ISLAMIC UNIVERSITY OF TECHNOLOGY

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Title of the thesis:

OPTIMIZING TRAFFIC SIGNAL DESIGN TO MINIMIZE DELAY

PRESENTED BY

M. A. AFRAHIM BHUIYAN (105419)

MD. RIZWANE MUZTABA KHAN (105435)

IRTIZA RAFID KHAN (105439)

SUPERVISED BY

DR. SHAKIL M. RIFAAT

ASSOCIATE PROFESSOR

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

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An undergraduate thesis submitted to the Department of Civil and Environmental Engineering of Islamic University of Technology, Board Bazar, Gazipur in partial fullfilment of the requirments for the degree

of

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Thesis approved as to style and content for the degree of B. Sc. Engineering (Civil and Environmental Engineering)

By

DR. SHAKIL M. RIFAAT

Associate Professor

Department Of Civil and Environmental Engineering

Islamic University Of Technology, Board Bazar, Gazipur

DECLARATION

We hereby declare that the undergraduate project work reported in this thesis has been performed by us entirely and this work has not been submitted elsewhere for any purpose (except for publication).

November, 2014

M.A AFRAHIM BHUIYAN

(Student ID: 105419)

MD. RIZWANE MUZTABA KHAN

(Student ID: 105435)

IRTIZA RAFID KHAN

(Student ID: 105439)

DR. SHAKIL M. RIFAAT

Associate Professor

DEDICATED

TO

OUR BELOVED PARENTS

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ABSTRACT

Every year, millions of dollars are lost in the global economy due to traffic congestion. Long hours spent on congested roadways are draining away valuable time, energy and money from the economy. Thus delay should be reduced to increase productivity and to minimize environmental pollution. The most economical way of this delay reduction is to redesign the signal timing because this design is not associated with spending money as well as consuming longer time. Only readjustment of signal timing is sufficient for this purpose. Hence, to optimize the signal timing for reducing delays has been taken as the main objective of this study. An intersection in Dhaka city (the capital of Bangladesh) has been chosen to achieve the goal of this study. This study will suggest that the new timing of the signal reduces total delay for all movements than the existing one. Particularly it will reduce the delay significantly for certain movements during peak hours. The result of the study will clearly justify the improvement of the junction performance by reducing delay in new signal timing.

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INTRODUCTION

1.1 GENERAL

This chapter briefly discuss about the background of the study, adverse effects of traffic congestion and indicates the relationship among delay, traffic signal timing and traffic congestion. Finally, the objective, scope of the study and organization of the thesis are presented accordingly.

1.2 BACKGROUND

Population in large cities (both in developed and developing countries) has swelled tremendously because people are constantly moving from rural areas to these cities. In general, cities of the developing countries are expanding too rapidly. About 50% of the developing world's urban population is relatively new to the cities. According to one reliable projection, by the year 2025, the population of Dhaka will jump to 25 million from its present 12 million. Although the future prosperity of towns and villages will reduce the extent of migration to Dhaka, its population is still expected to grow at an accelerated rate. Likewise other developing cities, this urbanization process results to grow traffic in Dhaka from several hundreds to hundreds of thousand motorized and non-motorized vehicles; the road network remains virtually the same for the last two decades. Therefore, pressure increases specially on major roads during peak hour, which is subsequently converted into traffic congestion. Delay due to congestion is considered as economic loss because the invaluable working hours as well as fuel cost have been lost. A report by the ***Texas Transportation Institute of Texas A&M University*** titled "***2005 Urban Mobility Report***" confirmed that in 2003 the average Twin Cities' (Minnesota) commuter wasted 43 hours in traffic and 28 gallons of fuel, resulting in an average loss of $722 per commuter. The cost of traffic congestion is staggering. ***Brian Ketcham***, a Brooklyn transportation consultant who studies such things, estimates that traffic costs the city nearly $30 billion a year due to losses in employee productivity, traffic accidents, air pollution, traffic noise and roadway damage. In another study by Gorham Gazette (A New York based Newspaper) informed that Congestion losses, in terms of reduced productivity for businesses -- wasted time for all motorists

-- are estimated to total $8.3 billion a year in New York City and nearly $22 billion for the region in the Year 2000. The New York State Department of Transportation has estimated that congestion increased the cost to deliver freight by about $10 billion a year in the New York portion of the metropolitan area in 1995, increasing the cost of doing business and discouraging people from staying in the region. However, the situation is not only true for developed countries like U.S.A; even it becomes more deteriorate for LDC countries like us. One of the World Bank funded project (DUTP, 1996) in Dhaka indicated that in 24 most congested intersections the annual delay cost totaled BDT 600,947,000 (US$ 14,308,262). In addition with the economic loss due to wastage of working hours, delay increases energy consumption, which is also counted as economic loss.

This traffic delay is also associated with environmental pollution specially air pollution because long time foul combustion in a stagnant place increases the air pollution. In a study by **Karim** (1997) titled, "**Traffic Pollution in Bangladesh & Metropolitan Dhaka a Preliminary Investigation"** indicates that the daily total emissions of NOx, HC, CO, PM, and SOx are estimated and burdened to city's air and equivalent to: 42, 39, 314, 14, and 42 tons/day, respectively. Daily average concentration of NOx (NO2, NO) were measured at 28 street locations in Dhaka city during November, 1996. The results showed extremely high concentrations of NO2 and NO in each location. In an economic evaluation of air pollution in Bangladesh, the World Bank estimated that nearly 15,000 deaths would be avoided annually (10,800 in Dhaka, 2,060 in Chittagong, 1,020 in Khulna, and 975 in Bogra) if the level of air pollution in four largest cities were reduced to the WHO annual average standard. It was also mentioned that the economic cost of the sickness and death due to air pollution is estimated to be $200-800 million per year, or 0.7% - 3.0% of GDP per year of the country.

The above discussion clearly indicates that delay should be reduced to increase productivity as well as minimize environmental pollution. Probably the best way to handle this problem is to increase the roadway capacity. This can be done by increasing the road width, which actually adds more lanes to the existing lanes. However, in most cases land acquire for adding more lanes is not possible since it is time consuming, expensive and cumbersome. Perhaps the most economical way of this delay reduction is to redesigning the signal timing because it does not associated with spending money as well as longer time. Only readjustment of signal timing is sufficient. Hence, to optimize the signal timing for reducing delays has been taken as the main objective of this study.

1.3 OBJECTIVE

The main objective of this study is to optimize signal timing as well as to minimize delay caused by traffic congestion at a signalized intersection, using Gulshan-2 intersection, as a case study. For this purpose, investigations on the existing traffic signal condition have to be carried on. This investigations play important roles to propose a new signal design related with minimization of delay in the intersection. Some alternative designs will be studied and then, by comparing them with the present condition, new design for signal timing will be proposed based on effectiveness. Besides calculating optimal signal timing, problems associated with intersection like pedestrian movement, faulty road sign, unauthorized parking, bus stoppage, vendors etc. will also be mentioned with probable solutions of these problems from engineering point of view. In addition, this study will also focus on the adverse effects of traffic congestion and how they are related to various sectors of our day to day life considering environment, human health, economic activities, productivity, accessibility, land use and so on.

1.4 SCOPE OF THE STUDY

Traffic congestion is a pandemic illness affecting many cities around the world. The most economical way of this delay reduction is to redesign the signal timing because this design is not associated with spending money as well as consuming longer time. In a study, a genetic algorithm-based signal optimization program that can handle oversaturated signalized intersections is presented. It is designed to search for a near-optimal traffic signal timing plan on the basis of a fitness value obtained from the mesoscopic simulator. There is another study developing a bi-level programming formulation and heuristic solution approach (HSA) for dynamic traffic signal optimization in networks with time-dependent demand and stochastic route choice.

Therefore, a new model has been developed and tested for traffic signal optimization based on the combination of three key techniques: 1) genetic algorithms (GAs) for the optimization task; 2) cellular-automata-based micro simulators for evaluating every possible solution for traffic-light programming times; and 3) a Beowulf Cluster, which is a multiple-instruction-multiple-data (MIMD) multicomputer of excellent price/performance ratio. As the traffic demand increases, it becomes vital to manage the overall movement within the limited resources without affecting the rate of traffic queue discharge through an approach and also to ensure safety at an intersection in an urban area. So the necessity of an effective traffic signal system is beyond question in a developing country like Bangladesh. Although there are some installations, traffic signal system is approaching lots of difficulties in controlling vehicular movements in the capital city Dhaka. So it is important to find out such difficulties that hinder the true implementation of traffic signal system in the roads. As the traffic signal system of Dhaka is time based, only readjustment of signal timing is sufficient for this purpose. Hence, the scope of this study is to readjust signal timing of the selected intersection by reducing delay. Effectiveness of the proposed design is evaluated by comparing with existing design.

1.5 ORGANIZATION OF THE THESIS

Chapter 1 is the introductory chapter, which indicates the Background, objective and the scope of this study.

Chapter 2 is literature review that discusses the adverse effects associated with traffic congestion. Important information and finding from these studies are also documented.

Chapter 3 describes the methodology of this work, which incorporates in brief how the objective of this work can be fulfilled.

Chapter 4 evaluates the existing performance of the present signal timing through the calculation of design flow, saturation flow, degree of saturation and delay per vehicle.

Chapter 5 incorporates proposed improved signal timing where the degree of saturation is pre-fixed. It also shows the effectiveness of proposed new design with the existing one by comparison of delay.

Chapter 6 narrates other problems associated with the intersection besides signal timing through photograph.

Chapter 7 is the concluding chapter, which focuses on the important findings of this study and the possibility of the extension of this work in future.

Chapter 2

LITERATURE REVIEW

A fast emerging component of the transportation problem in cities is the problem of traffic congestion. Traffic congestion is a condition on road networks that occurs as use increases, and is characterized by slower speeds, longer trip times, and increased vehicular queuing. The most common example is the physical use of roads by vehicles. When traffic demand is great enough that the signalized or non-signalized interaction between vehicles slows the speed of the traffic stream, this results in some congestion. Various factors such as road users characteristics, vehicle characteristics, faulty road design, unplanned or illegal roadside structures, unplanned signalized or non-signalized intersections, irregularity and delay in maintaining traffic signals in signalized intersections, carelessness of traffic rule enforcing authority etc. causes traffic congestion. Traffic signal timing as well as delay in a road network not only affect total user travel time and total amount of gaseous emissions but also create an inequity problem in terms of the change in travel costs of users travelling different locations. Traffic congestion has bitter effects on environment, human health, productivity as well as economic loss, road user's characteristics especially on behavior of drivers and pedestrians, socioeconomic development, travel time, travel cost, vehicular characteristics, accessibility. The literature review of this thesis is based on the effects of traffic congestion of both signalized & non-signalized intersections. Relevant researches regarding traffic congestion and delay are also presented. This review will provide some contents for the result in this study later on. Also a few positive sides of traffic congestion are also provided here.

2.1 EFFECT OF DELAY

2.1.1 Effect of delay on environment

One of the most harmful effects of traffic congestion is its impact on the environment. Despite the growing number of hybrid vehicles on the road, cars stopped in traffic still produce a large volume of harmful carbon emissions. Besides contributing to global warming, these emissions can cause more short-term and localized problems, such as smog and increased respiratory problems in a community due to poor air quality. Motor vehicles also produce sharp noises. Sometimes it gets intolerable for human of all ages. Again Motor vehicles having mechanical errors and because of aging vehicles produce toxic chemicals that sometimes mixes with rain water & causes air pollution.

2.1.1.1. Air pollution

Proportional components of air when fluctuate within a very high range means air pollution. Air pollution is mainly caused by burning of fossil fuel for power generation in production and transportation sectors. Various types of gases like CO2, CO, NO_x, SO_2, O_3 also known as greenhouse gases are emitted from these sectors.

The principal air-quality pollutant emissions from petrol, diesel and alternative fuel engines are carbon monoxide, oxides of nitrogen, un-burnt hydrocarbons and particulate matter. It is emissions of these pollutants that are regulated by the Euro emissions standards. Modern cars, if kept in good condition, produce only quite small quantities of the air quality pollutants, but the emissions from large numbers of cars add to a significant air quality problem. Carbon monoxide, oxides of nitrogen, and un-burnt hydrocarbons are gases, and are generally invisible. Particulate matter is usually invisible although under certain operating conditions diesel engines will produce visible particles, appearing as smoke. Petrol engines will also produce visible particles if they are burning engine oil or running “rich”, for example, following a cold start. Fine particles can also be produced by type and brake wear. Unlike emissions of CO2, emissions of the air quality pollutants are not directly linked to fuel consumption. Pollutant emission levels depend more on vehicle technology and the state of maintenance of the vehicle. Other factors, such as driving style, driving conditions and ambient temperature also affect them. However, as a starting point, all new passenger cars must meet minimum EU emissions standards. (VCA Office, Executive agency, Department of Transport, United Kingdom).

2.1.1.1. a. CO_2 emission

Road-traffic CO_2 emissions come from a number of sources. They include exhaust pipe emissions and contributions from friction processes and suspended road dust. This results in a complex mixture that includes PM and gaseous pollutants, such as nitrogen oxides (nitric oxide and nitrogen dioxide), carbon monoxide, carbon dioxide and VOCs, all of which pose risks to health. The CO_2 emissions of a car are directly proportional to the quantity of fuel consumed by an engine.

Carbon dioxide is a greenhouse gas. Motor vehicle CO_2 emissions are part of the anthropogenic contribution to the growth of CO_2 concentrations in the atmosphere which is believed by a majority of scientists to play a significant part in climate change. Motor vehicles are calculated to generate about 20% of the European Union's man-made CO_2 emissions, with passenger cars contributing about 12%. European emission standards limit the CO_2 emissions of new passenger cars and light vehicles. The European Union average new car CO_2 emissions figure dropped by 5.4% in the year to the first quarter of 2010, down to 145.6 g/km.

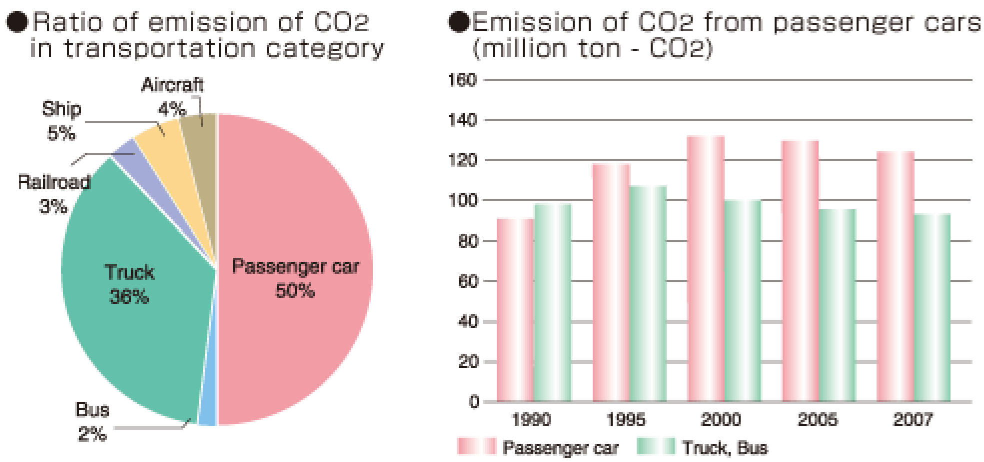

Fig. A [Adapted from database on greenhouse gas emissions by National Institute for Environmental Studies/Greenhouse Gas Inventory Office of Japan (GIO).]

