11		0.57	0.58	0.25		0.57		0.33	
Control Delay	37.0	24.8	0.2		25.6	21.7	0.4		22.8		0.6	
Queue Delay	0.0	0.0	0.0		0.0	0.0	0.0		0.0		0.0	
Total Delay	37.0	24.8	0.2		25.6	21.7	0.4		22.8		0.6	
LOS	D	C	A		C	C	A		C		A	
Approach Delay		24.9				16.0						
Approach LOS		C				B						

Intersection Summary	
Cycle Length: 60	
Actuated Cycle Length: 60	
Offset: 46 (77%), Referenced to phase 2:NWTL, Start of Green	
Natural Cycle: 60	
Control Type: Actuated-Coordinated	
Maximum v/c Ratio: 0.79	
Intersection Signal Delay: 15.1	Intersection LOS: B
Intersection Capacity Utilization 56.2%	ICU Level of Service B
Analysis Period (min) 15	

Splits and Phases: 3:

Lane Group	SWL	SWT	SWR
Lane Configurations			
Volume (vph)	479	0	616
Satd. Flow (prot)	3097	0	1358
Flt Permitted	0.950		
Satd. Flow (perm)	3097	0	1358
Satd. Flow (RTOR)			492
Lane Group Flow (vph)	571	0	648
Turn Type	custom		Free
Protected Phases			
Permitted Phases	8		Free
Detector Phase	8		
Switch Phase			
Minimum Initial (s)	4.0		
Minimum Split (s)	20.0		
Total Split (s)	20.0		
Total Split (%)	33.3%		
Yellow Time (s)	3.5		
All-Red Time (s)	0.5		
Lost Time Adjust (s)	0.0		
Total Lost Time (s)	4.0		
Lead/Lag			
Lead-Lag Optimize?			
Recall Mode	None		
Act Effct Green (s)	14.8		60.0
Actuated g/C Ratio	0.25		1.00
v/c Ratio	0.75		0.48
Control Delay	19.3		0.1
Queue Delay	0.0		0.0
Total Delay	19.3		0.1
LOS	B		A
Approach Delay			
Approach LOS			

Intersection Summary

1: Peshawar.Rd #1

Direction	All
Volume (vph)	7496
Total Delay / Veh (s/v)	65
Stops / Veh	0.49
Fuel Consumed (gal)	234
Fuel Economy (mpg)	11.9

2: Peshawar.Rd #1

Direction	All
Volume (vph)	7692
Total Delay / Veh (s/v)	39
Stops / Veh	0.45
Fuel Consumed (gal)	203
Fuel Economy (mpg)	15.0

3: Peshawar.Rd #1

Direction	All
Volume (vph)	4072
Total Delay / Veh (s/v)	15
Stops / Veh	0.51
Fuel Consumed (gal)	55
Fuel Economy (mpg)	11.8

4: Peshawar.Rd #1

Direction	All
Volume (vph)	7978
Total Delay / Veh (s/v)	98
Stops / Veh	0.70
Fuel Consumed (gal)	253
Fuel Economy (mpg)	4.8

5: Peshawar.Rd #1

Direction	All
Volume (vph)	8197
Total Delay / Veh (s/v)	0
Stops / Veh	0.00
Fuel Consumed (gal)	43
Fuel Economy (mpg)	27.3

9: Peshawar.Rd #1

Direction	All
Volume (vph)	6199
Total Delay / Veh (s/v)	0
Stops / Veh	0.00
Fuel Consumed (gal)	35
Fuel Economy (mpg)	27.3

10: Peshawar.Rd #1

Direction	All
Volume (vph)	5779
Total Delay / Veh (s/v)	0
Stops / Veh	0.00
Fuel Consumed (gal)	35
Fuel Economy (mpg)	27.3

14:

Direction	All
Volume (vph)	2207
Total Delay / Veh (s/v)	0
Stops / Veh	0.03
Fuel Consumed (gal)	18
Fuel Economy (mpg)	27.2

20:

Direction	All
Volume (vph)	2135
Total Delay / Veh (s/v)	0
Stops / Veh	0.03
Fuel Consumed (gal)	13
Fuel Economy (mpg)	26.8

