TRAFFIC SIGNAL DESIGN OF ISOLATED INTERSECTIONS FOR MIXED TRAFFIC OPERATION

BY

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ABSTRACT

The control of traffic in cities of developing countries such as Bangladesh has long been dependent on the use of fixed time traffic signals. The reasons are low capital cost, ease of installation and maintenance and, possibly, that they are technologically more appropriate in terms of hardware and software. Such dependence demands a more critical calculation of signal setting and hence good information on the prevailing traffic.

Some important variables for signal design are saturation flow, lost times, PCU values etc. Methods of measuring and predicting these signal design parameters have long been developed in the western world.

These well known procedures and measurement techniques are essentially applicable for homogeneous nature of traffic stream which is typically car dominated with vehicles moving in clearly defined lanes. Some vehicle types in developing countries are not dissimilar to those of the developed world, but the traffic operational conditions in a developing country like Bangladesh is quite different. These different traffic operation conditions are featured as heterogeneous vehicle mix i.e. both motorised and non-motorised vehicles comprise traffic stream, difference in driving behaviour and the lack of lane discipline in particular. Attempts to apply the signal design procedures and methods of measuring design parameters that are developed based on homogeneous traffic condition to the non-lane based mixed traffic operations do not always result in desirable success. There is, thus, a need for developing most appropriate signal design procedure and measurement techniques of the parameters involved to accommodate local prevailing traffic conditions.

In the light of this, a systematic signal design guidelines have been proposed to help local traffic engineers in signal design. Video recording and as well as manual method were used to collect data for customising different lane based signal design parameters for local condition. In addition, using these customised procedure and parameters, a computer software MIXSIG ( SIGnal design for MIXed traffic operations ) has been developed as an aid for the design and evaluation of signalised intersections. The salient features of this software are:

- adaptation of different approaches for the measurement of saturation flow values
- consideration of variable PCU (Passenger Car Unit) values for each vehicle type instead of unique value
- inclusion of red violation behaviour of drivers in calculations of initial and final lost times
- consideration of a special all red period to allow non-motorised vehicles to clear up junction
- consideration of forced gap acceptance behaviour during the right turning manoeuvre

MIXSIG is a user friendly and an easy-to-use package. It employs a flexible graphical input interface and its output includes signal timing results and phase diagram for different types of intersections.

It is expected that the proposed guidelines and the software will enable the field engineers to design signal methodically and thereby will contribute to alleviate the ever increasing traffic congestion in Bangladesh to some extent.
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<td>Signal Design for Mixed Traffic Operation</td>
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<td>PCU</td>
<td>Passenger Car Unit</td>
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<td>MUTCD</td>
<td>Manual on Uniform Traffic Control Devices</td>
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<td>SIDRA</td>
<td>Signalised and Unsignalised Intersection Design &amp; Research Aid</td>
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<td>OSCADY</td>
<td>Optimised Signal Capacity and Delay</td>
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<td>MOVA</td>
<td>Microprocessor Optimised Vehicle Actuation</td>
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<td>TRANSYT</td>
<td>Traffic Network Study Tool</td>
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<td>ARRB</td>
<td>Australian Road Research Board</td>
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<td>DITS</td>
<td>Greater Dhaka Metropolitan Area Integrated Transport Study</td>
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<td>Rajdhani Unnayan Corporation</td>
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<tr>
<td>DCC</td>
<td>Dhaka City Corporation</td>
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<td>NMV</td>
<td>Non-motorised Vehicle</td>
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<tr>
<td>CBD</td>
<td>Central Business District</td>
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<tr>
<td>DMP</td>
<td>Dhaka Metropolitan Police</td>
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<td>BRTA</td>
<td>Bangladesh Road Transport Authority</td>
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<td>TRRL</td>
<td>Transport and Road Research Laboratory</td>
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<td>HCM</td>
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CHAPTER 1

INTRODUCTION

1.1 Background

The control of traffic in cities of developing countries such as Bangladesh has long been dependent on the use of fixed time traffic signals. The reasons are low capital cost, ease of installation and maintenance and, possibly, that they are technologically more appropriate in terms of hardware and software. Such dependence demands a more critical calculation of signal setting and hence good information on the prevailing traffic. Some important variables for signal design are saturation flow, lost times, PCU values etc.

Methods of measuring and predicting these signal design parameters have long been developed in the western world whose traffic is generally dominated by cars moving strictly in lanes. In contrast, traffic in Bangladesh and in other developing countries is rendered more complex due to the heterogeneous characteristics of the traffic stream using the same right of way. The stream includes slow push carts at one extreme and the fast moving passenger cars to the other, with many intermediate types of vehicles depicting a wide variation in static and dynamic characteristics. As in mixed traffic operation no single vehicle clearly dominates the traffic system, prediction of saturation flow is more sensitive to the vehicle mix than in western countries where the traffic is largely motorised.

It is a common practice to express saturation flow in PCU/hour (PCU : passenger car unit; a car equivalent factor for a vehicle type) rather than vehicles/hour. In the mixed traffic,
particularly with the high proportion (30% - 70%) of non-motorised vehicles, the use of accurate PCU values to convert saturation flow into PCU/hour will be critical; it is less so for western traffic where 90% or more are cars.

Another feature of the traffic under study is the lack of lane concept, particularly for approaches involving turning vehicles. Traffic does not move in lanes and hence breaking down the analysis into individual lanes is not possible. Instead, all vehicles compete to utilise the available road space, ignoring the lane markings even where they exist. Narrow vehicles i.e. motor cycles and pedal cycles, can negotiate the spacing between larger vehicles to penetrate the front of the queue. This then restricts the freedom of other vehicles to discharge during the green period as quickly as possible as is the case in western traffic.

As such attempts to apply these signal design parameters and standard procedures that are developed based on homogeneous traffic condition to the non-lane based mixed traffic operations do not always result in desirable success. There is, thus, a need for studying these parameters comprehensively and for developing most appropriate signal design procedure to accommodate local prevailing traffic conditions.

1.2 Statement of the Problem

There has been very little work in the traffic signal field from developing countries in general. And in practice, traffic signals in Bangladesh are still intuitively designed in terms of timings. The understanding of the characteristics of the performance of traffic such as saturation flow, PCU value, lost time has been minimum if not non-existent. The signal timing and phasing are usually set by an electrical engineer rather than designed by a traffic engineer. As such, our signal settings are not responsive to the flow characteristics. There is no consistency between the signal timings and the traffic demand; as the fixed timing is maintained throughout the day.
Signal design itself is a very complicated field of study. It deals with the geometry and types of intersections, hourly variation of traffic flow, traffic composition, directional split, saturation flow, PCU value, lost time, pedestrian flow and many other aspects. The complicacy in signal design inspired the development of a computer package to make this issue simpler to the practising engineers even with minimum understanding of the subject.

Because of the limited work in the traffic signal for mixed traffic operation, it is intended in this study to use the basic procedures and relationships of lane based traffic system as a starting point and then customise these to cover the operational characteristics of traffic in Bangladesh in a sufficient level of detail.

1.3 Objectives of the Study

The signal design package is expected to be a helpful tool for practising engineers for signal design and phasing of isolated intersections for mixed traffic operation. In order to achieve this goal the main objectives of the proposed study are:

- To get the present scenario of traffic signal design in Dhaka Metropolitan area.
- To evaluate the performance of existing isolated signalised intersections.
- To increase understanding of related aspects of signalised traffic.
- To adapt different approach for the measurement of saturation flow values, CPU values and lost times.
- To collect data regarding traffic composition, geometry of roads, traffic flow, layouts, saturation flow, flow fluctuation, existing signal timing and phasing etc. from selected sites.
- To customise the standard signal design parameters and relationships for local traffic conditions.
• To include forced gap-acceptance behaviour during the right turning manoeuvre.
• To develop a computer package for signal design in mixed traffic and non lane based traffic operation in order to encourage the field engineers to design traffic signals in a scientific and systematic manner very easily.
• To apply the software developed for designing signals for selected intersections.

1.4 Methodology

In order to achieve the above objectives, at first a comprehensive literature review will be conducted which will give a basis of signal design methodology. Then, a clear picture of the present state of art of traffic signal design in Dhaka city will be obtained by gathering information from different relevant organisations. Later on, the signal design procedures and different related parameters for homogeneous traffic condition will be customised for local road traffic situation. In order to achieve this, data will be collected manually and as well as by video recording from selected sites. At the same time, observational data will be required to understand the mixed traffic behaviour and to device appropriate measurement techniques of the signal design parameters. Then signal design guidelines for heterogeneous traffic condition will be suggested. To make this guidelines and procedures user friendly to the field engineers, lastly a computer package will be developed.

The plan of research work is schematically presented in Fig 1.1 which also outlines the broad structure of the thesis.

1.5 Scope of Study

This study is concerned with the investigations of different signal design parameters and the procedures for designing isolated signal controlled intersections in urban areas under
mixed traffic conditions. This study also deals with the development of a signal design tool using established mathematical relationships developed in advanced countries and further expanding them by customising the signal design parameters to fit the prevailing condition of traffic of Bangladesh. This research is limited in the sense that it will not consider one important signal design aspect i.e. pedestrians. The outcome of this research is for specific use in Bangladesh and other developing countries having the same traffic condition.

1.6 Organisation of Thesis

In this study the research work carried out is divided into different topics and presented in eight chapters.

A brief review of the traffic characteristics prevailing in Bangladesh is presented in the first chapter with special emphasis on the objectives of this study. The chronological development of the package is also outlined.

Chapter 2 presents a brief description of traffic signals, its types, intersections etc. Different literature reviews are also presented in this chapter.

Chapter 3 deals with the present situation of traffic signals and other aspects of intersections in Dhaka city.

In Chapter 4 various components of the program for lane based traffic signal design are identified and described. Traffic signal design practices of different developed and developing countries are also enumerated in this chapter.

Chapter 5 describes the method of field study and estimation of different mixed traffic descriptive parameters for non-lane based package development and validation.
Chapter 6 deals with the expansion of the lane based package based on the field study.

Having developed the package the case studies of the two intersections selected are illustrated in Chapter 7.

The conclusions of the entire study and some recommendations for further research are presented in Chapter 8.

Detail data for saturation flow and flow profile calculation are given in Appendix A.

Guidelines are given for field engineers to design traffic signals in a systematic and easier way in the Appendix B.

A set of tables and some relevant signal design terminology are presented in Appendix C.
Study Plan

- Statement of problem
- Literature review
- Signal related problem identification
  - Field observation and gathering of different signal related informations from concerned organisations
  - Identification of need for traffic signal design for our road traffic situation
- Development of a computer software for lane based system
  - Collection of data from selected intersections
  - Expansion of the software developed to accommodate non lane based mixed traffic situation
- Verification and the possible validation of the software
  - Application of the software

Fig 1.1 Flow chart showing the outline of the thesis
CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In road traffic network 'at grade' junctions are very sensitive and important issue as this element of road produces maximum conflicts among the crossing, turning and merging vehicles. Intersections play a significant role specially for urban road network where vehicles face intersections frequently on their journey.

In a road traffic system, intersections are one of the prominent bottlenecks that interrupt smooth flow of traffic and thereby cause delays. Vehicle speed would have been much higher and journey time much lesser without these junctions. But where there is crossing, at grade intersections have to be provided as a natural solution. So, these junctions are becoming sensitive part with respect to the overall network. That is the reason the management of these junctions has to be done carefully rather than the link design. The overall performance and the capacity of the network will obviously be reduced due to faulty intersections in spite of having a very well designed link. To avoid unnecessary delay or to get an efficient traffic flow movement, these intersections need to be designed properly and carefully. Along with appropriate road geometry, the necessary traffic control devices are also needed to be applied properly.

A lot of research works have been carried out for better traffic control and management at intersections in the countries like USA, UK and Australia, whereas in Bangladesh only one such study (DITS[1]) had been undertaken. All the latest traffic engineering tools are
being applied to achieve maximum efficiency in these junctions. At the same time due to their enormous resource availability they are going for grade separations that give hundred percent efficiency. As we are not at the position to adopt this grade separation solution due to our severe resource constraints we have to seek for other optimisation methods of managing intersections. We have to apply proper management technique at the intersections to achieve maximum efficiency.

To optimise or to get maximum junction capacity the advanced countries have been applying many traffic control devices. A brief description of these traffic control devices are outlined below. Emphasis will be given on traffic signals only.

2.2 Traffic Control Devices

Traffic control devices include all signs, markings, and signals placed on or adjacent to a street or highway by public agencies in order to regulate, warn, or guide traffic.

Traffic control devices should be reasonable and appropriate for the traffic requirements at the location used. The use of a traffic control device at a location where it is not warranted tends to invite motor-vehicle operators to disregard the device and to have less respect for traffic control devices in general.

Traffic control devices should be properly designed. The size of the device, its shape, colours, contrast with the background, and lighting or reflectorisation should draw attention. The sign, marking, or signal should simply and forthrightly convey a clear and simple message. The use of uniform devices following the MUTCD[2] (Manual on Uniform Traffic Control Devices) simplifies the driver’s task of recognising and understanding the traffic control messages and tends to increase the level of observance.

It is important that devices be maintained to high standard to ensure that legibility and visibility are retained. When no longer needed, traffic control devices should be removed.
2.2.1 Traffic Signs

There are three functional classes of traffic signs: (1) regulatory, (2) warning, and (3) guide signs [3].

Regulatory signs give users notice of traffic laws or regulations. Warning signs direct attention to conditions on or adjacent to a street or highway that are potentially hazardous to traffic operations. Guide signs indicate route designations, directions, distances, point of interest, and other geographic or cultural information.

2.2.2 Traffic Markings

Markings consist of paint or some other material placed on the pavement, curb, or object to convey traffic regulations and warnings to drivers. Markings may be used alone or in combination with traffic signs or signals. Although markings are an effective and essential means of traffic control, they tend to be difficult to see in rainy weather and may be obliterated altogether by bad weather.

2.2.3 Traffic Signals

Traffic control signals are primarily used to control the movements of vehicular and pedestrian traffic at intersections. It is used to avoid vehicle conflicts and to reduce the number and severity of accidents at intersections. The layout of a typical intersection and potential conflict points at an intersection are shown in Fig 2.1 and Fig 2.2.

The traffic signal device (or head) is an assembly that contains one or more signal faces. Each signal face, except in pedestrian signals, is comprised of three to five optical units that display colour coded indications (red, yellow, green, green arrow, etc.) to the road user. Each optical unit consists of a lens reflector, lamp, and lamp socket assembly.
Fig 2.1 Typical Cross Intersection

Fig 2.2 Conflict points at a cross intersection
The optical units in each signal face are usually in a vertical line, arranged red, yellow, and green from top to bottom. The face may be amounted horizontally, with the red at the left, yellow next, and the green at the viewer’s right.

A steady circular red indication is used to prohibit traffic from entering an intersection or other controlled area. A steady circular yellow indication warns traffic of an impending change in the right-of-way assignment. A steady circular green indication permits traffic to proceed in one direction that is lawful and practical.

Steady red, yellow, and green arrow indications may be used under certain conditions, for example, where certain movements are prohibited or impossible and where turning movements are protected by the signal from conflicting movements. The Manual on Uniform Traffic Control devices (MUTCD) recommends that at least two signal faces be provided on each approach to a signalised intersection. To ensure adequate visibility, the Manual gives specifications for the location and height of signals and minimum visibility distance for various approach speeds.

Traffic signals are operated by electromechanical or electronic controllers that switch the signal indications on and off in accordance with a plan selected by the traffic engineer. A brief description of the historical development of traffic signal is outlined below.

2.2.3.1 Historical Development of Traffic Signals

The first traffic signal was installed in Westminster in 1868 and was of the semaphore-arm type with red and green gas lamps for night use [4]. Unfortunately however, an explosion occurred and no further experiments of this nature were tried for half a century. In 1918 the first manually operated three-colour light signals were installed in New York, and in 1925 manually operated coloured light signals were used by the police in Piccadilly, London. The following year the first automatically operated traffic signals in Great Britain were installed at Wolverhampton.
The natural development of traffic control methods led from manually operated to automatic fixed-time signals, where predetermined ‘stop’ and ‘go’ periods were alternately timed off. These signals helped to ease traffic conditions but were not efficient at junctions where the traffic volume varied considerably; ‘program’ controllers were therefore introduced to alter the length of the ‘stop’ and ‘go’ periods in steps throughout the day to fit in with a prearranged plan. Some streets having a large number of cross-roads were later equipped with fixed-time signals at each intersection along the route, and the signals were linked together in such a way that the green periods appeared to ‘progress’ along the road, allowing groups of vehicles more or less uninterrupted travel at a predetermined speed through the series of intersections. This was an improvement where a series of intersections could be dealt with together, but at isolated intersections traffic was still being delayed unnecessarily; this was due to the inflexibility of fixed-time signals and also to lack of knowledge of the settings which would give minimum overall delay.

At the beginning of the 1930s a first attempt at vehicular control of signals was made in the United States of America by placing microphones at the side of the road and requesting drivers to sound their horns. There were many objections to this scheme, and a method using electrical contacts placed in the paths of vehicles was subsequently tried. This method has survived in principle up to the present day although pneumatic tubes are now generally used in Great Britain. Air displaced in the tubes by a vehicle passing over them operates electrical contacts housed in a sealed compartment at the side of the road. Other types of detectors, e.g. inductive detectors, radar, magnetic and ultrasonic detectors, have been used abroad and some of these are being considered or are undergoing trials in U.K.

The first vehicle-actuated signals in Great Britain were installed in 1932 at the junction of Gracechurch Street and Cornhill in the City of London. Unfortunately history repeated itself, and when the signals were switched into service an explosion occurred owing to seepage of gas into the controller cabinet. Despite this unhappy incident vehicle-actuated
signals soon became established and three years later the first linked systems, consisting entirely of vehicle actuated controllers, were installed in London and Glasgow.

2.2.3.2 Types of Signals Available

There are essentially two types of signals in general use: fixed-time and vehicle-actuated. An intermediate type, semi-vehicle-actuated signals, with detectors on the side roads only, is discussed later.

Fixed-Time Signals

With fixed-time signals the green periods, and hence the cycle times are predetermined and of fixed duration. The controllers are simple and relatively inexpensive but they are necessarily inflexible and require careful setting. They are most successfully used in linked systems. They can be equipped with time switches to alter the settings at certain periods of the day, to cover different traffic conditions.

Vehicle-Actuated Signals

With vehicle-actuated signals the green periods are related to the traffic demands, using detectors which are normally installed on all approaches. In the absence of demands the signals will rest indefinitely on the phase which was last served. The controller consists of several low voltage electronic timers.

The basic technique in traffic-actuated control utilises the following two basic timing features: 1. Initial vehicle interval and 2. Vehicle extension (passage time).

A typical intersection approach with a vehicle detector is illustrated in Figure 2.3. The distance from the detector to the stop line influences the timing to be allocated to both the initial vehicle interval and the vehicle extension.
Fig 2.3 Traffic detection on intersection approach.

Semi-Vehicle-Actuated Signals

With semi-vehicle-actuated signals detectors are installed on the side roads only and the right-of-way normally rests with the main road, being transferred immediately (or at the end of a pre-set period) to the side road when a vehicle passes over the side-road detector.

Co-ordinated Control Systems

When two or more junctions are in close proximity on a main traffic route, some form of linking is necessary to reduce delays and prevent continual stopping. The purpose of a linked system is to pass the maximum amount of traffic without enforced halts, while allowing for the claims of cross-street traffic. Sometimes minimum overall delay to all streams, including the side-road streams, is sought. Alternatively, or additionally, linking may be employed to prevent the queue of vehicles at one intersection from extending back and interfering with another. The several basic forms of linking are described below. Of
these the simultaneous, alternate and flexible progressive systems require a master controller and may be used where several installations are linked together.

Area Traffic Control

Consideration is now being given to the use of digital computers to provide systems of area traffic control. The purpose of such control is to reduce delays by

(a) better methods of linking signals according to the traffic situation at any given time;
(b) diversion of traffic away from congested routes to alternative routes where spare capacity is available; and
(c) lane-switching, or switching of peak-period one-way systems, on tidal-flow routes.

Digital computers can provide additional facilities for

(a) preventing forward movement from one signal installation when the queue back from the next installation reaches a critical point;
(b) giving priority to forward movement at the next installation in order to clear the queue;
(c) banning of right turns (accompanied by re-routing) when this manoeuvre causes disruption of through-traffic movement;
(d) switching in and out of special facilities for right-turning traffic in accordance with the general traffic requirements of the area; and
(e) emergency arrangements for traffic control when normal conditions are interrupted by accidents, roadwork, special events, weather and so on.

2.3 Pedestrian Signals

Normally at intersections controlled by signals the requirements of pedestrians are catered for in two ways. One method is to provide a crossing marked out in studs in front of the
stop line for use by pedestrians during normal signal timings, i.e. no special phases are 
given for them. This arrangement is normally used at intersections where turning traffic is 
not heavy. In the second method 'pedestrians' movements are controlled by separate 
signals during a special phase. This is a more positive method as well traffic is halted 
before the pedestrian phase is given, but it causes greater delay to vehicles.

Pedestrian signals have two aspects. The current Traffic Signs Regulations and General 
Directions in U.K provide for the introduction of one aspect showing a red figure of a 
stationary man on a black background and the other showing a green figure of a walking 
man on a black background. Other present signals show the word ‘WAIT’ in red on a 
black background, and the word ‘CROSS’ in white or green on a black background. With 
the present signals, the ‘CROSS’ indication is usually displayed for a pre-set period of 6 to 
10 seconds according to the pedestrian flow, and is followed by a clearance period of 2 to 
8 seconds during which all vehicle signals are at red and no signal is displayed to 
pedestrians. The ‘WAIT’ signal to pedestrians is then displayed coincident with the 
red/amber of the next vehicular phase, and continues until the green pedestrian signal is 
next given. The combined length of the pedestrian phase, the clearance period, and the 
following red/amber period is usually based on the time taken to cross the road at 4 
ft/second. Where pedestrian flows are very heavy, longer times are given if the traffic 
situation permits. If the transit time to the pedestrian crossing for traffic starting up on the 
next vehicular phase is appreciable, appropriately shorter times may be given. When, 
however, the transit time permits of a reduced clearance period it is essential on multi- 
phase installations to ensure that adequate clearance is given to each possible following 
phase [4].

In general in U.K a short all-red period is usually inserted before the green pedestrian 
signal is displayed to ensure that traffic is clear of the crossing before pedestrians are 
signalled to cross. The pedestrian phase may be introduced either (a) by operation of a 
push-button-this is the normal arrangement and avoids unnecessary delay to vehicles, or
(b) automatically; this may be desirable particularly with linked signal systems to prevent signals with a pedestrian phase getting seriously out of step with adjacent signals [4].

Although pedestrians may normally be allowed to cross over any of the approaches to an intersection there will usually be one on which the pedestrian problem is most acute. The pedestrian phase should immediately follow the end of the vehicular phase on this approach.

These signal arrangements can also be used for pedestrian crossings sited between junctions. With one type of pedestrian-operated signal no vehicle detectors are installed and right-of-way normally rests with the traffic, but when the push-button is depressed the pedestrian receives right-of-way immediately (provided a pre-set minimum right-of-way period for vehicles has expired since the pedestrian phase was last called). It is often possible to omit vehicle detectors without difficulties arising particularly in linked systems, but where vehicle approach speeds are high the installation of detectors enables the change to a pedestrian phase to be made wherever possible during a gap in the traffic, thus avoiding arbitrary changes which, with a 3-second amber, may give traffic insufficient warning to stop. In such cases it is suggested in U.K that the detectors, being for fast vehicles, should be sited some 250 to 300 ft from the crossing rather than at the standard distance [4].

One difficulty with pedestrian signals as described above is that the pedestrian phases and clearance periods, being of fixed duration, have to be set to meet average conditions. This results in unnecessary delays to vehicles when only a few pedestrians wish to cross, and to inadequate time for pedestrians at their peak periods. Experiments are, therefore, in hand with a more flexible type of control for pedestrian crossings, where the signal sequence to vehicle includes a flashing amber period following the red signal: during this period vehicles must give way to any pedestrians wishing to cross, but may move over the crossing in the absence of pedestrians. Detectors would be required only where vehicle approach speeds were high. *Zebra crossing* (uncontrolled) are a common type of
pedestrian crossing in urban area but the delay which the cause to vehicles increases greatly with increasing flow of pedestrians. It has been estimated in U.K that, with pedestrian flows across the road of more than about 1000 per hour the signal controlled pedestrian crossing gives less delay to vehicles than the Zebra crossing.

2.4 Warrants for Signals

Broadly speaking, the three primary aims of signal control are:

(a) to reduce traffic conflicts and delay;
(b) to reduce accidents;
(c) to economise in police time.