CO_2 is the main byproduct of burning of fossil fuels. Emission of CO_2 and its amount depends on vehicle types & their ages, speed, types of fuel. Among energy using sectors transportation is the largest emitter of CO_2 (Greene L., 2006)

Again CO_2 emissions vary greatly depend on average vehicle speed for various types of vehicles trajectories. Heavy congestion results in slower speeds and greater speed fluctuation, resulting higher CO_2 emission (Barth M., Boriboonsomsim k., 2008). In a traffic congested area CO_2 emission is high and with the passage of time, CO_2 concentration of that area increases gradually. As a result, environmental condition becomes worse, causes bitter effect on human health. At off pick period, congestion is less. So, CO_2 emission is less than traffic congested area at pick period. CO_2 emission can be reduced by 7% during pick hour in highway with less congestion by increasing vehicle speed 60mph than congested area (Schrank, D., and T. Lomax, 2005). So, it can be said that, emission of CO_2 in congested area is worse than less congested area.

2.1.1.1. b. Other gas emissions

Except CO_2, by burning of fossil fuels, vehicles also produce NOx (Nitrogen di Oxide, Nitric Oxide),CO, SO_2, VOC, Particulate matters (PM10,PM2.5)etc. These are also called `Greenhouse gas` as well as `Exhaust gas`. In a certain area, due to congestion, GHG concentration increases. In effect, they cause temperature rise, air pollution and ecological damage.

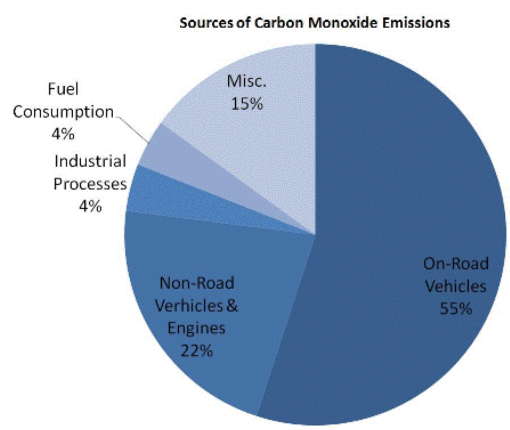

Fig.B [Adopted from "Products by combustion" associated by Department of Energy & mineral Engineering, Pennsylvania State University]

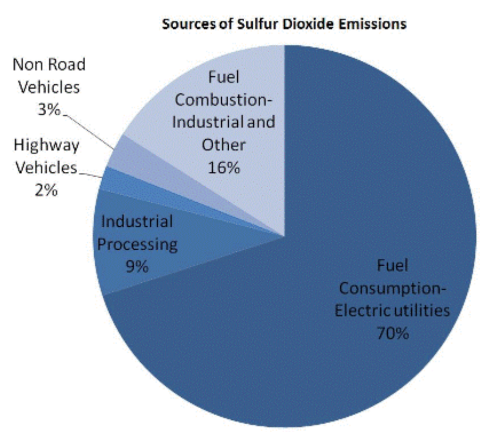

Fig.C [Adopted from "Products by combustion" associated by Department of Energy & mineral Engineering, Pennsylvania State University.]

In a research, Michael ET. Al mentioned that,

1. Emissions of nitrogen oxides increased steadily during the 1980s, by about 25%, owing to increasing road traffic congestion.

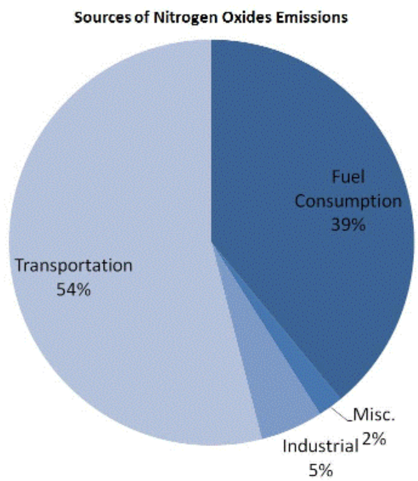

Fig.D [Adopted from "Products by combustion" associated by Department of Energy & mineral Engineering, Pennsylvania State University]

2. Ozone is not primary emissions of road traffic congestion. Ozone is formed in the lower atmosphere by complex reactions that involve VOCs, carbon monoxide and nitrogen oxides in the presence of sunlight. This may result in episodes of summer smog with high concentrations of ozone, such as occurred in the summer of 2003 over large areas of Europe
3. Nitrogen oxides are mainly emitted as nitric oxide: usually 90–95% of nitrogen oxides. Freshly emitted nitric oxide reacts rapidly with ozone to form nitrogen dioxide
4. PM emissions from road traffic come from exhaust pipes, tire wear, brake linings and suspension of road dust. The physical and chemical characteristics of PM emitted from each of those sources differ substantially. Across the 31 countries that submitted data to the EEA in 2000, the greatest Contributors to emissions of primary PM10 and gases leading to the formation of secondary PM10 was the road-transport (22%), Again, using anti-knocking material in fuel used by vehicles cause Lead (Pb) emission and it increases during traffic congestion.

2.1.1.2. Noise pollution

Noise is often defined as unwanted sound which is the result of pressure changes in a medium (usually air), caused by vibration or turbulence. (Khilman, WHO, 2004) mentioned that noise pollution is nowadays the third most hazardous environmental type of pollution, preceded only by air (gas emission) and water pollution. Noise pollution is a significant environmental problem in rapidly developing built-up cities. .. Recent researches clearly demonstrate that road traffic noise has been the predominant source of annoyance; no other single noise has been of comparable importance. It is due to the large number of automotive vehicles in comparison with other machines.

Noise pollution is one of the most prevalent sources of environmental complaint in the European Union (EU). Especially in densely populated urban areas and residential areas near highways, railways and airports (Mitchell P., UKNA, 2009). Road traffic congestion increases noise pollution at pick hours. Traffic horns, sound of engine causes unbearable pain to the road users especially children and old age people and pedestrian. Sometimes, due to loudness of horn, road users (Drivers & pedestrians) delay to response. Sometimes, noise makes them uncomfortable and anxious.

2.1.2 Effects on health

2.1.2. a. Health effect due to air pollution

Burning of fossil fuels by vehicles causes emission of gases mentioned before. In a congested area, because of this gases, human suffers from various health problems. (EU emissions standards set by VCA Office, Executive agency, Department of Transport, United Kingdom) The possible effect of this gases on human health are:

CO2- causes human respiratory problem, cough, optical problem etc.

CO - Carbon monoxide reduces the blood’s oxygen carrying capacity which can reduce the availability of oxygen to key organs. Extreme levels of exposure might occur due to blocked fuels in domestic boilers, can be fatal. At lower concentrations CO may pose a health risk, particularly to those suffering from heart disease.

NO_x - Oxides of nitrogen react in the atmosphere to form nitrogen dioxide (NO_2) which can have adverse effects on health, particularly among people with respiratory illness. NOx also contributes to smog formation, acid rain, can damage vegetation, contributes to ground level ozone formation and can react in the atmosphere to form fine particles (‘secondary particles’).

Particulate matter (PM) - Fine particles have an adverse effect on human health, particularly among those with existing respiratory disorders.

HC - Hydrocarbons, contribute to ground level ozone formation leading to risk of damage to the human respiratory system. In addition, some kinds of hydrocarbons are carcinogenic and they are also indirect greenhouse gases.

[EU emissions standards set by VCA Office, Executive agency, Department of Transport, United Kingdom]

2.1.2. b. Health effect due to noise pollution

In contrast to many other environmental problems, noise pollution continues to grow and is accompanied by an increasing number of complaints from people exposed to the noise. The growth in noise pollution is unsustainable because it involves direct, as well as cumulative, adverse health effects. These health effects are high during traffic congested area. Major Effects of noise pollution in traffic congested area are: (Adopted from EU emissions standards set by VCA Office, Executive agency, Department of Transport, United Kingdom)

- **Hearing Problems**:

Any unwanted sound that our ears have not been built to filter can cause problems within the body. Our ears can take in a certain range of sounds without getting damaged. Man made noises such as jackhammers, horns, machinery, airplanes and even vehicles can be too loud for our hearing range. Constant exposure to loud levels of noise can easily result in the damage of our ear drums and loss of hearing. It also reduces our sensitivity to sounds that our ears pick up unconsciously to regulate our body’s rhythm.

- **Health Issues**:

Excessive noise pollution due to traffic congestion can influence psychological health. Studies show that the occurrence of aggressive behavior, disturbance of sleep, constant stress, fatigue and hypertension can be linked to excessive noise levels. These in turn can cause more severe and chronic health issues later in life.

- **Sleeping Disorders**:

Loud noise can certainly hamper our sleeping pattern and may lead to irritation and uncomfortable situations. Without a good night sleep, it may lead to problems related to fatigue and our performance may go down in office as well as at home.

- **Cardiovascular Issues**:

Blood pressure levels, cardio-vascular disease and stress related heart problems are on the rise. Studies suggest that high intensity noise causes high blood pressure and increases heart beat rate as it disrupts the normal blood flow.

- **Trouble Communicating**:

High decibel noise can put trouble and may not allow two people to communicate freely. This may lead to misunderstanding and you may get difficult understanding the other person. Constant sharp noise can give you severe headache and disturb your emotional balance.

2.1.3 Effects on vehicle crashes & accident possibilities

There is an ongoing debate among transport planners and safety policy makers as to whether there is any association between the level of traffic congestion and road safety. One can expect that the increased level of traffic congestion aids road safety and this is because average traffic speed is relatively low in a congested condition relative to an uncongested condition, which may result in less severe crashes. The relationship between congestion and safety may not be so straightforward, however, as there are a number of other factors such as traffic flow, driver characteristics, road geometry, and vehicle design affecting crash severity.

Average traffic speed is relatively low in a congested condition in contrast to an uncongested condition which may lead to less severe traffic crashes (Quddus A. et. al., 2010). However, this may increase the occurrence of traffic conflicts often resulting in more slight injury crashes.

Traffic congestion mainly depends on road user characteristics. One of the main reasons of crash or accident is driver’s aggression, frustration, carelessness. Drivers get frustrated because of delay in road. So when they get any chance to move, they do hurry to get rid of jam. As a result, crashes and accident possibility increases. Sometimes, drivers are not willing to maintain traffic signal. They increase vehicle speed near intersection to avoid traffic jam that increases possibility of road accident

According to David Shinar's (1998) driver aggression is caused by frustration because of traffic congestion and delays.

Lajunen et al. (1999) shows that the relationships between exposure to congestion (rush-hour driving) and aggressive violations were investigated in Great Britain, Finland and the Netherlands. Partial correlations showed that the frequency of rush-hour driving did not correlate statistically significantly with driver aggression.

2.1.4 Productivity loss

It is an old saying, but true as ever: “Time is money.” A company that can produce quality products in less time than its competitors is likely to be more profitable and productive. An urban area where employees travel less time to get to work is likely to be more productive than one where travel times are longer, all things being equal. The city, with too many roads choked by too many cars, buses and taxis is slowing down every day. The economic consequences are increasingly dire. Crippling congestion is costing severely in lost productivity. We sit in traffic-clogged roads; wait for buses that never seem to arrive on schedule. Now a day’s congestion is unbearable and it has become a national tragedy.

If people of the capital city are asked which one is their number one problem that frustrates them most, possibly all will say in chorus that "traffic congestion is the problem and they never want to put up with it". It is time which is being robbed from people and from their families and lives. But who will give it back? Not surprising that we are losing both time and money in congested roads, given our failure to introduce a mass transit in the city of millions.

Motorists burn extra fuel as they crawl along in stop-start traffic on the choked roads. Normally, cars use three to four times more fuel on congested roads than when traffic is flowing at a normal speed. When a car is at a standstill, stopping and starting or moving slowly in heavy traffic, it can run about 4.0 km per liter of oil. If the same car moves in free-flowing traffic, travelling at 50km/h or more, the fuel consumption drops to one fourth. This is something which is, probably, less discussed. Apart from these, the government pays a huge amount of money for importing fuel while gas, the country's valuable natural resource, is being wasted due to congestion.

Traffic congestion in the United States costs the average urban rush hour traveler 47 hours and 28 gallons of gasoline per year, for an annual cost of $794 per traveler (Hartman, 2008). The extra gasoline consumed also produces 546 additional pounds of carbon dioxide, along with other pollutants such as carbon monoxide. Much of this congestion is the result of individuals failing to account for externalities. Traffic volume often exceeds the optimal level because of excessive driving by individuals who fail to internalize the congestion time costs they impose on others. It is for this reason that the use of tolls can improve the efficiency of congested roads and highways.

Arnott and Small (1994) have shown that the cost of driving as well as loss due to traffic congestion is quantifiable. Though having their actual choices, drivers have demonstrated a willingness to pay, on average, about $1.33 to save 10 minutes travel time or $8 per hour. This figure does not include the cost of disruption from the unpredictability of traffic delays, the cost of inconvenient schedules caused by attempts to avoid delays, nor the cost of extra fuel, accidents and air pollution. Even without taking all of these additional factors into account, the annual cost of driving delays comes to $48 billion or $640 per driver

Texas Transportation Institute (2009) tracks a quarter century of traffic patterns in 439 U.S. urban areas from 1982 through 2007. Travelers spent one hour less stuck in traffic in 2007 than they did in 2006 and wasted one gallon less gasoline than the year before (Schrank D. and Lomax T., 2009). The differences, though small, point to a break in near-constant growth in traffic over 25 years.

Other highlights from the research illustrating the effects of the nation's traffic problems:

1. The overall cost (based on wasted fuel and lost productivity) reached $87.2 billion in 2007 - more than $750 for every U.S. traveler.
2. The total amount of wasted fuel topped 2.8 billion gallons - three weeks' worth of gas for every traveler.
3. The amount of wasted time totaled 4.2 billion hours - nearly one full work week (or vacation week) for every traveler.

   (Schrank D. & Lomax T., 2009)

2.1.5 Effect on socio economic development

One of the fundamental problems of man since antiquity is that of overcoming the friction of distance both in space and time. Man has been on the move from one place to another seeking for a means of survival. The emergence of modern means of transportation in the world and most importantly in developed & developing countries has a remarkable influence on the socio-economic development of rural & urban areas. Transport is indispensable for the well-functioning and development of economic activities, for the production and distribution of goods and services as well as for trade.

Transportation to some in the urban & rural settings is a choice not a concern. Transportation enhances the process of Economic growth in countries by making needed services available to people.

Todaro. M.P. (1981) viewed development as a multi-dimensional process involving change in structure, habit attitude and institution as well as acceleration of economic growth. There is a significance relationship between transportation and development process.

According to Department of Economic and Social Affairs, Economic Commission for Europe (ECE) (2001), Transport has, therefore, been at the very basis of the economic development in western European ECE member countries in the past decades, contributing to the economic prosperity and social wellbeing of their citizens. In particular, it has played a most strategic role in the opening up of peripheral and isolated ECE countries and regions and in their integration into the national, European and/or global economy. The transport sector has itself become an important sector of the economic activity in western European ECE countries where it accounts on average for about 7% of GDP and for more than 10% of employment. But all the developments and economic growth can be interrupted if there is a higher rate of traffic congestion in the industrial area. Traffic congestion is evidence of social and economic vitality; empty streets and roads are signs of failure.