31: Peshawar.Rd #1

Direction	All
Volume (vph)	6878
Total Delay / Veh (s/v)	0
Stops / Veh	0.00
Fuel Consumed (gal)	39
Fuel Economy (mpg)	27.3

1: PeshawarRd.#1

Direction	All
Volume (vph)	8670
Total Delay / Veh (s/v)	99
Stops / Veh	0.47
Fuel Consumed (gal)	313
Fuel Economy (mpg)	8.9

2: PeshawarRd.#1

Direction	All
Volume (vph)	7133
Total Delay / Veh (s/v)	18
Stops / Veh	0.48
Fuel Consumed (gal)	164
Fuel Economy (mpg)	18.0

3: PeshawarRd.#1

Direction	All
Volume (vph)	3000
Total Delay / Veh (s/v)	19
Stops / Veh	0.55
Fuel Consumed (gal)	44
Fuel Economy (mpg)	10.9

4: PeshawarRd.#1

Direction	All
Volume (vph)	7030
Total Delay / Veh (s/v)	64
Stops / Veh	0.95
Fuel Consumed (gal)	191
Fuel Economy (mpg)	5.7

5: PeshawarRd.#1

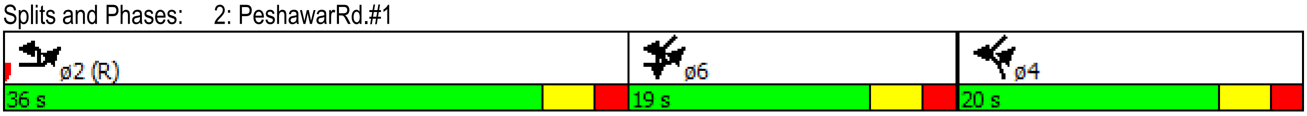
Direction	All
Volume (vph)	9405
Total Delay / Veh (s/v)	0
Stops / Veh	0.00
Fuel Consumed (gal)	53
Fuel Economy (mpg)	27.3

Lane Group	EBU	EBL	EBR	NBL	NBR	SWU	SWL	SWR
Lane Configurations								
Volume (vph)	442	2258	944	732	154	373	422	1808
Satd. Flow (prot)	1652	5797	1439	4536	1411	0	3236	3249
Flt Permitted	0.950	0.950		0.950			0.950	
Satd. Flow (perm)	1652	5797	1439	4536	1411	0	3236	3249
Satd. Flow (RTOR)			350		108			776
Lane Group Flow (vph)	456	2328	973	755	159	0	820	1864
Turn Type	Prot	NA	Free	NA	Free	Prot	NA	Free
Protected Phases	2 6	2		4		6 4	6	
Permitted Phases			Free		Free			Free
Detector Phase	2 6	2		4		6 4	6	
Switch Phase								
Minimum Initial (s)		4.0		4.0			4.0	
Minimum Split (s)		27.0		20.0			19.0	
Total Split (s)		36.0		20.0			19.0	
Total Split (%)		48.0%		26.7%			25.3%	
Yellow Time (s)		3.0		3.0			3.0	
All-Red Time (s)		2.0		2.0			2.0	
Lost Time Adjust (s)		0.0		0.0			0.0	
Total Lost Time (s)		5.0		5.0			5.0	
Lead/Lag								
Lead-Lag Optimize?								
Recall Mode		C-Max		None			None	
Act Effct Green (s)	50.2	31.2	75.0	14.8	75.0		33.8	75.0
Actuated g/C Ratio	0.67	0.42	1.00	0.20	1.00		0.45	1.00
v/c Ratio	0.41	0.97	0.68	0.84	0.11		0.56	0.57
Control Delay	7.1	34.4	2.6	39.3	0.2		17.1	0.7
Queue Delay	0.0	0.0	0.0	0.0	0.0		0.0	0.0
Total Delay	7.1	34.4	2.6	39.3	0.2		17.1	0.7
LOS	A	C	A	D	A		B	A
Approach Delay		22.8		32.5			5.8	
Approach LOS		C		C			A	

Intersection Summary

Cycle Length: 75
Actuated Cycle Length: 75
Offset: 1 (1%), Referenced to phase 2:EBL, Start of Green
Natural Cycle: 75
Control Type: Actuated-Coordinated
Maximum v/c Ratio: 0.97
Intersection Signal Delay: 17.8 Intersection LOS: B
Intersection Capacity Utilization 81.3% ICU Level of Service D
Analysis Period (min) 15