The Ministry of Transport, U.K considers the minimum justification for signal control to be an average flow over 16 hours of the day of about 300 vehicles per hour of which at least 100 vehicles per hour are on the minor roads. This would be equivalent to a peak-hour total flows entering the intersection (taken as about 10 per cent of the 16-hour total) of about 500 vehicles per hour [4].

Signal control may be expected to reduce certain types of accident (e.g. collisions between vehicles moving at right angles to each other) but is likely to increase some other types of accident (e.g. nose-to-tail collisions). A knowledge of the average number of accidents per annum at a particular site, and a study of movements before impact, may help in deciding whether signal control will be beneficial, and whether or not there is a *prima facie* case for considering signals on safety grounds. Records show that the average number of personal injury accidents per annum at signalled junctions is about two for Great Britain and six for the greater London area [4].

Signals are installed, even if the above warrants are not satisfied, if they are needed to form part of a linked system.
In the U.S.A., where fixed-time signals are common, the traffic warrants for this type of signal are given in the Manual of Uniform Traffic Control Devices for Streets and Highways. There are many times more signals per 100 miles of urban road in the U.S.A. than in Great Britain, probably because of the grid-iron pattern of streets common to most American cities, which lends itself to linked signal systems. In the U.S.A. the minimum vehicular warrant for fixed-time signals in urban areas is a major-road flow (both directions combined) of 500 or 600 vehicles per hour for each of 8 hours of the day and a flow on the busier minor road (approach direction only) of 150 or 200 vehicles per hour for the same 8 hours of the day. Where operating conditions on a major road are such that minor-road traffic suffers undue delay or hazard in crossing or entering the major road, the above warrants are adjusted to 750 to 900 vehicles per hour for the major road and 75 or 100 vehicles per hour for the busier minor road. The minimum warrant for pedestrian signals is 150 persons per hour crossing the major road on the busier crossing for each of 8 persons per hour of the day, coupled with a major-road flow of 600 vehicles per hour for the same hour (1000 vehicles per hour if there is a median island). In rural area and in isolated built-up areas the minimum warrants are 70 per cent of the requirements given above [4].

2.5 Reviews of Some Traffic Signal Design Software

Some popular signal design software that are being widely used around the world include SIDRA, OSCADY, MOVA, MULATM, TRANSYT, NETSIM, TRAFFICQ to name a few.

2.5.1 SIDRA (Signalised & Unsignalised Intersection Design and Research Aid)

The SIDRA package for lane based traffic system has been developed by the Australian Road Research Board (ARRB) as an aid for design and evaluation of signalised
intersections. With SIDRA version 4, it has been extended to the analysis of roundabouts and other unsignalised intersections [5].

Since its first release in 1984, the use of SIDRA has grown steadily over the years to make SIDRA version 4, it has been extended to the analysis of roundabouts and other unsignalised intersections.

Since its first release in 1984, the use of SIDRA has grown steadily over the years to make SIDRA the best-selling software package developed by ARRB. In June 1992, it was in use by about 210 organisations/sites in 36 countries. This included 100 practising organisations/sites in Australia (State road and traffic authorities, councils and consultants).

SIDRA employs a flexible input method that allows the user to specify a large number of parameters related to intersection geometry, signal phasing and traffic flows. Different
methods of volume counts allow the specification of heavy vehicle volumes as separate or percentage figures.

SIDRA allows the user to analyse intersections with very simple to very complex geometry and signal phasing.

SIDRA output is extensive, and includes capacity, timing and performance results reported for individual lanes, individual movements (or lane groupings), movement groupings (such as vehicles and pedestrians), and for the intersection as a whole.

In contrast to modelling by simulation, SIDRA uses an analytical modelling approach coupled with an iterative approximation method of computation to match the capacity and signal timing results.

2.5.2 OSCADY (Optimised Signal Capacity and Delay)

A computer program, OSCADY, has been developed to model capacities, queues and delays at isolated traffic signal junctions. The program includes recently derived empirical formulae for saturation flow calculations, routines to optimise signal settings and time-dependent equations for queue and delay prediction. The user inputs include geometric characteristics of the junction, signal timing arrangements, and demand flow information. OSCADY is intended to model peak period operation, although longer periods can be considered. The program can model most staging arrangements at three or four arm junctions. OSCADY can either implement supplied timings or be used to calculate suitable ones. Queues and delays are calculated for each of a succession of short time segments (usually 10 or 15 minutes) within the modelled period. Both existing or proposed layouts can be assessed, and the effects of possible modifications examined. The program can be used on most types of computers (including microcomputers), and both batch and interactive versions are available [6].
2.5.3 MOVA (Microprocessor Optimised Vehicle Actuation)

More than half of the UK's signalised junctions are controlled by independently operated (uncoordinated) signals with green times varying in response to local traffic flows. MOVA is the new signal control strategy researched and developed by TRRL for such isolated intersections. Data from vehicle detectors on the junction approaches are analysed by an on-line microprocessor implementing the MOVA program; the duration of the green signals are controlled by a delay and stops minimising logic, or if any approaches become oversaturated (congested), by a capacity maximising process. Subject to a final large-scale trial, MOVA is intended as a general replacement for the gap-seeking, D-system vehicle-actuated (VA) control currently in use. It is found that MOVA reduces vehicle delay by an average of about 13 per cent throughout the working day, compared with up-to-date D-system VA; further benefits are likely where, as is often the case, critical VA controller settings (maximum green times) are based on out-of-date traffic data [7].

2.5.4 TRANSYT (TRAffic Network StudY Tool)

TRANSYT (TRaffic Network Study Tool) is probably the most widely known and used traffic model. TRANSYT/7 is used in the USA, while TRANSYT/8 is the version used in the UK, Australia and elsewhere. It is used for the off-line calculation of traffic signal timings in co-ordinated traffic signal networks. TRANSYT is essentially a macroscopic simulation model that optimises the traffic signal settings with respect to objective functions like delay [8].

2.5.5 MULATM

MULATM, a traffic planning model designed for studying local street networks. It can account for detailed street networks, including individual street and intersection characteristics, and can be used to study the effects of different control devices and
measures such as street closures, roundabouts, humps and ‘slow points’. The possible
location of these devices can be studied so that the location to achieve particular
objectives (such as speed control or traffic diversion) may be met. For an engineer or
planner the model offers a systematic tool for the investigation of possible effects of
alternate traffic management schemes, and the selection of appropriate plans to meet
established goals and objectives [8].

2.5.6 NETSIM

NETSIM is one of the most generally used microsimulation models of traffic movement
on networks. It is a microscopic traffic simulation model developed by the US Federal
Highway Administration. NETSIM can be used to evaluate a wide mix of traffic control
and management strategies including fixed and vehicle actuated signal control, sign
control, special use lanes and geometric design characteristics [8].

2.5.7 TRAFFICQ

TRAFFICQ is a UK Department of Transport model intended for the detailed study of
relatively small road networks, but which may contain complex traffic and pedestrian
control techniques. All commonly encountered traffic management systems may be
modelled. This includes a variety of types of traffic signal control, such as vehicle and
pedestrian-actuated signals, which may be either linked on unlinked to a common cycle,
and several types of priority control junctions, including roundabouts and pedestrian
crossings [8].

2.6 Mixed Traffic Studies

It could be noted that all the above mentioned packages have been developed for use in
advanced countries where the traffic stream consists mainly of passenger cars and vehicles
follow lane discipline. So far, only three such comprehensive works have been reported
dealing with mixed traffic stream. Among them, one is a general study (DITS study [1]) of mixed traffic behaviour related to traffic signal design and the other two (MIXSIM [9] and MORTAB [10]) are traffic stream modelling for mixed traffic operation. Brief discussions of these studies are presented in the following sections.

2.6.1 DITS Study

There has been little work in the traffic signal field from developing countries in general. In Bangladesh so far only one extensive study in this field has been reported. The study was undertaken by PPK Consultants Pty Ltd, Australia in association with Delcan International Corporation, Canada and Development Design Consultants, Bangladesh. The observations of this study regarding the scenario of traffic signals and other relevant aspects that existed in Dhaka city are summarised as follows:

In 1981, there were only 15 signalised intersections and another 15 were proposed in the Integrated Urban Development Plan. Prior to 1977, RAJUK was responsible for signal installation and control. In the early 1980's control of signal was transferred to Police Traffic Division with RHD engineers assigned to help. This experiment lasted only a year before signals were reassigned to DCC. Traffic signals have increased over recent years with 12 signals being installed in just the last two years.

In Dhaka, a total of 44 signalised intersections are currently operating. Table 2.1 summarises the basic details of these intersections. No intersection have a separate pedestrian phase and pedestrians must compete with continual left turn movements to cross road at intersections.

Discussions with all relevant parties including the Police Traffic Division, DCC and private sector firms responsible for signal installation, revealed that the location of traffic signals was decided on judgement alone. While signal warrants usually consider two main factors:
traffic volume and accident rates, no traffic counts or accident data is routinely collected by the authorities that would provide an objective basis for new signals.

<table>
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<th>Cycle Time (sec)</th>
<th>Max Green (sec)</th>
<th>No. of phases</th>
<th>No. of approaches</th>
<th>Turn restricted</th>
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Table 2.1: Signalised Intersection Inventory.
Green times are allocated on judgement and cycle times are uniform throughout the day (i.e. local traffic signals have one cycle for both peak and off peak periods). Poles are poorly located. Current practice prefers poles and signal heads to be located on the approach well before the stop line which is usually away from the intersection. Intersection capacity is reduced by the frequent stopping of public transit vehicles, especially buses, tempos and rickshaws, inside the intersection. There is no practice of clearways in Dhaka which severely inhibits the performance of intersections.

The guidelines that were suggested for the betterment of the chaotic situation regarding traffic signals are described below:

2.6.1.1 Traffic Signals

Signal Layout

Signal layout should consider the needs of pedestrians, clearance for turning paths of vehicles from other approaches, any signalised movement, such as left turns, bus stopping and bus lane requirements, and the needs of NMV. Primary signals located on the left side of the approach is the norm for traffic signals in Dhaka; secondary signals, located across the intersections for the benefit of vehicles that have stopped beyond the primary signal, are not used despite most primary signals being placed too far back.

Cycle Lengths

Cycle lengths should be as short as possible to prevent drivers losing patience and violating the signal. The maximum recommended time for a two phase signal is 120 seconds with no more than 80 seconds green time allocated to any one phase. Most signals in Dhaka operate on three phases with a cycle range between 44 and 156 seconds, well beyond the recommended maximum of 200 seconds for cycles with more than 2 phases.
Amber Phase

Amber phase lengths need to consider both the width of the junction and the approach speed. Amber times consisting of a minimum 4 seconds have been recommended. In Dhaka, the majority of movements at many signalised intersections are by rickshaw. Both rickshaws and pedestrians travel slower than motorised vehicles and amber phase should account for this reduced speed. Adequate amber phases are essential as the alternative, an all-red clearance phase, is not always respected in developing countries where driver observance is a problem.

Flashing

Flashing operations are appropriate for when traffic volumes decrease to half or less of the stated volume warrants for four or more consecutive hours.

2.6.2 MORTAB (MOdel for Road Traffic Behaviour)

In this simulation model, a stream of mixed traffic in a lane with a certain width in a steady state condition was considered to obtain the speed-flow-density relationship. It was not clear, however, whether the model will treat a wider approach as being two separate lanes or as a single wide lane. As in mixed traffic operation due to the lack of lane discipline, width of the approach will affect the behaviour of the stream significantly, lane based approach is arguable. Moreover, as this model has been developed for straight stretches of roadway it can not be applied for intersection analysis.

2.6.3 MIXSIM (SIMulation Model for MIXed Traffic Operation)

In this model, the traffic stream behaviour of mixed traffic operation was simulated. This model is more flexible than MORTAB as all the shortcomings in the MORTAB model was overcome by the MIXSIM model. This model has been applied for studying different
signal design related parameters, particularly PCU values for mixed traffic operation. In this research, some results of the MIXSIM model have been used.

2.7 Summary

It can be easily seen from the above discussion that all the western countries have gone way ahead in the field of traffic signal design and other relevant aspects. Numerous software are available for their practising field engineers in this branch. But no such work has been undertaken in this particular field in Bangladesh. Moreover no standard signal design methodology has been established yet. In fact traffic signals are still intuitively designed in our country. Although DITS study gave some important guidelines for improving junction performance and the other two simulation models only simulated traffic stream behaviour for mixed traffic operation, they did not propose any standard signal design method for the mixed traffic condition. It is therefore revealed that there is need for a comprehensive study in this respect.
CHAPTER 3

ROAD TRAFFIC SITUATION IN DHAKA CITY

3.1 Introduction

Dhaka is the capital and the biggest metropolitan city of Bangladesh. It is the centre of all commercial, business, government, private and other activities. Dhaka is growing at a fast rate with the prospect of emerging as a mega city in the next century. This rapid urbanisation process has made Dhaka one of the most densely populated cities in the whole world. Due to this population boom, one of the main problems that has evolved and which has been a serious concern is the overall degradation of the road traffic system in Bangladesh. At times of the day all the major signalised and unsignalised intersections are severely congested. And the ultimate victims are the road users. Their commodities, urgent documents and they themselves can not reach the destination on time as a result of the long delays produced by the bottlenecks. This problem is worst in the central business district (CBD) like Motijheel. Most of Dhaka City including the business-commercial areas are already built up to such an extent that the construction of new infrastructures to alleviate this problem is almost impossible. Because of resource limitation the only option left is to implement proper traffic management schemes. Control of traffic so as to minimise the delay or the congestion particularly in the intersections requires a systematic implementation of traffic management schemes with available resources. By utilising the existing structure and applying appropriate management techniques the efficiency of the
present system can be enhanced considerably. One of these techniques is the optimisation of traffic signals in Dhaka City. Before going for optimisation of traffic signals a comprehensive study is required to get an overall idea about the traffic signal practice in Dhaka city as the system which has to be managed has to be understood first. It would help to know about the existence of the gaps and the scope for improvements in traffic signal design practice.

As a result one of the major part of this research was to gather various traffic signal related information from related organisations. It is worth mentioning that it is a very difficult task to get information from different government or non-government organisations but for this research required information were collected from different organisations connected with traffic signal design and implementation in Bangladesh. The methodology of collecting these information is discussed below.

3.2 Methodology of Data Collection

This data collection part was a comprehensive work considering the difficulties involved in extracting information from different government organisations. In the first part of this data collection process some preliminary ideas were gathered about the persons or organisations responsible for different aspects of traffic signal design in Bangladesh with particular emphasis on Dhaka City. Based on these information several organisations and authorities were contacted over telephone and the research plans were described to them. Different organisations which were contacted included Roads & Highways Department, Dhaka City Corporation, Bangladesh Road Transport Authority, Dhaka Metropolitan Police and Micro Electronics. For the convenience of the relevant authorities or persons, depending on the nature of the information required for different aspects of signal design a set of questionnaires were prepared and sent to them. The questionnaires are illustrated in the following section.

- Boundary of Dhaka Metropolitan area.
• Types of intersections that are encountered in Dhaka City.
• Total number of junctions in Dhaka City. (Signalised, Unsignalised, Pedestrian)
• Nature of police control in intersections. Number of police personnel used per junction.
• Hierarchy of power for traffic signal design.
• Who is responsible for traffic signal design? Is there any traffic engineer involved for this?
• Any future scheme for signal related management.
• If there is any control room to monitor the inspection of traffic signals.
• Basis of designing intersections layout.
• How warrant for traffic signal for a particular junction is set?
• Type of signal controller used: Whether the controllers are fixed type or vehicle actuated type. Whether the signal timings are based on fixed plan or variable plan i.e. whether there is scope to change the signal timings according to the traffic demand or not. What is the present practice in Dhaka City in this regard?
• Basis of traffic signal design in Dhaka Metropolitan City: Are the signal timings set following any traffic signal design methodology?
• Standard signal sequence in Dhaka City: What is the standard signal sequence in Dhaka City? Is it same for all signalised intersections? If not, then what is the basis of change in signal sequence?
• Is there any intersection where red is shown simultaneously in the signals of all the approaches? What is the duration of amber time in different intersections? Is it same for all the junctions? If not then what is the basis for the change in amber time.
• What is the maximum number of phases that are used in any particular signal in Dhaka City? What are the different types of phasing that are used in the signals in Dhaka City?
• Are the characteristics of traffic, layout of intersection, directional distribution, composition of traffic etc. taken into account while designing a traffic signal in Dhaka city? If yes then how are they incorporated?
Fortunately answers from all the organisations to which the questionnaires were sent were received and from the answers of the relevant authorities the information that were gathered are given briefly hereunder.

- The boundary of Dhaka metropolitan area consists of Tongi at one side, Gabtali at another, Buriganga at other side and Jatrabari and Postogola at the remaining side.
- The intersections that are seen in Dhaka city are mainly of three different types, namely a) simple Cross junctions, b) T junctions, c) Roundabouts.
- There are 58 traffic signals (including the one last installed at Azampur bus stand, Uttara Model Town) and 7 pedestrian signals in Dhaka City.
- Authorities and organisations involved in traffic signal design in Dhaka Metropolitan area are Dhaka Metropolitan Police, Dhaka City Corporation and Micro Electronics.
- There is no involvement of any traffic engineer whatsoever in any phase of traffic signal design in whole Bangladesh let alone Dhaka metropolitan area.

From the above findings it was very clear that most of the information were incomplete and needed further elaboration. It was also clear that some of the information that were asked for were also missing. As a result need was felt for further discussions with the relevant persons concerned with traffic signal design. They were contacted and interviewed to clear out the discrepancies. An inventory of the list of the persons contacted with their designations and the organisations with which they are connected is given in Appendix C.

The findings from the interviews are given in details below that will hopefully give a clear picture of traffic signalling practice in Dhaka metropolitan area.

- It is the Dhaka Metropolitan Police(DMP) who decides the warrant for traffic signal for a particular priority junction. Based on qualitative rather than quantitative measurement of traffic flow and subjective judgement on the overall performance of the intersections the
DMP decides on the issue of warrant for a traffic signal. Dhaka metropolitan police also determines the signal timings in different intersections. The method of signal timing determination has no scientific basis and involves no engineering practice. They do not conform to any guidelines of traffic signals and solely depends on intuitive judgement and qualitative rather than quantitative traffic count for determination of signal timings. DMP are solely responsible for signal timing determination and no other organisations are involved in this aspect of traffic signal design.

- Dhaka Metropolitan Police have classified different intersections into four categories depending on the severity of the congestion or the jams produced in these intersections. These four categories are: a) Class I, b) Class II, c) Class III, d) Class IV.

1. Class I intersections are those where minimum four or more police personnel are employed in order to control the traffic.
2. Class II intersections are the intersections where three to four police personnel are always on duty.
3. Two or three traffic police are employed in the Class III intersections.
4. Class IV intersections that produce comparatively less congestion are controlled by one or two traffic police.

- The Roads & Highways Department has got nothing to do with the installation or any other aspect of traffic signal in the Dhaka metropolitan area. Dhaka City Corporation is the sole authority for installing and implementing traffic signals within the Dhaka Metropolitan area. Dhaka City Corporation gets the information about the warrant for a traffic signal in a particular priority junction from DMP. And it is the sole responsibility of the City Corporation to make all the necessary arrangements for signal installation. It is a pity that there is no involvement of a trained personnel with some sort of technical background in traffic engineering let alone a traffic engineer in Dhaka City Corporation. The Electrical Engineering division of Dhaka City Corporation deals with all the different parts of traffic signal design and installations. Their working principals include: getting feedback from the DMP about the signal timings and also about the warrant for a traffic signal for a particular junction, calling tenders for the traffic signals and its installation and issuing work permits to the contractors who gets the work. Dhaka City Corporation does
not have any control room or any controlling cell to monitor the traffic signals. As a result they do not remain up to date about the signals' condition, whether it is functioning properly, whether it is out of order, whether it needs maintenance etc. Due to this lack of information quick repair or maintenance work can not be undertaken in case of any system disorder. Though the Dhaka City Corporation has couple of employees employed for this purpose the mode of transport they use for inspecting the traffic signals is bicycle. This tells the whole story. Such is the pathetic plight of knowledge of the personnel concerned with traffic signals in DCC that a simple query like the standard signal sequence in Dhaka City was not answered properly (the information was subsequently obtained from Micro Electronics). But one thing has to be said in favour of the City Corporation that they have to work within a lot of limitations. The opinion that was unanimously obtained was that they have severe shortage of funds.

- Dhaka City Corporation has been giving the contracts regarding traffic signals to an electrical engineering firm named Micro Electronics. They are the only contractors who have been installing traffic signals in different parts of Dhaka metropolitan area since 1987. They are associated with the installation of the signals, its maintenance and its repair work. The maintenance and repair works are done by them in response to the requests made by the Dhaka City Corporation to them. The signal timings that are decided by the DMP are given to them and they install the signals with this timing given.

- All the traffic signals that are being used in Dhaka city are isolated traffic signals. There is no co-ordinated or area controlled traffic signals in Dhaka metropolitan area. But a suggestion had been put forward by the Chairman, Bangladesh Road Transport Authority to bring some of the closely spaced traffic signals under co-ordination. He specifically pointed that the traffic signals at Chairmanbari, Banani Road No 11, Mohakhali bus station and Mohakhali level crossing can be brought under co-ordination to facilitate better movement of traffic on the Airport Road.

- All the traffic signals in Dhaka city are fixed time signals. There are no signals that are actuated by the vehicles. It would also not be feasible to use vehicle actuated signals for the local road traffic situation which will be discussed later.

- The controllers that are used in all the traffic signals are all fixed plan. That is the
timings of a particular signal remain same throughout the 24 hours of the day which means the signal shows green for the same time in a peak hour period and in a totally off peak period. This is not only illogical but also absurd and leads to more confusion. Micro Electronics manufacture these controllers. It will be very interesting to note that all these fixed plan controllers can easily be changed to variable plan to meet the traffic demand with a minimum amount of effort. By modifying the program that Micro uses for the fixed plan signal controllers a little bit it can be changed to a variable plan signal controller. That will help to set the signal timings according to the traffic demands and the variations of traffic flow throughout the day. In consequence, unnecessary and unwanted delay at junctions could be avoided. But so far Micro Electronics has not yet received any instructions for changing the fixed plan controller to variable plan from any of the decision making authority regarding traffic signals. This shows the lack of interest and unwillingness to spare a little bit of time on the part of these authorities where a little involvement could have changed the whole scenario.

- The standard signal sequence that is provided by Micro Electronics as per requirement of DCC and DMP is not unique. Generally two types of signal sequences are used. One is red, red/amber, green, amber, red and the other is red, green, amber, red. There is no explanations available about the reasons for using this two types of traffic signal sequence. So it is very clear that this is done without any scientific basis.

- At no intersection in Dhaka city red is shown in all the signals of all the approaches. This is known as all red, which is very helpful in clearing all the vehicles that could not clear the intersections and remain trapped at the end of any signal phase. It is particularly important for wide junctions and where slow moving vehicles are present in the discharging traffic stream. Here also it is very clear that no thought has been put for the betterment of the traffic system.

- The time that is provided for amber period is not also consistent for all the traffic signals. Different amber times are used for different signals in Dhaka city. This different amber period is also used based on judgement rather than on traffic engineering grounds. Same is the case about the time provided for red/amber period.

- According to Micro Electronics most of the traffic signals in Dhaka city are two phase
signals. There are some three or four phase signals where right turning volume in some of the arms is very high.

Above are the findings based on the information gathered from different organisations directly related to traffic signal design, its installation, maintenance, repair etc.

3.3 Field Observations

To supplement the information gathered a field survey was conducted for two weeks during the month of January 1996. In order to elaborate the picture obtained regarding the road traffic system qualitative field observations were made of different signal performances, signal design and junction layouts of Dhaka city. The interesting points of the field observations are enumerated below.

Firstly, different priority junctions in Dhaka were observed.
- More than half of the observed intersections in Dhaka rely on priority junction control. One of the most striking observation is that - traffic signals are not always allocated to the locations with the greatest need, with priority junction control often used beyond its capability.
- Despite the heavy reliance on priority junctions, road signs and lane markings are virtually non-existent. The physical absence of road signs renders any priority junctions ineffective. Without the clarification and reminder of road signs and markings, priority is determined by vehicle status or driver’s aggression rather than road type (major/minor).
- Poor road discipline is also seen in inefficient and unsafe cornering practices. Additional conflicts points are created as turning vehicles routinely move to the middle or opposite side before turning. Instead of queuing, vehicles often pull aside of the front vehicle turning to produce multiple and unsynchronised turning movement. While the use of medians prevents these practices, few minor roads have medians. Lane delineation is rare and not enforced. Physical channellisation measures such as traffic islands are very rarely used.
- Sight visibility and turning radii are often obstructed by parked vehicles. Rickshaws and baby taxis prefer to wait at intersections corners so as to improve their chances of finding customers. Unrestricted access further aggravates the congestion and safety performance of junctions.