The Texas Transportation Institute (TTI), for example, placed the cost of metropolitan traffic congestion in 75 of the over 300 US metropolitan areas at $68 billion in the year 2000. Cities exist because they promote social interactions and economic transactions.

Traffic congestion occurs where lots of people pursue these ends simultaneously in limited spaces. Culturally and economically vibrant cities have the worst congestion problems, while declining and depressed cities don't have much traffic. Despite congestion, a larger number and wider variety of social interactions and economic transactions can be consummated in large, crowded cities than elsewhere.

2.1.6 Effect on accessibility

Accessibility is an individual and social phenomenon. Accessibility is a broad concept with a wide range of interpretations, some of which reflect benefits and costs to individuals and others more concerned with social welfare. Hansen (1959) introduced the concept of accessibility to transportation planning by defining it as "the potential of opportunities for interaction" enabled by urban transportation systems. Lynch (1981) expanded upon the concept, ascribing social prerogatives to accessibility such as diversity of choice, equity among groups and individuals, and individual control. Accessibility may also serve as the most important factor in explaining regional form and function: access to activities shapes how people use a site and determines its value (Wachs and kumagai, 1973; Giuliano, 2004).

Transportation researchers have developed a range of methods to quantify accessibility (levinson and krizek ,2005). One of the most important distinctions among these methods is between place based accessibility and person based accessibility (Ewan et al., 2003). Measures of place based accessibility, such as cumulative opportunity and gravity measures, generally measure the spatial and temporal distribution of activity sites relative to a point, adjusted by the ease of reaching these activity sites (Hansen, 1959; Handy and Niemier, 1997). Congestion in U.S. Metropolitan areas has increased steadily in recent years (Schrank and Lomax, 2007). While nobody likes to sit in traffic, congestion levels are at best an indirect and imperfect measure of people's and firms' access to opportunities. As such, widely cited measures of the economic costs of congestion that simply tally people's time spent in traffic are conceptually problematic and, perhaps misleading. Congestion measures reflect potential mobility, but do not reveal individuals' relative access to jobs and activities, or firms' relative access to suppliers and customers. Wachs and kumagai (1973), Handy (2002), Levine and Garb (2002) argue that transportation planning should focus on increasing access to destinations rather than increasing mobility on transportation networks. While conceptually distinct, congestion and accessibility are related. The perception that congestion makes it harder for individuals to access opportunities is rational on its face, yet congestion also arises because an area offers attractive opportunities to large numbers of people and firms. A central tenet of urban economics is that cities form and grow because they foster such agglomeration economies, which increase productivity but also introduce negative externalities such as congestion (Fernon, 1972; Fujita, 1996; Arnott et. al., 1998; Glaeser et al., 2003). Furthermore, a traveler's perceived burden of congestion is highly variable, depending on the purpose, timing, and other aspects of the trip (Evans et al., 2005). As a result, the relationship between congestion and accessibility is complex and far from a simple inverse relationship.

They propose a conceptual framework that enumerates the potential influences that congestion and accessibility exert on one another. This framework contains three major components:

1. Congestion tends to decrease mobility and indirectly reduce accessibility.

2. Congestion is associated with agglomeration and with increased accessibility, even if congestion detracts from the benefits of agglomeration.

3. Experiences with congestion cognitively alter an individual's opportunities and access to opportunities. These factors create a complex relationship between congestion and accessibility, a

relationship that varies substantially among individuals and small areas within a given region. By reducing mobility, congestion may limit accessibility as well.

However, the relationship between mobility and accessibility is likely not unitary. An area can have high levels of accessibility even without high levels of mobility if destinations are near one another conversely, an area can have high levels of mobility and low levels of accessibility in areas where destinations are more remote. Accessibility and mobility could also have an inverse relationship. Traditional congestion relief policies attempt to increase mobility by expanding transportation capacity. Some capacity expansion critics claim that increasing mobility has a perverse effect because it induces destinations to move further apart from each other, ultimately leading to higher travel times and costs (Levine and Garb, 2002).

2.1.7 Effects on land use

Land use is the human use of land. Land use involves the management and modification of natural environment or wilderness into built environment such as settlements and semi-natural habitats such as arable fields, pastures, and managed woods. There is considerable controversy over whether increasing the density of development (i.e., a higher number of persons or employees per square mile of land) would reduce or increase traffic congestion. Some researchers argue that compact, mixed-use development is inherently more efficient and sustainable, using less land and reducing private vehicle use rates by bringing people and activities closer together, and also providing densities that are capable of supporting walking and effective transit services. Other researchers say that conventional patterns of low-density development with different land uses (residential, commercial, industrial, institutional), separated from each other and reachable only by car, are much more in character Better data on the relationship between land uses and traffic congestion could help lead to better decisions that could help reduce traffic congestion, improve air quality, enable safer travel, and lower roadway infrastructure costs.

To reduce the congestion, especially in the narrow streets, it`s necessary to increase the spacing. But in order to do that, the agricultural lands around that place have to be used. Besides, if there are markets placed at the roadside, for expanding the space of narrow roads, these markets are demolished. These causes loss for both the government and the land owners.

Highways have had a tremendous impact on the patterns of land development. The land-use changes enabled by better roadways and encouraged by land use and public facility policies rapidly increased travel demand. They concluded that integrating land use and transportation at the regional level is the best answer to traffic congestion and a host of other urban ills. (Moore T. and Thorsnes P., 2007).

Land use and transportation planning & traffic congestion at the local government level and assesses planning and policy issues raised by various strategies being utilized to address congestion problems. At the local level congestion and land use planning often are carried out as largely separate functions. This separation reflects differences in education and training of the planners responsible for land use and the engineers responsible for transportation and occurs in part because many transportation facilities and services are provided by state and regional rather than local agencies. One result is that transportation and land use plans are rarely coordinated and often are inconsistent. Such inconsistencies were less of a concern in the past, when the tradition of providing transportation services on demand lessened the need for detailed plan coordination (Deakin E. A., 1990)

In the absence of congestion pricing, coordinated land use planning can provide the most lasting mobility dividends over the long run. Land use planning needs to be resurrected as a bonfire approach to managing traffic. Shifts in the location of workplaces from downtowns served by transit to suburban settings where individuals are compelled to use their own cars are at the heart of today's congestion dilemma (Cervero, R., 1989).

2.2 POSITIVE SIDES OF TRAFFIC CONGESTION:

It does not follow that congestion is an evil that should be fought at all costs. Congestion has the benefit of encouraging motorists to re-time their trips so that expensive road space is in full use for a greater number of hours per day. The standard response to congestion is to expand road space somehow, perhaps by widening an existing road or else by adding a new road, bridge or tunnel. However, this could well result in increased traffic flow, otherwise known as induced demand, causing congestion to appear somewhere else. Moreover, Braess's paradox (credited to the German mathematician Dietrich Braess) shows that adding road capacity might make congestion worse even if demand does not increase. It has been argued that traffic congestion, by reducing road speeds in cities, could reduce the frequency and severity of road accidents.

In a nutshell, Traffic congestion is one of those things which we put up with in our lives of quiet desperation. Although it is more than a problem, little or few actions are visible except to scream for implementing mega projects and to arrange meetings, seminars etcetera as if the problem would be solved overnight. Over the years, traffic problem has been generating a number of negative effects:

- It wastes time of motorists and passengers.
- Delays, which may result in late arrival for employment, meetings and education, are liable for lost business, disciplinary action or other personal losses.
- Inability to forecast travel time accurately, leads drivers to allocate more time to travel and less time on productive activities.
- Wasted fuel increases air pollution and emissions.
- Wear and tear on vehicles as a result of frequent acceleration and braking, leading to more frequent repairs and replacements.
- Stressed and frustrated motorists, at times, are engaged in competition, resulting in road accidents.

We are forced to spend an excessive amount of our time for transportation and the experience is irritating as well as painful downright. From the gravity of the problem of traffic congestion, as discussed above, it is clear that it is a problem that causes national loss.

Chapter 3

METHODOLOGY

The methodology of this study can be classified into 3 steps. The first step is to evaluate the existing signal timing for different movements. Second step consists of redesigning of the signal timing and comparing with the existing one based on delay calculation. Finally, other problems associated with the intersection, for example, road safety, roadway marking etc., are identified and solution from engineering perspective is proposed. The methodology that consists with the above stated three steps is shown in figure 2.1, figure 2.2 and figure 2.3 respectively. In the following discussion how the objective of our study can be accomplished are describe in brief.

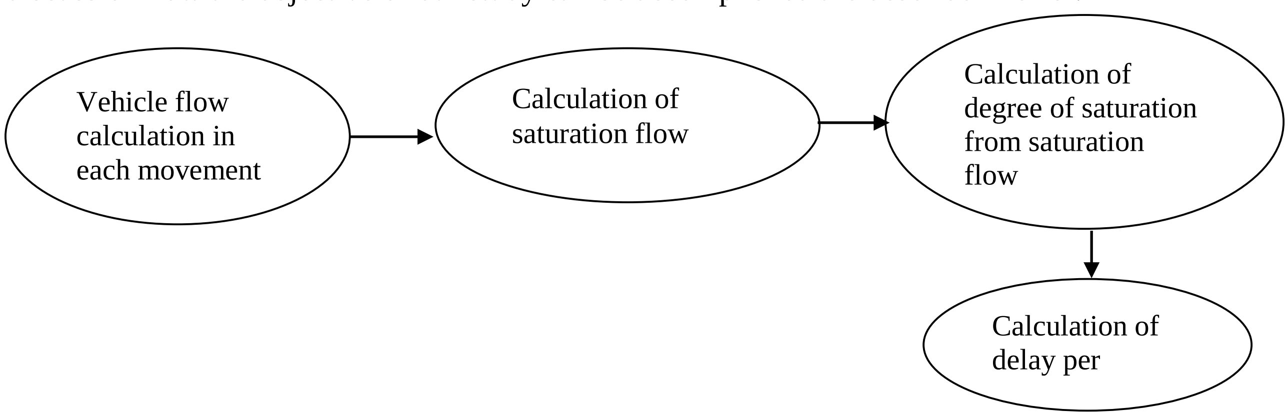

Figure 2.1: Step to evaluate the existing signal timing performance

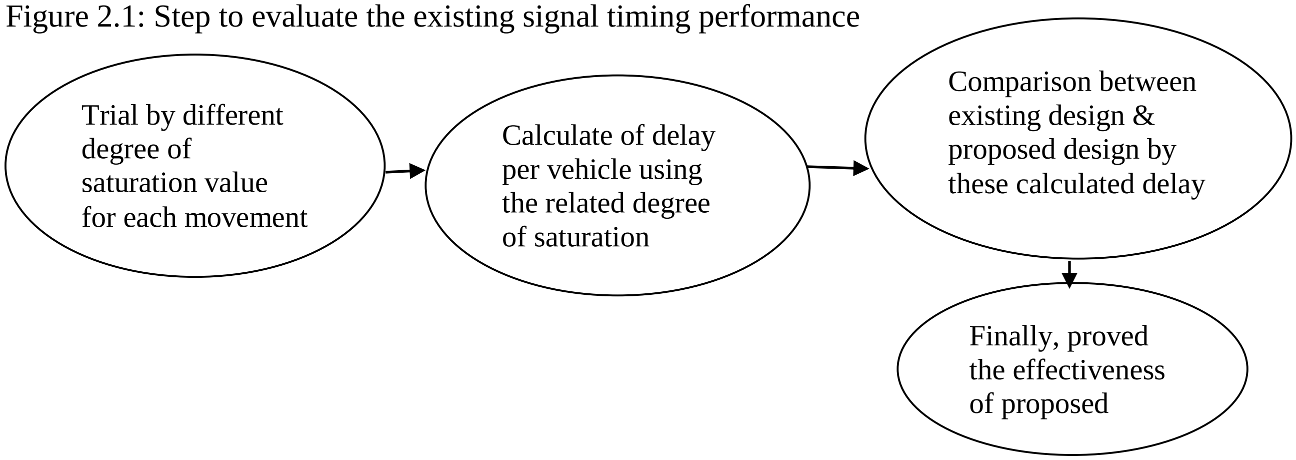

Figure 2.2: Steps to calculate the optimal design & compare with proposed design

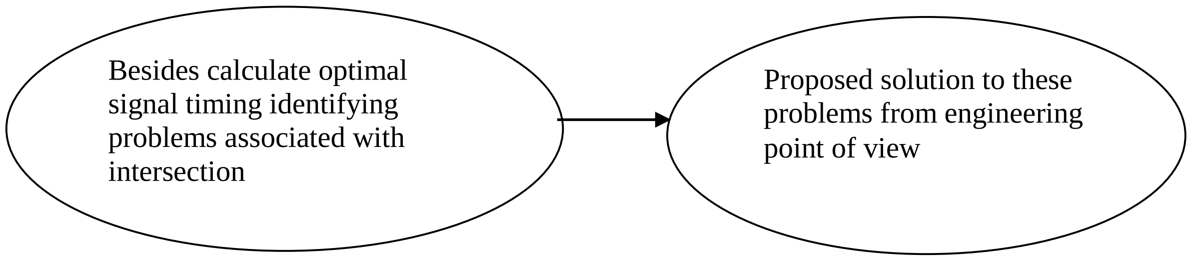

Figure 2.3: Identifying other problem related to intersection.

Each separate queue leading to the intersection and characterized by its direction, lane usage and right of way provision is called a movement. The allocation of right of way to individual movements is determined by the signal phasing system. A phase change occurs when at least one movement losses right of way and at least one other movement gains right of way. The layout of the junction along with 4 phases in signal timing is shown in figure 2.4. There are 16 lanes in this approaching intersection, which constitute 12 movements. Arrows in the figure 2.4 below present the directions of all the movements. Intersection between Kemal Ataturk Avenue and Madani Avenue and between Gulashan North Avenue and Gulshan Avenue Road has been selected in this study. These roads play an important link to connect between Dhaka Mymensingh Highways and Pragati Avenue (Two major roads in Dhaka City).