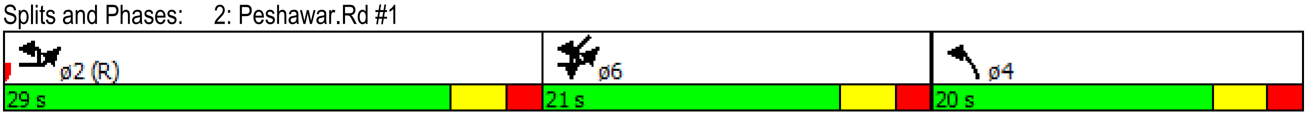
Splits and Phases: 2: PeshawarRd.#1



Lane Group	EBU	EBL	EBR	NBL	NBR	SWU	SWL	SWR
Lane Configurations								
Volume (vph)	706	2191	786	554	253	407	457	2338
Satd. Flow (prot)	1652	5797	1439	4536	1425	0	3268	3217
Flt Permitted	0.950	0.950		0.950			0.950	
Satd. Flow (perm)	1652	5797	1439	4536	1425	0	3268	3217
Satd. Flow (RTOR)			322		252			425
Lane Group Flow (vph)	735	2282	819	577	264	0	900	2435
Turn Type	Prot	NA	Free	NA	Free	Split	NA	Free
Protected Phases	2 6	2		4		6	6	
Permitted Phases			Free		Free			Free
Detector Phase	2 6	2		4		6	6	
Switch Phase								
Minimum Initial (s)		4.0		4.0		4.0	4.0	
Minimum Split (s)		27.0		20.0		19.0	19.0	
Total Split (s)		29.0		20.0		21.0	21.0	
Total Split (%)		41.4%		28.6%		30.0%	30.0%	
Yellow Time (s)		3.0		3.0		3.0	3.0	
All-Red Time (s)		2.0		2.0		2.0	2.0	
Lost Time Adjust (s)		0.0		0.0			0.0	
Total Lost Time (s)		5.0		5.0			5.0	
Lead/Lag								
Lead-Lag Optimize?								
Recall Mode		C-Max		None		None	None	
Act Effct Green (s)	46.5	25.5	70.0	13.5	70.0		16.0	70.0
Actuated g/C Ratio	0.66	0.36	1.00	0.19	1.00		0.23	1.00
v/c Ratio	0.67	1.08	0.57	0.66	0.19		1.21	0.76
Control Delay	11.3	69.6	1.6	29.9	0.3		133.0	1.7
Queue Delay	0.0	0.0	0.0	0.0	0.0		0.0	0.0
Total Delay	11.3	69.6	1.6	29.9	0.3		133.0	1.7
LOS	B	E	A	C	A		F	A
Approach Delay		43.9		20.6			37.1	
Approach LOS		D		C			D	

Intersection Summary	
Cycle Length: 70	
Actuated Cycle Length: 70	
Offset: 0 (0%), Referenced to phase 2:EBL, Start of Green	
Natural Cycle: 90	
Control Type: Actuated-Coordinated	
Maximum v/c Ratio: 1.21	
Intersection Signal Delay: 38.7	Intersection LOS: D
Intersection Capacity Utilization 86.8%	ICU Level of Service E
Analysis Period (min) 15	