Then different signalised intersections were observed.
- Majority of the junctions have inadequate space available for best design practices. As the signal phase and the cycle times are judgement based few turn restrictions have been thought necessary and channellisation little used.
- At most of the approaches traffic signals have been placed too far away from the edge of the cross road and thereby leaving a large road space between the signal or stop line and the edge of the cross road. In reality, this acts as a big stimulus for the drivers and indulge to cross the stop line during queue formation at red signal. Because of this, the leader of the stopped vehicles could not see the signal and as such discharge operation start with confusion and the delayed and confused starting operation from the current phase encourage drivers from the previous phase to violate red at change of signal that causes unnecessary vehicular conflicts within the intersection and increase accident potential substantially. Sometimes the red jumpers from the previous phase become trapped by the oncoming vehicles from the current phase and reduces junction performance greatly.
- Most of the intersections do not have any stop line to enforce the vehicles to stop. Only four intersections in the whole Ramla area have got stop lines. The placement of these stop lines are also faulty as they are marked beyond the signals on most points. As a result if the vehicles stop according to the stop line they can not see the signals.
- Signals are fixed plan and fixed time to meet only the peak time traffic demand. This type of signal is inefficient in other times of the day.
- Primary signals located on the left side of the approach is the norms for traffic signals in Dhaka; secondary signals, located across the intersection for the benefit of vehicles that have stopped beyond the primary signal, are not used despite most primary signals being
placed too far back. The Greater Dhaka Metropolitan Area Integrated Transport Study recommended three signal layouts which is shown in Fig 3.1.

- Little consideration is given to pedestrians with vehicles allowed to queue over the rare pedestrian crossing. No pedestrian phases are used nor are there refuge island provided.

- Irregularities were observed in placements of green, amber and red lights in both the horizontal and vertical traffic signals. The placement of the green, amber and red lights are different for different signals. Two signals with placement of light in different order in two opposing approaches of an intersection was also observed. A suggestion regarding this aspect of traffic signal was made by the Chairman, BRTA to DCC and he also indicated about the right practice in this connection by providing a figure which is shown in Fig 3.2.

- Amber clearance phases are different for different junctions and are inadequate at some sites for safe rickshaw clearance.

- All types of junctions suffer from misuse, due to stoppage near the intersection in the absence of any intersection clearway guidelines in Bangladesh.

- The signal sequence that is used in traffic signals is not also unique. Two types of signal sequences were observed. No signal has all red phase to clear the trapped vehicles.

- The road links in the road network of Dhaka Metropolitan City are small. As such, vehicles arrive from the upstream junction in a group and platoon dispersion does not take place. In this situation co-ordinated or linked traffic system would be the best solution.

- Strict discipline is seen in the starting and stopping operations during the observance of traffic week and as such better performance of the intersections has been observed which implies that whatever improved and appropriate measures have been taken for improving junction performance for the local traffic situation, their effectiveness depends on the involvement of traffic police.
Fig 3.1 Recommended Traffic Signal layout
Fig 3.2 Placement of signals proposed by BRTA
3.4 Summary

In summary the picture that depicts the traffic signal practice in Dhaka is a very gloomy picture. Proper resources that are provided are not being utilised as there is no involvement of a traffic engineer who can ensure this proper utilisation, there is no scientific method of signal design, there is no utilisation of the variable plan capability of the signal controller, the placements of signals are faulty, there are no secondary signals, presence of traffic police is inadequate, there are no co-ordinated signals for the main arteries and also area controlled traffic signals are absent.

At present as there is no standard signal design practice followed in Bangladesh the main objective of the research is to propose a systematic basis of calculating signal timing and phasing by customising the signal design methods developed in lane-based traffic operation, to accommodate the non-lane based mixed traffic operation in Bangladesh. Another goal of this research is to develop a user friendly computer package to make signal design and planning more simpler and thereby encouraging field engineers to calculate signal time methodically. Although field observations revealed that co-ordinated/area traffic signal control would be the most suitable for the road network in Dhaka Metropolitan City, this study will consider only the isolated signalised intersections which will be the basis of designing other types of signal controllers.
CHAPTER 4

SIGNAL DESIGN METHODOLOGY
FOR LANE BASED SYSTEM

4.1 Introduction

In an uncontrolled intersection crossing, conversing and diverging moment of traffic streams are found to occur. The conflicting moments of traffic from different approaches of the intersection result in the reduction of speeds and thereby causing delay, increased congestion and greater possibility of accidents. When the frequency and severity of these intersection conflicts between vehicles increase, regulation and control of traffic become necessary which may be done by the installation of traffic signals.

The primary aims of signal control at an intersection are: a) to reduce conflicts and hence the potential for accidents, b) to better regulate and stabilise traffic movements and c) hence reduce delays.

The installation of traffic signals provides a temporal split in vehicles rights-of-way. It is at the change of right-of-way that the accident potential is highest. As a result this split has to be done wisely and based on scientific theory. All the signal design practice that exist all over the world are based on one main criteria, that is delay minimisation.

Based on this criterion several relationship and signal design methods have been derived which will be illustrated subsequently in this chapter. Development of signal design software for the lane based system is also presented here.
Some important terminology that are relevant to this research work are illustrated in Appendix C for better understanding of the subject.

4.2 Signal Design Parameters

The most important factor that a field engineer or a signal designer has to understand is the capacity of the intersection. The amount of traffic that can pass through a signal-controlled intersection from a given approach depends on the green item available to the traffic and on the maximum flow of vehicles past the stop line during the green period. It has been demonstrated in many studies [4,11,12,13,14] that the saturation flow, lost times and passenger car equivalents are the main parameters which influence the design and performance of signal controlled intersections. In consequence their concept, definition and measurement have been a subject for study in this research work.

4.2.1 Saturation Flow

The maximum flow or saturation flow that can be accommodated by each arm at a signal controlled intersection is a key factor in the determination of capacity and signal settings.

4.2.1.1 Concept

It is a well known property of traffic signals that when the light turns green on an approach gaining right-of-way, the rate of vehicle discharge across the stop line quickly rises to a steady values, and remains constant until either the queue of vehicles waiting to pass through the signal is exhausted after which the rate of flow across the stop line is determined by the arrival rate or the end of green period, whichever comes sooner. The initial discharge rate is lower during the first few seconds while vehicles are accelerating to reach their normal speed. There may also be a lower discharge rate at the end of the saturated period when the amber signal indicates the imminence of the end of the stage. The constant rate at which the queue discharges across the stop line is defined as
'saturation flow' [4,11,12] and is generally expressed in vehicles or passenger car units (PCU) per hour of green time.

For calculation purposes, the saturated situation is simplified as an 'effective green period' through which flow is assumed to occur at the saturation rate, with 'lost' times at the start and end when no flow takes place. This concept was developed initially in the U.K. at the Road Research Laboratory [4,15] in the early 1960's and can be illustrated graphically in the Fig 4.1.

The curve in this figure is thus replaced by a rectangle of equal area, where the height is the saturation flow and the total lost time is equal to the combined green and amber periods minus the effective green time. An advantage of this concept is that capacity is then directly proportional to effective green time.

If \( G \) = combined green and amber periods (sec), \( g \) = effective green time (sec), \( c \) = cycle time (sec), \( l \) = lost time (sec) and \( s \) = saturation flow (vehicles/hour)

Then capacity = \( \frac{gs}{c} \) vehicles per hour

where \( g = G - l \) sec
The simple discharge curve is not appropriate in the case of right turning vehicles subjected to opposing flow, as vehicles may be forced to wait until a suitable gap appears in the opposing stream before they can cross. Often due to a saturation ‘plug’ of opposing vehicles at the start of green period, right turners may not be able to depart initially, and sometimes a number of vehicles may be waiting to clear the junction at the start of the amber period. Thus the saturation flow, defined as the average rate of discharge of right turning vehicles over the period of saturation, is highly dependent on the characteristics of the opposing flow. This situation also applies to lanes containing a mixed flow of both straight ahead and right turning vehicles. For these situations, the saturation flow is affected by a number of factors in addition to the level and characteristics of the opposing flow. These factors will include the proportion of right turning vehicles in the stream and the number of right turning vehicles that can wait to turn right before straight ahead vehicles are blocked i.e. the ‘storage space’ available.

4.2.1.2 Methods of Measurement

The three principal methods available for the calculation of saturation flows are described hereunder:

(a) **The Road Note 34 Method**

The saturation flow measurement method given in Road Note 34 is applicable to either constant or variable green periods. The basis of this method is to divide the saturated portion of each green period into short intervals of time and to average the flows in those saturated intervals which are free from ‘lost time’ effects, to give a measure of saturation flow. Each approach road at an intersection is considered separately and the method consists of recording the number of vehicle discharging from the queue in successive 0.1 minute intervals, the duration of the green period (including amber) and the cycle time. It
has been found convenient to use two ‘split second’ hand stop watches graduated in tenths
and hundreds of a minute. All timing should be recorded to the nearest 0.01 minute.

Watch 1, which should be left running throughout a test, is used to give the starting item
of each successive green period, using the split-second timer. It may be sufficient, in some
instances, to time only the total period of observation to obtain the average cycle time.
The final time should be the start of green for the period following the last recorded green
period.

Watch 2 should be started at the beginning of each green period and used to time off
successive 0.1 minute intervals, the number of vehicles discharging in each interval being
recorded on the form (Table 4.1). The reference point for counting vehicles may be taken
approximately a vehicle length after the stop-line i.e. as the rear wheels cross the stop-line.
This simplifies the counting of vehicles which over shoot the stop-line when halting. At
sites having pedestrian crossings it has been found convenient to use the line of studs as a
reference point. When the flow is no longer at the saturation level because the queue has
disappeared on one or more lanes the recording of the flows in 0.1 minute intervals should
be discontinued and any vehicles passing after the end of the last complete 0.1 minute
interval of saturated flow should be recorded in the column headed “Others” in Table 4.1.
When, as often happens, saturation ends part way through a 0.1 minute interval (partly
saturated intervals are not required for the saturation flow calculation) the count already
started in that interval should be continued for the rest of the green period (ignoring
further 0.1 minute intervals) to obtain the total number of “Others”. Although the timing
must stop at the end of the amber, any vehicles crossing on the ‘red’ must be included in
the last interval count, or in “Others” as appropriate. Any vehicles that cross the
observation point but fail to complete their journey through the intersection must not be
counted until the next green period has started.

In practice the exact end of saturation is difficult to determine. It is better to assume it
ends early rather than late because lack of ‘pressure’ often causes a false reduction in the
saturation flow at the end of the queue. Watch 2 should be stopped at the end of the amber period and the reading recorded in the “Start Red” column of Table 4.1. The times “Start Green” and “Start Red” in Table 4.1 should be entered during the red time and the watches reset ready for the next cycle. An indication is also given in the “Saturated or Unsaturated” column if the cycle is fully saturated. When saturation conditions do not last throughout the green period any completed unit intervals after the initial one and upto the time saturation ends may be used in the calculation of saturation flow.

<table>
<thead>
<tr>
<th>Start Green (min)</th>
<th>No of vehicles per 6 sec interval</th>
<th>Others</th>
<th>Saturated or Unsaturated</th>
<th>Start Red (min)</th>
<th>Last interval Sat. Period No. (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.1</td>
<td>0.2</td>
<td>0.3</td>
<td>0.4</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>0.6</td>
<td>0.7</td>
<td>0.8</td>
<td>0.9</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.1 Saturation flow calculation data sheet

The number of unit intervals and the duration of the last interval often vary from cycle to cycle. In such cases the procedure is to combine all the last intervals to give an ‘average’ last interval. Thus, the last two columns in Table 4.1 headed “Last interval of saturated periods” are first completed for each fully saturated period only by entering the duration of the last interval in the time column and transferring the number of vehicles in that interval to the number column. If, however, this last interval is less than 0.03 minutes this would mean that the amber commenced during the previous 0.1 minute interval and any falling off of the flow would not be confined solely to the last saturated interval. In such cases the last intervals is combined with the preceding 0.1 minute interval (to give a time of 0.11 or 0.12 minutes. Each column is then summed to complete the bottom two lanes as shown in Table 4.1. vehicles of the respective 0.1 minute interval by the number of samples available for that interval.
The average last interval is obtained from the fully saturated periods only. It represents the flow per 0.1 minute. The saturation flow per 0.1 minute is obtained by summing all the saturation flow per 0.1 minute interval barring the first 0.1 minute interval and the last interval. This method is suitable for measuring traffic not moving in lanes, since the lanes themselves are not distinguishable Obviously this method can be applied on a lane-by-lane basis. A drawback of this method is that it does not allow PCU values of different vehicles types to be calculated from observed data.

b) The Average Headway Method

It is the most commonly used alternative to the TRRL counting method. Based on Scraggs [16] this method requires data in time headway between vehicles as they cross the stop line. Time headway of a vehicle is measured as the time between the crossing of the stop line by the rear wheels of the vehicle preceding it, and its own rear wheels. The measurement requires sophisticated equipment and the recording process should be able to detect different types of vehicles. Saturation flow \( S \) is then calculated directly from equation 4.1 below in peculiar as the reciprocal of the average headway of saturated straight on passenger cars

\[
S = \frac{3600}{h_{l-1}} \text{ PCU/hour}
\]

where \( h_{l-1} \) is the average headway between light vehicles in seconds.

At the beginning of discharge, as the headway of few front vehicles of a saturated stream are longer due to the fact that these vehicles are still accelerating when they cross the stop line, the first three or four vehicles are excluded from the calculation of the saturation flow. Vehicles which cross the stop line during the amber or red periods are also excluded from the calculation. When saturation conditions do not last throughout the green period any completed unit intervals after the initial one and upto the time saturation ends may be used in the calculation of saturation flow. Note that data recorded in time headway can be
reinformed to Road Note 34 method for comparison, although obviously the reverse cannot be achieved.

c) Multiple Linear Regression Methods

In the recent years a number of alternative methods of processing the data collected in classified vehicle counts format have been developed in an attempt to obtain simultaneous estimations of all the properties of the discharge process. These methods involved multiple linear regression techniques which have been used by a number of researchers [17,18,19] By the use of extensive statistical manipulation, Branston and Zuylen [17] introduced two methods known as ‘asynchronous’ and ‘synchronous’ multiple regression based on counting methods, which are described in the following articles. For both methods, the green period is divided into three time periods, the first period begins at the start of green contiguously, the middle period covers the time when the departure rate is constant and in saturated state and the last period ends when the amber light shows. The end of the last counting period of full saturated cycles is fixed at the change to the amber light, but the ends of the first and middle may be chosen either.

i) as an arbitrary point of time, termed as asynchronous counting and

ii) to corresponded with the instant of departure of a specific vehicle termed as synchronous counting.

i. Asynchronous Multiple Regression

In this method, vehicle departures are recorded over time periods T which begin and end at an arbitrary point of time. A typical mathematical expression of this model is given below.

\[ L = S.T - S.\delta.l_1 - a_1.M - a_2.H - a_3.BC - a_4.MC - a_5.C \]

where:
L = number of light vehicles recorded in time interval T.
M = number of medium vehicles recorded in time interval T.
H = number of heavy vehicles recorded in time interval T.
BC = number of buses or coaches recorded in time interval T.
MC = number of motorcycles recorded in time interval T.
C = number of bicycles recorded in time interval T.
S = saturation flow in time interval T (in PCU/hr)
h = initial lost time in seconds.
δ = dummy variable (1 for the first counting interval or 0 for the other intervals). The time interval is typically 6 seconds or a multiple of it.
a₁ to a₅ = passenger car equivalents for the corresponding vehicle types.

This equation incorporates 5 vehicles classes in addition to light vehicles which have an assumed PCU value of 1 and a term 'S₀₁,' to cater for the reduction in saturation flow during the first counting interval of a green aspect. In its simple state, when only light vehicles are present in a second or subsequent counting interval, equation 4.2 reduces to L = ST and the saturation flow, S, is simply L/T. Where streams of traffic contain different vehicles class, unknowns of this model are estimated using multiple linear regression technique. The data for this model, i.e. the number of L, M, H, BC, MC, and C in time interval T may be obtained using the Road Note 34 procedure. Then regressing the measured value of L against T and the measured values of M, H, BC, MC and C, the values for S, h₁ and a₁ to a₅ can be estimated simultaneously.

ii. Synchronous Multiple Regression

A number of researches [13,17,18] have used 'synchronous' regression in their studies as an alternative technique to asynchronous regression for the calculation of saturation flows and lost times. In this method the number of vehicle departures of each class are recorded over time periods beginning and ending with the instant of departure of a vehicle (the first vehicle departed being excluded) and the counting periods are defined as:
\[ T = h_L L + h_M M + h_H H + h_{BC} BC + h_{MC} MC + h_C C \]

where:

- \( T \) = Length of vehicles counting period.
- \( L \) = number of light vehicles recorded in time interval \( T \).
- \( M \) = number of medium vehicles recorded in time interval \( T \).
- \( H \) = number of heavy vehicles recorded in time interval \( T \).
- \( BC \) = number of buses or coaches recorded in time interval \( T \).
- \( MC \) = number of motorcycles recorded in time interval \( T \).
- \( C \) = number of bicycles recorded in time interval \( T \).

\( h_L \) to \( h_C \) = coefficients representing the average headway for different vehicle class.

In its simplest form, when only light vehicles are present in a stream, equation 4.3 reduces to \( T = h_L L \), and a measure of \( T \) and \( L \) would give a direct value of \( h_L \). However, when traffic streams contain different types of vehicles, the coefficients in equation 4.3 are estimated by regressing the measured value of the time interval (\( T \)) against the numbers of each vehicle class counting in that time interval. As zero vehicles departures should correspond to a time period of zero, regression plane is constrained to pass through the origin to avoid infinite headway being calculated from the equation.

In this method the saturation flow can be obtained as the reciprocal of the average headway from the standard equation 4.1.

d) Other Methods

Akcelik[20] proposed a different approach of saturation flow measurement by splitting the green period into three intervals. The first interval covers the initial 10 seconds, the middle interval covers the rest of the green period while saturated and the last interval includes the period after the end of green covering amber and the following red period. The middle and last interval are not necessarily contiguous, unless a cycle is fully saturated. Vehicles
are counted as they cross the stop line and the saturation period is considered to end when
the vehicles which were stopped during the red period as well as those which arrive at the
back of the queue and are stopped during the green period cross the stop line. If the
saturation period is less than 10 seconds, that particular cycle is excluded from the
observation. The departures in the third interval are counted in fully saturated conditions
i.e. when a queue still exist at the end of the green period. The saturation flow (S in
vehs/hr) is calculated as follows:

\[
S = \frac{X_2}{T_1 - 10n}
\]

where \( X_2 \) : total no. of vehicles in the middle intervals of \( n \) cycles;
\( T_1 \) : total saturation time (first and middle intervals); \( n \) : no. of cycles observed.

4.2.1.3 Comments

The practicability of the Road Note 34 and average headway methods has been compared
by Hounsell [21] and he found that saturation flows calculated by using these two methods
are quite similar.

About the prediction of saturation flows by multiple regression techniques, different
conclusions have been found in many studies [13, 18, 21, 22, 23]. Branstoll and Gipps [18]
in their study have shown that the regression model produces more accurate prediction of
saturation flow than the Road Note 34 method. While Kimber, McDonald and Hounsell
[21] and the Southampton University Study [23] have proved that the asynchronous
regression model produces lower estimates of saturation flows than those obtained by
other methods. A similar result has been obtained in other studies.

Hounsell [21] has found that the synchronous regression model gives good prediction of
saturation flows, which is comparable to the average headway method. The added benefit
of this method is that data are recorded in the form of a simpler classified vehicle count format.

4.2.2 Lost Times

A description of the concept and measurement methods of 'lost time' is given below.

4.2.2.1 Concept

The traffic flow takes some time to reach the saturation level after the onset of green. Equally during the amber period the rate of the flow falls away, in anticipation of the red signal.

The time lost due to start-up effects at the beginning of the green phase is defined as 'initial lost time' and the time lost by vehicles not making full use of amber period is termed as 'end lost time'. Then the 'total lost time' is the combination of these two lost times. This lost time controls how much green time is effectively lost to traffic due to driver reaction times, acceleration/deceleration effects at the start and end of each green phase.

4.2.2.2 Methods of Measurement

The methods described previously are also applicable for the estimation of lost times. In this section these methods are described in relation to the lost times.

a) The Road Note 34 Method

In this method it is assumed that the initial lost time due to the start-up effects are restricted to the first 0.1 minute interval of each phase, while the ending lost times are taken to occur in the last interval of the amber period. Based on this assumption the initial lost time is calculated by the difference in time between the time provided for the first 0.1
minute interval and the time that would be required if the same number of vehicles had been discharged at the saturation flow rate.

A similar reasoning can be formulated for calculating the end lost time. However, the time interval considered in this case varies between two to eight seconds. If the last time interval is less than two seconds, it will be combined with the preceding six seconds interval and if it is greater than eight seconds it will be divided into two intervals, one of six seconds and the remainder which will be considered in the end lost time calculation. The equation for calculating both lost times is given below:

\[ l = t - \frac{n}{s} \] .......................... 4.5

where \( l \) = lost time (initial or end) in seconds.  
\( t \) = time interval considered (6 seconds for the initial lost time and 2-8 seconds for the end lost time)  
\( n \) = number of vehicles discharged during the time period \( t \) considered  
\( s \) = saturation flow in veh/sec.

The total lost time is then obtained by adding calculated initial and end lost times.

b) The Average Headway Method

The lost times are estimated by subtracting from the actual time (the first and last few seconds of the green phase) taken by a given number of vehicles to cross the stop line, the average time for the same number of saturated straight ahead passenger cars (i.e. with an average headway). According to this:

\[ l = t_n - n.h_{\text{av}} \] .......................... 4.6

where

\( l \) = initial or end lost time.
\( t_a \) = actual time period considered (at the beginning or at the end of the green phase).
\( h_{lt} \) = average headway between light vehicles at the saturation flow condition.

Once lost times are obtained for the initial and end periods, a total lost time can be calculated by summation.

c) Multiple Linear Regression Methods

The asynchronous multiple regression model given in equation 4.2 allows estimates of initial lost time simultaneously with the saturation flow and PCU values. On the other hand, in the synchronous model as the counting period for \( T \) is chosen to exclude the end effects, equation 4.3 does not allow estimates of initial or end lost times.

4.2.2.3 Comments

For calculating initial lost times in the Road Note 34 the hypothesis that start-up effects are limited to the first six seconds interval is not appropriate for all cases. Analyses [12,21] have shown that starting lost times usually extend beyond the first six seconds to which they have been traditionally restricted, to about twelve seconds at many sites. Therefore, this method usually underestimate the lost times at most sites.

Compared to the Road Note 34 method, the average headway method is preferable due to its flexibility of analysis of the periods over which acceleration and deceleration effects occur. Although lost times can be calculated using asynchronous regression model recent work [21] has shown that it gives biased value for initial lost time.

4.2.3 Passenger Car Unit (PCU)

The traffic operations at a signalised intersection would be very much easier and simplified if all vehicles in the traffic stream were of an identical size and travelled straight ahead only. In practice, however, the operations are complicated because the traffic stream...
normally consists of an inseparable mixture of different types of vehicles performing different manoeuvres at the traffic junction. The time taken by a vehicle to depart from the stop line varies considerably from vehicle to vehicle, because of the variations in their length, weight, power and driver behaviour. Also the time used by a vehicle to perform a turning movement, at an intersection, depends on its type.

In respect of its road-capacity requirements each type of vehicle is equivalent to a number of passenger cars and this is called the 'passenger car unit' (PCU) equivalent. Scraggs[16] defined PCU factor as: under saturated conditions if a particular type of vehicle requires 'X' times as much time at an intersection as is required by an average passenger car, then that type is equivalent to X PCU. It is needed to remove the effects of traffic composition from saturation flow calculations.

4.2.3.1 Concept

As saturation flows at intersection are affected by the proportion and type of vehicles in the traffic stream, attempts have been made to bring all vehicle types making different manoeuvres to a homogeneous unit so that flows can be converted to a common base. Thus all vehicles can be classified according to the number of standard passenger cars to which they are equivalent. A great deal of research [4,13,17,24] has been carried out to measure this equivalent factor for different types of vehicles.

4.2.3.2 Methods of Measurement

The passenger car unit factors are usually computed by comparing the departure time of cars at the stop line and the identical measure for all other types of vehicles. Methods developed for the calculation of PCU factors are discussed in the following section.
a) Webster's Method

This method is based on public road observations and controlled test track experiment, carried out by Webster et al.[25,26], using cars, taxis, light, medium, and heavy commercial vehicles and some double-decker buses. The test track experiment was performed by varying the percentage of goods vehicles from zero to hundred. Subsequent public road observations in London [27] and Glasgow [22] involved 70 signal controlled intersections, in the PCU analysis. Vehicle departures were recorded at the stop line by means of event-recorder techniques. The average number of light and goods vehicles per cycle were calculated as follows:

\[
\bar{n}_l = \frac{1}{N} \sum_{i=1}^{N} n_{li}
\]  \hspace{2cm} \text{4.7}

\[
\bar{n}_g = \frac{1}{N} \sum_{i=1}^{N} n_{gi}
\]  \hspace{2cm} \text{4.8}

where: \(\bar{n}_l\) = average number of light vehicles per cycle.