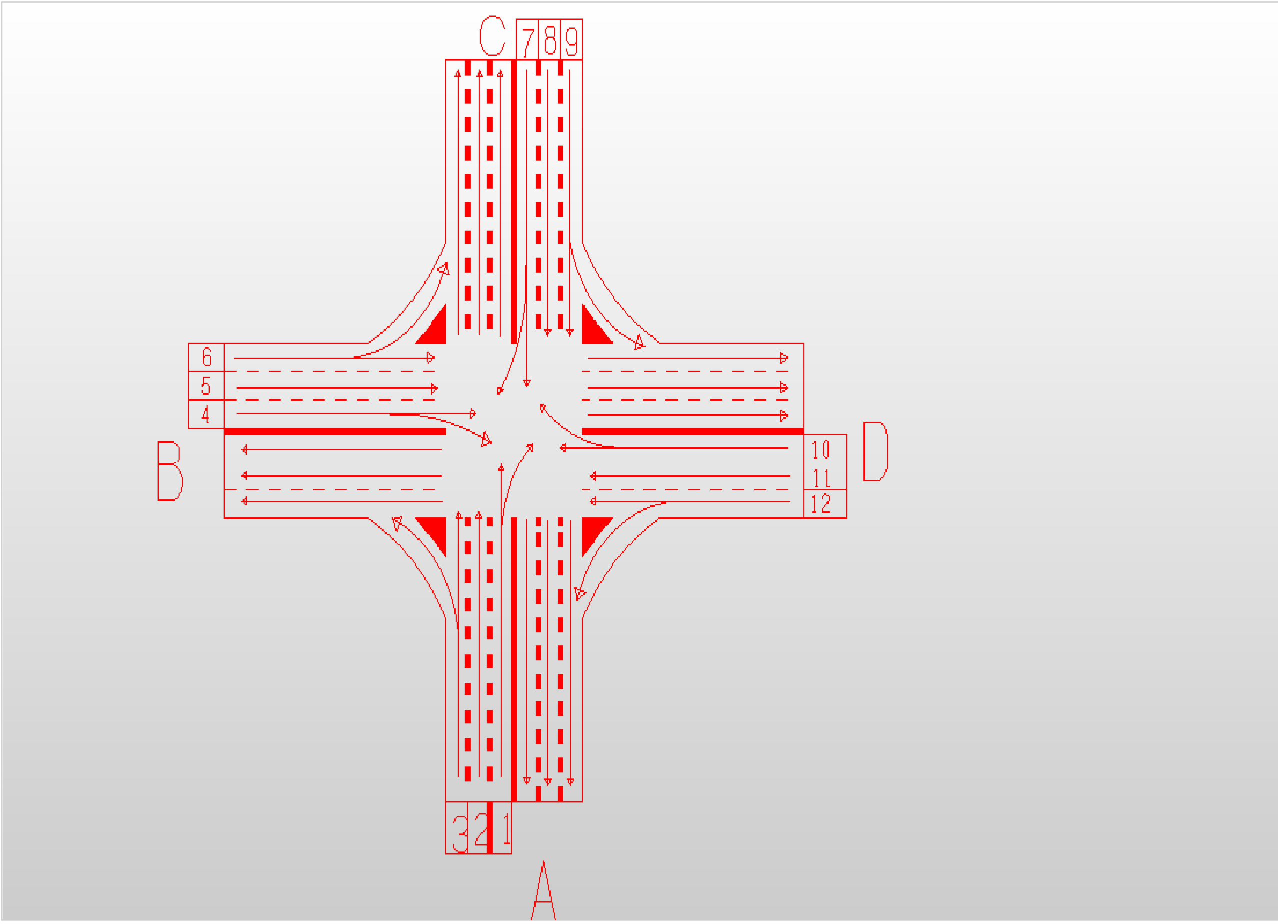

Fig 2.4: The plan view of intersection

A=Kemal Ataturk Avenue

B=Gulshan North Avenue

C=Madani Avenue

D=Gulshan Avenue

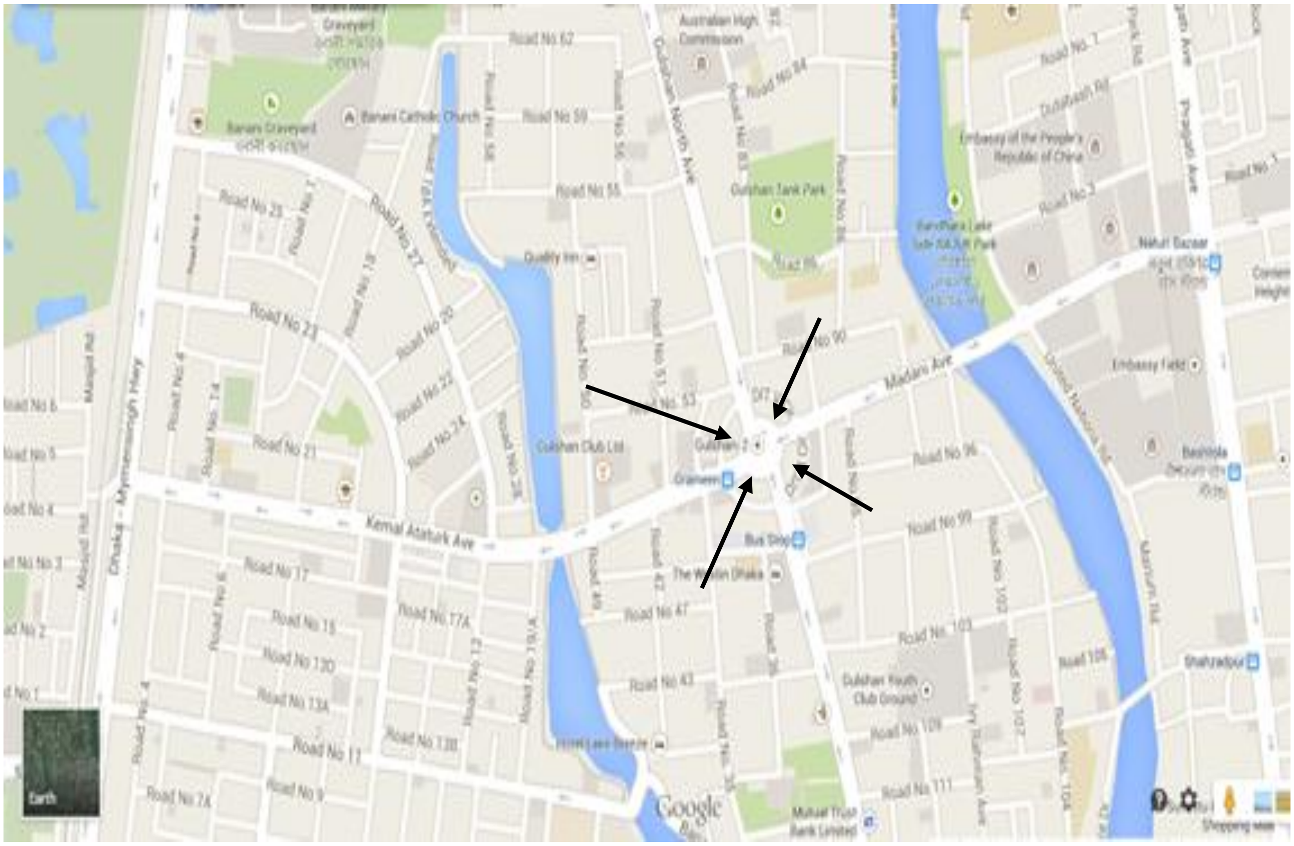

Fig 2.5: Intersection in Google map

The junction consists of four phases, A, B, C and D is shown above in figure 2.4. In phase A, movements 1, 2,3,6,9 and 12 get right of way. In phase B, movements 4, 5, 6,9,12 and 3 get right of way. In phase C, movements 7, 8, 9, 12, 3 and 6 get right of way. In phase B, movements 4, 5, 6,9,12 and 3 get right of way. In phase D, movements 10, 11, 12, 3, 6 and 9 get right of way.

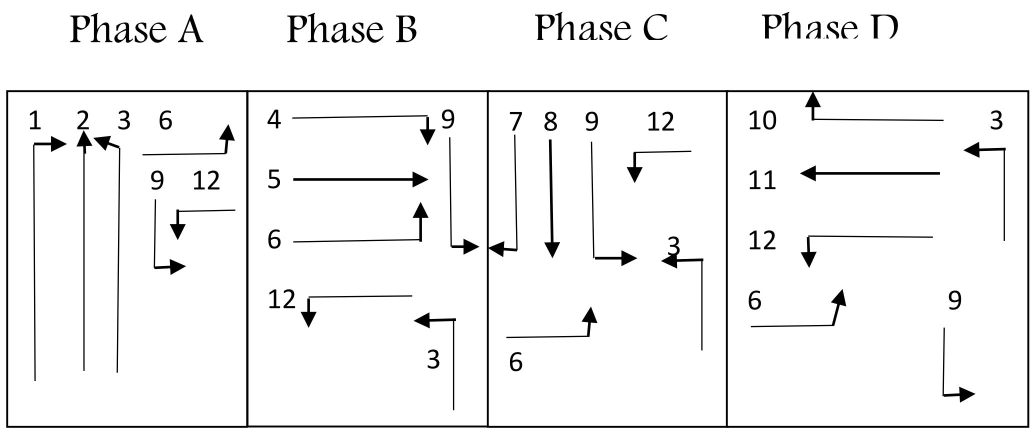

Fig 2.6: The phase movement diagram for the junction

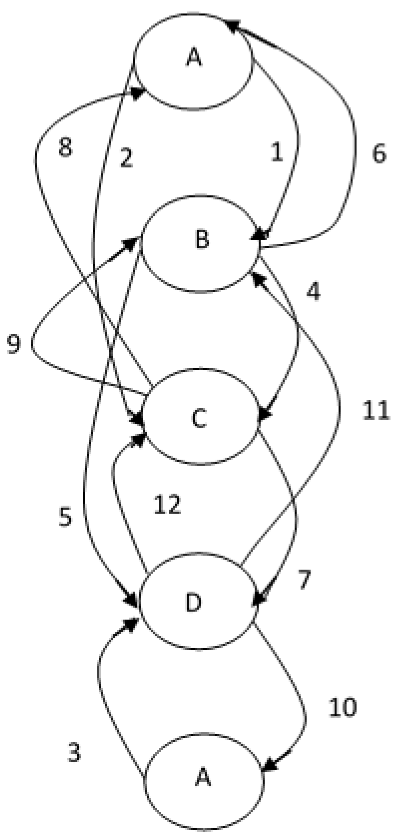

Fig 2.7: Movement diagram

Table 2.1: Phase movement matrix

Movement	Starting Phase	Terminating Phase
1	A	B
2	A	C
3	A	D
4	B	C
5	B	D
6	B	A
7	C	D
8	C	A
9	C	B
10	D	A
11	D	B
12	D	C

To collect data for evaluating the performance of existing signal timing, following equipments are to be used,

I. Stop watch
II. Tape
III. Vehicle counter

The performance of the junction is to be evaluated based on the following factors:

- Degree of saturation of the junction
- Delay per vehicle

Before any analysis can be done to evaluate the performance of the junction, we will have to obtain the following parameters for the 11 movements.

I. Saturation flow, s
II. Delay per vehicle, D_v

To obtain these parameters, cars passing through the junction at each movement during the green time are counted. Different types of vehicles within the traffic stream make it difficult to express flow in terms of vehicle. To overcome this problem flow value is calculated by converting all the vehicles to a common type usually the passenger car (PCU). It is the method of expressing various types of vehicles having different characteristics in a common equivalent unit. It is needed to remove the effect of traffic composition from flow calculation. One car is considered to one unit. In respect of its road occupancy and operational requirements, each type of vehicle is then converted into equivalent number of passenger car or cars. The converted factors for calculating PCU are as follows:

Table 2.2: PCU conversion

Vehicle	PCU
Car	1
Microbus	1
Bus/Truck	3
Baby taxi	0.75
Rickshaw	3.5
Van	4
Minibus	2

These conversion factors will convert the various vehicles to equivalent of the passenger cars such that a fair comparison, in term of road space occupied can be found in each 6 seconds interval. For example, if there is a total of 3 motorcycles, 6 cars, 1 bus and a 1 truck passing through the junction, the PCU for that interval is calculated as such.

Total PCU = Σ(no. of vehicle passing) (PCU conversion)

= 3(0.75) +6(1) +1(3) +1(3)

= 14.25

The calculated PCU value is then utilized to find the degree of saturation for each movement. When the signal changes to green from red, the flow across the stop line increases rapidly. At this time the departure rate is lower than the saturation flow rate. Within few seconds vehicle accelerate to normal running speed. Similarly the departure rate will drop below the saturation flow during the period after the end of green because some vehicles stop and others do not.

The maximum rate of flow in vehicles per hour that can pass through an intersection approach or lane group under prevailing roadway and traffic conditions assuming that the approach or lane group has 100 % of real time available as effective green time is called a saturation flow. Degree of saturation is then calculated by using this saturation flow. The degree of saturation of a movement, which measures the level of utilization of the green period, is given by the flow capacity ratio. The value of the degree of saturation should lie between the values of 0.7 to 0.9. If the value is not in the mentioned range, changes to the timing of the junction can be done to improve the performance of the junction. The performance of the junction is evaluated by delay calculation. Calculated degree of saturation is employed to find out this delay. Finally, delay per vehicle is calculated by using some mathematical equations.

The green time ratio is expressed by the symbol u where **$u=g/c$**. g denotes effective green time where c denotes the cycle time. The flow ratio is expressed by design flow and saturation flow, **$y = q/s$** where q indicates design flow and s indicates saturation flow. After calculating u and y, they are used to calculate the degree of saturation, x by the equation **$x = y/u$**.

As the target of our study is to minimize delay, a new design of signal timing is proposed by changing the different degree of saturation values for different movements. After giving some trials by these values an optimal design is achieved. This re-designed timing will not only minimize the overall delays for all the movements but also significantly reduces delay for some movements.

The delay is generally presented delay per vehicle in a movement.

Total delay per vehicle, **$D_v = ½ * c_{(1-u)}{}^2 / (1-y) + n_r(1-u)/q(1-y)$ ... …. ….. (1)**

Where, D_v = Average delay per vehicle

u = Green time ratio

y = Flow ratio

q = Design flow

n_r = The average overflow queue

The average overflow queue n_r, will naturally depend on the degree of saturation x. At low x, the expected expression of the overflow queue obtained empirically is

$$\mathbf{n_r = \frac{1}{2} * e^{-1.33}\Phi/(1-x)} \quad \ldots \ \ldots. \ \ldots.. \ (2)$$

Where

$$\mathbf{\Phi = (1-x)qc/x^{3/2}} \quad \ldots \ \ldots. \ \ldots.. \ (3)$$

Besides this optimized signal timing design, certain anomalies related to the intersection are focused. How these anomalies create problems to the intersection operations are also shown by photographs. These photographs have been taken from different points near the intersection. From the engineering point of view how to handle these problems are also discussed and solutions have also been proposed.

Chapter 4

ANALYSIS OF EXISTING SITUATION

To analyze the existing situation of signal timing on the selected intersection, three major works have to be done. The first one is the counting of vehicle flow of the existing design. The second one is to calculate the saturation flow by these counted vehicles, which will later be employed to obtain the degree of saturation for each movement, and the rest is to calculate the delay per vehicle. In the following section the details description of these four steps of works are given along with relevant equations whenever necessary.

4.1 PCU

It is the method of expressing various types of vehicles having different characteristics in a common equivalent unit. It is needed to remove the effect of traffic composition from flow calculation. One car is considered to one unit. In respect of its road occupancy and operational requirements each type of vehicle is then converted into equivalent number of passenger car or cars. The conversion factors for calculating PCU are as follows:

Table 3.1: PCU conversion

Vehicle	PCU
Car	1
Microbus	1
Bus/Truck	3
Baby taxi	0.75
Rickshaw	3.5
Van	4
Minibus	2

4.2 COUNTING OF VEHICLE FLOW

The movement timings and flow rates of vehicles for all ten movements at the junction are recorded and a total of two sets of data was collected on 28th august, 2005.one set of data was collected during the pick period from 8.30am to 9.30am in the morning and the other set of data was collected during the pick period from 4.30 pm to 5.30 pm in the evening. The counted flow is used to calculate the saturation flow. Another data has been taken for design flow. For this purpose data was collected during pick period, the same time for saturation flow. Data has been taken of twenty minutes for each movement. After that the vehicle flow is converted into pcu and subsequently presented as design flow (vph). The design flow for all 9 movements are shown in table table3.2 (a) and 3.2(b)

table3.2 (a): design flow calculation (morning peak)

Movement	q (veh per hr)
1	1358.294
2	4949.698
3	5097.780
4	604.8
5	4142.016
6	1591.38
7	627.624
8	4185.792
9	3272.544
10	1078.920
11	3727.476
12	2935.440

Table 3.2(b): Design flow calculation (Evening Peak)

Movement	q (veh per hr)
1	1056.240
2	4411.246
3	5123.693
4	1234.591
5	5929.2
6	2672.136
7	539.460
8	3010.061
9	2202.552
10	1180.980
11	4817.484
12	2716.589

4.3 CALCULATION OF SATURATION FLOW

When the green period at a traffic signal commences, vehicles take a few seconds to accelerate to normal running speed, but after this initial period the queue discharges at a more or less constant rate. This rate is called the saturation flow. It is expressed in vehicles per hour of green time.