Splits and Phases: 2: Peshawar.Rd #1



Lane Group	EBL	EBT	WBU	WBT	WBR	SBL	SBR
Lane Configurations							
Volume (vph)	1166	2305	543	1899	145	1482	1130
Satd. Flow (prot)	3090	4622	1608	4622	1439	4536	1398
Flt Permitted	0.950		0.087			0.950	
Satd. Flow (perm)	3090	4622	147	4622	1439	4536	1398
Satd. Flow (RTOR)					17		196
Lane Group Flow (vph)	1178	2328	548	1918	146	1497	1141
Turn Type	Split	NA	D.P+P	NA	Free	NA	Free
Protected Phases	2	2	4	4		6	
Permitted Phases		4 6	2		Free		Free
Detector Phase	2	2	4	4		6	
Switch Phase							
Minimum Initial (s)	4.0	4.0	4.0	4.0		4.0	
Minimum Split (s)	19.0	19.0	19.0	19.0		25.0	
Total Split (s)	52.0	52.0	53.0	53.0		45.0	
Total Split (%)	34.7%	34.7%	35.3%	35.3%		30.0%	
Yellow Time (s)	3.0	3.0	3.0	3.0		3.0	
All-Red Time (s)	2.0	2.0	2.0	2.0		2.0	
Lost Time Adjust (s)	1.0	0.0	1.0	1.0		1.0	
Total Lost Time (s)	6.0	5.0	6.0	6.0		6.0	
Lead/Lag							
Lead-Lag Optimize?							
Recall Mode	Max	Max	Max	Max		None	
Act Effct Green (s)	46.0	150.0	93.0	47.0	150.0	39.0	150.0
Actuated g/C Ratio	0.31	1.00	0.62	0.31	1.00	0.26	1.00
v/c Ratio	1.24	0.50	1.00	1.32	0.10	1.27	0.82
Control Delay	161.8	0.4	81.3	191.4	0.1	172.6	5.4
Queue Delay	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Delay	161.8	0.4	81.3	191.4	0.1	172.6	5.4
LOS	F	A	F	F	A	F	A
Approach Delay		54.6		157.6		100.3	
Approach LOS		D		F		F	

Intersection Summary	
Cycle Length: 150	
Actuated Cycle Length: 150	
Natural Cycle: 150	
Control Type: Semi Act-Uncoord	
Maximum v/c Ratio: 1.32	
Intersection Signal Delay: 99.1	Intersection LOS: F
Intersection Capacity Utilization 117.0%	ICU Level of Service H
Analysis Period (min) 15	

Splits and Phases: 1: PeshawarRd.#1

Lane Group	EBL	EBT	WBU	WBT	WBR	SBL	SBR
Lane Configurations							
Volume (vph)	843	2188	422	2382	401	784	476
Satd. Flow (prot)	3030	4532	1608	4577	1454	4581	1384
Flt Permitted	0.950		0.100			0.950	
Satd. Flow (perm)	3030	4532	169	4577	1454	4581	1384
Satd. Flow (RTOR)					37		156
Lane Group Flow (vph)	869	2256	435	2456	413	808	491
Turn Type	Split	NA	D.P+P	NA	Free	NA	Free
Protected Phases	2	2	4	4		6	
Permitted Phases		4 6	2		Free		Free
Detector Phase	2	2	4	4		6	
Switch Phase							
Minimum Initial (s)	4.0	4.0	4.0	4.0		4.0	
Minimum Split (s)	19.0	19.0	19.0	19.0		25.0	
Total Split (s)	46.0	46.0	76.0	76.0		28.0	
Total Split (%)	30.7%	30.7%	50.7%	50.7%		18.7%	
Yellow Time (s)	3.0	3.0	3.0	3.0		3.0	
All-Red Time (s)	2.0	2.0	2.0	2.0		2.0	
Lost Time Adjust (s)	1.0	0.0	1.0	1.0		1.0	
Total Lost Time (s)	6.0	5.0	6.0	6.0		6.0	
Lead/Lag							
Lead-Lag Optimize?							
Recall Mode	Max	Max	Max	Max		None	
Act Effct Green (s)	40.0	150.0	110.0	70.0	150.0	22.0	150.0
Actuated g/C Ratio	0.27	1.00	0.73	0.47	1.00	0.15	1.00
v/c Ratio	1.08	0.50	0.55	1.15	0.28	1.20	0.35
Control Delay	105.1	0.4	24.1	110.6	0.5	158.1	0.7
Queue Delay	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Delay	105.1	0.4	24.1	110.6	0.5	158.1	0.7
LOS	F	A	C	F	A	F	A
Approach Delay		29.5		85.5		98.6	
Approach LOS		C		F		F	

Intersection Summary	
Cycle Length: 150	
Actuated Cycle Length: 150	
Natural Cycle: 150	
Control Type: Semi Act-Uncoord	
Maximum v/c Ratio: 1.20	
Intersection Signal Delay: 65.0	Intersection LOS: E
Intersection Capacity Utilization 100.0%	ICU Level of Service F
Analysis Period (min) 15	

Splits and Phases: 1: Peshawar.Rd #1