\(n_l\) = number of departing light vehicles per cycle.

\(N\) = number of cycles in a set (taken as 12).

\(\bar{n}_g\) = average number of goods vehicles per cycle.

\(n_g\) = number of departing goods vehicles per cycle.

The PCU value was estimated as a reciprocal of slope of the straight line drawn through the values of \(n_l\) and \(n_g\). This method is, consequently, unable to estimate more than two types of vehicles at a time.

b) The Average Headway Method

The most common method of determining PCU factor is known as the headway ratio and used by many researchers viz. Scraggs[16], Webster[25], Miller[27], Kimber et al[28].
4.2.3.3 Comments

c) Multiple Linear Regression Methods

Passenger car unit of different vehicle classes previously considered in the asynchronous regression model can be obtained simultaneously with the saturation flows and lost times. On the contrary, from synchronous regression model given in equation 4.3, PCU factor for each vehicle class can be calculated by dividing its mean headway estimate from the regression with that for cars. This is similar to the conventional Scraggs [16] method although, of course, the average headway’s are estimated using regression rather than from direct measurements.

4.2.3.3 Comments

The methods developed for estimating passenger car unit are quite similar to those for saturation flow. An exception occurs in the Road Note 34 method, PCU factors cannot be
obtained using this method. Among the three methods described above, research studies[21,22] recommended that direct measurement of headway's or synchronous regression model produces the best estimates of PCU factors. Hounsell [21] has shown in his study, by means of a simulation exercise, that PCU factors which result in minimum vehicular delay at signalised intersection are those calculated by the average headway method. Synchronous regression model also gives good approximation of PCU factors from simpler vehicles count data. On the other hand, University of Southampton work [23] has shown that asynchronous multiple regression model gives slightly lower estimates of PCU factors than the other methods.

4.3 Factors Affecting Saturation Flow

4.3.1 Approach and Lane Width

Variations in the effect of the approach and lane widths on saturation flow have been reported in a number of studies. Observations of traffic flow made by the Road Research Laboratory[26] at intersections in the London area and also in some larger cities, supplemented by controlled experiments at the Laboratory test track, have shown that the saturation flow(S) expressed in passenger car units per hour with no parked vehicles is given by the equation:

\[ S = 525 W \text{ PCU/hr}; \]  \hspace{1cm} 4.10

where \( W \) is the width of the approach in metres.

This formula is applicable to approach widths from 5.5m to 18m (the maximum width tested). For widths between 3m and 5.5m the relationship is not linear but shows a slight step effect and the saturation flow can be estimated from following table.

The width is assumed to be constant for at least the length of the approach (defined as the length which will accommodate the queue which can just pass through the intersection during a fully saturated green period).
where 2.5m < \( W \) < 4.0m.

In order to obtain saturation flow for the whole approach at stopline they suggested using as many narrow lanes as possible.

A study carried out by Kimber et al[28], based on database from 64 sites throughout UK, suggested a basic saturation flow of 2080 PCU/hr for a lane width of 3.25m and increase of 100 PCU/hr per meter width in excess of the standard width. They also found a
reduction of 140 PCU/hr for the nearside lane. These values were obtained from the mean saturation flow over all sites where gradients were not found to affect flows.

In Australia, Leong[29] investigated the effect of lane widths on saturation flow. He applied headway ratio method to calculate saturation flow values. The majority of his lane widths were in the range 2.75m to 3.5m and he concluded that lane width has very little effect upon saturation flows. Results from subsequent investigations by the Australian Road Research Board confirmed his conclusion. Miller[27] who dealt with lane width instead of approach width, observed that the lane width in the range 2.0 to 4.8 meters had a small effect on saturation flow. Akcelik[20] also affirmed that there is no need for adjustment for saturation flow within a lane width range of 3.0m to 3.7m. In this range, he proposed a single saturation flow i.e. 1850 PCU/hr. For lane widths outside this range an adjustment factor \( f_W \) is to be applied against the standard value above.

\[
\begin{align*}
    f_W &= 0.55 + 0.14w \quad \text{for } w < 3.0m \\
    f_W &= 0.83 + 0.05w \quad \text{for } w > 3.7 \text{ m}
\end{align*}
\]

He also supported Miller’s idea of obtaining saturation flow lane by lane and then summing them, rather than estimating for the whole approach width.

**Flared approach[1]**

<table>
<thead>
<tr>
<th>Input:</th>
</tr>
</thead>
<tbody>
<tr>
<td>( w ) = Normal half width of the road at the intersection</td>
</tr>
<tr>
<td>( w_f ) = Half width of the flair at the intersection</td>
</tr>
<tr>
<td>( d_1 ) = Length of flair upto intersection</td>
</tr>
<tr>
<td>( d'_1 ) = Length of approach occupied by the queue which can just pass through the intersection during a fully saturated green period</td>
</tr>
</tbody>
</table>

\[
d'_1 = s_u \cdot w_u \cdot g \cdot v = s_u \cdot g \cdot A
\]

where, \( s_u \) = saturation flow per unit width  
\( w_u \) = width of a lane  
\( g \) = effective green period  
\( v \) = average distance between successive vehicles (front to front) in a stationary queue
\[ A = v \cdot w_e = \text{effective queuing area of a vehicle (which may be taken as about 220 ft}^2) \]

CASE 1 (\(d'_1 > d_1\))

Saturation flow in this case is considered to be constant at a value appropriate to the width \(w\).

\[
\text{Gain in effective green time} = \frac{w \cdot d_1}{2A_s \cdot w}
\]

CASE 2 (\(d'_1 < d_1\))

Saturation flow \((a_s)\) appropriate to the width at \(A = s_0 (w + w'_1)\)

\[
\text{Gain in effective green time} = \frac{d'_1 (w_1 - w'_1)}{2A_s (w + w_1)}
\]
U.S Highway Capacity Manual [24] proposed a saturation flow i.e. 1800 PCU/hour based on a 12 ft (3.65 m) lane width. For other widths, a correction of three percent for each foot deviation from the standard lane width is applicable.

4.3.2 Effect of Gradient

In UK, Dick[30] investigated this issue based on 21 sites at the London area with gradient ranging from -5.2 to +8.1 percent. The gradient was defined as the average slope between the stop line and a point on the approach 61 m before it. He observed that the saturation flow increased or decreased by 3 percent for each 1 percent of uphill or downhill gradient of the approach. Later on Webster and Cobbe[4] found similar results. On the other hand, Martin and Voorhees[13] investigated 47 sites and found no significant effect of gradient on saturation flow. A recent study by Kimber et al [28] revealed that one percent increase in uphill gradient causes a decrease in saturation flow of about 2 percent and there is no relationship between saturation flow and downhill gradient.

American HCM[24] recommended an adjustment factor of 0.5 percent for each percent of gradient. In Australia, Akcelik[20] found similar results adopted by HCM.

4.3.3 Effect of peak period

Saturation flow of the off peak period = 0.94 x Saturation flow of the peak period [4]

4.3.4 Effect of Turning Vehicles

Allowance for turning vehicles was studied by Archer et al[31], based on six approaches in London. In his study he basically compared, the observed straight on saturation flow in PCU/hr and average saturation flow of all traffic (including left and right turners) in PCU/hr. The difference in saturation flow between all straight on and all traffic was represented by:
In Road Note 34[15], the effect of right turning vehicles is treated by the provision of correction factor:

\[ L\alpha + R\beta = K \] .......................... 4.17

where \( K \): effect of all turning vehicles in reducing the straight on saturation flow;
\( L \): percentage left turning;
\( R \): percentage right turning;
\( \alpha, \beta \): factor(tcru) for left and right turner as appropriate.

He observed that the through car unit(tcru) for left turning was 1.25 and for right turning 1.75. He also indicated an increase of 15 percent on saturation flow for approaches whose traffic was well defined by lane markings and a reduction of 12 percent for those with no lane markings.

In Road Note 34[15], the effect of right turning vehicles is treated by the provision of correction factor:

\[ F = 1 + \frac{0.75 n_r}{n_1 + n_2 + n_3 + n_4} \] .......................... 4.18

where \( n_r \): flow of right turning vehicles;
\( n_{1,4} \): flow of cars, medium, buses and tram respectively.

Track test experiments were conducted by Webster[32] in order to determine the relationship between radii and saturation flow for right turning movements at a signalised intersection. Observing the headway between straight ahead and right turning vehicles in a standard composition of 75 percent lights and 25 percent heavies, he gave the following relationship:

\[ S = \frac{1800}{1 + 1.5/r} \text{ PCU/hr; for single-file stream} \] .......................... 4.19
However, for right turning movements with no opposing flow the results were quite different.

\[
S = \frac{1550}{1 + 1.49/r} \\
\text{PCU/hr; for double file stream} \quad \text{.......................... 4.22}
\]

where: \( S = \) saturation flow and \( r = \) turning radius in meters.

These expressions apply to turning vehicles encountering no opposing flow and in an exclusive right-turning lane. Where there is opposing flow and/or the turning vehicles are intermixed with straight ahead vehicles different rules apply.

The general saturation flow relationships suggested by the Road Research Laboratory include the effects of left-turning traffic present when the studies were made. The proportion of left-turners was about 10 percent. If, however, the proportion of left-turners exceeds 10 percent, an adjustment is made for the excess over 10 percent by assuming that the PCU for left-turner is equivalent to 1.25 times the PCU for straight-ahead vehicle.

A very close result to the Webster formula has been found from test track experimental data by Kimber[14], for the left turning movement.

\[
S = \frac{1795}{1 + 1.49/r} \\
\text{.......................... 4.21}
\]

where: \( S = \) saturation flow and \( r = \) turning radius in meters.
For right turns against opposing flow experimental results led to a linear relationship as follows:  
\[ S_r = 1286 - 0.78 \, qst \]  .................................................. 4.23  
where \( S_r \) = right turn saturation flow in PCU/hr.  
\( qst \) = opposing straight-through flow in veh/hr.  
Although non-linear regression was tried, no significant result was achieved.

In the subsequent investigation, Kimber et al.[28] have produced a formula combined with the proportion of turning vehicles in the following equation:

\[ S_t = \frac{S_o}{1 + 1.5f/r} \]  .................................................. 4.24  
where \( S_t \): adjusted saturation flow; \( S_o \): basic saturation flow;  
\( f \): proportion of turning vehicles; \( r \): radius of curvature of vehicle path (m).

In American Manual[24], adjustment factors for right and left turning movements are recommended based on-

i) the exclusive or shared lane movements;

ii) type of signal phasing;

iii) proportion of turning movement.

The following adjustment factors are used to cater for unopposed turning vehicles by multiplying it with the basic saturation flow:

\[ f_{RT} = 0.85 \] for unopposed right turn(left turn in UK)  
\[ f_{LT} = 0.90 \] for unopposed left turn(right turn in UK)  

The results from the studies of the Australian Road Research Board conducted by Akcelik[20] yielded a tcu (through car unit) equivalent of 1 and 1.25 for cars in normal
and restricted unopposed turning and 2.0 and 2.50 for heavy goods vehicles for the same condition. In the case of opposed turning he gave a factor $e_o$ for car and $e_o + 1$ for heavy vehicles, where $e_o$ is represented in the following equation:

$$e_o = \frac{0.5g}{(su.gu + nf)}$$

where $g = $ green time in seconds
$s = $ saturation flow for the opposing traffic in tcu/hr
$su = $ opposed turn saturation flow in veh/hr
$gu = (sg - qc)/(s - q)$ unsaturated part of the opposing movement
$nf = $ number of turning vehicles per cycle.

### 4.3.5 Effect of Vehicle Composition

The effect of different types of vehicle on saturation flow at traffic signals is allowed for by the use of passenger car units, which represent the effect of varying vehicle types relative to the passenger car. These equivalents as suggested by Kimber et al.[28] are given below:

<table>
<thead>
<tr>
<th>Type</th>
<th>Equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light vehicles</td>
<td>1.0 (by definition)</td>
</tr>
<tr>
<td>Medium commercial vehicles</td>
<td>1.5</td>
</tr>
<tr>
<td>Heavy commercial vehicles</td>
<td>2.3</td>
</tr>
<tr>
<td>Buses and Coaches</td>
<td>2.0</td>
</tr>
<tr>
<td>Motorcycles</td>
<td>0.4</td>
</tr>
<tr>
<td>Pedal cycles</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Akcelik[20] defines a commercial vehicle as any vehicle with more than two axles or with dual tyres on the rear axle and gives a through car equivalent of 2 for all commercial vehicles/buses/coaches together.
The American method is to apply a factor which reduces or increases the capacity and service volumes 1 percent for each percentage of trucks (medium or heavy goods vehicles) and through buses in the approach stream above or below 5 percent. Although passenger car equivalency factors are not used in intersection capacity computations, the Highway Capacity Manual states that one truck can be considered to be equivalent to two passenger cars.

4.3.6 Effect of Parked Vehicles

Vehicles parked on the approach or the exit have been reported to affect the saturation flow at the intersection[4,20,24,26]. Webster and Cobbe[4] formulated an equation to define the effective loss of width due to parking:

\[ c_I = 5.5 - 0.9(z - 25)/k \]

where \( c_I \) = effective loss of carriageway width;
\( z \) = clear distance between stop line and parked vehicles in ft;
\( k \) = green time in seconds.

A factor of 1.5 is used if a lorry or wide van is parked.

In USA, this effect is implicit in the diagrams for calculating volume of service, which assumes that a parked vehicle near an intersection has an influence greater than simply the physical space occupied by it. That is because, passing drivers fear sudden manoeuvres by parked vehicles or doors opening in their path. The practice has recommended a distance of 250 ft from the stop line from which the parking vehicles have no effect on the junction capacity.

Miller[27], assuming the space occupied per vehicle of 24 ft, indicated a clear distance \( D \) of:
\[ D = \frac{Sg}{150} \]

where, \( S \) is saturation flow in veh/hr and \( g \) is green time in secs. Within this distance the nearside lane saturation flow should be corrected by the factor, \([p+F(1-p)]\), where, \( p \) is the proportion of \( D \) used and \( F \) is the proportion of \( S \) reduced.

### 4.3.7 Effect of Site Characteristics

The effects of pedestrians and site characteristics are allowed for by designating a site classification as good, average or poor. Webster and Cobbe\([4]\) assigned factors of 1.2, 1.0, 0.8 respectively for saturation flow correction. Akcelik\([20]\) proposed a desegregation of basic saturation flow into environmental classes A(ideal), B(average), C(poor) and lane types 1(through lane), 2(any type of turning traffic) and 3(restricted turning i.e. small radius or some pedestrian interference). Basic saturation flow ranges 1270 (C3) up to 1850 (A1) PCU/hr.

The HCM\([24]\) divides the area into two categories and assigns the associated factors:

- a. Central business district (CBD) factored by 0.9
- b. Other areas factored by 1.0

### 4.4 Capacity of the Whole Intersection

The capacity of the whole intersection is dependent on the total amount of lost time (\( L \)) in the cycle. Lost time is \( \sum(l-a) + \sum l \). The rest of the cycle is 'useful' time and is shared among the phases. If the signals are correctly set the 'predominant' approaches of the phases (i.e. those with the highest ratios of flow in saturation flow) all reach capacity simultaneously. The other approaches will therefore have spare capacity. The ultimate capacity of the intersection can be defined as the maximum flow which can pass through the intersection with the same relative flows on the various approaches and with the
existing proportions of turning traffic. Assuming that right-turners do not cause the saturation flow to fall after the first few seconds of green time, then the capacity will increase as the cycle time increases, since the ratio of lost time to useful time decrease (the effect becomes negligible when the cycle is very long).

In practice, it is usual to set an upper limit of 120 seconds for the cycle time, although in special cases this is increased. If the capacity were taken as the flow which could just be accommodated by such a cycle the delays would generally be excessively high. A practical capacity of 90 per cent of this maximum possible flow, which produces generally acceptable delays, is recommended.

In general, if the ratio of the flow to the saturation flow of the predominant arm of each phase is denoted by $\gamma$, then the cycle time, $C_m$, which is just long enough to pass all the traffic, is given by

$$C_m = \frac{L}{1 - \gamma} \quad \text{.................................. 4.28}$$

where $\gamma$ is the sum of the $\gamma$ values over the phases and $L$ is the total lost time $\{\sum(t - a) - \sum t\}$.

The maximum value of $\gamma$ which can be accommodated is therefore

$$\gamma = 1 - \frac{L}{C_m} \quad \text{.................................. 4.29}$$

If, for practical purposes, $C_m$ is taken as 120 seconds and $\gamma_{max}$ is 90 per cent of the maximum possible $\gamma$ value then

$$\gamma_{max} = 0.9 - 0.0075L \quad \text{.................................. 4.30}$$

where $L$ is in seconds. The percentage reserve capacity is then given by

$$100(\gamma_{max} - \gamma) \quad \frac{1}{\gamma} \quad \text{.................................. 4.31}$$
4.5 Optimum Settings: Fixed-Time Signals

4.5.1 Cycle Time

In deducing an expression for the cycle time which gives the least delay to all traffic, it has been found sufficiently accurate to select one arm only from each phase to represent that phase. Provided (as is usually the case) the lost times are more or less the same for different arms of the same phase, the arm with the highest ratio of flow to saturation flow is selected as the predominant arm and this ratio is denoted by the symbol $Y$.

By differentiating the equation for the overall delay at an intersection with respect to the cycle time it was found that the cycle time with the minimum delay could be represented by

$$\epsilon_n = \frac{15L+5}{1-Y_1-Y_2-\cdots-Y_n} = \frac{15L+5}{1-Y} \text{ seconds} \quad \text{..........................4.32}$$

where $Y_1, Y_2, \ldots, Y_n$ are the maximum ratio of flow to saturation flow for phases 1, 2, \ldots, n, $Y = \sum Y$ and $L$ is the total lost time per cycle (in seconds). This cycle time will be referred to as the 'optimum cycle time'.

Under light traffic conditions the optimum cycle time as deduced from this formula may be very short. From a practical point of view, including safety considerations, it may be desirable to regard a cycle time of about 25 seconds as the lower limit. It may also be desirable to regard a cycle time of about 2 minutes as the upper limit, since the gain in capacity with very long cycles is often insignificant. This limit may be exceeded only in exceptional circumstances (e.g. at multi-phase junctions or under conditions where at times the primary function of the signals is to facilitate traffic movement on one route at the expense of another, for example at weekends on holiday routes).

Some examples of the variation of delay with cycle time are shown in Fig. 4.3. It has been found that for cycle times within the range threequarters to one and-a-half times the
optimum value the delay is never more than 10 to 20 per cent above that given by the optimum cycle. For most practical purposes this result may be used in deducing a compromise cycle time when the level of flow varies considerably throughout the day. It would, of course, be better either to change the cycle time to take account of this or, as is more common, to use vehicle-actuated signals. However, if it is desired to use a single setting of fixed time signals, the simple approximate method outlined below may be used.

(1) Calculate the optimum cycle time for each hour of the day when the traffic flow is medium or heavy, e.g. between the hours of 7 a.m. and 7 p.m., and average the results over the day.

(2) Evaluate three-quarters of the optimum cycle time calculated for the heaviest peak hour.

(3) Select whichever is the greater as the cycle time.

Fig 4.3 Effect on delay of variation of cycle length
4.5.2 Green Times

A simple rule for setting the green times to give the least overall delay to all traffic using the intersection was derived from the delay equation. It was found that the ratio of the effective green times should equal the ratio of the \( y \) values, i.e.

\[
\frac{g_1}{g_2} = \frac{y_1}{y_2}
\]

.................................4.33

where \( g_1 \) and \( g_2 \) are the effective green items of phases 1 and 2 respectively. This rule can be extended to 3-or more phase operation. Strictly, the green time ratio should be made a few per cent nearer to unity if they \( y \)-value ratio differs appreciably from unity, but for most practical purposes the effect is too small to be of significance. Also, it has been shown that where the two arms of a single phase have different values of the ratio \( q/s \), approximately minimum overall delay is still obtained by dividing the cycle according in the \( y \) values as given above, even though the \( q/s \) ratio of the other arm(s) of the phase may vary between zero and \( y \).

If \( c_e - l \) is the total effective green time in the cycle the above rule gives

\[
g_1 = \frac{y_1}{y} (c_e - l)
\]

.................................4.34

\[
g_2 = \frac{y_2}{y} (c_e - l)
\]

.................................4.35

The way in which the delay varies with the ratio of the green periods is shown in Fig. 4.3 for four different cycle times. If the delay should be kept within the limits of 10 to 20 percent above the minimum possible, the green times (assuming the cycle time is the optimum value) should not differ from the optimum values by more than one-fifth of the total lost time per cycle. This means, that the proportional latitude for green-time setting is very much less than that for the cycle-time setting. If the cycle time is shorter than the optimum value the latitude is reduced even more, but if it is longer than the optimum value the latitude is increased, e.g. in the example illustrated in Fig. 4.4 the change in \( g_{NS} \) or
necessary to shift from one asymptote to the other is 10 seconds when \( c = 40 \) seconds (optimum), but when \( c = 80 \) seconds the corresponding change is 30 seconds. Thus it is better to have a cycle time longer than optimum if there is the likelihood of appreciable error in setting the green-time ratio.

Where the level of traffic flow is varying throughout the day and a single value of green time is required for each phase, it is suggested, in view of the findings given above
regarding latitude, that the total effective green item in the cycle $c_t - t$ should be divided in proportion to the average $y$ values (for each phase) for peak periods only, i.e.

$$\frac{g_1}{g_2} = \frac{(v_1)_{\text{peak}}}{(v_2)_{\text{peak}}}$$

where $(v_1)_{\text{peak}}$ is the average $y$ value during peak periods for phase 1, and $(v_2)_{\text{peak}}$ that for phase 2. If these values are likely to be appreciably different from the optimum ones for any peak period the cycle item should be increased to a value greater than that which would otherwise be obtained from the rules given under ‘Cycle time’ above.

Just as it was necessary to set limits on the cycle time for particle purposes, so it is necessary to avoid having green items too short and this is catered for automatically with existing controllers which have a minimum green period of 7 seconds.

4.5.3 Early Cut-off / Late release

*Separate right-turning lanes.* When the right-turning lanes are separated from the other traffic, calculations of the $q/s$ values should be made for each independent stream. The $y$ value for the phase as a whole will be the larger of the two values calculated.

*Separate left-turning lanes.* When there are exclusive left-turning lanes separate calculations of the $q/s$ values should be made for the left-turning streams as well as for the other traffic, and the larger $q/s$ value taken to represent the phase as a whole.

If there is a slip-road so that left-turning traffic can flow at any time, without coming under the control of the signals, the $y$ value for the phase should relate to the flow and saturation flow of the other traffic, i.e. that excluding left-turners. When there is a left filter and there are exclusive left-turning lanes the procedure to be adopted is similar to, though a little more complicated than, that given above for use when there is an early cut-off feature.
Use of left filter with no exclusive left-turning lanes. In this case an estimate has to be made of the number of vehicles likely to be able to take advantage of the left filter, which will depend on the flow of left-turning traffic and on the geometry of the intersection. Both these factors can affect the likelihood of left-turners being blocked by those proceeding straight ahead. Vehicles which are able to take advantage of the left filter (expressed as a flow) should be subtracted from the combined flow, and the q/s value for this arm based on the flow so modified.

4.6 Australian Practice

There are some differences in the relationships used in Australia and also in the method of determining saturation flow to those that were earlier discussed. A brief description of the methods used in Australia will be given below.

4.6.1 Formulae Describing Operating Characteristics

The capacity of any approach to any intersection is the maximum sustainable rate at which vehicles can pass through the intersection from that approach under the prevailing conditions. The actual rate at which vehicles cross the stop line is the same as the capacity if the approach is fully saturated with traffic.

The capacity of an approach depends strongly upon the fraction of the time for which there is a green signal showing for that approach. If the saturation flow on an approach is \( s \) vehicles per hour of green, then the capacity of the approach is \( s_g/e \) vehicles per hour. Where there are different phases for the different movements from an approach, this formula should be applied separately to each movement.

If the arrival flow on one approach is \( q \), vehicles/hour, to provide adequate capacity there must be
The cycle length equals the sum of the effective green times plus the time lost between phases, that is

\[ L + \sum_{i=1}^{n} g_i = c \]  \hspace{1cm} (4.39)

From 4.41 and 4.42 it can be seen that, in order for the capacity on all approaches to be adequate, there must be

\[ \sum_{i=1}^{n} y_i \leq 1 - \frac{L}{c} \]  \hspace{1cm} (4.40)

where \( n \) is the number of phases. This formula holds for fixed cycle or vehicle actuated signals.