The average level of flow in saturated intervals of the green period, but excluding the beginning and end intervals, has taken as the saturation flow. The graph can be simplified to the rectangular form, the height of which is equal to the saturation flow and the area to the total number of vehicle discharge during a fully saturated green period.

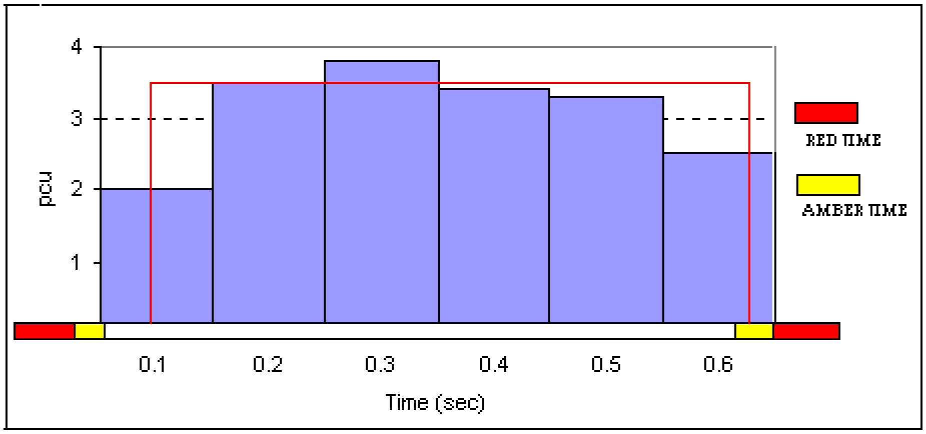

Figure 3.1: Typical saturation flow calculation using counter data

During saturation flow calculation pick period data (8.30 am to 9.30 am) and (4.30pm to5.30pm) have been utilized. Data has been collected every 6 second interval. A sample data sheet is shown in Table 3.3.For each movement five sets of data have been taken. Then the data is converted into PCU. Table 3.4 is an example, which shows the converted PCU value.

Table3.3: Data collection sample for one cycle

Vehicle	Time (sec)											
	6	12	18	24	30	36	42	48	54	60	66	72
Motorcycles Baby taxi												
Bus												
Car												
Mini bus												

Table 3.4: PCU conversion

	movement 1				
time	cycle1	cycle2	cycle3	cycle4	cycle5
6	4	0	0	1	0
12	3	2	2	0	1.5
18	4	3.5	1	0	3
24	3	1	2	0	3
30	3	1	2	0	1
36	3	1	4	0	1
42	6	2	0	0	1
48	2.75	1	0	1	1
54	7.75	1	0	1	1
60	0	3	1	0.5	1
66	0	4.5	1	1.5	0.5
72	0	2	0.75	2	0.5
78	3	2	1.75	4	0.5
84	2	1	2	1	0.5
90	2	1	1	0	0.5
96	1	1	2	0	1
102	2	1	2	0	1
108	2	1	0.5	0	1.75
114	0	1	15	0	0
120	0	1	1	0	1

This PCU value is then utilized to obtain saturation flow. The saturation flow have been calculated the average rectangular height. The sample saturation flow calculation for one movement is shown figure 3.2

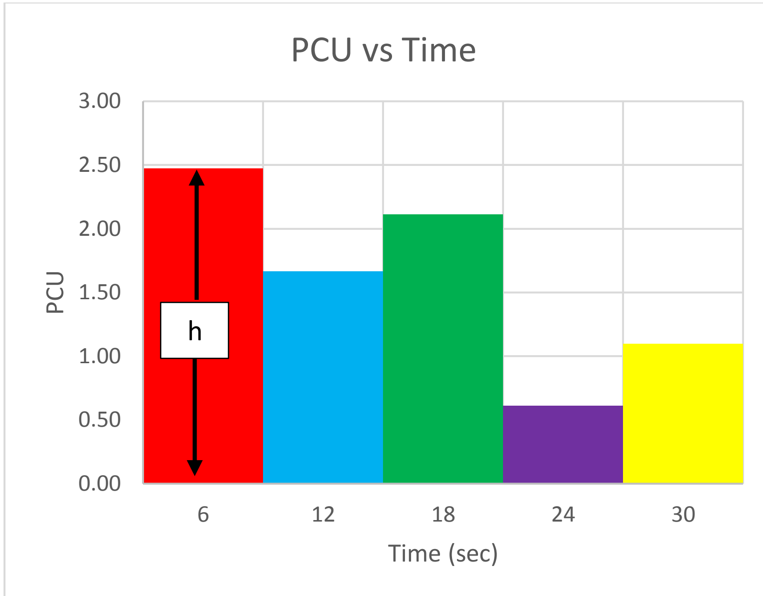

Fig. 3.2: Movement 1

According to the above table 3.4, Average saturation flow calculation:

Σ(Height of rectangle × green time excluding first and last interval) = h × (Total green time excluding first and last interval)

$\Rightarrow$ h =2.47

Similar method is applied to calculate the saturation flow for all other movements. The saturation flow for all 9 movements is shown in Table 3.5(a) and 3.5(b) and the relevant graphs for these calculations are shown in Appendix A.

Table 3.5(a): Table design flow and saturation flow (Morning peak)

Movement	s (veh per hr)
1	5731.2
2	21614.4
3	22860
4	3456
5	23011.2
6	9093.6
7	2728.8
8	19468.8
9	14875.2
10	4795.2
11	15861.6
12	13046.4

Table 3.5(b): Table design flow and saturation flow (Evening peak)

Movement	s (veh per hr)
1	4694.4
2	19432.8
3	25747.2
4	6746.4
5	26352
6	15012
7	3996
8	22132.8
9	16315.2
10	5248.8
11	19663.2
12	11462.4

4.4 DEGREE OF SATURATION

The calculated saturation flow is then employed to identify the degree of saturation. To calculate the degree of saturation, the definition of green time ratio and flow ratio should be known.

4.5 GREEN TIME RATIO

The green time ratio is expressed by the symbol u where u=g/c. g denotes effective green time where c denotes the cycle time.

4.6 FLOW RATIO

The flow ratio is expressed by design flow and saturation flow, y = q/s where q indicates design flow and s indicates saturation flow. After calculating u and y, they are used to calculate the degree of saturation, x by the equation x = y/u. Cycle time and green time are obtained from field. The value of cycle time is 120 sec. However, green time varies from phase to phase. In phase A, it is 30sec, in phase B it is 30 and in phase C it is 42 sec.

Subsequently, using the cycle time and different green time for different phases, the flow ratio (y), green time ratio (u) and the degree of saturation (x) of 9 movements are calculated. Results are summarized in Table 3.6(a).and 3.6(b)

Table 3.6(a): Calculation of degree of saturation (Morning peak)

Movement	q	s	y (q/s)	g (sec)	c(sec)	u (g/c)	x=y/u
1	1358.294	5731.2	0.237	120	480	0.25	0.948
2	4949.698	21614.4	0.229	120	480	0.25	0.916
3	5097.780	22860	0.223	120	480	0.25	0.892
4	604.800	3456	0.175	90	480	0.1875	0.933
5	4142.016	23011.2	0.180	90	480	0.1875	0.960
6	1591.380	9093.6	0.175	90	480	0.1875	0.933
7	627.624	2728.8	0.230	120	480	0.25	0.920
8	4185.792	19468.8	0.215	120	480	0.25	0.860
9	3272.544	14875.2	0.220	120	480	0.25	0.880
10	1078.920	4795.2	0.225	150	480	0.3125	0.720
11	3727.476	15861.6	0.235	150	480	0.3125	0.752
12	2935.440	13046.4	0.225	150	480	0.3125	0.720

Table 3.6(b): Calculation of degree of saturation (Evening peak)

Movement	q	s	y (q/s)	g (sec)	c(sec)	u (g/c)	x=y/u
1	1056.240	4694.4	0.225	150	660	0.227	0.990
2	4411.246	19432.8	0.227	150	660	0.227	0.999
3	5123.693	25747.2	0.199	150	660	0.227	0.876
4	1234.591	6746.4	0.183	180	660	0.273	0.671
5	5929.200	26352	0.225	180	660	0.273	0.825
6	2672.136	15012	0.178	180	660	0.273	0.653
7	539.460	3996	0.135	90	660	0.136	0.990
8	3010.061	22132.8	0.136	90	660	0.136	0.997
9	2202.552	16315.2	0.135	90	660	0.136	0.990
10	1180.980	5248.8	0.225	240	660	0.364	0.619
11	4817.484	19663.2	0.245	240	660	0.364	0.674
12	2716.589	11462.4	0.237	240	660	0.364	0.652

4.7 DELAY CALCULATION

The values of x ranging from 0.614 to 0.948 are obtained from morning Table 3.6(a). and 0.614 to0.958 are obtained from evening Table 3.6(b) According to practical consideration, the degree of saturation limit in between the values of 0.7 to 0.9 is well acceptable. Though our obtained values are near to the acceptable range still there is a scope to reduce the delay and improve the junction performance.

The delay is generally presented delay per vehicle in a movement.

Total delay per vehicle, $\mathbf{D_v = ½ * c_{(1-u)}{}^2 / (1-y) + n_r(1-u)/q(1-y)}$

Where

D_v = Average delay per vehicle

u = Green time ratio

y = Flow ratio

q = Design flow

n_r = The average overflow queue

The average overflow queue n_r, will naturally depend the degree of saturation x. At low x, the expected expression of the overflow queue obtained empirically is

$$\mathbf{n_r = \frac{1}{2} * e^{-1.33}\Phi/(1-x)}$$

Where

$$\mathbf{\Phi = (1-x)qc/x^{3/2}}$$

The values of the average delay per vehicles D_v for each movement are summarized in Table: 3.7(a) and 3.7(b)

Table 3.7(a): Calculation of average delay per vehicle (Morning peak)

Movement	X	q (vps)	$e^{-1.33}$	Φ	n_r	D_v (sec)
1	0.948	0.377	0.26448	10.19468	25.926	244.532
2	0.916	1.375	0.26448	63.23827	99.554	245.528
3	0.892	1.416	0.26448	87.13266	106.688	246.472
4	0.933	0.168	0.26448	5.962166	11.826	261.372
5	0.960	1.510	0.26448	30.82275	101.900	260.083
6	0.933	0.442	0.26448	15.68618	31.114	261.374
7	0.920	0.174	0.26448	7.571793	12.516	245.390
8	0.860	1.163	0.26448	97.99441	92.561	248.014
9	0.880	0.909	0.26448	63.42527	69.894	247.010
10	0.720	0.300	0.26448	65.99663	31.169	238.538
11	0.752	1.035	0.26448	188.9324	100.742	235.759
12	0.720	0.815	0.26448	179.2909	84.676	238.537
						∑=2972.608

Table 3.7(b): Calculation of average delay per vehicle (Evening peak)

Movement	X	q (vps)	Φ	$e^{-1.33}$	n_r	D_v (sec)
1	0.990	0.293	1.9632	0.26448	25.9607	342.8063
2	0.999	1.225	.8097	0.26448	107.0755	342.4986
3	0.876	1.423	142.0412	0.26448	151.4785	348.902
4	0.671	0.343	135.5034	0.26448	54.4644	354.778
5	0.825	1.647	253.8602	0.26448	191.8293	334.3093
6	0.653	0.742	322.0383	0.26448	122.7260	358.4666
7	0.99	0.150	1.005	0.26448	13.2905	373.2912
8	0.997	0.836	1.6628	0.26448	73.2936	372.7917
9	0.99	0.612	4.1006	0.26448	54.2252	373.2912
10	0.619	0.328	169.3584	0.26448	58.7814	319.3062
11	0.674	1.338	520.2688	0.26448	211.0418	309.6682
12	0.652	0.755	329.3811	0.26448	125.1635	313.1317
						∑=4143.241

Chapter 5

PROPOSED IMPROVED SIGNAL TIMING

5.1 PROPOSED IMPROVED SIGNAL TIMING

As the target of the study is to improve the junction performance, reduction of delay for various movements may be one way to fulfill this target. This can be done by re-designing signal timings which is possible by reassuming different degree of saturation values for various movements. Several trials have been performed with these assumed degrees of saturation values. All these values are within the range between 0.7 to 0.9 which is practically acceptable. Five trials have been executed by assuming degree of saturation values 0.9, 0.85, 0.80, 0.75, 0.70, and for all movements. Using this values delay per vehicle has been calculated for all movements, which gives a basis to compare the effectiveness between present signal timing and proposed signal timing. These calculations are presented from Table 4.1(a) to 4.6(b) below:

Table 4.1(a): Calculation of delay per vehicle by assuming degree of saturation value 0.9 (Morning peak)

Movements	x	q (vps)	c	U	Y	$e^{-1.33}$	Φ	n_r	D_v
1	0.9	0.377	360	0.263	0.237	0.26448	15.89572	21.02028	181.9962
2	0.9	1.375	360	0.254	0.229	0.26448	57.97509	76.66547	183.8747
3	0.9	1.416	360	0.248	0.223	0.26448	59.7038	78.95149	184.9675
4	0.9	0.168	360	0.25	0.175	0.26448	7.083502	9.367126	173.4152
5	0.9	1.51	360	0.244	0.18	0.26448	63.66719	84.19262	176.8641
6	0.9	0.442	360	0.2	0.175	0.26448	18.63636	24.64446	193.7035
7	0.9	0.174	360	0.244	0.23	0.26448	7.336484	9.701666	188.3488
8	0.9	1.163	360	0.256	0.215	0.26448	49.03639	64.84504	179.77
9	0.9	0.909	360	0.239	0.22	0.26448	38.32681	50.68284	188.0418
10	0.9	0.3	360	0.26	0.225	0.26448	12.64911	16.72701	180.4232
11	0.9	1.035	360	0.265	0.235	0.26448	43.63943	57.70819	180.6819
12	0.9	0.815	360	0.24	0.225	0.26448	34.36342	45.44171	188.8298

∑=2200.9167

Table 4.1(b): Calculation of delay per vehicle by assuming degree of saturation value 0.9 (Evening peak)

Movements	x	q (vps)	c	U	Y	$e^{-1.33}$	Φ	n_r	D_v
1	0.9	0.293	540	0.263	0.225	0.26448	18.53095	24.50507	268.7673
2	0.9	1.225	540	0.254	0.227	0.26448	77.4758	102.4529	275.0984
3	0.9	1.423	540	0.248	0.199	0.26448	89.99842	119.0127	269.1381
4	0.9	0.343	540	0.25	0.183	0.26448	21.69322	28.68682	262.6699
5	0.9	1.647	540	0.244	0.225	0.26448	104.1654	137.7469	280.7004
6	0.9	0.742	540	0.2	0.178	0.26448	46.9282	62.05721	291.6156
7	0.9	0.150	540	0.244	0.135	0.26448	9.486833	12.54526	251.4946
8	0.9	0.836	540	0.256	0.136	0.26448	52.87328	69.9189	244.9991
9	0.9	0.612	540	0.239	0.135	0.26448	38.70628	51.18465	254.3456
10	0.9	0.328	540	0.26	0.225	0.26448	20.74454	27.4323	270.6348
11	0.9	1.338	540	0.265	0.245	0.26448	84.62255	111.9037	274.6126
12	0.9	0.755	540	0.24	0.237	0.26448	47.75039	63.14447	287.6994