Formula 4.44 gives an upper limit of \( \sum y_i \). It is desirable in practice that traffic should rarely be heavy enough for this limit to be reached.

**4.6.2 Formulae for Signal Settings**

From 4.44 it follows that the minimum cycle length such that it is just possible to provide a capacity equal to the arriving flow on all approaches is

\[ L\left[1 - \sum_{i=1}^{n} y_i \right] \]
Using this cycle length there would be very long delays and very long queues.

Formulae for settings for fixed-time signals to minimise the overall average delay have been given by Webster and Miller. The two pairs of formulae give very similar results. In general the uncertainty in the values of the parameters (lost time, arrival and saturation flows) produces much larger errors than the differences between the formulae. Probably the best compromise between the two sets of formulae for accuracy and simplicity is the following formulae.

\[ \text{Cycle length} \quad c = \frac{L + 2\sqrt{L \cdot s}}{1 - \sum_{i=1}^{n} y_i} \]

where the saturation flow \( s \) which is used is the lowest of those for any of the representative moments.

4.6.3 Measurement of Saturation Flows

Method 1: Tape Recorder Method

Attempts were made to use the Road Research Laboratory method. In this method a stop watch is started when the signal changes to green and the observer records in the appropriate columns on a form the counts of vehicles crossing the stop line in regular time intervals (say 5-sec intervals) until the end of the green, noting also the duration of the green and the time at which saturation flow ceased. The end of saturation flow is defined as when the last vehicle which had been stopped or almost stopped in the queue had crossed the stop line. A separate person counts each lane and the observers were asked also to classify vehicles as cars or commercial vehicles and to record turning movements. The definition of a commercial vehicle was that used by Leon that is, any vehicle with more than two axles, or with dual tyres at the rear. Thus cars towing caravans were classified as commercial vehicles. Exceptions were made to the definition in the cases of horse and carts, tractors and bulldozers, all of which can be classified as commercial vehicles.
This method was not very satisfactory as the observers were asked to record too much information. However it was found that if the information was recorded into a tape recorder, then the observers could record all the necessary information in the time available. Also, interruptions to traffic movement (e.g. taxis making U-turns, buses cutting across lanes to turn right, vehicle breakdowns, etc.) could be recorded as they happened, instead of having to scribble some note in the comments column after the phase. At first (in Adelaide), whatever tape recorders could be obtained were used, soon it was found that, with conventional tape recorders, it can be difficult turning over and re-threading a tape on a street corner in a strong wind. For the other cities Philips EL 3301 battery-operated tape recorders were used which incorporate a cassette holding both spools to which the tapes are permanently attached. the tapes were played back later in the office and the data were transferred onto paper.

The principal advantage of the tape recorder method is that the time involved in analysis is fairly short, enabling a large number of sites to be studied. The data from a tape could be read off, analysed and checked by one person in a few hours.

The accuracy of this method depends upon the observer's reaction time in starting and stopping the stop watch, and the sample size. In one lane, the average headway between consecutive vehicles after about the fourth is usually of the order of 2 sec, with a standard deviation equal to about half the mean. If the items of crossing the stop line were exactly recorded then the standard error in estimating the mean headway would be approximately $\sqrt{\frac{1}{4N}}$ times the mean, where $N$ is the number of vehicles in the sample. The saturation flow has been estimated by dividing the total number of vehicles in the saturated flow by the total item of saturation flow less an estimate of the difference between the item lost in acceleration and the observer's reaction time in starting the stop watch. That is,

$$s = \frac{N}{T - n}$$

where $s$ is the saturation flow.
\( T \) is the total duration of saturation flow
\( n \) is the number of phases used, and
\( \alpha \) is the difference between the lost time and the observer's reaction time.

This accuracy is adequate for most purposes, but greater accuracy is needed to estimate lost times and the effects of trucks and turning vehicles.

Method 2: Pen Recorder' Method

This was basically the method used by Leong. A light-sensitive resistance was attached to the lens of the green signal and a tape switch was placed across each lane about 6 ft over the stop line. The signals received from these detectors were recorded on an Esterline-Angus 20-pen recorder. Using this method it was possible to read items of events from the chart to an accuracy of about 0.1 sec. Push-buttons were used to record trucks and turning vehicles on the charts, and to record interruptions.

The disadvantage of this method was that it required several days work to read the information from a chart. The method is only suitable for intersections with good lane discipline.

The tape recorder method has been used to give fairly large samples to measure the effect of environment, while the pen recorder method has been used at a small number of sites to test the basic model to investigate headway distributions and to measure the effects of trucks and turning vehicles.

4.7 Indian Practice

4.7.1 General Design Data for Intersection Signal System

1. Cycle length for two phase signal is mostly 40 to 60 seconds.
2. Timing of yellow colour varies from 3 to 5 seconds, higher values being adopted for higher speeds. This time is computed on the basis of time required to stop the vehicle at stop line and time required to clear the intersection from the vehicles already entered before change of colour.

3. Timing for green light may be nearly 20 secs.

4. Timing for red light is slightly less than green light timing.

5. Clearance of pedestrian time is calculated on the basis of pedestrian's walking speed of 1.2 m/sec [33].

I. Trial Method of Cycle Design

Let A and B be two roads intersecting at a point and it is required to design cycle length for this intersection.

1. For 15 minutes take traffic counts on road A and B, simultaneously at the same intersection.

2. Let \( N_1 \) and \( N_2 \) be the traffic counts of 15 minute for A and B roads respectively.

3. Assume suitable trial cycle length of say \( C \) secs.

4. Based on assumed value of \( C \) calculate the number of cycles in 15 minutes period as follow:

\[
\frac{15 \times 60}{C} = \frac{900}{C}
\]

5. Assume 2.5 seconds head-way time and calculate green light periods \( G_A \) and \( G_B \) for roads A and B as follows

\[
G_A = \frac{2.5 \times N_1 C}{900} \quad \text{and} \quad G_B = \frac{2.5 \times N_2 C}{900}
\]

6. Assume yellow periods of \( Y_A \) and \( Y_B \) for A and B Roads.

7. Calculate the cycle time \( C_i = G_A + G_B + Y_A + Y_B \)

8. If the calculated cycle length \( C_i \) works out approximately equal to the assumed cycle, \( C \), the cycle length is accepted as design cycle. Otherwise trials are repeated.
II. Design on basis of pedestrian crossing time

This procedure is adopted when two phase signal unit at a cross-road is to be designed, together with pedestrian signals.

1. Select yellow interval from 3 to 5 seconds depending upon the speed of approaching vehicles. For speeds up to 50 km/hr yellow period is 3 secs, 50-65 km/hr speed, 4 secs, and 65 - 80 km/hr range it is 5 secs.

2. Calculate pedestrian clearance time based on 1.2 m/sec speed. This item depends upon the speed of walking over the width of the carriage way.

3. Red light interval should be kept minimum equal to Pedestrian crossing time plus time required for pedestrians to start crossing. This red time is equal to minimum green + yellow time for the cross road.

4. Minimum green time is computed based on the pedestrian clearance time for cross-road plus initial interval for starting the pedestrians to cross minus yellow period. This equals red time for cross road minus yellow interval for the cross road. If pedestrian signals are installed, initial interval which is known as walk period should not be less than 7 seconds. If there is no pedestrian signal this interval may be taken as minimum 5 seconds.

5. Now based on heaviest approach volume per hour, actual green light time is calculated. Cycle length so computed should be adjusted for next higher 5 seconds. The extra or excess time is distributed to green light timings proportionately to the approaching traffic volume.

6. The values thus obtained are computed on the basis of percentage, as the controller settings are in percent of cycle.

7. Timing so calculated are set in the controller and operation is watched at site during peak traffic hour. If need arises corrections may be done in the timings at site.
4.8 Summary

From the above discussions it can be seen that the proper way of signal design includes, the details study of saturation flow, PCU values, lost time etc. and the factors which affect these parameters. For the calculation of sensible signal timing the concept and the measurement techniques of these parameters need to be understood very well. It is also revealed from the literature review, that by and large the signal design concept is almost the same in different countries. The fundamental delay minimising cycle equation (4.2) which was established by Webster (U.K) is adopted by all other country including India even where traffic operation is mixed and non-lane based.

4.9 Development of Lane-Based Signal Design Software

4.9.1 Introduction

According to the objectives of this study initially it was decided to develop a computer package, for the lane-based traffic system, based on all the established relationships and signal design guidelines mainly followed in the U.K. Later on this package will be expanded for the local traffic condition by customising the relevant parameters/relationships and modifying the guidelines adopted for the lane-based signal design. The development procedure of lane-based traffic signal design software is presented below.

4.9.2 Language Used for the Software

Turbo C was taken as the language to develop the computer package. It is one of the world’s most widely used C compiler. It is known for its speed of compilation and the efficiency of the code that it process. In fact, it has been used to produce some of the best known software products. It will most likely be a very long time before C is deemed
obsolete as a programming language. C is a flexible, high-level, structured programming language. It is largely machine independent. Programs written in C are easily ported from one computer to another. One of the main objectives of this research was to develop a software with a very user friendly graphics interface. The most important feature of Turbo C that prompted me to use it as my software language to fulfil my objective is its very powerful graphics feature. It has one of the most powerful graphics features of all the programming languages.

4.9.3 The Software Development

Parameters

In the developed software the optimum cycle time was calculated based on Equation (d) [Appendix C]. An empirical relationship was used [Equation 4.10] to calculate the saturation flow values. The PCU values that were used in the software were taken from Art 4.3.5. The initial and final lost times were calculated based on Equation 4.5. Equation (e) [Appendix C] was used to calculate the green time split for different approaches of an intersection.

Types of Intersections Considered

In the development of the software two types of intersections were considered for signal design. These two types are: a) Cross junction, b) T junction.

Types of Signal Planning Considered

Different signal planning that are frequently seen in the actual field condition were considered in the development of the software. Different modules were used for different signal plans. The signal plans that were incorporated in this software are:
a) Simple two phases in cross junction, b) Three phases with heavy right turn in cross junction, c) Late release in cross junction, d) Early cut-off in cross junction, e) Simple two phases in T junction, f) Three phases with heavy right turn in T junction.

4.9.4 Main Features of the Software

The main features of this computer package are given below:

• It is an easy-to-use package. It can be used in any IBM compatible personal computer.
• It has got a graphical interface which will be very useful for the users and pleasing in sight.
• The software employs a very easy input method that can be used by users even with minimum knowledge in computers and traffic engineering.
• It can deal with a few different intersection types and also with a few different movement pattern for a particular intersection.
• It can also calculate saturation flow getting input from the users very easily.
• This package gives the signal timing for different traffic movement for a particular intersection.
• It also gives different signal phases in the form of bar diagrams and timing also with graphics to easily facilitate user's understanding.
• With blinking arrows it indicates about the movement that are taking place for a particular place. With the arrows that are not blinking it indicates the movement that are suspended for a particular phase.
• Finally the software gives an output showing the different phase diagrams for a complete signal cycle and also the different green times for different phases.

4.10 Conclusions

The software developed here is based on the well established procedures practised in U.K which is applicable only for lane-based homogeneous traffic system. As such expansion of
this software is needed to accommodate the traffic features of Bangladesh. This will be
described in a subsequent chapter. Traffic signal design is totally dependent on some main
parameters namely saturation flow, lost time, road width, pedestrian flow etc. Extensive
field survey has to be undertaken in order to collect data for the measurement of the above
mentioned parameters. These data will be representative of the present traffic condition in
Bangladesh. A brief description of the procedure and methods of data collections are
outlined in the following chapter.
CHAPTER 5

DATA COLLECTION AND ANALYSIS

5.1 Introduction

In the road network in Dhaka city the links that exist do not permit the use of isolated traffic signals. Isolated traffic signals are used where the arrival pattern of the vehicles are random. But due to the very short length of the links the arrival pattern of vehicles that exist in Dhaka is in the form of platoons. As a result of the short link lengths platoon dispersion is not possible. That is why field observations suggest that either co-ordinated traffic signals for a particular artery or area control network for an area is needed. Even though as there are no such works regarding traffic signal design the aim of the research study is the development of a signal designing computer package for fixed time traffic signal design that can adequately represent the non-lane based mixed traffic behaviour, enabling the investigation of different aspects of the system. Though it is relatively easier, expansion of this can be done in the future. Because of the nature of developing cities, fixed time signals have been the only choice for some decades now from a practical and financial point of view. The implementation of newer and more efficient signalling systems such as vehicle actuated, demand responsive or area traffic control is rarely economically justifiable.

The dependence upon a fixed time signalling system demands a more critical calculation of timings and therefore a good understanding of the prevailing traffic,
especially information concerning saturation flow and the related passenger car unit values. It is, therefore, of utmost importance that all these parameters that will be used as input and for other purposes for the software development, are carefully assessed using information from actual traffic situations. In order to do that, sufficient data from mixed traffic situation should be measured and analysed.

Due to the unavailability of data from the mixed traffic operation, it was quite a challenge in this study to collect all the necessary and relevant data for package modification.

This chapter deals with the data collection and analysis processes of the study. Two specific sites were selected for data collection purpose (Bangla Motor intersection and Mogbazar intersection). Typical layouts of these two junctions are given in Fig 5.13 and Fig 5.14. Data from study sites were collected during June and July 1996. Then detailed analysis of the data was undertaken in order to estimate the typical values of the measured traffic parameters that were subsequently used as various inputs for the computer software.

The method of data collection and analysis is outlined in this chapter and the results are presented for the two basic sets of data: i) parameter estimation and software modification and ii) comparative study of signal timing and planning.

5.2 Objectives of Data Collection

The objectives of the field survey were:

1. To obtain a better understanding of the nature of traffic in non-lane based mixed traffic operation.
2. To obtain comprehensive data from selected intersections. These include the basic input data such as: geometric layout, red violation period, signal timing, flow, proportion of motorised and non-motorised vehicles, vehicle mix, proportion of turning vehicles, vehicle arrival pattern and discharge profiles.
3. To determine flow fluctuation and saturation flow for selected sites from all the approaches of the selected intersections.

5.3 Method of Data Collection

The above mentioned field observations were conducted in the following ways:

1. Qualitative observation of mixed traffic behaviour - for modification of different aspects of the package developed for lane based case.
2. Direct measurement - for estimation of geometric and traffic signal planning and timing data.
4. Video recording - for classified vehicle counts data during discharge process to calculate saturation flow and the directional split.

5.4 Site Selection

The main criteria for selecting the sites under study were:

1. To find the availability of vintage point for video recording.
2. To include wide varieties of vehicles types and traffic situations such as with/without non-motorised vehicles and saturated/under saturated flow conditions.
3. To get traffic stream with variations such as small proportion of right turn vehicles and low opposing flow, high proportion of right turners and high opposing flow.
4. To get approach with sufficiently long length, so that intersection can be considered as isolated and vehicle arrival at upstream can occur randomly.
5. To study both the ideal case (with no side friction and no interference) as well as the non-ideal case (with side friction and interference by parked vehicles, bus stops etc.).
6. To study approaches with large width as well as narrow width.
7. To consider the importance of the intersection in the overall traffic network.

It was, therefore, essential to select sites based on the above requirements. In order to do this, it was necessary to conduct a preliminary survey of all the available sites in the study area. The aim was to identify the sites which were most suitable for the final survey. Another purpose of the preliminary survey was to train the surveyors about the classified vehicle counts and also about the identification of different vehicle categories.

5.5 Preliminary Survey

The sites were inspected in terms of the above mentioned criteria and two isolated intersections were chosen for the final survey work. The characteristics of these sites are given in Table 5.1.

<table>
<thead>
<tr>
<th>Intersection Name</th>
<th>Approach*</th>
<th>Type of road**</th>
<th>Turning Movements***</th>
<th>Vehicle mix****</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bangla Motor Hotel Sonargaon(N)</td>
<td>Two way; DC</td>
<td>A,L</td>
<td>Without NMV</td>
<td></td>
</tr>
<tr>
<td>Bangla Motor Mogbazar(E)</td>
<td>Two Way; DC</td>
<td>A,L</td>
<td>With NMV</td>
<td></td>
</tr>
<tr>
<td>Bangla Motor Hotel Sheraton(S)</td>
<td>Two Way; DC</td>
<td>A,L,RO</td>
<td>Without NMV</td>
<td></td>
</tr>
<tr>
<td>Bangla Motor Eastern Plaza(W)</td>
<td>Two Way; DC</td>
<td>A,L,RO</td>
<td>With NMV</td>
<td></td>
</tr>
<tr>
<td>Mogbazar Tongi diversion(N)</td>
<td>Two Way;DC</td>
<td>A,L</td>
<td>With NMV</td>
<td></td>
</tr>
<tr>
<td>Mogbazar Mouchak(E)</td>
<td>Two way;DC</td>
<td>A,L,RO</td>
<td>With NMV</td>
<td></td>
</tr>
<tr>
<td>Mogbazar Kakrail(S)</td>
<td>Two way;DC</td>
<td>A,L,RO</td>
<td>With NMV</td>
<td></td>
</tr>
<tr>
<td>Mogbazar Bangla Motor(W)</td>
<td>Two way;DC</td>
<td>A,L,RO</td>
<td>With NMV</td>
<td></td>
</tr>
</tbody>
</table>

Note: * N = North; S = South; E = East; W = West; ** DC = dual carriageway; *** A = ahead; L = left; RO = right opposed; **** NMV = non motorised vehicles

Table 5.1 Geometric and traffic characteristics of sites surveyed.

The overall objectives of this survey were-

i) to get the best position for video recording related to the visibility of the approach to be surveyed, of the stop line and of the signals.
ii) to fix the best time for data collection.

iii) to get an idea about the number of surveyors which would be required for the simultaneous data collection such as upstream classified vehicle counts, video recording to cover discharge process, existing cycle time measurement and traffic information from other approaches of the intersection. Note that, depending on the flow levels and proportion of turning vehicles, number of surveyors were varied with the different sites according to the needs.

iv) to give adequate training to the surveyors so that they could understand their work properly and know the way how to do it. Training was also given so that they can identify different categories of vehicles. They were also told to count vehicles according to classification for five minutes to evaluate their performance.

v) to see the problems which may occur during the final survey work.

5.6 Problems Identified

Based on the preliminary survey, the following problems were identified-

1. during the preliminary video transcription of the discharge process a problem was noticed- when there was a large vehicle blocking the view, judgement could not be made accurately whether there was any vehicle discharging behind the blocking area. In order to deal with this problem, it was proposed that during video recording whenever this kind of situation would be encountered, if there was any blocked vehicle(s) then the surveyor would shout out the number(s) and the type(s) of vehicle(s) so that it could be recorded by the audio system of the video recorder.

2. during the preliminary survey it was observed that in order to record the discharge process during the green period effectively by video camera, the video camera has to be set along the line of the stop line for that particular approach. But as there are no secondary signals in any intersections in Bangladesh and also due to the faulty placement of signals (in many cases they are placed even before the stop line) the signal light could not be focused at the same time while recording the vehicle movements. As a result no information can be obtained about the change of phases and the instance when these changes are taking place without which the whole field
survey becomes meaningless. To alleviate this problem an observer with one green flag and one red flag was stationed at such a point from where he could easily see the signal under recording and at the same time the video camera could cover him during the discharge process recording. The observer would raise his green flag high at the instance of green commencing in the signal and the red flag at the start of red which will recorded by the video camera. Later during the data analysis process from the video camera the instance of green or red commencing could be easily ascertained.

5.7 Important Observations of the Sites Surveyed

In the Bangla Motor intersection the west approach (towards Eastern Plaza) the traffic volume is always very low. As a result flow never reaches the saturation rate and the east approach (towards Mogbazar) will always govern the design. So, classified vehicle counts of the west approach was not performed. Similarly at the Mogbazar intersection the North arm will always govern the design of signals for the North-South arm.

The only approach (south approach-towards Hotel Sheraton) where right turn is allowed and a separate right turning phase is provided faces a problem of another sort. The right turners that could not pass during the right turning phase or arrive later on form a queue that leads to the reduction of effective road width for the through traffic which becomes a major problem for the traffic police during the peak period (afternoon) for that particular approach.

In the Mogbazar intersection there is a filter for right turners for the south approach (towards Kakrail) which is of no use. The traffic in the North approach (Tongi diversion) and the South approach is shown green simultaneously and same green time is allowed for both the North and South approach. As a result practically the right turners in the South approach cross the intersection based on gap acceptance rather on the filter signal showing green. For this case this filter signal is totally ineffective.
During measuring flow fluctuation throughout the day, it was observed that at off peak period most of the drivers violate red specially when there were a few or no vehicles in the opposing arms. This may be due to the fact that at present the same cycle time (which is usually designed considering peak traffic flow) maintained throughout the day even at off peak and no flow period. This encourages the drivers to ignore traffic signal.

5.8 Vehicle Classification

The traffic stream in Bangladesh comprises various types of vehicles and no single vehicle dominates in the stream. As such for calculation of saturation flow, vehicle classification is needed to represent all types of vehicles available in the study area adequately. Each vehicle in the study area is considered to be under one of the following headings, so that the composition of the traffic could be accurately determined. Traffic has been classified into two major groups i.e. a) motorised and b) non-motorised. These two major groups have also been sub-divided into thirteen classes by the Roads and Highways Department. The classes are as follows:

a) Motorised:

b) Non-Motorised:
   7) Bicycle; 8) Tricycle(Rickshaw) and rickshaw van; 9) Push cart.

5.9 Data Collection and Analysis

Data were collected from the selected sites to obtain the input variables like classified vehicle counts, saturation flow and flow profiles against which the software would be calibrated for local traffic conditions. The characteristics of the sites surveyed can be seen in Table 5.1.
i) Basic data- Geometric layout, red violation and signal timing were measured directly in the field.

ii) Saturation flow- To capture the discharge process, video recording was conducted from a vintage point.

The video data were analysed to obtain vehicle mix proportion, turning proportion and classified six seconds vehicle counts data. The total number of vehicles passing the stopline per cycle formed the throughput data.

5.10 Observations of Mixed Traffic Behaviour

The vehicle composition in the western countries is mainly car dependent. But in Bangladesh there are thirteen different types of vehicles starting from heavy trucks to push carts and no single vehicle clearly dominates in the traffic stream. In order to get a detailed and comprehensive picture of such mixed traffic behaviour, it was decided to use a video camera which has the advantage of providing a permanent and comprehensive record of traffic movements, which can readily be used to obtain the repeated field picture as many times as required during analysis. An added advantage is that one may obtain many sets of information regarding mixed stream characteristics from the same recorded film.

Although video recording provides the most detailed and accurate information regarding the flow of vehicles at traffic signals, especially for the classified vehicles count for the total approach, the extraction of data in a workable format is a tedious and time consuming occupation.

Information was recorded by a National M-7 video camera on 180 minutes VHS tapes, and a time-base was superimposed on the films. A useful feature of the equipment was the zoom lens which enabled the best view of the intersections and their approaches.

In order to obtain a better understanding of the nature of the mixed traffic behaviour the video analysis was done qualitatively as well as quantitatively.
5.11 Qualitative Analysis

This was done by observing the recorded film critically. To summarise the findings, the following is a list of points describing the behaviour of traffic which would be considered in developing the non-lane based mixed traffic signal design software.

i) At upstream a clear segregation of motorised and non-motorised vehicles is observed. In general motorised vehicles occupy the right part of the road whereas non-motorised vehicles take the left part.

ii) Queue is built up based on the optimum road space utilisation criterion i.e. when a vehicle joins with the queue, main stimulus is the front gap irrespective of the lane in which it is available. As a result it has been observed that straight ahead vehicles, regardless of the type whether motorised or not, occupy any position across the road based on the available space. Consequently, the maximum interactions between motorised and non-motorised vehicles are observed during the subsequent discharge process. Note also that due to the arbitrary position of the vehicle across the road width, not all the spaces can be filled up during the queue formation. Another feature of the queue formation is that the smaller sized vehicles such as pedal cycles and motorcycles use inter-vehicular space to come in front of the queue.

iii) At most of the approaches traffic signals have been placed too far away from the edge of the cross road and thereby leaving a large road space between the signal or stop line and the edge of the cross road. In reality, this acts as a big stimulus for the drivers and indulge to cross the stop line during queue formation at red signal indication. Because of this, during the subsequent discharge operation the following problems arise -

- the leader of the stopped vehicles fail to see the signal and as such discharge operation start with confusion.
- usually drivers start to move on sometimes by intuition, hearing horn from its trailing vehicles and seeing slowing discharge process from the cross road.
- the delayed and confused starting operation from the current phase encourage drivers from the previous phase to violate red at change of signal that causes
unnecessary vehicular conflicts within the intersection and increase accident potential substantially. Sometimes the red jumpers from the previous phase become trapped by the oncoming vehicles from the current phase and reduces junction performance greatly.

- causes disorderly movement of vehicles through junctions and no clear pattern could be seen during the start off and stopping operation at the change of signal.

iv) From the observations it is learnt that when the proportion of right turners and as well as opposing flow is low, the right turning manoeuvres follow the gap acceptance criteria. But when the proportion of right turning vehicles is high and at the same time opposing flow is also high, right turning manoeuvres follow a very complex negotiation process with the opposite straight ahead vehicles instead of gap acceptance criteria which will be discussed in details in the next chapter.

v) Another interesting observation is the performance of the non-motorised vehicles at the end of green period. As the intersections in Dhaka are quite wide in nature and the non-motorised vehicles take more time than the motorised vehicles to clear the junctions the slow moving NMVs that violate the red signal become trapped at the end of green period. A special all red period should be provided for such vehicles to clear the intersections.

Based on these above findings, extension and modification of the lane based computer software are described in the next chapter.

5.12 Quantitative Analysis

This included measurement of saturation flow values, flow fluctuation, directional split and identification of vehicle classification for the couple of sites selected with varying approach widths and mix proportions.

Saturation flow

The saturation flow should be directly measured from the field and not from empirical relationships which is the case for developing countries. As it would be obtained from

The usefulness of the following expression is for evaluating the saturation flow rate (S):

\[ S = \frac{c}{v_a} \]

where:

- \( S \) is the saturation flow rate
- \( c \) is the capacity of the intersection
- \( v_a \) is the average service flow rate

This expression can be used to calculate the saturation flow rate based on the capacity and the average service flow rate of the intersection.
direct field measurement there is no needs for reduction of its value due to road side friction.

**Basis:** This includes the measurement of saturation flow values using the British TRRL Road Note 34 method.

**Site:** Saturation flow was measured in the Bangla Motor (North, South and East approach) and the Mogbazar (North, East and West approach) intersections.

**Counting method:** For this purpose, classified vehicle counts data for the total approach width were extracted from the video recording. The slow playback and variable speed facilities of the video were useful to get better accuracy in the extraction of data. In order to see the effect of non-motorised vehicles on the discharge process as well as for the preliminary observation of the saturation flow at different vehicle mix proportions, both with and without non-motorised vehicles sites were selected for data extraction.

**Duration and time of calculation saturation flow:** The time that was selected to perform classified vehicle counts for the measurement of saturation flow was the peak period for the respective arms when oversaturated flow conditions were observed. This peak period happens to be the morning peak for North (8:30am) and East (8:30am) approach for Bangla Motor intersection and the North (8:30) approach for Mogbazar intersection. In case of the South (2:30pm) approach of Bangla Motor intersection and East (2:30pm) and West (2:30pm) approach of Mogbazar intersection the peak flow arrives in the afternoon.

**No of cycles:** The video recording was performed for fifteen consecutive cycles at each arm of the selected junctions. But for the calculation of the saturation flow for each arm five fully saturated cycle was selected from video recording and data from these cycles were used.

Detailed data sheets for saturation flow calculation are given in Appendix A. Data in consolidated form are presented in the form of histogram from Fig 5.1 to 5.6.

Saturation flow for respective arms were calculated considering the PCU values reported by Hoque[9] which will be explained in the following chapter. The values adopted are given in Table 6.1-6.4. From Fig 5.1-Fig 5.6 it can be seen that at Bangla Motor intersection, the maximum saturation flow (5593 PCU/h) was obtained for the North approach and the minimum (3100 PCU/h) was obtained for the East approach.
This could be due to the presence of non-motorised vehicles at the East approach. The saturation flow for the North arm was obtained to be higher than that of the South arm because of the presence of right turners at the South arm. At Mogbazar, the North arm had the maximum saturation flow (3566 PCU/h) and the West arm had the minimum (3066 PCU/h). As right turning is prohibited at the North arm, that is why it had the highest saturation flow value. Measured saturation flow of the six arms and the proportion of right turns of the two selected intersections are given in Table 5.2.

<table>
<thead>
<tr>
<th>Intersection Name</th>
<th>Approach</th>
<th>Percent of Right Turn</th>
<th>Percent of NMV</th>
<th>Saturation flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bangla Motor</td>
<td>Hotel Sonargaon(N)</td>
<td>-</td>
<td>-</td>
<td>5593 PCU/h</td>
</tr>
<tr>
<td>Bangla Motor</td>
<td>Mogbazar(E)</td>
<td>-</td>
<td>46%</td>
<td>3100 PCU/h</td>
</tr>
<tr>
<td>Bangla Motor</td>
<td>Hotel Sheraton(S)</td>
<td>4%</td>
<td>-</td>
<td>4506 PCU/h</td>
</tr>
<tr>
<td>Mogbazar</td>
<td>Tongi diversion(N)</td>
<td>-</td>
<td>43%</td>
<td>3566 PCU/h</td>
</tr>
<tr>
<td>Mogbazar</td>
<td>Mouchak(E)</td>
<td>41%</td>
<td>37%</td>
<td>3535 PCU/h</td>
</tr>
<tr>
<td>Mogbazar</td>
<td>Bangla Motor(W)</td>
<td>30%</td>
<td>29%</td>
<td>3066 PCU/h</td>
</tr>
</tbody>
</table>

Table 5.2 Observed saturation flow values, directional split and proportion of NMV

Lost time

The lost time calculation for any arm of a particular intersection of Dhaka city is a very complex process. From the qualitative observations of the selected intersections it was seen that the vehicle discharge process during the commencement of green and after the commencement of red is very complicated and totally site dependant. At some points the queuing vehicles start long after the commencement of green due to the presence of the red violating opposing vehicles in their path. Another complex feature at the end of the green period is the red violation phenomena.

Flow fluctuation at selected sites

As signal design should be responsive to traffic demand, arrival flow profile of all approaches of an intersection has to be known for proper design of traffic signal. Fixed
time traffic signals are more sensitive to the traffic flow than the vehicle actuated signals. As all the traffic signals in Bangladesh are of fixed time type it is of particular importance that flow variation for the whole day is available for a particular approach for accurate and demand based signal design. To get the flow profile of the selected sites extensive field survey was carried out. The details of this field survey is outlined below.

**Time:** The field survey was performed in the six arms (Table 5.1) of the selected sites concurrently from 6:00am to 12:00am.

**Duration:** This field survey that included 5 minutes manual classified vehicle counts in every 30 minutes period, was carried out for consecutive five days a week for two weeks throughout the specified time period.

**No of surveyors:** A total number of eleven surveyors were engaged to conduct the field survey. For recording classified vehicle counts there were three surveyors for arms with heavy traffic flow and two for light flow. An extra surveyor was employed to supervise the whole survey work.

The PCU values used for converting the counted vehicles to their equivalent passenger cars were obtained from Hoque[9]. The vehicle count for flow profile were performed in the upstream portion of each arm whereas the directional split of each arm was obtained by video recording concurrently. This directional split is given in Table 5.2. Detailed data sheets for flow fluctuation calculation are given in Appendix A. Data in consolidated form are presented in the form of flow profile from Fig 5.7 to 5.12. From these figures it was observed that for both the Bangla Motor and the Mogbazar intersections the morning peak was at the North approach and the afternoon peak was at the South approach which is the reflection of commuter movements. The cross arms are showing more or less same picture where almost average flow can be obtained throughout the day.

5.13 Summary

In this section data were observed both qualitatively and quantitatively for the measurement of saturation flow, flow fluctuation etc. In the following chapter
Modifications of the developed software based on gathered information will be outlined in details.
Fig 5.1 Saturation flow histogram of East approach at Burj Khalifa intersection

Saturation flow = 3100 pcu/h
Green time = 36 sec
Cycle time = 162 sec
Approach width = 38 ft
Saturation flow = 4506 pc/h
Green time = 114 sec
Cycle time = 162 sec
Approach width = 34 ft

Fig. 5.2 Saturation flow histogram of South approach at Bingle Manor intersection
Saturation flow = 5995 pphpd
Green time = 90 sec
Cycle time = 162 sec
Approach width = 35 ft

Time - seconds

Fig 5.3: Saturation flow histogram of North approach at Bangla Motor intersection
Saturation flow = 3535 pvp/h
Green time = 66 sec
Cycle time = 171 sec
Approach width = 33 ft

Fig. 5.4: Saturation flow histogram of East approach at Nghiaor Intersection
Fig 5.5 Situation flow histogram of West approach at Mobile intersection.
Saturation flow = 3566 pcv/h
Green time = 54 sec
Cycle time = 171 sec
Approach width = 36 ft

Fig 5.6 Saturation flow histogram of North approach at Mughar intersection
Fig 5.7 Flow profile of West approach at Mogbazar intersection

Fig 5.8 Flow profile of East approach at Mogbazar intersection
Fig 5.9 Flow profile of North approach at Mogbazar intersection
Fig 5.10 Flow profile of North approach at Bangla Motor intersection

Fig 5.11 Flow profile of South approach at Bangla Motor intersection
Fig 5.12 Flow profile of East approach at Bangla Motor intersection
Fig 5.13 Typical layout of Bangla Motor intersection
Fig 5.14 Typical layout of Mogbazar intersection
CHAPTER 6

THE SOFTWARE DEVELOPMENT FOR
NON-LANE BASED SYSTEM

6.1 Introduction

In the previous chapter the program and the methodology that was described for signal design, phasing and planning is for a very well designed environment i.e. a car dominated lane based system. In this environment the queue formation and the discharge follow a very clear and well defined pattern. Not only that, the right turning manoeuvres that takes place in those environment is based on gap acceptance theory which is also a well defined phenomenon. That is why the signal design and the phasing plans adopted in those environment i.e. the western countries are very well established and well structured. On the contrary, in Bangladesh the traffic flow is non-lane and mixed traffic based. No such clear picture can be obtained about the queue formation and discharge. Red violation is very common that effects the starting operation of the cross phase. The right turning manoeuvres also show some distinct features that are very much different from that observed in the advanced countries. Almost all the right turning manoeuvres are forced. Right turns based on gap acceptance are basically non-existent. To accommodate these diversified situations the program that was developed and mentioned earlier, needs modification. Different aspects of this modifications will be dealt with in the following sections.
6.2 Basic Input Parameters

6.2.1 Saturation Flow

The various procedures to calculate saturation flow for the advanced countries had already been described in details in Chapter 4. Normally to measure saturation flow from the field, Road Note 34 method is used. In this method, as described earlier, the green time for any arm is subdivided into a number of 6 second time slices. Then classified vehicle counts are performed in each of these 6 seconds period. The method is described elaborately in Chapter 4. But there are some striking dissimilarities between the calculation of saturation flow from the field in advanced countries and the calculation of saturation flow form the field that is used in this research for mixed traffic operation.

First of all in the western countries saturation flow is counted on lane by lane basis. But as there is no lane concept that exists in Bangladesh the vehicle counts for saturation flow calculation has to be performed for the whole width of the approach. Besides in the countries like U.S and U.K there are many well established empirical relationships for the calculation of saturation flow. The characteristics of all their major road are almost alike and they can be easily bracketed in one whole groups. Most of the road junctions have unique features and are ideal in nature. As a result they can apply these empirical equations quite successfully for their road traffic system. But in Bangladesh no clear pattern can be sighted for different intersections. Each of the intersection varies from the other in some way. Some intersections do not have non-motorised vehicles whereas most of them have non-motorised vehicles. There are some approaches which are free from side friction. On the other hand there are also many approaches that are plagued with side friction of different sorts. They can not be termed ideal. It is easily evident from these facts that the saturation flow parameter like all the other signal design parameters is site specific. For this reason different empirical relationships already developed in the western countries can not be used for the saturation flow calculation of the road network in
Bangladesh. Even development of empirical relationships in the context of Bangladesh will not be beneficial due to the very unpredictable nature of the road traffic system. So what should be done is that- take each arm of an intersection separately, study it quantitatively and qualitatively and calculate the saturation flow directly using the Road Note 34 method based on the observations made. As a result, the effect of side friction and composition of vehicles will be included in the saturation flow. This saturation flow will be a reflection of actual traffic situation. When performing the classified vehicle counts for each 6 seconds time slice (according to Road Note 34) the manual counting method, the method usually applied in the western countries will be error prone as the vehicle counts have to be performed for the whole width of the approach and the major approaches in Bangladesh are quite wide. Another reason not to use the manual counting method is the total number of vehicle categories that ply on the streets in Bangladesh. The vehicle categories of Bangladesh are much more varied than that can be seen in the western countries. As a result, it is suggested in this research would be to use video camera technique for performing classified vehicle counts to calculate saturation flow. The advantages that are available by using video technique is illustrated in details in the data collection chapter. After the video recording is completed the classified vehicle counts have to be performed by playing back the cassette in a video cassette recorder. A video cassette recorder with slow motion facilities will surely help the counting process a great deal.

Road Note 34 recommends vehicle counts for fifteen fully saturated green period. A lesser number of saturated green periods will also do. But the more the number of fully saturated green period, the better will be the reflection of field condition in the saturation flow. In this software a separate module is used to help the user calculate saturation flow. Firstly the user has to input the green time that is used in the signal for a green period. Then he has to enter the number of fully saturated cycle that were used for video recording. Next thing the user has to input is the Passenger Car Equivalent for different classified vehicle (PCU will be discussed later). Then the user will give the number of different classified vehicles obtained from video playback for each 6 seconds time slice as well as the last interval for the arm under consideration for different fully saturated cycles. The module
will then show the total PCU values for each 6 seconds interval as well as the last interval for all the saturated cycles that were used for data collection. Then it will also show the saturation flow value in PCU/hour for that particular arm. In this way the saturation flow of all the arms of a given intersection can be calculated using this very user friendly program segment.

6.2.2 Passenger Car Equivalent

In the western countries different methods are used to calculate PCU values which were discussed earlier in Chapter 4. PCU value calculation may be done by Headway Method, Regression Method, etc. Physically, PCU value is based on the impact that a vehicle produces on the whole stream. The impact means the impact of its speed, its occupancy on the stream etc. The concept is that the performance of car is not biased; if it is allowed to move freely then based on the performance of the car, the performances of other vehicles are obtained. The traffic composition in the western countries is totally car dominated and consists of all motorised vehicles. So they calculate the PCU values for different vehicles taking the base value of car as unity. In this PCU concept each vehicle has a unique value. But a contrasting picture exists in Bangladesh. The traffic composition here is unlike all the western countries. The most striking feature of the traffic composition is the presence of non-motorised vehicles in a considerable proportion. There are different vehicle categories in Bangladesh. The Roads and Highways Department identified thirteen different class of vehicles. They are 1) Heavy truck, 2) Medium Truck, 3) Small truck, 4) Bus, 5) Mini Bus, 6) Micro Bus, 7) Utility, 8) Car, 9) Auto Rickshaw, 10) Motor cycles, 11) Bicycle, 12) Cycle Rickshaw, 13) Cart. This is the vehicle classification that is used in all parts of this research. In the context of Bangladesh it was seen from the research work of Hoque[9], if there is non-motorised vehicles in the traffic stream then the performance of the car in the stream which is the base unit in PCU value calculation, varies a lot. This variation mainly depends on the proportion of the non-motorised vehicles in the traffic stream. The presence of non-motorised vehicles has a direct bearing on the discharge performance of the base unit i.e. car. The more the proportion of non-motorised vehicles
the lesser will be the performance of the car. So the performance of a car with non-
motorised vehicles in the stream and the performance of a car without non-motorised
vehicles in the stream is not same. As a result the PCU values of other vehicles have to be
obtained with respect to the car which is in a traffic stream with non-motorised vehicles.
Still there is no such device to do this in the field, but it has been done by simulation in the
research of Hoque. S[9]. Some of the tables showing different PCU values for different
categories depending upon the proportion of non-motorised vehicles are given below
which were taken from the research work of Hoque.S.

<table>
<thead>
<tr>
<th>Proportion of NMV</th>
<th>6 seconds intervals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3.5m</td>
</tr>
<tr>
<td>Motor-Cycle</td>
<td>0.02</td>
</tr>
<tr>
<td>Auto-Rickshaw</td>
<td>0.70</td>
</tr>
<tr>
<td>Tempo</td>
<td>0.76</td>
</tr>
<tr>
<td>Mini-Bus/Truck</td>
<td>1.43</td>
</tr>
<tr>
<td>Truck</td>
<td>1.99</td>
</tr>
<tr>
<td>Bus</td>
<td>1.96</td>
</tr>
</tbody>
</table>

Table 6.1 PCU estimates without non-motorised vehicles in the traffic stream

<table>
<thead>
<tr>
<th>Proportion of NMV</th>
<th>6 seconds intervals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7.0m</td>
</tr>
<tr>
<td>Cycle</td>
<td>0.18</td>
</tr>
<tr>
<td>Rickshaw</td>
<td>1.23</td>
</tr>
<tr>
<td>Push-cart</td>
<td>2.77</td>
</tr>
<tr>
<td>Motor-Cycle</td>
<td>0.01</td>
</tr>
<tr>
<td>Auto-Rickshaw</td>
<td>0.20</td>
</tr>
<tr>
<td>Tempo</td>
<td>0.27</td>
</tr>
<tr>
<td>Mini-Bus/Truck</td>
<td>1.02</td>
</tr>
<tr>
<td>Truck</td>
<td>1.69</td>
</tr>
<tr>
<td>Bus</td>
<td>1.45</td>
</tr>
</tbody>
</table>

Table 6.2 PCU estimates with 10% non-motorised vehicles in the traffic stream
Table 6.3 PCU estimates with 20% non-motorised vehicles in the traffic stream

<table>
<thead>
<tr>
<th>Proportion of NMV</th>
<th>6 seconds intervals</th>
</tr>
</thead>
<tbody>
<tr>
<td>20%</td>
<td>7.0m</td>
</tr>
<tr>
<td>Cycle</td>
<td>0.31</td>
</tr>
<tr>
<td>Rickshaw</td>
<td>0.76</td>
</tr>
<tr>
<td>Push-cart</td>
<td>1.48</td>
</tr>
<tr>
<td>Motor-Cycle</td>
<td>-0.64</td>
</tr>
<tr>
<td>Auto-Rickshaw</td>
<td>0.24</td>
</tr>
<tr>
<td>Tempo</td>
<td>0.32</td>
</tr>
<tr>
<td>Mini-Bus/Truck</td>
<td>1.01</td>
</tr>
<tr>
<td>Truck</td>
<td>1.25</td>
</tr>
<tr>
<td>Bus</td>
<td>1.14</td>
</tr>
</tbody>
</table>

Table 6.4 PCU estimates with 30% non-motorised vehicles in the traffic stream

<table>
<thead>
<tr>
<th>Proportion of NMV</th>
<th>6 seconds intervals</th>
</tr>
</thead>
<tbody>
<tr>
<td>30%</td>
<td>7.0m</td>
</tr>
<tr>
<td>Cycle</td>
<td>0.19</td>
</tr>
<tr>
<td>Rickshaw</td>
<td>0.60</td>
</tr>
<tr>
<td>Push-cart</td>
<td>1.28</td>
</tr>
<tr>
<td>Motor-Cycle</td>
<td>-0.22</td>
</tr>
<tr>
<td>Auto-Rickshaw</td>
<td>0.17</td>
</tr>
<tr>
<td>Tempo</td>
<td>0.23</td>
</tr>
<tr>
<td>Mini-Bus/Truck</td>
<td>0.84</td>
</tr>
<tr>
<td>Truck</td>
<td>1.69</td>
</tr>
<tr>
<td>Bus</td>
<td>1.41</td>
</tr>
</tbody>
</table>

6.2.3 Lost Time

In the road traffic system of the western countries, the traffic flow takes some time to reach the saturation level after the onset of green. Equally during the amber period the rate of the flow falls away, in anticipation of the red signal.
The time lost due to start up effects at the beginning of the green phase is defined as 'initial lost time' and the time lost by vehicles not making full use of amber period is termed as 'End lost time'. Then the total lost time is the combination of the two lost time. This lost time controls how much green time is effectively lost to traffic due to driver reaction time, acceleration/declaration effects at the start and end of each green phase. This initial and final lost times are negative in nature for the advanced countries where traffic rules and regulations and law enforcement are very strict. Vehicles in the traffic stream in those countries have to stop at the onset of amber and cannot start before the commencement of the green.

In contrast, picture in Bangladesh is totally the opposite to that seen in the western countries. Due to the lack of interest on the part of the law enforcing agencies the enforcement is not strict. As a result, vehicles behave whimsically at the start and end of each green period. Their discharge pattern at the start and end of each green period for different arms of different intersections vary a lot. The main reason for this is the faulty placement of signals in different junctions and the non-existence of secondary or filter signals. The problems that arise from this faulty placement of signals had already been described in details in the Data Collection Chapter (Chapter 5). Due to the faulty placement of signals the leader in waiting queue does not know the exact instance of the green commencing. Taking advantage of the confusion of the leaders of a queue awaiting green, the vehicles in the cross phase continue to cross the intersection violating the red signal. So the lost time for this cross phase then becomes positive instead of begin negative. For the same reasons mentioned above, the vehicles in the waiting queue take more time to start than usual in most of the arms. During the saturation flow calculation it was seen that no vehicles crossed from the waiting queue even during the first 12 seconds of the green period. In this case the initial lost time will be more than usual and negative in nature.

So it is very clear from the above discussion that the nature of lost times for different arms of even the same intersection varies from approach to approach. As the other parameters
it is also very much site specific. In this research the lost time of the different arms of the
sites surveyed was calculated individually. Before the calculation of the lost times the
discharge pattern at the start and end of each green period was analysed qualitatively first
to get a better understanding about their nature. So it is suggested that lost times of
different arms be calculated and their nature determined based on qualitative analysis. The
calculated lost times of the seven arms of the two sites surveyed during data collection are
outlined below.

<table>
<thead>
<tr>
<th>Approach</th>
<th>Green time gain at the end of green period (due to red violation)</th>
<th>Initial loss due to delayed start</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>East</td>
<td>+5.77sec</td>
<td>-5.83sec</td>
<td>-0.06sec</td>
</tr>
<tr>
<td>North</td>
<td>+1.87sec</td>
<td>-5.93sec</td>
<td>-4.06sec</td>
</tr>
<tr>
<td>South</td>
<td>+1.79sec</td>
<td>-11.99sec</td>
<td>-10.2sec</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td>-14.32sec</td>
</tr>
</tbody>
</table>

Table 6.5 Lost time calculation for Bangla Motor intersection

<table>
<thead>
<tr>
<th>Approach</th>
<th>Green time gain at the end of green period (due to red violation)</th>
<th>Initial loss due to delayed start</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>East</td>
<td>-1.89sec</td>
<td>-5.94sec</td>
<td>-4.05sec</td>
</tr>
<tr>
<td>West</td>
<td>+1.78sec</td>
<td>-5.94sec</td>
<td>-4.16sec</td>
</tr>
<tr>
<td>South</td>
<td>+5.63sec</td>
<td>-5.98sec</td>
<td>-0.35sec</td>
</tr>
<tr>
<td>North</td>
<td>+1.82sec</td>
<td>-5.86sec</td>
<td>-4.04sec</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td>-12.6sec</td>
</tr>
</tbody>
</table>

Table 6.6 Lost time calculation for Mogbazar intersection

6.2.4 All Red Phase

Generally most of the urban intersections in Bangladesh are very wide. It was found from
the field observation that an intersection like Mogbazar has a width of 140 ft at one side
and 120 ft at the other. This calls for a special treatment in the signal phasing which is
presently absent at the moment. This special signal planning is known as all red period.
This all red period is provided to facilitate the vehicles to clear the intersection which have
already entered the junction during the ambler phase preceding the red or the vehicles that
have violated the red and become trapped across the path of the vehicles of the cross phase. In the western countries they usually provide 2 sec time for this clearance. This clearance period known as 'all red' where all the signals in all the arms of the intersection are shown red simultaneously depends on the width of the intersection for the western countries as their vehicle composition is all motorised. In order to consider this all red period for the road traffic system in Dhaka there is one more important consideration that has to be taken into account. As most of the intersections in the urban area have non-motorised vehicles the all red period has to be designed depending on the width of the intersection as well as the clearance period needed by the non-motorised vehicles to clear the conflict points. From the research of Hoque, S[9] it was seen that these non-motorised vehicles travel at their maximum speed to clear the conflict points to avoid collision with the vehicle of the cross phase. This clearance period of the non-motorised vehicles to clear the conflict points was calculated to be 4-5 seconds depending on to sites from the videos analysis. Considering all these facts it is suggested that 5 sec all red period is provided for the intersections where there are non-motorised vehicles. It is also suggested that 2 sec all red period as used in western countries should be used for the intersections with all motorised vehicles.