∑=3231.7758

Table 4.2(a): Calculation of delay per vehicle by assuming degree of saturation value 0.85 (Morning peak)

Movements	x	q (vps)	c	U	Y	$e^{-1.33}$	Φ	n_r	D_v
1	0.85	0.377	360	0.279	0.237	0.26448	25.97806	22.90202	180.0403
2	0.85	1.375	360	0.269	0.229	0.26448	94.74757	83.52859	182.35
3	0.85	1.416	360	0.262	0.223	0.26448	97.57277	86.01926	183.8713
4	0.85	0.168	360	0.265	0.175	0.26448	11.57643	10.20568	171.9883
5	0.85	1.51	360	0.259	0.18	0.26448	104.0501	91.72958	175.4255
6	0.85	0.442	360	0.212	0.175	0.26448	30.45704	26.85065	193.5023
7	0.85	0.174	360	0.259	0.23	0.26448	11.98987	10.57016	186.8167
8	0.85	1.163	360	0.271	0.215	0.26448	80.13922	70.65	178.2735
9	0.85	0.909	360	0.253	0.22	0.26448	62.63676	55.21999	186.9493
10	0.85	0.3	360	0.25	0.225	0.26448	20.6722	18.22442	189.4336
11	0.85	1.035	360	0.26	0.235	0.26448	71.31908	62.87425	187.6099
12	0.85	0.815	360	0.27	0.225	0.26448	56.15947	49.50967	180.9911

∑=2197.2517

Table 4.2(b): Calculation of delay per vehicle by assuming degree of saturation value 0.85 (Evening peak)

Movements	x	q (vps)	c	U	Y	$e^{-1.33}$	Φ	n_r	D_v
1		0.85	0.293	540	0.279	0.225	0.26448	30.28477	26.69877
2		0.85	1.225	540	0.269	0.227	0.26448	126.6172	111.6246
3		0.85	1.423	540	0.262	0.199	0.26448	147.0827	129.6667
4		0.85	0.343	540	0.265	0.183	0.26448	35.45282	31.25488
5		0.85	1.647	540	0.259	0.225	0.26448	170.2355	150.0781
6		0.85	0.742	540	0.212	0.178	0.26448	76.69385	67.6126
7		0.85	0.150	540	0.259	0.135	0.26448	15.50415	13.66831
8		0.85	0.836	540	0.271	0.136	0.26448	86.40978	76.17807
9		0.85	0.612	540	0.253	0.135	0.26448	63.25692	55.76672
10		0.85	0.328	540	0.25	0.225	0.26448	33.9024	29.88805
11		0.85	1.338	540	0.26	0.245	0.26448	138.297	121.9214
12		0.85	0.755	540	0.27	0.237	0.26448	78.03754	68.79718

∑=3226.8030

Table 4.3(a): Calculation of delay per vehicle by assuming degree of saturation value 0.80 (Morning peak)

Movements	x	q (vps)	c	U	Y	$e^{-1.33}$	Φ	n_r	D_v
1	0.80	0.377	360	0.296	0.237	0.26448	37.93489	25.08229	178.3079
2	0.80	1.375	360	0.286	0.229	0.26448	138.3567	91.48051	180.6311
3	0.80	1.416	360	0.279	0.223	0.26448	142.4823	94.20829	182.1627
4	0.80	0.168	360	0.281	0.175	0.26448	16.90467	11.17725	170.7745
5	0.80	1.51	360	0.275	0.18	0.26448	151.9408	100.4622	174.2045
6	0.80	0.442	360	0.225	0.175	0.26448	44.47539	29.40682	193.5445
7	0.80	0.174	360	0.275	0.23	0.26448	17.50841	11.57644	185.5165
8	0.80	1.163	360	0.288	0.215	0.26448	117.0246	77.37588	176.5862
9	0.80	0.909	360	0.29	0.22	0.26448	91.46636	60.47693	176.8913
10	0.80	0.3	360	0.265	0.225	0.26448	30.18692	19.95938	188.569
11	0.80	1.035	360	0.275	0.235	0.26448	104.1449	68.85987	186.729
12	0.80	0.815	360	0.285	0.225	0.26448	82.00779	54.22299	180.1166

∑=2174.0338

Table 4.3(b): Calculation of delay per vehicle by assuming degree of saturation value 0.80 (Evening peak)

Movements	x	q (vps)	c	U	Y	$e^{-1.33}$	Φ	n_r	D_v
1	0.80	0.293	540	0.296	0.225	0.26448	44.22383	29.2405	263.3205
2	0.80	1.225	540	0.286	0.227	0.26448	184.8949	122.2512	270.2457
3	0.80	1.423	540	0.279	0.199	0.26448	214.7799	142.011	265.057
4	0.80	0.343	540	0.281	0.183	0.26448	51.77056	34.23034	258.6701
5	0.80	1.647	540	0.275	0.225	0.26448	248.5893	164.3655	276.4794
6	0.80	0.742	540	0.225	0.178	0.26448	111.9935	74.04931	291.3764
7	0.80	0.150	540	0.275	0.135	0.26448	22.64019	14.96954	247.7127
8	0.80	0.836	540	0.288	0.136	0.26448	126.1813	83.43022	240.6601
9	0.80	0.612	540	0.29	0.135	0.26448	92.37197	61.07571	239.2634
10	0.80	0.328	540	0.265	0.225	0.26448	49.50655	32.73339	282.8535
11	0.80	1.338	540	0.275	0.245	0.26448	201.9505	133.5283	283.8033
12	0.80	0.755	540	0.285	0.237	0.26448	113.9556	75.34667	274.424

∑=3193.8660

Table 4.4(a): Calculation of delay per vehicle by assuming degree of saturation value 0.75 (Morning peak)

Movements	x	q (vps)	c	U	Y	$e^{-1.33}$	Φ	n_r	D_v
1	0.75	0.377	360	0.316	0.237	0.26448	52.23865	27.63187	176.0776
2	0.75	1.375	360	0.305	0.229	0.26448	190.5256	100.7794	178.8377
3	0.75	1.416	360	0.297	0.223	0.26448	196.2067	103.7844	180.8023
4	0.75	0.168	360	0.3	0.175	0.26448	23.27876	12.31341	169.098
5	0.75	1.51	360	0.293	0.18	0.26448	209.2317	110.6741	172.9168
6	0.75	0.442	360	0.24	0.175	0.26448	61.24532	32.39599	193.5412
7	0.75	0.174	360	0.293	0.23	0.26448	24.11015	12.75317	184.1451
8	0.75	1.163	360	0.25	0.215	0.26448	161.15	85.24103	199.0071
9	0.75	0.909	360	0.26	0.22	0.26448	125.9547	66.62433	195.9046
10	0.75	0.3	360	0.265	0.225	0.26448	41.56922	21.98823	194.9828
11	0.75	1.035	360	0.275	0.235	0.26448	143.4138	75.85938	193.1382
12	0.75	0.815	360	0.285	0.225	0.26448	112.9297	59.73468	186.3558

∑=2224.807

Table 4.4(b): Calculation of delay per vehicle by assuming degree of saturation value 0.75 (Evening peak)

Movements	x	q (vps)	c	U	Y	$e^{-1.33}$	Φ	n_r	D_v
1	0.75	0.293	540	0.316	0.225	0.26448	60.89891	32.21275	260.0269
2	0.75	1.225	540	0.305	0.227	0.26448	254.6115	134.6779	267.5625
3	0.75	1.423	540	0.297	0.199	0.26448	295.765	156.4462	263.0775
4	0.75	0.343	540	0.3	0.183	0.26448	71.29121	37.70981	256.1307
5	0.75	1.647	540	0.293	0.225	0.26448	342.3225	181.073	274.4356
6	0.75	0.742	540	0.24	0.178	0.26448	154.2218	81.57632	291.3714
7	0.75	0.150	540	0.293	0.135	0.26448	31.17691	16.49117	245.8816
8	0.75	0.836	540	0.25	0.136	0.26448	173.7593	91.91079	271.2163
9	0.75	0.612	540	0.26	0.135	0.26448	127.2018	67.28397	264.9809
10	0.75	0.328	540	0.265	0.225	0.26448	68.17352	36.06069	292.4742
11	0.75	1.338	540	0.275	0.245	0.26448	278.0981	147.1012	293.5445
12	0.75	0.755	540	0.285	0.237	0.26448	156.9238	83.00556	283.9301

∑=3264.6321

Table 4.5(a): Calculation of delay per vehicle by assuming degree of saturation value 0.70 (Morning peak)

Movements	x	q (vps)	c	U	Y	$e^{-1.33}$	Φ	n_r	D_v
1	0.70	0.377	360	0.339	0.237	0.26448	69.52133	30.64468	173.4936
2	0.70	1.375	360	0.327	0.229	0.26448	253.5592	111.7677	176.6958
3	0.70	1.416	360	0.319	0.223	0.26448	261.1199	115.1005	178.6776
4	0.70	0.168	360	0.321	0.175	0.26448	30.98033	13.65599	167.4913
5	0.70	1.51	360	0.314	0.18	0.26448	278.4541	122.7413	171.3039
6	0.70	0.442	360	0.257	0.175	0.26448	81.50776	35.92825	193.6534
7	0.70	0.174	360	0.314	0.23	0.26448	32.08677	14.1437	182.4276
8	0.70	1.163	360	0.329	0.215	0.26448	214.465	94.53519	172.7211
9	0.70	0.909	360	0.307	0.22	0.26448	167.6257	73.88864	183.0458
10	0.70	0.3	360	0.31	0.225	0.26448	55.32201	24.38569	182.9485
11	0.70	1.035	360	0.315	0.235	0.26448	190.8609	84.13063	183.1911
12	0.70	0.815	360	0.32	0.225	0.26448	150.2915	66.24779	178.7177

∑=2144.367

Table 4.5(b): Calculation of delay per vehicle by assuming degree of saturation value 0.70 (Evening peak)

Movements	x	q (vps)	c	U	Y	$e^{-1.33}$	Φ	n_r	D_v
1	0.70	0.293	540	0.339	0.225	0.26448	81.04674	35.72504	256.2108
2	0.70	1.225	540	0.327	0.227	0.26448	338.8473	149.3623	264.3579
3	0.70	1.423	540	0.319	0.199	0.26448	393.6161	173.5042	259.9859
4	0.70	0.343	540	0.321	0.183	0.26448	94.87725	41.82146	253.697
5	0.70	1.647	540	0.314	0.225	0.26448	455.5768	200.8162	271.8759
6	0.70	0.742	540	0.257	0.178	0.26448	205.2447	90.47091	291.5402
7	0.70	0.150	540	0.314	0.135	0.26448	41.49151	18.28927	243.5882
8	0.70	0.836	540	0.329	0.136	0.26448	231.246	101.9322	235.3924
9	0.70	0.612	540	0.307	0.135	0.26448	169.2854	74.62021	247.588
10	0.70	0.328	540	0.31	0.225	0.26448	90.7281	39.99253	274.4227
11	0.70	1.338	540	0.315	0.245	0.26448	370.1042	163.1403	278.4261
12	0.70	0.755	540	0.32	0.237	0.26448	208.8406	92.05598	272.2927

∑=3149.3782

Assuming mixed degree of saturation value has performed the rest trial.

Table 4.6(a): Calculation of delay per vehicle by assuming degree of saturation mixed value (Morning peak)

Movements	x	q (vps)	c	U	Y	$e^{-1.33}$	Φ	n_r	D_v
1	0.70	0.377	360	0.319	0.237	0.26448	69.52133	30.64468	181.9561
2	0.70	1.375	360	0.342	0.229	0.26448	253.5592	111.7677	170.4533
3	0.70	1.416	360	0.324	0.223	0.26448	261.1199	115.1005	176.5827
4	0.75	0.168	360	0.284	0.175	0.26448	23.27876	12.31341	175.4626
5	0.75	1.51	360	0.261	0.18	0.26448	209.2317	110.6741	185.9343
6	0.75	0.442	360	0.321	0.175	0.26448	61.24532	32.39599	160.914
7	0.75	0.174	360	0.254	0.23	0.26448	24.11015	12.75317	201.1042
8	0.75	1.163	360	0.336	0.215	0.26448	161.15	85.24103	163.0937
9	0.80	0.909	360	0.381	0.22	0.26448	91.46636	60.47693	141.2203
10	0.80	0.3	360	0.381	0.225	0.26448	30.18692	19.95938	142.1314
11	0.80	1.035	360	0.307	0.235	0.26448	104.1449	68.85987	173.2693
12	0.80	0.815	360	0.257	0.225	0.26448	82.00779	54.22299	192.002

∑=2064.124

Table 4.6(b): Calculation of delay per vehicle by assuming degree of saturation mixed value (Evening peak)

Movements	x	q (vps)	c	U	Y	$e^{-1.33}$	Φ	n_r	D_v
1	0.70	0.293	540	0.319	0.225	0.26448	81.04674	35.72504	268.7081
2	0.70	1.225	540	0.342	0.227	0.26448	338.8473	149.3623	255.0184
3	0.70	1.423	540	0.324	0.199	0.26448	393.6161	173.5042	256.9378
4	0.75	0.343	540	0.284	0.183	0.26448	71.29121	37.70981	265.7711
5	0.75	1.647	540	0.261	0.225	0.26448	342.3225	181.073	295.0957
6	0.75	0.742	540	0.321	0.178	0.26448	154.2218	81.57632	242.2519
7	0.75	0.150	540	0.254	0.135	0.26448	31.17691	16.49117	268.5265
8	0.75	0.836	540	0.336	0.136	0.26448	173.7593	91.91079	222.2718
9	0.80	0.612	540	0.381	0.135	0.26448	92.37197	61.07571	191.0148
10	0.80	0.328	540	0.381	0.225	0.26448	49.50655	32.73339	213.1971
11	0.80	1.338	540	0.307	0.245	0.26448	201.9505	133.5283	263.3463
12	0.80	0.755	540	0.257	0.237	0.26448	113.9556	75.34667	292.5326

∑=3034.6720

Table 4.7(a): Calculation of delay per vehicle by assuming degree of saturation mixed value (Morning peak)

Movements	x	q (vps)	c	U	Y	$e^{-1.33}$	Φ	n_r	D_v
1	0.70	0.377	360	0.339	0.237	0.26448	69.52133	30.64468	173.4936
2	0.90	1.375	360	0.327	0.229	0.26448	57.97509	76.66547	154.4118
3	0.90	1.416	360	0.319	0.223	0.26448	59.7038	78.95149	156.3028
4	0.70	0.168	360	0.321	0.175	0.26448	30.98033	13.65599	167.4913
5	0.85	1.51	360	0.314	0.18	0.26448	104.0501	91.72958	154.1225
6	0.85	0.442	360	0.257	0.175	0.26448	30.45704	26.85065	175.1571
7	0.70	0.174	360	0.314	0.23	0.26448	32.08677	14.1437	182.4276
8	0.75	1.163	360	0.329	0.215	0.26448	161.15	85.24103	165.8901
9	0.70	0.909	360	0.307	0.22	0.26448	167.6257	73.88864	183.0458
10	0.70	0.3	360	0.31	0.225	0.26448	55.32201	24.38569	182.9485
11	0.90	1.035	360	0.315	0.235	0.26448	43.63943	57.70819	160.3318
12	0.80	0.815	360	0.32	0.225	0.26448	82.00779	54.22299	165.772