6.2.5 Forced Right Turning

Normally two phase signals are provided with no special consideration for the right turning vehicles if the proportion of right turns and the number of opposing vehicles are small. But if the right turn is considerable the opposing flow has to be taken into consideration. In the western countries if the proportion of the right turners is small no exclusive right turning phase is provided assuming the right turners will cross the intersection accepting the gap in the opposing flow. But in Bangladesh the right turners remain in an advanced position and initially at the instance of commencement of green a plug of waiting right turners cross the intersection. Then the random crossing starts. When considering the random crossing the opposing flow has to be taken into consideration also.
The presence of non-motorised vehicles in the opposing flow will make the whole right turning manoeuvre more complex and completed. The initial discharge of the plug of right turners is not bad, it sometimes enhance the capacity of the intersection. But the problem arises where there are more right turners after this plug. They start following the initial plug and at one stage they become an obstruction for the opposing flow. These vehicles could have crossed the intersection accepting gaps if the opposing flow solely consists of motorised vehicles. But if there are non-motorised vehicles in the opposing flow and in the right turns then the right turners can not cross the cross road accepting gaps due to the slow movement process of the NMV. Then the right turning manoeuvres become 'forced'. Due to this forced right turning behaviour a number of special signal phasing plan can be suggested. They are either separate phase for right turns or late release or early out off. These forced right turning manoeuvres can be mainly seen in the case of high opposing flow and the right turns consisting of non-motorised vehicles and needs to be addressed separately.

6.3 Expansion of MIXSIG

The software developed in Chapter 4 was for lane based system. All the main modules for the calculation of saturation flow, lost time, PCU values etc. have been changed in the light of the above discussion to cover non-lane based system. Then several trial runs were made with arbitrary data to see if the modified program was running properly or not. Then it was verified by comparing manually calculated signal timings for a particular set of data with that of timing output from MIXSIG. At this stage a few programming refinements were needed to make MIXSIG error free. Typical screen dump from MIXSIG can be seen in Fig 6.1 - Fig 6.4. Although it was intended to verify the MIXSIG output with the field data, considering delay as the measure of effectiveness, but it was not possible due to time limitation and as well as difficulties in getting permission from the relevant authorities.
6.4 Summary

From the above discussions it can be seen that the road traffic system in Bangladesh varies from that of the western countries in different aspects. These aspects were elaborately outlined in this chapter. As a result the modification needed to be made to the relationships developed by the western countries for signal design and phasing to accommodate local traffic system were outlined. In order to show the application of MIXSIG two separate case studies using this package are given in the following chapter.
Figure 6.1 Typical MIXSIG Input Interface For Cross Intersection

- Green (E-N) = 18 sec
- Green (E-W) = 18 sec
- Lost time in sec (e1) = 2
- Flow in w/h = 200
- Saturation flow in w/h = 2000
- Road width (E-W) in m = 12
- Walking speed (m/s) = 1.2
- Flow in w/h = 200
- Saturation flow in w/h = 2000
- Intergreen in sec (p1) = 9
- Intergreen in sec (p2) = 9

Figure 6.2 Typical MIXSIG Output Phase Diagram For Cross Intersection

- North
- Green (E-W) = 18 sec
- Green (N-S) = 18 sec
- Lost time in sec (e2) = 2
- Flow in w/h = 200
- Saturation flow in w/h = 2000
- Intergreen in sec (p1) = 9
- Intergreen in sec (p2) = 9

PHASE DIAGRAM

- Green (N-S) = 18 sec
- Green (E-W) = 18 sec
**Figure 6.3** Typical MIXSIG Input Interface For T-Intersection

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**Figure 6.4** Typical MIXSIG Output Phase Diagram For T-Intersection
CHAPTER 7

APPLICATION OF THE SOFTWARE

7.1 Introduction

To experiment with the software developed in the previous chapter two comparative studies have been carried out to show its application and usefulness. In order to see the performance of the MIXSIG software this experiment will be based on comparative study i.e. signal timings from MIXSIG will be compared with the signal timings that are presently in practice in the two selected sites (Bangla Motor and Mogbazar). In this purpose sufficient data have been collected from the two sites to calculate signal timings.

7.2 Parameters Used for Calculation

Flow Fluctuation

For proper signal design and planning flow fluctuations at a junction is an important input to the MIXSIG. It shows the traffic demands which vary throughout the day and it also gives vehicle arrival patterns. Detail data sheets for the flow profiles of different arms of the two selected sites are given in Appendix A and the resulting plots to show the flow variations are presented in the data collection chapter (Fig 5.1- Fig 5.4). From those plots
two distinct time periods were obtained. One of these periods show high traffic demand which is termed as peak period and the other periods show low traffic demand which is termed as off-peak period. Pre-peak periods at these two junctions are not considered as these periods existed only for short duration. For design purpose, simplified forms of those plots have been prepared considering the mean values which will be used as design flow values for peak and off-peak periods. Based on these mean values, the same plots have been redrawn and presented in this chapter in simplified forms (Fig 7.3 - Fig 7.8).

Saturation Flow

Detail data sheets to calculate the saturation flows of different arms of the two sites are given in Appendix A. The calculated saturation flow (see Table 5.2) of the different arms are:

Saturation flow for North arm at Bangla Motor intersection, $S_{N,BM} = 5593$ PCU/h
Saturation flow for South arm at Bangla Motor intersection, $S_{S,BM} = 4506$ PCU/h
Saturation flow for East arm at Bangla Motor intersection, $S_{E,BM} = 3100$ PCU/h
Saturation flow for North arm at Mogbazar intersection, $S_{N,MB} = 3566$ PCU/h
Saturation flow for East arm at Mogbazar intersection, $S_{E,MB} = 3535$ PCU/h
Saturation flow for West arm at Mogbazar intersection, $S_{W,MB} = 3066$ PCU/h

PCU Values

The PCU values were taken from the research findings of Hoque [2] based on the road widths and the proportion of non-motorised vehicles for any particular approach. These PCU value tables are presented in Chapter 6 (Table 6.1 - Table 6.4).

Lost Times

Lost time for North arm at Bangla Motor intersection, $l_{N,BM} = -10.2$ sec
Lost time for South arm at Bangla Motor intersection, $l_{SBM} = -4.06$ sec
Lost time for East arm at Bangla Motor intersection, $l_{EBM} = -0.06$ sec
Lost time for North arm at Mogbazar intersection, $l_{NBMB} = -4.04$ sec
Lost time for South arm at Mogbazar intersection, $l_{SBMB} = -0.35$ sec
Lost time for East arm at Mogbazar intersection, $l_{EBMB} = -4.05$ sec
Lost time for West arm at Mogbazar intersection, $l_{WBMB} = -4.16$ sec

Total lost time for Bangla Motor intersection, $L_{BM} = -14.32$ sec
Total lost time for Mogbazar intersection, $L_{MB} = -12.6$ sec

Road Width

Road width for North arm at Bangla Motor intersection, $W_{NBMB} = 35$ m
Road width for South arm at Bangla Motor intersection, $W_{SBMB} = 34$ m
Road width for East arm at Bangla Motor intersection, $W_{EBMB} = 38$ m
Road width for North arm at Mogbazar intersection, $W_{NBMB} = 36$ m
Road width for East arm at Mogbazar intersection, $W_{EBMB} = 33$ m
Road width for West arm at Mogbazar intersection, $W_{WBMB} = 35$ m

Intergreen Period

As the Bangla Motor intersection mainly consists of motorised vehicles a 3 seconds amber period, 2 seconds red-amber period and 3 seconds all red period are considered for signal timing calculation.

So,
the intergreen period for all the phase of Bangla Motor intersection, $I_{BM} = 3+2+3 = 8$ sec

But the Mogbazar intersection comprises a high proportion of non-motorised vehicles. For this reason a 4 seconds amber period, 3 seconds red-amber period and 5 seconds all red period are considered for signal timing calculation.

So, the intergreen period for all the phase of Mogbazar intersection, $I_{MB} = 4+3+5 = 12$ sec
7.3 Signal Plans

Based on qualitative and quantitative studies, the field engineer who will use the MIXSIG software has to decide himself about the signal plans to use in a particular intersection. Then the user can select the signal plan from the software menu and proceed accordingly.

Plan for Bangla Motor Intersection

As it was observed from the field observation, that the proportion of right turns is low for the South approach; a two phase two stage signal plan is suggested for this intersection which is similar to the plan already in practice. In phase 1, stage 1 the through traffic and the right turners from the South approach will be shown green with the late release of the through traffic from North approach. In phase 1, stage 2 the through traffic from both the North and South approach will be shown green. In phase 2, green signal will be shown to the East and West approach.

This late release plan is suggested for two reasons: 1) Initially the group of right turners waiting to cross the intersection can clear during the late release stage without any conflicts with the opposing flow and the right turners that arrive later on can clear the intersection by accepting suitable gaps or at the end of the phase, exploiting amber and as well as all red period. 2) In this plan as, a group of right turning vehicles discharge quickly at the beginning of green period and hence through traffic from the same approach can use the whole width of the road for discharging, which leads to the increased junction capacity.

Plan for Bangla Motor Intersection

In this intersection high proportion of right turns is observed at East approach. So, a three phase signal plan is suggested for the Mogbazar intersection which is also already in practice. In phase 1, the through traffic from the North and South arms will be shown
green. In phase 2, the right turners and the through traffic from the West arm will be shown green and in phase 3, green will be shown to the through traffic and the right turners from the East arm.

7.4 Right Turns Manoeuvring Times

During the saturation flow vehicle counts, average number of right turns (in PCU) per cycle was calculated for all the approaches where right turn is allowed for the two selected sites, which are given below.

Number of right turns per cycle for the South arm at Bangla Motor intersection, 
\[ N_{NSBM} = 8 \text{ PCU} \]

Number of right turns per cycle for the West arm at Mogbazar intersection, 
\[ N_{NWMB} = 7 \text{ PCU} \]

Number of right turns per cycle for the East arm at Mogbazar intersection, 
\[ N_{NEMB} = 28 \text{ PCU} \]

Besides it is also calculated that for the Bangla Motor intersection in every 5 sec 2 PCU complete their turning manoeuvre i.e. each PCU takes 2.5 sec to complete turning manoeuvre. And for the Mogbazar intersection in every 6 sec 3 PCU complete their manoeuvre i.e. each PCU takes 2.0 sec to complete turning manoeuvre.

7.5 Signal Timings Calculation (Based on MIXSIG)

Based on above parameters and planning, the signal timings calculated by using MIXSIG software have been given below. These signal timings along with the existing one are shown with the help of bar diagrams. Detailed background calculations of MIXSIG are given in Appendix C.
7.5.1 Bangla Motor Intersection

For the North-South arms at this intersection, North is the dominant arm. As such, signal timing for the North-South arms is calculated based on the North arm. Due to this, the South arm will get added advantage but overall capacity will increase as the right turners from South are cleared by late release.

Signal Design Calculation

a) Peak Period

Controller setting of green time for North arm = 63 sec
Controller setting of green time for South arm = 51 sec
Controller setting of green time for East arm = 36 sec
Green time for late release stage = 23 sec
Cycle time = 149 sec

b) Off-peak Period

Controller setting of green time for North arm = 22 sec
Controller setting of green time for South arm = 25 sec
Controller setting of green time for East arm = 8 sec
Green time for late release stage = 7 sec
Cycle time = 67 sec

7.5.2 Mogbazar Intersection

For the North-South arm in this intersection north is the dominant arm. So, signal timing for the North-South arm will be calculated based on the North arm.
Signal Design Calculation

a) Peak Period

Controller setting of green time for North arm = 44 sec
Controller setting of green time for West arm = 35 sec
Green time for the right turners from the West arm = 17 sec
Controller setting of green time for East arm = 42 sec
Green time for the right turners from the East arm = 59 sec
Cycle time = 174 sec

b) Off-peak Period

Controller setting of green time for North arm = 23 sec
Controller setting of green time for West arm = 14 sec
Controller setting of green time for East arm = 23 sec
Cycle time = 96 sec

The above calculated and as well as the existing cycle times and phasing for Bangla Motor and Mogbazar intersections are schematically shown in the following figures (Fig 7.1- Fig 7.2).
Fig 7.1 Phase diagrams for Bangla Motor intersection
Phase diagram for peak period using MIXSIG

Phase diagram for off-peak period using MIXSIG

Existing phase diagram for whole day

Fig 7.2 Phase diagrams for Mogbazar intersection
7.6 Comparative Study

From the comparison it can be seen that the peak period timings calculated from the MIXSIG software and the existing signal timings are more or less same for the Mogbazar intersection. But there are significant variations in these two timings in the case of Bangla Motor intersection. The most interesting finding from the timing comparison is that the large variation between the calculated and existing timings for the off-peak periods. It implies that unnecessary lengthy cycles are used in these two intersections during the off-peak period when there are significantly low traffic demands. In consequence this produces long time stopping and unwanted delays to vehicles which could be avoided by using demand responsive signal plans. Although the signal controllers in Dhaka have the capability to accommodate variable plans, but due to negligence or ignorance till now fixed plan signal timing is on practice throughout the day. Because of this faulty practice, besides significant amount of time loss for each cycle during the off-peak periods, a tendency to disregard the signals develops in the behaviour of the drivers and as such they indulge themselves to violate the traffic rules. It is, therefore, inferred that the capabilities of the signal controllers to accommodate variable plans need to be exploited for improvement of the junctions' performance, which can be easily done without any cost.
Fig 7.3 Design flow value for peak and off peak period of East approach at Mogbazar intersection
Fig 7.4 Design value for peak and off peak period of North and South approach at Mogbazar intersection
Fig 7.5 Design flow value for peak and off peak period of West approach at Mogbazar intersection
Fig 7.6 Design flow value for peak and off peak period of North approach at Bangla Motor intersection
Fig 7.7 Design flow value for peak and off peak period of South approach at Bangla Motor intersection
Fig 7.8 Design flow value for peak and off peak period of East approach at Bangla Motor intersection
CHAPTER 8

SUMMARY AND CONCLUSIONS

8.1 Summary

Traffic signal is a very important element for traffic control and management. It is more important in the context of the road traffic system in Bangladesh as there is less or almost no scope of expansion of the existing infrastructure within the urban area. The management schemes that had been taken are also at their minimum level. So for the optimisation of the road traffic network researches have to be carried out. Besides, traffic in Bangladesh consists of two distinct categories of vehicles i.e. motorised vehicles and non-motorised vehicles. The characteristics of these vehicles differ widely even within the same class, though they all use the same sight of way (total approach). An almost total lack of lane discipline makes the traffic system mixed and heterogeneous in nature. Since the behaviour of mixed traffic is intricate, empirical approach can not be seen as the appropriate solution. The present signal design practice is also a faulty one. That is why attempts were made to conduct a comprehensive study on this issue.

With this view, initially signal related information were gathered from different organisations and authorities which have given a complete idea about the gaps in the present signal design practice, the extent of involvement of different authorities, types of controllers used and at the same time measures to be taken based on research carried out in the context of developing countries. Then a comprehensive field observations was carried out to supplement the information collected from different authorities.
Before developing a systematic signal design method for the road traffic situation in Bangladesh a comprehensive literature review was conducted. Based on this review work relevant signal design parameters and relationships were identified for customising in local traffic environment. In this respect two signalised intersections were selected for data collections. Both video technique and manual method were used for detail data collection. Finally a user friendly computer package (MIXSIG) was developed customising different signal design parameters for the local condition. Later on two case studies were carried out by using MIXSIG software.

It was intended to verify the MIXSIG output with the field data considering delay as the measure of effectiveness, but it was not possible due to time limitation and as well as difficulties in getting permission from the relevant authorities. In order to help the field engineers, in this research a systematic signal design guideline is also suggested which is given in the Appendix B. The main findings of this research along with the suggestions, recommendations and study limitations are given below.

8.2 Findings from Field Observations

The field observations led to the following major findings:

1. No scientific or systematic signal design methodology is adopted in any phase of traffic signal design in Bangladesh. Signals are still intuitively designed based on judgement by lay men or by electrical engineers getting feedback from the Metropolitan Police authority about the signal timing.

2. The signal controllers that are used in various traffic signals are of fixed time type and are designed to accommodate variable signal plan according to traffic demand. But all these controllers are being underused only by using for fixed time fixed plan condition. As, same signal timings are shown throughout the day a restlessness on the part of the drivers are observed who try to take advantage of the situation by violating red if there is less or no flow in the cross arms. This situation could have
been easily modified to variable plan to make it more responsive to the traffic
demand.

3. Most of the intersections do not have any stop line. The placement of the stop
lines, zebra crossings is also wrong.

4. In all the intersections the stopping and discharge pattern follow a very haphazard
way which leads to disorder and chaos. This is mainly due to faulty placement of
signals, absence of secondary signals and to same extent ignorance of the drivers.

5. From field observations it was seen that within the urban area the road links in the
road network are very small. Due to the short length of the links vehicles arrive at
a downstream intersection in groups after the discharge from an upstream junction.
There is no scope for platoon dispersion. As a result the design of the downstream
signal is influenced by the upstream one which clearly implies for co-ordination of
such signals to minimise the delay and maximise the capacity. But in practice all
the signals in Dhaka city are designed considering isolated (without co-ordination)
junctions. Field observations revealed that for road links between Shahbag to
Bangla Motor and Mohakhali Rail Crossing to Banani Chairman Bari co-ordinated
signal will be the most useful measure. On the other hand in the heart of the city
i.e. in the CBD area like Motijheel where the road network is of zigzag pattern,
area control should be the best traffic controlling scheme.

8.3 Main Features of the Computer Package

- the computer package MIXSIG is a user friendly tool which was developed
keeping in mind the inhibitions on the part of field engineers to follow scientific
signal design approach.

- It is a very user friendly package to enable the field engineers to use it even
without knowing the in depth concepts about the parameters and the different
variables used in it.

- it can accommodate different signal plans according to the needs of the users based
on actual field condition.
- it will take the road width, amber period, intergreen period, flow value as input variables in a very simple way from the user in a beautiful graphical interface environment.
- it will give the saturation flow as output knowing the PCU values and the classified vehicle counts for any approach of an intersection.
- another output of the package is the signal timing for different approach of an intersection with the help of phase diagram in the form of bars.
- it will also display different associated vehicular movements that takes place in different approach alongwith the signal indications.
- finally the user can get a printed output of the signal timings and the phase diagram shown with the help of arrows.

8.4 Findings from the Application of MIXSIG

Two junctions were selected (Bangla Motor, Mogbazar) to compare existing signal timings with the calculated timings from MIXSIG. For these two junctions, geometric as well as traffic data were collected to measure the relevant signal design parameters. Later on these parameters were given as input to the MIXSIG software to calculate the signal timings. The main observations based on this comparative study is given below.

- It is seen from the field observation that for the two selected sites the signal plan is same throughout the day. This plan is for peak period which is also used for off peak and minimum flow period. This practice is very illogical. From the field study and flow profile curves it can be easily predicted that three distinguishable signal planning can be given for these two sites. One is for the peak period, one is for off peak period and the other is for 0.00 AM to 6:00 A.M.
- The time period from 0.00 AM to 6:00 AM which was not considered for field observation is the period where almost no flow occurs. Flashing ambers can be shown in all the arms during this period where vehicle can cross with caution.
• It can be seen from the comparison of timing suggested by the software and the timing presently used for off-peak period that there is a considerable amount of time lost for each cycle during the off peak hours. These lost times cause unnecessary delay to the road users. This delay and the impatience of the drivers due to long cycle time during off peak flow, can be removed by using variable signal planning. With time this will lead to an improvement of the respect of the drivers to the traffic signals and help to minimise delay.

• For the Mogbazar intersection an all red of 5 sec should be shown between phase change. This is due to the presence of non motorised vehicles in high proportion in the traffic stream. This all red should be provided to give an opportunity to the NMVs which become trapped at the end of their respective own green phase to clear the conflict points.

8.5 Limitations of the Research

Although the research objectives were to study comprehensively the existing signal design practices in Bangladesh and development of a systematic signal design procedure for mixed traffic operation and maximum efforts have been given accordingly, even then this research suffers from the following limitations.

• This software has been developed along the lines of fundamental signal cycle time design equation developed by the western countries. Refinements are needed for the minimum cycle time design relationship developed for local environment to check its applicability for local traffic network.

• Performance of MIXSIG could not be verified.

• Effectiveness of signal timing obtained from MIXSIG needs to be verified with the help of delay measurement before and after the implementation of the suggested planning and timing for a particular intersection.

• The software deals only with the traffic signal design of an isolated intersection whereas most of the junctions within Dhaka City are not isolated. Rather they are linked in nature. Though it is expected that expansion of isolated signal design
concept for co-ordinated signals can be carried out by studying vehicle arrival pattern from the upstream junction and providing appropriate offset.

- Special pedestrian phase during signal design were not considered.

8.6 Suggestions

Based on the field observations and information gathered from different organisations the following suggestions have been proposed which have to be implemented along with the systematic signal timing design and planning.

- Signal sequence should be consistent. That is same signal sequence should be used in all the signals.

- As traffic split is provided with the help of signals at signalised intersections, in the case of priority junctions the same is done with the help of road signs and markings. Proper giveaway and stopline should be present at priority junctions to provide efficient traffic split which is absent at present.

- Secondary signals must be provided at all the junctions to supplement primary signals.

- The placement of primary and secondary signals should be such that the vehicle drivers, who cross the stop line during queue formation, can easily get an unobstructed view of the signals.

- Despite all the traffic engineering measures there is a significant importance of the involvement of the traffic police for effective implementation of these measures. During the observance of traffic week it was observed that the performance of the same junction varies a lot with and without effective police control. Qualitatively more discipline in the starting and stopping operations can be observed when there were sufficient number of traffic police at the junction. This implies that in the context of Bangladesh whatever engineering measures may be taken, its success will always depend on the performance and the involvement of traffic police. So effective and sufficient number of traffic police should be deployed in all the important junctions.

- For signal design the guidelines which have been given in Appendix B should be followed by the field engineers.
8.7 **Recommendations for Further Research**

This study has suggested several possible research lines that need to be studied, so that an improved understanding of mixed traffic and an enhanced performance of MIXSIG can be obtained.

1. Minimum delay cycle time equation should be established based on the environment of Bangladesh.
2. PCU values should be determined considering the road traffic situation of Bangladesh.
3. Warrant for traffic signals should also be determined for the existing traffic situation.
4. Relationships showing the variations of flow with cycle time should be developed for this country for better signal design and planning.
5. Research should be carried out about the effect of flared lanes for right turns on traffic signal design.
6. Cycle time vs. delay relationships should be established for optimum signal setting for local condition.
7. The variations of delay with major/minor flow should be established in the context of Bangladesh.
8. In the sites observed there were no signal controlled pedestrian crossing facilities. Presently opportunity based pedestrian crossing facilities like zebra crossings are provided. The random crossing effect of the pedestrians in the Mogbazar intersection was incorporated during the calculation of saturation flows. But if controlled crossing facilities with the help of barriers could be provided for the pedestrians then signals could have been designed including the pedestrian phase.
9. Detail analysis of the behaviour of right turning vehicles i.e. forced gap acceptance, normal gap acceptance may be carried out in further research.
REFERENCES


APPENDIX A

SAMPLE DATA SHEETS

Due to space limitation two typical sample data sheets are furnished here. One of these data sheets show the data obtained from traffic counts for the calculation of saturation flow of the East approach at Bangla Motor intersection. The other data sheets show the average of the consecutive five day traffic counts for the calculation of flow variations for the North arm at Bangla Motor intersection.
### Traffic Count for Saturation Flow Calculation of East Approach at Bangla Motor Intersection

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| **Umbly**                        | 0   | 0   | 0   | 0   | 0   | 0         |        |         |
| **Heavy Truck**                  | 0   | 0   | 0   | 0   | 0   | 0         |        |         |
| **Moderate Truck**               | 0   | 0   | 0   | 0   | 0   | 0         |        |         |
| **Small truck**                  | 0   | 0   | 0   | 0   | 0   | 0         |        |         |
| **Car**                          | 0   | 0   | 0   | 0   | 0   | 0         |        |         |
| **Auto Rickshaw**                | 0   | 0   | 0   | 0   | 0   | 0         |        |         |
| **Motor Cycle**                  | 0   | 0   | 0   | 0   | 0   | 0         |        |         |
| **Bicycle**                      | 0   | 0   | 0   | 0   | 0   | 0         |        |         |
| **Cyclone Rickshaws**            | 0   | 0   | 0   | 0   | 0   | 0         |        |         |
| **Total**                        | 0   | 0   | 0   | 0   | 0   | 0         |        |         |

<p>| <strong>Bus</strong>                          | 0   | 0   | 0   | 0   | 0   | 0         | 29.70  | 5       |
| <strong>Mini Bus</strong>                     | 0   | 0   | 0   | 0   | 0   | 0         | 5.95   |         |
| <strong>Micro Bus</strong>                    | 0   | 0   | 0   | 0   | 0   | 0         |        |         |
| <strong>Umbly</strong>                        | 0   | 0   | 0   | 0   | 0   | 0         |        |         |
| <strong>Heavy Truck</strong>                  | 0   | 0   | 0   | 0   | 0   | 0         |        |         |
| <strong>Moderate Truck</strong>               | 0   | 0   | 0   | 0   | 0   | 0         |        |         |
| <strong>Small truck</strong>                  | 0   | 0   | 0   | 0   | 0   | 0         |        |         |
| <strong>Car</strong>                          | 0   | 0   | 0   | 0   | 0   | 0         |        |         |
| <strong>Auto Rickshaw</strong>                | 0   | 0   | 0   | 0   | 0   | 0         |        |         |
| <strong>Motor Cycle</strong>                  | 0   | 0   | 0   | 0   | 0   | 0         |        |         |
| <strong>Bicycle</strong>                      | 0   | 0   | 0   | 0   | 0   | 0         |        |         |
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Note: The table represents the number of vehicles per 6 seconds interval, totaling the PCUs and providing a sample average.
Data sheet for flow fluctuation for the North arm at Bangla Motor intersection

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In order to design traffic signals for the road traffic condition in Bangladesh the practising field engineers need to calculate or measure different parameters in the field. As described earlier, due to the non-lane based mixed traffic situation no empirical relationship can be applied to measure different signal design parameters. All these parameters are site specific. Both quantitative and qualitative analysis are required in order to get a basic idea about them and to measure them. So the methods or procedures to calculate these parameters for local system is quite different to those already established in the western countries. The procedures on the methodologies to measure these parameters are given hereunder briefly to help the field engineers to identify the requirements and solutions of traffic signal design.