∑=2021.395

Table 4.7(b): Calculation of delay per vehicle by assuming degree of saturation mixed value (Evening peak)

Movements	x	q (vps)	c	U	Y	$e^{-1.33}$	Φ	n_r	D_v
1	0.70	0.293	540	0.339	0.225	0.26448	81.04674	35.72504	256.2108
2	0.90	1.225	540	0.327	0.227	0.26448	77.4758	102.4529	231.0184
3	0.90	1.423	540	0.319	0.199	0.26448	89.99842	119.0127	227.4294
4	0.70	0.343	540	0.321	0.183	0.26448	94.87725	41.82146	253.697
5	0.85	1.647	540	0.314	0.225	0.26448	170.2355	150.0781	244.6073
6	0.85	0.742	540	0.257	0.178	0.26448	76.69385	67.6126	263.6946
7	0.70	0.150	540	0.314	0.135	0.26448	41.49151	18.28927	243.5882
8	0.75	0.836	540	0.329	0.136	0.26448	173.7593	91.91079	226.0828
9	0.70	0.612	540	0.307	0.135	0.26448	169.2854	74.62021	247.588
10	0.70	0.328	540	0.31	0.225	0.26448	90.7281	39.99253	274.4227
11	0.90	1.338	540	0.315	0.245	0.26448	84.62255	111.9037	243.6831
12	0.80	0.755	540	0.32	0.237	0.26448	113.9556	75.34667	252.5687

∑=2964.5912

Table 4.8(a): Calculation of delay per vehicle by assuming degree of saturation mixed value (Morning peak)

Movements	x	q (vps)	c	U	Y	$e^{-1.33}$	Φ	n_r	D_v
1	0.70	0.377	360	0.339	0.237	0.26448	69.52133	30.64468	173.4936
2	0.90	1.375	360	0.327	0.229	0.26448	57.97509	76.66547	154.4118
3	0.85	1.416	360	0.319	0.223	0.26448	97.57277	86.01926	160.6775
4	0.70	0.168	360	0.321	0.175	0.26448	30.98033	13.65599	167.4913
5	0.90	1.51	360	0.314	0.18	0.26448	63.66719	84.19262	149.9468
6	0.85	0.442	360	0.257	0.175	0.26448	30.45704	26.85065	175.1571
7	0.70	0.174	360	0.314	0.23	0.26448	32.08677	14.1437	182.4276
8	0.85	1.163	360	0.329	0.215	0.26448	80.13922	70.65	155.166
9	0.80	0.909	360	0.307	0.22	0.26448	91.46636	60.47693	169.9372
10	0.70	0.3	360	0.31	0.225	0.26448	55.32201	24.38569	182.9485
11	0.85	1.035	360	0.315	0.235	0.26448	71.31908	62.87425	164.8012
12	0.90	0.815	360	0.32	0.225	0.26448	34.36342	45.44171	156.3181

∑=1992.777

Table 4.8(b): Calculation of delay per vehicle by assuming degree of saturation mixed value (Evening peak)

Movements	x	q (vps)	c	U	Y	$e^{-1.33}$	Φ	n_r	D_v
1	0.70	0.293	540	0.339	0.225	0.26448	81.04674	35.72504	256.2108
2	0.90	1.225	540	0.327	0.227	0.26448	77.4758	102.4529	231.0184
3	0.85	1.423	540	0.319	0.199	0.26448	147.0827	129.6667	233.7948
4	0.70	0.343	540	0.321	0.183	0.26448	94.87725	41.82146	253.697
5	0.90	1.647	540	0.314	0.225	0.26448	104.1654	137.7469	237.9801
6	0.85	0.742	540	0.257	0.178	0.26448	76.69385	67.6126	263.6946
7	0.70	0.150	540	0.314	0.135	0.26448	41.49151	18.28927	243.5882
8	0.85	0.836	540	0.329	0.136	0.26448	86.40978	76.17807	211.4676
9	0.80	0.612	540	0.307	0.135	0.26448	92.37197	61.07571	229.8572
10	0.70	0.328	540	0.31	0.225	0.26448	90.7281	39.99253	274.4227
11	0.85	1.338	540	0.315	0.245	0.26448	138.297	121.9214	250.476
12	0.90	0.755	540	0.32	0.237	0.26448	47.75039	63.14447	238.1649

∑=2924.3724

Table 4.9(a): Calculation of delay per vehicle by assuming degree of saturation mixed value(Morning peak)

Movements	x	q (vps)	c	U	Y	$e^{-1.33}$	Φ	n_r	D_v
1	0.70	0.377	360	0.319	0.237	0.26448	69.52133	30.64468	181.9561
2	0.85	1.375	360	0.329	0.229	0.26448	94.74757	83.52859	157.9836
3	0.80	1.416	360	0.339	0.223	0.26448	142.4823	94.20829	157.8159
4	0.70	0.168	360	0.336	0.175	0.26448	30.98033	13.65599	161.6181
5	0.90	1.51	360	0.381	0.18	0.26448	63.66719	84.19262	126.198
6	0.90	0.442	360	0.356	0.175	0.26448	18.63636	24.64446	134.0119
7	0.70	0.174	360	0.381	0.23	0.26448	32.08677	14.1437	154.9153
8	0.80	1.163	360	0.35	0.215	0.26448	117.0246	77.37588	151.9686
9	0.80	0.909	360	0.324	0.22	0.26448	91.46636	60.47693	163.1164
10	0.70	0.3	360	0.325	0.225	0.26448	55.32201	24.38569	176.6197
11	0.80	1.035	360	0.33	0.235	0.26448	104.1449	68.85987	163.8928
12	0.90	0.815	360	0.365	0.225	0.26448	34.36342	45.44171	139.3368

∑=1869.433

Table 4.9(b): Calculation of delay per vehicle by assuming degree of saturation mixed value (Evening peak)

Movements	x	q (vps)	c	U	Y	$e^{-1.33}$	Φ	n_r	D_v
1	0.70	0.293	540	0.319	0.225	0.26448	81.04674	35.72504	268.7081
2	0.85	1.225	540	0.329	0.227	0.26448	126.6172	111.6246	236.3622
3	0.80	1.423	540	0.339	0.199	0.26448	214.7799	142.011	229.631
4	0.70	0.343	540	0.336	0.183	0.26448	94.87725	41.82146	244.801
5	0.90	1.647	540	0.381	0.225	0.26448	104.1654	137.7469	200.2885
6	0.90	0.742	540	0.356	0.178	0.26448	46.9282	62.05721	201.7515
7	0.70	0.150	540	0.381	0.135	0.26448	41.49151	18.28927	206.8522
8	0.80	0.836	540	0.35	0.136	0.26448	126.1813	83.43022	207.1099
9	0.80	0.612	540	0.324	0.135	0.26448	92.37197	61.07571	220.6315
10	0.70	0.328	540	0.325	0.225	0.26448	90.7281	39.99253	264.9296
11	0.80	1.338	540	0.33	0.245	0.26448	201.9505	133.5283	249.0953
12	0.90	0.755	540	0.365	0.237	0.26448	47.75039	63.14447	212.2923

∑=2742.4530

There can be several trials. But we designed based on the trials above, The comparison of delay per vehicle for all movements between proposed design and existing design by assuming different degree of saturation values are summarized in Table 4.10(a)& 4.10(b) below. This comparison can also be shown by graphical representation in figure 4.1(a) & 4.1(b)

Table 4.10(a): comparison of total delay per vehicle for all movements between proposed signal timing and existing signal timing (Morning peak)

Degree of Saturation	Delay for proposed design (sec)	Delay for existing design(sec)	% Reduction
0.9	2200.917	2972.608	-25.960
0.85	2197.2517	2972.608	-26.083
0.8	2174.0338	2972.608	-26.864
0.75	2224.807	2972.608	-25.156
0.7	2144.367	2972.608	-27.862
0.7 (1-3), 0.75 (5-8),0 .8(9-12)	2064.124	2972.608	-30.562
0.7(1,4,7,9,10),0.9(2,3,11),0.85(5 ,6)0.8(12),0.75(8)	2021.395	2972.608	-31.999
0.7(1,4,7,10),0.8(9),0.85(3,6,8,11),0.9((2,5,12)	1992.777	2972.608	-32.962
0.7(1,4,7,10),0.8(3,8,9,11),0.85(2),0.9(5,6,12)	1869.433	2972.608	-37.111

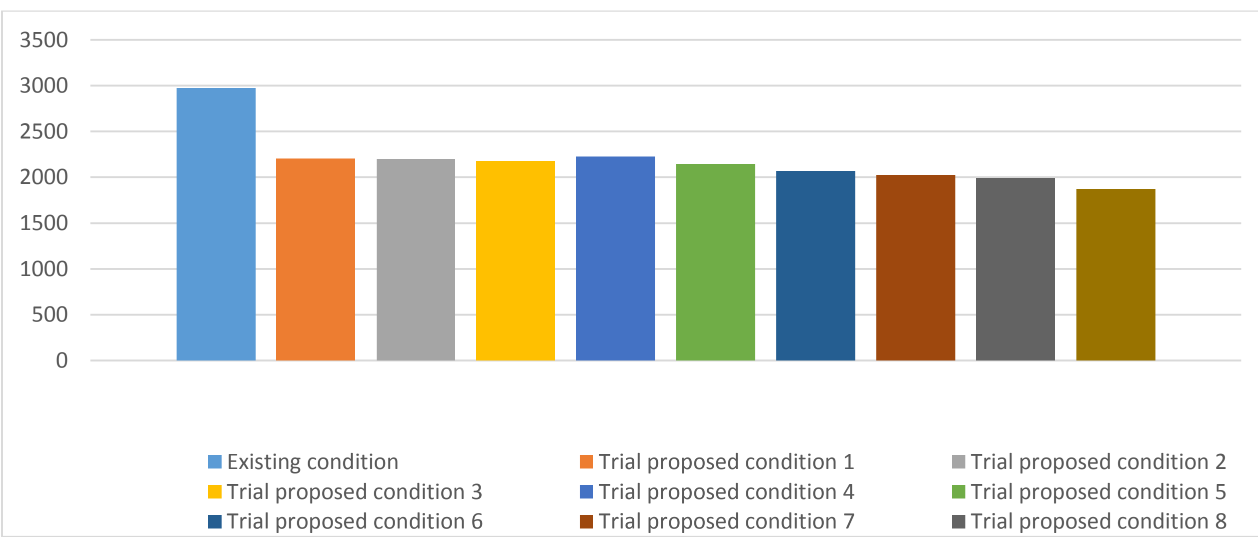

Figure 4.1(a): The comparison of delay per vehicle for all movement between proposed design and existing design condition (Morning Peak)

Table 4.10(b): comparison of total delay per vehicle for all movements between proposed signal timing and existing signal timing (Evening peak)

Degree of Saturation	**Delay for proposed design (sec)**	**Delay for existing design(sec)**	**% Reduction**
0.9	3231.7758	4143.241	-21.999
0.85	3226.8030	4143.241	-22.119
0.8	3193.8660	4143.241	-22.914
0.75	3264.6321	4143.241	-21.206
0.7	3149.3782	4143.241	-23.988
0.7 (1-3), 0.75 (5-8),0 .8(9-12)	3034.672	4143.241	-26.756
0.7(1,4,7,9,10),0.9(2,3,11),0.85(5,6)0.8(12),0.75(8)	2964.5912	4143.241	-28.448
0.7(1,4,7,10),0.8(9),0.85(3,6,8,11),0.9((2,5,12)	2924.3724	4143.241	-29.418
0.7(1,4,7,10),0.8(3,8,9,11),0.85(2),0.9(5,6,12)	2742.453	4143.241	-33.809

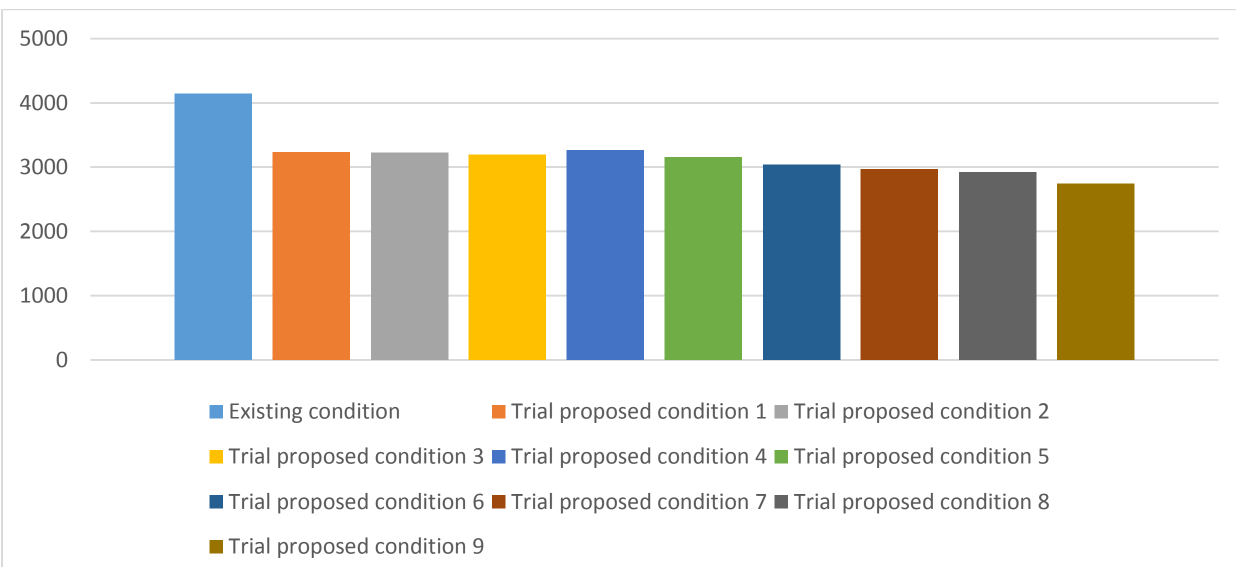

Figure 4.1(b): The comparison of delay per vehicle for all movements Between proposed design and existing design condition (Evening peak)

Fig: 4.1(a) & 4.1(b) clearly indicates that except the degree of saturation values 0.9, 85, 0.8 all other values improve the situation by minimizing delays than the existing condition. Among them, when the degree of saturation value is 0.7 for movement(1,4,7,10),0.8 for movement (3,8,9,11),0.85 for movement (2) and 0.9 for movement (5,6,12) delay reduces maximum (-37.111 %) for table 4.10(a) & (-33.809%) for table 4.10(b) reduction from present design. Hence, degree of saturation value 0.7 for movement(1,4,7,10),0.8 for movement (3,8,9,11),0.85 for movement (2) and 0.9 for movement (5,6,12) has been taken for proposed design.

5.2 NEW SIGNAL TIMING (Morning peak and Evening Peak)

To design new signal timing along with green time, the critical movement is needed to be identified since critical movements determine the capacity and timing requirements of the intersection. If sufficient time is allocated to all the critical movements to meet their capacity requirement, then all movements will have sufficient capacity. Movement time and intergreen time are required to identify critical movement. The intergreen time for each movement has been taken from fields using stopwatch. The q and s value is used as they were in existing design. Movement time can be calculated from the equation, $t = cu+l$ to calculate the movement time, cycle time is needed to be assumed for trial. In first iteration c is assumed 120. The Table 4.8 shows the calculation of movement time in details.