Vehicle Classification

There are various types of vehicles in the traffic stream in Bangladesh with wide varieties of static and dynamic performance. To convert these different types of vehicles into a common unit, they need to be classified based on their road occupancy and discharge
performance. Roads and Highways department has published one such classification which is used throughout this research and illustrated in the data collection chapter.

**Saturation Flow**

The saturation flow is the most important parameter for traffic signal design. The saturation flow has to be measured along the line of Road Note 34 with minor modifications for local road traffic situation. First of all, classified vehicle counts have to be performed with the help of video camera. The advantages of using video camera were described earlier in the data collection chapter. The video camera should be positioned at a vintage point and the line of sight of the camera should be along the line of the stop line (imaginary stop line in absence of stop line in the field). Before the video recording a pilot survey should be conducted in order to find suitable location for the placement of video camera to cover the approach under consideration adequately. This pilot survey would also help to fix the suitable survey period by identifying the time of oversaturated flow condition for a particular approach. The vehicle counts have to performed for the whole width of the approach. Video recording of at least fifteen fully saturated cycles has to be done. After the video recording is over a digital time clock has to be superimposed on the video cassette with the help of video hiring agency to facilitate vehicle counts. From the video recording classified vehicle counts for each 6 seconds of green time have to be performed from the slow motion video playback. Also the directional split and the number of left turning vehicles discharging during the red period have to be measured. Then the classified vehicles counted has to be converted to its PCU by multiplying by appropriate PCU values. Then the saturation flow can be calculated as described in chapter 4 and Chapter 6. By using this software the saturation flow can also be calculated very easily. The user has to give input the appropriate PCU values and the number of classified vehicles for each time slice for different saturated green period and the program will give the saturation flow for that particular approach as output.
PCU Values

PCU values are also very important parameter for traffic signals design in Bangladesh unlike western countries, where traffic stream consists of only 3-4 types of vehicles with clear domination of car. The vehicle composition here consists of thirteen different types including non-motorised vehicles. As such for the local condition saturation flow is very sensitive to the PCU values than that of western countries. Research results revealed that the PCU values are not unique for all the intersections in this country. It is a site specific parameter and mainly depends on the presence of non-motorised vehicles and their proportion in the traffic stream. The field engineer may choose his appropriate PCU values from the tables given in Chapter 6 if the proportion of non-motorised vehicles in the approach under consideration is known.

Lost Time

Another site specific parameter for signal design is the lost time. According to the theories developed in lane based traffic operation, time losses occur at the intersections both at the start and the end of the green period due to initial starting delay and the final cautious restricted movement. But in Bangladesh it is seen that initially time can be gained by the starting of discharge operation before the signal is green. Again in general at most of the intersections, instead of loss, time is also gained at the end of green as vehicles of the just concluded green phase continue to violate red by taking advantage of the delayed start of the cross stream vehicles. As a result it is important for the field engineer to know first whether time is lost or gained at the start and end of green period for each approaches of an intersection. Then the lost time (both initial and final) has to be calculated from the saturation flow histogram as described in chapter 6. The total lost time for an approach can be obtained by combining these initial and final lost times. Then lost times of all the approaches would have to be combined to get the lost time for the intersection.
Flow Fluctuation

It is also an important input for making fixed time signal more responsive with the arrival traffic demand at an intersection. To know the variation of flow throughout the day both quantitative and qualitative data collection is needed. Qualitative data collection includes field observation regarding the behaviour of right turning vehicles (forced or gap accepted), amount of right turns (light or heavy) etc. Quantitative data collection requires classified vehicle counts for at least two weeks (excluding Fridays). The vehicle counts have to be performed at upstream from 6:00 A.M to 12:00 A.M (18 hours) for six constructive working days in each week. Because of completely different flow pattern observed in weekends, Friday vehicle counts need to be considered separately. To know the average flow variations classified vehicle counts have to be done manually for 5 minutes at thirty minutes intervals throughout the time period mentioned above. For this manual vehicle counts, depending on the arrival traffic volume two to four persons have to be engaged at each arm of the intersection. Then the mean flow variation throughout the day could be obtained by taking average of 12 days vehicle counts. Video recording has to be done for each arm of an intersection to know the directional split and number of left turning vehicles that discharge during red period. Actual demand at the intersection have to be calculated by deducting the volume of left turning vehicles at red period from the total arrival flow. These flow variations throughout the day would have to be plotted to see the flow profiles. Using these flow profiles the field engineer will identify peak, off peak, minimum flow conditions in order to suggest sensible signal timing and planning. It is recommended that in order to get better performance of a signalised intersection, vehicle counts for flow variations should be performed once in every six months to update the existing signal design and planning.

Signal Plans

Based on field observation and arrival flow diagram, the traffic engineer has to decide about the appropriate number of plans to accommodate flow fluctuations at an
intersection. During working days, in general three different levels of flows could be identified for which signal timings need to be calculated separately. These are peak, off peak and minimum flow conditions. For the six hour period (12:00 AM to 6:00 AM) where almost no flow occurs, amber flashing should be suggested for all the approach of an intersection to allow vehicle crossings without stopping at the junctions.

If the proportion of right turners is moderate then the late release phase can be suggested to clear the right turners. During the late release stage the initial plug of right turners waiting for turning can easily clear the junction without causing conflicts with the flow from opposite stream. The right turners that arrive later on can then cross accepting appropriate gaps or causing minimum conflicts. For this reason the late release is more useful than early cut-off option.

If the proportion of right turners is high then exclusive right turning phase should be provided for the turning vehicles to clear the intersection.

Signal Design Using MIXSIG

Knowing different signal design parameters and plans, the field engineer can use the MIXSIG software for designing traffic signals. To give inputs into the software there is a user friendly interface, which is discussed earlier. Based on the inputs the software will calculate signal timings for different approaches. For better understanding it will display the different vehicular movements according to signal timings and planning. The software will also give a phase diagram with signal timings as output.

Analytical Procedures for Traffic Signal Design

Instead of using MIXSIG for manual calculation of traffic signals design the field engineer can use the following fundamental relationships and the methods developed in the western countries with appropriate modifications.
PHASE SEQUENCE: RED, RED/AMBER, GREEN, AMBER

\[ a, \text{ AMBER PERIOD: 3 Seconds} \]
\[ \text{RED/AMBER PERIOD: 2 Seconds} \]
\[ c : \text{Cycle time} \]
\[ g, \text{EFFECTIVE GREEN TIME : The sum of the green period and the amber period less the lost time for the particular phase.} \]
\[ l, \text{INTERGREEN TIME : Time from the end of the green period of the phase losing right-of-way to the beginning of the green period of the phase gaining right-of-way.} \]
\[ l, \text{LOST TIME FOR A SINGLE PHASE: The time in a cycle which is effectively lost to traffic movement in the phase because of starting delays and the falling off of the discharge rate which occurs during the amber period.} \]
\[ L, \text{TOTAL LOST TIME PER CYCLE : The sum of the lost times for each phase and those periods when all signals show red or red with amber.} \]

\[ L = \sum (l - a) + \sum l \]

\[ q, \text{FLOW : Average number of vehicles passing a given point on the road in the same direction per unit of time.} \]
\[ s, \text{SATURATION FLOW : Average rate of flow past the stop line over that portion of the green period during which there is a queue, but ignoring the first few seconds of green whilst the rate of discharge is increasing.} \]
\[ y : \text{Maximum ratio of flow to saturation flow for a given phase.} \]

\[ y = \frac{q}{s} \]

\[ Y: \text{Summation for the whole intersection of the y values corresponding to each phase.} \]

\[ Y = \sum y \]
\( c_0 \), **OPTIMUM CYCLE TIME**: The cycle time which gives the least average delay to all vehicles using the intersection.

\[
\begin{align*}
c_0 &= \frac{15L + 5}{1 - Y} \text{ seconds (L in sec)}
\end{align*}
\]

\( c_m \), **MINIMUM CYCLE TIME**: The cycle time which is theoretically just long enough to pass the traffic through the intersection.

\[
\begin{align*}
c_m &= \frac{L}{1 - Y}
\end{align*}
\]

**Green split**

\[
\begin{align*}
g_1 &= \frac{y_1}{y_2} \\
g_2 &= \frac{y_2}{y_2}
\end{align*}
\]

where \( g_1 \) and \( g_2 \) are the effective green times of phases 1 and 2 respectively.

If \( c_o - l \) is the total effective green time then

\[
\begin{align*}
g_1 &= \frac{y_1}{Y} (c_o - L) \\
g_2 &= \frac{y_2}{Y} (c_o - L)
\end{align*}
\]

\( G \) : Combined green and amber periods \( G = k + a = g + l \)

\( k \) : Controller setting of green time.

**Summary**

It can be easily inferred from all the discussions that a field engineer can get a better idea about how to design traffic signals using this research. In a country where traffic signals are still designed intuitively and where there is an inhibition on the part of the field engineers not to follow any established signal design practice this research will definitely help them to get interested in systematic and scientific traffic signal design. They can also use the software with minimum knowledge of traffic engineering. They can work in very simple and user-friendly environment and fulfil their needs.
APPENDIX C

Table: List of persons contacted for questionnaire survey

<table>
<thead>
<tr>
<th>Name of the Organisation</th>
<th>Name of the person contacted</th>
<th>Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roads and Highways</td>
<td>Mr. Mohammad Ali</td>
<td>Assistant Engineer</td>
</tr>
<tr>
<td>Department</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dhaka City Corporation</td>
<td>Mr. Kamruzzaman</td>
<td>Chief Engineer</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bangladesh Road Transport</td>
<td>Mr. Abdur Rab</td>
<td>Deputy Director (Traffic)</td>
</tr>
<tr>
<td>Authority</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Micro Electronics</td>
<td>Mr. Mofi Ud Doula</td>
<td>Chairman</td>
</tr>
<tr>
<td>Dhaka Metropolitan Police</td>
<td>Mr. Rahim</td>
<td>Senior Assistant Commissioner</td>
</tr>
</tbody>
</table>

Signal Design Related Terminology

The following few important terminology have been defined based on Fig 1.

PHASE: A phase is the sequence of conditions applied to one or more streams of traffic which, during the cycle, receive simultaneous identical signal indications.

PHASE SEQUENCE: RED, RED/AMBER, GREEN, AMBER

a, AMBER PERIOD: 3 Seconds
RED/AMBER PERIOD: 2 Seconds

c : Cycle time

\[ g, \text{ EFFECTIVE GREEN TIME } : \text{The sum of the green period and the amber period less the lost time for the particular phase. (Fig 4.1)} \]

\[ l, \text{ INTERGREEN TIME } : \text{Time from the end of the green period of the phase losing right-of-way to the beginning of the green period of the phase gaining right-of-way.} \]

\[ G : \text{Combined green and amber periods} \quad G = k + a = g + l \]

\[ r, \text{ EFFECTIVE RED TIME } : \text{Time during which the signal is red or red with amber on a particular phase, plus the lost time for that phase.} \quad r = c - g \]

\[ L, \text{ TOTAL LOST TIME PER CYCLE } : \text{The sum of the lost times for each phase and those periods when all signals show red or red with amber.} \]

\[ L = \sum (l - a) + \sum l \quad \text{..................................(a)} \]

\[ q, \text{ FLOW } : \text{Average number of vehicles passing a given point on the road in the same direction per unit of time.} \]
SATURATION FLOW: Average rate of flow past the stop line over that portion of the green period during which there is a queue, but ignoring the first few seconds of green whilst the rate of discharge is increasing.

WIDTH OF APPROACH AT THE STOP LINE: Measured from the curb to inside of pedestrian refuge or centre line, whichever is the nearer, or to inside of the central reserve in the case of a dual carriageway.

$y$: Maximum ratio of flow to saturation flow for a given phase.

$$y = \frac{q}{s} \hspace{1cm} \text{(b)}$$

$Y$: Summation for the whole intersection of the $y$ values corresponding to each phase.

$$Y = \sum y \hspace{1cm} \text{(c)}$$

$\lambda$: Proportion of the cycle which is effectively green for a particular phase. \[ \lambda = \frac{y}{c} \]

OPTIMUM CYCLE TIME: The cycle time which gives the least average delay to all vehicles using the intersection.

$$c_0 = \frac{15L + 5}{1 - y} \text{ seconds (L in sec)} \hspace{1cm} \text{(d)}$$

MINIMUM CYCLE TIME: The cycle time which is theoretically just long enough to pass the traffic through the intersection.

$$c_m = \frac{L}{1 - y}$$

GREEN SPLIT

$$\frac{g_1}{g_2} = \frac{y_1}{y_2} \hspace{1cm} \text{(e)}$$

where $g_1$ and $g_2$ are the effective green times of phases 1 and 2 respectively.

If $e_o - l$ is the total effective green time then

$$g_1 = \frac{y_1}{Y}(e_o - l)$$

$$g_2 = \frac{y_2}{Y}(e_o - l)$$

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Signal Design Calculation for Bangla Motor Intersection

a) Peak Period

\[ Y_{N,BM} = \frac{q_{N,BM}}{S_{N,BM}} = \frac{3461}{5593} = 0.62 \]
\[ Y_{S,BM} = \frac{q_{S,BM}}{S_{S,BM}} = \frac{2534}{4506} = 0.56 \]
\[ Y_{E,BM} = \frac{q_{E,BM}}{S_{E,BM}} = \frac{1325}{3100} = 0.43 \]

So, \( Y_{BM} = 0.62 \)

Optimum Cycle Time, \( C_{o,BM} = \frac{(1.5 \times L_{BM} + 5)}{(1 - Y_{BM})} = \frac{(1.5 \times 14.32 + 5)}{(1 - 0.62)} \]
\[ = \frac{69.69}{sec} = 70 \ sec \]

Effective green time for North arm, \( g_{N,BM} = \frac{Y_{N,BM}}{Y_{BM}} \times (C_{o,BM} - L_{BM}) \]
\[ = \frac{0.62}{0.62} \times (70 - 14.32) \]
\[ = 55.68 \ sec = 56 \ sec \]

Combined green and amber time for North arm = \( g_{N,BM} + I_{N,BM} = 56 + 10.02 = 66.02 \ sec \)

Controller setting of green time for North arm = 66 - amber period = 66 - 3 = 63 sec

Effective green time for South arm, \( g_{S,BM} = \frac{Y_{S,BM}}{Y_{BM}} \times (C_{o,BM} - L_{BM}) \]
\[ = \frac{0.56}{0.62} \times (70 - 14.32) \]
\[ = 50.29 \ sec = 50 \ sec \]

Combined green and amber time for South arm = \( g_{S,BM} + I_{S,BM} = 50 + 4.06 = 54.06 \ sec \)

Controller setting of green time for South arm = 54 - amber period = 54 - 3 = 51 sec

As \( g_{N,BM} > g_{S,BM} \), North arm will govern the design to calculate green time for North-South approach.

Effective green time for East arm, \( g_{E,BM} = \frac{Y_{E,BM}}{Y_{BM}} \times (C_{o,BM} - L_{BM}) \)
Combined green and amber time for East arm = \( g_{E,BM} + l_{E,BM} = 39 + 0.06 = 39.06 \text{ sec} \)

Controller setting of green time for East arm = 39 - amber period = 39 - 3 = 36 sec

Green time for late release stage = Extra clearance period + Time taken for each PCU to complete turning manoeuvre \( \times \) No. of right turners per cycle (PCU)

\[ = 3 + 2.5 \times 8 = 23 \text{ sec} \]

So, Cycle time = 23 + 63 + 39 + 3 \( \times \) \( I_{BM} \) = 125 + 24 = 149 sec

b) Off-peak Period

\( y_{N,BM} = \frac{q_{N,BM}}{s_{N,BM}} = \frac{1030}{5593} = 0.184 \)

\( y_{S,BM} = \frac{q_{S,BM}}{s_{S,BM}} = \frac{1333}{4506} = 0.30 \)

\( y_{E,BM} = \frac{q_{E,BM}}{s_{E,BM}} = \frac{425}{3100} = 0.14 \)

So, \( y_{BM} = 0.30 \)

Optimum Cycle Time, \( C_{o,BM} = \frac{1.5L_{BM} + 5}{1-Y_{BM}} = (1.5 \times 14.32 + 5)/(1-0.30) \)

\[ = \frac{37.83}{0.7} = 38 \text{ sec} \]

Effective green time for North arm, \( g_{N,BM} \)

\[ = y_{N,BM}/Y_{BM} \times (C_{o,BM} - L_{BM}) \]

\[ = 0.184/0.30 \times (38 - 14.32) \]

\[ = 14.52 \text{ sec} = 15 \text{ sec} \]

Combined green and amber time for North arm = \( g_{N,BM} + l_{N,BM} = 15 + 10.02 = 25.02 \text{ sec} \)

Controller setting of green time for North arm = 25 - amber period = 25 - 3 = 22 sec

Effective green time for South arm, \( g_{S,BM} \)

\[ = y_{S,BM}/Y_{BM} \times (C_{o,BM} - L_{BM}) \]

\[ = 0.30/0.30 \times (38 - 14.32) \]

\[ = 23.68 \text{ sec} = 24 \text{ sec} \]

Combined green and amber time for South arm = \( g_{S,BM} + l_{S,BM} = 24 + 4.06 = 28.06 \text{ sec} \)

Controller setting of green time for South arm = 28 - amber period = 28 - 3 = 25 sec
As \( g_{SBM} > g_{NBH} \). South arm will govern the design to calculate green time for North-South approach.

Effective green time for East arm, \( g_{EBM} = \frac{y_{EBM}}{Y_{BM}}(C_{OBM} - L_{BM}) \)

\[ = \frac{0.14}{0.30}(38 - 14.32) \]

\[ = 11.05 \text{ sec} = 11 \text{ sec} \]

Combined green and amber time for East arm = \( g_{EBM} + I_{EBM} = 11 + 0.06 = 11.06 \text{ sec} \)

Controller setting of green time for East arm = 11- amber period = 11-3 = 8 sec

As during off peak period the number of right turners are very small a minimum green time which is 7 sec is suggested for the late release stage.

So, Cycle time = 7 + 25 + 11 + 3 * \( I_{BM} = 43 + 24 = 67 \text{ sec} \)

**Signal Design Calculation for Mogbazar Intersection**

a) Peak Period

\( y_{NMB} = \frac{q_{NMB}}{S_{NMB}} = 2039/3566 = 0.57 \)

\( y_{WMB} = \frac{q_{WMB}}{S_{WMB}} = 1384/3066 = 0.45 \)

\( y_{EBM} = \frac{q_{EBM}}{S_{EBM}} = 1918/3535 = 0.54 \)

So, \( Y_{MB} = 0.57 \)

Optimum Cycle Time, \( C_{OBM} = \frac{(1.5*L_{MB} + 5)}{(1-Y_{MB})} = \frac{(1.5*12.6 + 5)}{(1-0.57)} \)

\[ = 55.58 \text{ sec} = 56 \text{ sec} \]

Effective green time for North arm, \( g_{NMB} = \frac{y_{NMB}}{Y_{MB}}(C_{OBM} - L_{MB}) \)

\[ = \frac{0.57}{0.57}(56 - 12.6) \]

\[ = 43.4 \text{ sec} = 44 \text{ sec} \]

Combined green and amber time for North arm = \( g_{NMB} + I_{NMB} = 44 + 4.04 = 48.04 \text{ sec} \)

Controller setting of green time for North arm = 48- amber period = 48-4 = 44 sec

Effective green time for West arm, \( g_{WMB} = \frac{y_{WMB}}{Y_{MB}}(C_{OBM} - L_{MB}) \)

\[ = \frac{0.45}{0.57}(56 - 12.6) \]

\[ = 34.26 \text{ sec} = 35 \text{ sec} \]
Combined green and amber time for West arm: \( g_{W,MB} + l_{W,MB} = 35 + 4.16 = 39.16 \) sec

Controller setting of green time for West arm: \( K_{W,MB} = 39 - 4 = 35 \) sec

Green time for the right turners from the West arm: \( G_{RTW,MB} = \) Extra clearance period +

Time taken for each PCU to complete turning manoeuvre * No. of right turners per cycle (PCU)

\[ = 3 + 2 * 7 = 17 \text{ sec} \]

As, \( K_{W,MB} > G_{RTW,MB} \), Green time for this phase will be designed based on \( K_{W,MB} \).

Effective green time for East arm, \( g_{E,MB} = Y_{E,MB}/Y_{MB}*(C_{o,MB} - L_{MB}) \)

\[ = 0.54/0.57*(56 - 12.6) \]

\[ = 41.11 \text{ sec} = 42 \text{ sec} \]

Combined green and amber time for East arm: \( g_{E,MB} + l_{E,MB} = 42 + 4.05 = 46.05 \) sec

Controller setting of green time for East arm: \( K_{E,MB} = 46 - 4 = 42 \) sec

Green time for the right turners from the East arm: \( G_{RTE,MB} = \) Extra clearance period +

Time taken for each PCU to complete turning manoeuvre * No. of right turners per cycle (PCU)

\[ = 3 + 2 * 28 = 59 \text{ sec} \]

As, \( G_{RTE,MB} > K_{E,MB} \), Green time for this phase will be designed based on \( G_{RTE,MB} \).

So, Cycle time = 44 + 35 + 59 + 3 * \( L_{MB} = 138 + 36 = 174 \) sec

b) Off-peak Period

\[ y_{N,MB} = q_{N,MB}/S_{N,MB} = 1120/3566 = 0.314 \]

\[ y_{W,MB} = q_{W,MB}/S_{W,MB} = 566/3066 = 0.185 \]

\[ y_{E,MB} = q_{E,MB}/S_{E,MB} = 1108/3535 = 0.313 \]

So, \( Y_{MB} = 0.314 \)

Optimum Cycle Time, \( C_{o,MB} = (1.5*L_{MB} + 5)/(1-Y_{MB}) = (1.5*12.6 + 5)/(1-0.314) \)

\[ = 34.84 \text{ sec} = 35 \text{ sec} \]

Effective green time for North arm, \( g_{N,MB} = y_{N,MB}/Y_{MB}*(C_{o,MB} - L_{MB}) \)

\[ = 0.314/0.314*(35 - 12.6) \]

\[ = 22.4 \text{ sec} = 23 \text{ sec} \]

Combined green and amber time for North arm: \( g_{N,MB} + l_{N,MB} = 23 + 4.04 = 27.04 \) sec
So, Cycle time = 23 + 14 + 23 + 3 * I\textsubscript{MB} = 60 + 36 = 96 sec

Controller setting of green time for North arm = 27 - amber period = 27-4 = 23 sec

Effective green time for West arm, g\textsubscript{W,MB} = \frac{Y\textsubscript{W,MB}}{Y\textsubscript{MB}} * (C\textsubscript{0,MB} - L\textsubscript{MB}) = \frac{0.185}{0.314} * (35 - 12.6) = 13.2 sec = 14 sec

Combined green and amber time for West arm = g\textsubscript{W,MB} + I\textsubscript{W,MB} = 14 + 4.16 = 18.16 sec

Controller setting of green time for West arm, K\textsubscript{W,MB} = 18 - amber period = 18-4 = 14 sec

Effective green time for East arm, g\textsubscript{E,MB} = \frac{Y\textsubscript{E,MB}}{Y\textsubscript{MB}} * (C\textsubscript{0,MB} - L\textsubscript{MB}) = \frac{0.313}{0.314} * (35 - 12.6) = 22.33 sec = 23 sec

Combined green and amber time for East arm = g\textsubscript{E,MB} + I\textsubscript{E,MB} = 23 + 4.05 = 27.05 sec

Controller setting of green time for East arm, K\textsubscript{E,MB} = 27 - amber period = 27-4 = 23 sec

So, Cycle time = 23 + 14 + 23 + 3 * I\textsubscript{MB} = 60 + 36 = 96 sec