Table 4.11(a): Calculation of movement time (Morning peak)

c = 300

PHASE	MOVEMENTS	q	s	I	X	y (q/s)	u		t=cu+I
A	1	1358.294	5731.2	6	0.7	0.237	0.34	0.34	108
	2	4949.698	21614.4	6	0.85	0.229	0.27	0.27	87
	3	5097.780	22860	6	0.8	0.223	0.28	0.28	90
B	4	604.800	3456	6	0.7	0.175	0.25	0.25	81
	5	4142.016	23011.2	6	0.9	0.180	0.20	0.20	66
	6	1591.380	9093.6	6	0.9	0.175	0.19	0.19	63
C	7	627.624	2728.8	6	0.7	0.230	0.33	0.33	105
	8	4185.792	19468.8	6	0.8	0.215	0.27	0.27	87
	9	3272.544	14875.2	6	0.8	0.220	0.28	0.28	90
D	10	1078.920	4795.2	6	0.7	0.225	0.32	0.32	102
	11	3727.476	15861.6	6	0.8	0.235	0.29	0.29	93
	12	2935.440	13046.4	6	0.9	0.225	0.25	0.25	81

Using these movements time, different alternatives are shown in Table 4.9 to identify critical movement.

Table 4.11 (b) Different alternative for movement

T(1,6)	171
T(2,8)	174
T(3,10)	192
T(1,4,7,10)	**396**
T(1,5,10)	276
T(2,7,10)	294
T(1,4,10)	291

From the Table 4.10, the critical movements are (2, 5, and 8) as it takes the maximum time. After that using y, u, l values for critical movement's intersection parameters Y, U and L are calculated. The calculations are as follows

Y=y1+y4+y7+y10 0.867

U=u1+u4+u7+u10 1.24

L=l1+l4+l7+l10 24

c=1.4*L+6/1-Y 297.744

Then the cycle time is calculated using equation, c=1.4*L+6/1-Y=88.75 say 89 Sec

Cycle time c=89 is then used in second iteration. The details are shown in table 4.10

Table 4.12 (a): Calculation of movement time (Morning peak)

c = 298

Phase	Movements	q	s	I	X	y (q/s)	u		t=cu+I
A	1	1358.294	5731.2	6	0.7	0.237	0.34	0.34	107.32
	2	4949.698	21614.4	6	0.85	0.229	0.27	0.27	86.46
	3	5097.780	22860	6	0.8	0.223	0.28	0.28	89.44
B	4	604.800	3456	6	0.7	0.175	0.25	0.25	80.5
	5	4142.016	23011.2	6	0.9	0.180	0.20	0.20	65.6
	6	1591.380	9093.6	6	0.9	0.175	0.19	0.19	62.62
C	7	627.624	2728.8	6	0.7	0.230	0.33	0.33	104.34
	8	4185.792	19468.8	6	0.8	0.215	0.27	0.27	86.46
	9	3272.544	14875.2	6	0.8	0.220	0.28	0.28	89.44
D	10	1078.920	4795.2	6	0.7	0.225	0.32	0.32	101.36
	11	3727.476	15861.6	6	0.8	0.235	0.29	0.29	92.42
	12	2935.440	13046.4	6	0.9	0.225	0.25	0.25	80.5

Table 4.12 (b) Different alternative for movement

T(1,6)	169.94
T(2,8)	172.92
T(3,10)	190.8
T(1,4,7,10)	**393.52**
T(1,5,10)	274.28
T(2,7,10)	292.16
T(1,4,10)	289.18

From the table 4.12 critical movements is again calculated following the previous mentioned procedure. Again the critical movement is 2, 5, and 8). Hence the cycle time is 86 sec. allocating green time for critical movements (2, 5, and 8) are presented below

$Y=y_1+y_4+y_7+y_{10}=.0867$

$U=u_1+u_4+u_7+u_{10}=1.24$

$L=l_1+l_4+l_7+l_{10}=24$

c=1.4*L+6/1-Y=297.7444, say 298

$g_1=(C-L)*u_1/U=75.13$

$g_4=(C-L)*u_4/U=55.24$

$g_7=(C-L)*u_7/U=72.92$

$g_{10}=(C-L)*u_{10}/U=70.71$

Phase A

G_a+I_a=81.13 say 82, (Assuming effective green time, g = G, displayed green time)

Phase B

G_b+I_b=61.24 say 62

Phase C

G_c+I_c=78.92 say 79

Phase D

$G_d + I_d = 76.71$ say 77

Fig 4.2(a): Proposed New Signal Timing (Morning peak)

According to the above procedure we can calculate the Proposed New Signal Timing for (Evening peak)

c = 540

Table 4.13 (a): Calculation of movement time (Evening peak)

PHASE	MOVEMENT	q	s	I	X	y (q/s)	u		t=cu+I
A	1	1056.240	4694.4	6	0.7	0.225	0.32	0.32	178.8
	2	4411.246	19432.8	6	0.85	0.227	0.27	0.27	151.8
	3	5123.693	25747.2	6	0.8	0.199	0.25	0.25	141
B	4	1234.591	6746.4	6	0.7	0.183	0.26	0.26	146.4
	5	5929.200	26352	6	0.9	0.225	0.25	0.25	141
	6	2672.136	15012	6	0.9	0.178	0.20	0.20	114
C	7	539.460	3996	6	0.7	0.135	0.19	0.19	108.6
	8	3010.061	22132.8	6	0.8	0.136	0.17	0.17	97.8
	9	2202.552	16315.2	6	0.8	0.135	0.17	0.17	97.8
D	10	1180.980	5248.8	6	0.7	0.225	0.32	0.32	178.8
	11	4817.484	19663.2	6	0.8	0.245	0.31	0.31	173.4
	12	2716.589	11462.4	6	0.9	0.237	0.26	0.26	146.4

Table 4.13 (b)Different alternative for movement

T(1,6)	292.8
T(2,8)	249.6
T(3,10)	319.8
T(1,4,7,10)	612.6
T(1,5,10)	498.6
T(2,7,10)	439.2
T(1,4,10)	504

$Y=y_1+y_4+y_7+y_{10}=0.768$

$U=u_1+u_4+u_7+u_{10}=1.09$

$L=l_1+l_4+l_7+l_{10}=24$

c=1.4*L+6/1-Y= 170.69 say 171

c = 171

Table 4.14 (a): Calculation of movement time (Evening peak)

PHASE	MOVEMENT	q	s	I	X	y (q/s)	u		t=cu+I
A	1	1056.240	4694.4	6	0.7	0.225	0.32	0.32	60.96
	2	4411.246	19432.8	6	0.85	0.227	0.27	0.27	52.17
	3	5123.693	25747.2	6	0.8	0.199	0.25	0.25	48.54
B	4	1234.591	6746.4	6	0.7	0.183	0.26	0.26	50.70
	5	5929.200	26352	6	0.9	0.225	0.25	0.25	48.75
	6	2672.136	15012	6	0.9	0.178	0.20	0.20	39.82
C	7	539.460	3996	6	0.7	0.135	0.19	0.19	38.98
	8	3010.061	22132.8	6	0.8	0.136	0.17	0.17	35.07
	9	2202.552	16315.2	6	0.8	0.135	0.17	0.17	34.86
D	10	1180.980	5248.8	6	0.7	0.225	0.32	0.32	60.96
	11	4817.484	19663.2	6	0.8	0.245	0.31	0.31	58.37
	12	2716.589	11462.4	6	0.9	0.237	0.26	0.26	51.03

Table 4.14 (b) Different alternative for movement

T(1,6)	100.78
T(2,8)	87.24
T(3,10)	109.50
T(1,4,7,10)	211.61
T(1,5,10)	170.68
T(2,7,10)	152.11
T(1,4,10)	172.63

$Y=y_1+y_4+y_7+y_{10}$ =0.768

$U=u_1+u_4+u_7+u_{10}$=1.09

$L=l_1+l_4+l_7+l_{10}$=24

c=1.4*L+6/1-Y=170.69 say 171

$g_1=(C-L)*u_1/U$=43.16

$g_4=(C-L)*u_4/U$=35.06

$g_7=(C-L)*u_7/U$=25.62

$g_{10}=(C-L)*u_{10}/U$=43.16

Phase A

G_a+I_a=49.16 say 50

Phase B

G_b+I_b=41.06 say 42

Phase C

G_c+I_c=31.62 say 32

Phase D

$\mathbf{G_d+I_d}$=49.16 say 50

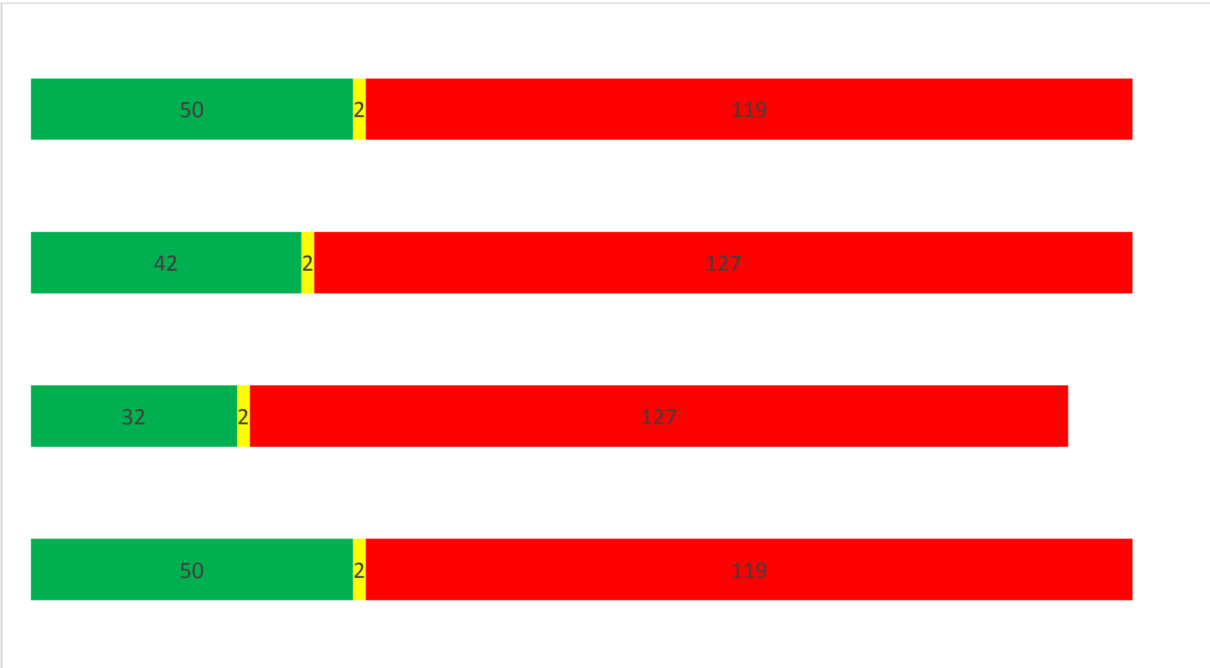

Fig: 4.2(b) Proposed New Signal Timing (Evening peak)

Chapter 6

OTHER PROBLEMS ASSOCIATED WITH THE INTERSECTION

In the previous chapter the calculation of optimal cycle was shown and suggested changing the signal timings of the intersection to these times to improve performance. The efficiency of the intersection does not totally depend on the signal timing. There are also some other factors such as, road marking, median, parking, buses stoppage, footpath, and pedestrian facilities. There are some problems and solutions of those problems have been suggested along with some photo and figures as shown below

Photo: 01

Photo: 02

Problem: Vehicles are parked illegally on the outer lane of the roadway approaching intersection. Therefore, the movement of vehicles on the outer lane of this busy road is hindered. This results a large vehicle queue.

Proposed Solution: A warning sign should be placed which shows the prohibition of illegal parking. For this purpose strictly followed traffic policy and enforcement is necessary to be imposed by the concern authority.


Photo: 03 Photo: 04

Problem: There is zebra crossing found in above pictures. (3and 4) but they are blocked by cars. These pictures indicate the pedestrians are crossing the road with risk, which increases the chances of accidents near intersection. This situation not only increases the probability of accidents but also slow down the movement of vehicles moving through the other sides.

Proposed Solution: Provide ideal zebra crossing near the intersection along with road sign indicating legal path for pedestrian crossing and no parking on intersection. Another solution is to build public awareness that shows the dire consequences of illegal crossing and enforce instant fines to drivers who park their cars on zebra crossing


Photo: 05 Photo: 06

Problem: In the above pictures passengers are found illegally get on and down from the bus. Therefore, vehicles behind this bus should slow down and consequently result traffic congestion. Again when the pedestrians look for vehicles, they often block the major portion of road. Creating traffic congestion is not the only reason; safety of onboard passengers should also be consideration.

Proposed Solution: Illegal passengers pick up should be prohibited particularly near the intersection. If possible a bus bay can be constructed. Warning sign can also be erected and instant fine can be charged to the violators of this rule.

Photo: 07 Photo: 08

Problem: photo 07 and 08, show that pedestrians are crossing the roads during the green periods. It is a great risk for pedestrians. Again this illegal crossing slows down the movement of vehicle during green periods.

Proposed solution: A warning sign should be placed which shows the prohibition of illegal road crossing. For this purpose strictly followed traffic policy and enforcement is necessary to be imposed by the concern authority

Photo: 09

Problem: It is a common picture in our country that street vendors are selling their goods from vehicle to vehicle when vehicles are stacked due to congestion. It is very risky for the vendors while vehicles start to move. Again it slows down vehicle during green periods.

Proposed solution: On street vendors should be banned from the roads. For this purpose strictly followed traffic policy and enforcement is necessary to be imposed by the concern authority

Chapter 7

CONCLUSION

The main objective of the study is to optimize the signal timing. This has been done to minimize delay since delay causes economic loss as well as environmental pollution. Gulshan-2 intersection has been chosen to fulfill the objective of the study. This intersection comprises Kemal Ataturk Avenue, Gulshan North Avenue, Madani Avenue, Gulshan Avenue with 12 movements.

At first performance of the existing design is evaluated. For this purpose relevant data has been collected from field to calculate design flow, saturation flow, degree of saturation and finally delay per vehicle for each movement. After that a new design has been proposed based on several trails. Assumed different degree of saturation values have been used to perform trails. Finally, the degree of saturation value 0.7 for movements 1, 4, 7, 10; 0.8 for movements 3, 8, 9, 11; .85 for movement 2; 0.9 for movements 5, 6, 12 gives the optimal result. The optimality is achieved when the delay reduces most. This study suggests that the new timing of the signal reduces total delay for all movements 37.11 %(Morning peak) & 33.81% (Evening peak) than the existing one.

The above figures clearly justify the improvement of the junction performance in new signal timing. This re-designed timing will not only minimize the overall delays for all the movements but also significantly reduces delay for some movements.

Besides the signal timing, some other problems are also identified which also effects the operation of the intersection. These problems may not only play a vital role to increase delay at intersection but also increases the chances of road crashes. Pedestrian safety is also associated with them. Such types of problems arise from improper road marking, illegal parking, unplanned buses stoppage, illegal footpath usage etc.

In future, rearranging the movements in different phases by redesigning can extend this work. In that case, the retiming of the signal will not be based on the assumed degree of saturation value like this work rather it will depend on combination of different movements in a phase on a number of trials basis.

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