SAFE AND EFFICIENT PEDESTRIAN CONTROL MECHANISM

S.H.DAMITH

This thesis was submitted to the Department of Civil Engineering of the University of Moratuwa in partial fulfillment of the requirement for the Degree of Master of Science.

Supervised By

Professor J.M.S.J.Bandara

Department of Civil Engineering

University of Moratuwa

Sri Lanka

SAFE AND EFFICIENT PEDESTRIAN CONTROL MECHANISM

MASTER OF SCIENCE

S.H.DAMITH

UNIVERSITY OF MORATUWA

SRI LANKA

December 2005

DECLARATION

I, Sella Hewage Damith, here by declare that the content of this thesis is the output of original research work carried out over a period of 15 months at the Department of Civil Engineering, University of Moratuwa, Sri Lanka. Whenever the work done by others was used, it was mentioned appropriately as a reference.

....

S.H. Damith.
Department of Civil Engineering.
University of Moratuwa.
Sri Lanka.

UOM Verified Signature

Prof. J.M.S.J. Bandara.
Department of Civil Engineering.
University of Moratuwa.
Sri Lanka

ABSTRACT

Pedestrians are legitimate users of the transportation system and they should, therefore, be able to use this system safely and without unreasonable delay. Pedestrians have a right to cross roads safely, Planers and Engineers, therefore, have a professional responsibility to plan, design, and provide safe crossing facilities.

Major findings of recent accident studies have identified that pedestrians comprise a significant proportion of' serious injuries and fatalities. Furthermore it has found that one half of pedestrian fatalities have occurred while the pedestrian was crossing the road but not on a marked pedestrian crossing. As the majority of pedestrian accidents occur while crossing a road, the need of safe and efficient pedestrian crossing facilities could arguably be the most important pedestrian safety factor.

Generally, the cost of installation and maintenance of pedestrian crossing needs to be balanced against associated benefits such as time saving and safety. Therefore, installation of pedestrian crossing at a location of a road is being considered, delay is one of the major term that should be considered and it will be significantly differ upon the type of crossing introduced to a particular location. Some time there would be additional delay by introducing crossing where it is not needed or inappropriate

In Sri Lanka, the practice of deciding where to install pedestrian crossing considerably differs from other countries, and engineers have been got to use their judgment arbitrarily and sometimes influenced by political or pubic pressure in reaching decisions,

Goal of this study is, to prepare a background to develop set of guidelines to assist in determining the appropriate crossing facility for a given location of a road, based on the relationship between pedestrian and vehicle flow and their delays. These relationships help to develop a more efficient pedestrian crossing facility that minimizes total delay for both pedestrians and vehicles.

ACKNOWLEDGMENT

I am deeply indebted to my supervisor, Professor J.M.S.J. Bandara, Head, Transportation Engineering Division, Department of Civil Engineering of University of Moratuwa for his constant support. Without his help, this work would not be possible. I would also like to thank Professor Amal. S. Kumarage, Mr. M.B.S. Fernando and other staff of the Transportation Engineering Division of the Department of Civil Engineering of University of Moratuwa and their support and advice is appreciated.

I would also like to thank Professor (Mrs.) N. Rathnayke, Head of Department of Civil Engineering of University of Moratuwa, Director Post Graduate Studies of University of Moratuwa for giving opportunity to do this research work and Asian Development Bank for providing funds.

I would like to thank my friends Gayan Liyanage, Randu Harischandra, Kathiswaran, L.G. Kasun, L.G. Ruwani and Jayasnka those gave outstanding help in collecting data in the field.

I dedicate this thesis to my mother.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1. INTRODUCTION

1.1 PROBLEM STATEMENT

Walking is becoming more popular due to growing concerns for energy efficient transportation, time-space mobility constraints and environmental pollution. In Sri Lanka, neighborhoods have become more suburban, with sprawling land-use and the increasing need for automobiles. In addition, with increased vehicle-kilometers traveled per trip and congestion, drivers are more prone to stress on the roadway and increasingly tending to behave irresponsibly, otherwise known as "road rage". Combined with increased number of pedestrians, the consequences can be fatal. This problem is present when crossing the road where pedestrians and vehicles often have conflicting movements and needs.

Pedestrians are legitimate users of the transportation system and they should, therefore, be able to use this system safely and without unreasonable delay. Pedestrians have a right to cross roads safely, Planers and Engineers, therefore, have a professional responsibility to plan, design, and install safe crossing facilities. Pedestrians should he included as "design users" for all streets.

1.2 ACCIDENT PROFILE

Pedestrians are also vulnerable road users. Major findings of recent accident studies have identified that pedestrians comprise a significant proportion of' serious injuries and fatalities. It was found that there were 7.232 pedestrian casualties due to road accident in 2002. This was 30% of all road accident in that year. There were 815 pedestrian fatalities in 2002. This was 37% of all road fatalities in 2002. (Kumarage. 2003)

In general, well-marked crossings (especially zebra crossings) increase driver awareness of pedestrians and increase the likelihood that drivers will yield right of way. Crosswalk markings can also be used to encourage pedestrians to choose the safest location to cross. However it is believed that pedestrian crossings can also give pedestrians an increased sense of security and reduced level of attention that may result in more collisions between pedestrians and those motorists who do not yield the right of way. Another popular explanation that has been given for the correlation between crosswalk markings and increased pedestrian accidents is that marking concentrate crossing activity at those locations, but statistics reveled that jay walking may be attributed to some accidents; the absence of marked crossings where necessary is another possible cause.

It has found that one half of (i.e.52%) of pedestrian fatalities (as well as other injury related pedestrian accidents) have occurred while the pedestrian was crossing the road but not on a marked pedestrian crossing. (Kumarage, 2003)

As the majority of pedestrian accidents occur while crossing a road, the need of safe and efficient pedestrian crossing facilities could arguably be the most important pedestrian safety factor. The aim of introduction of pedestrian crossing facilities is to provide pedestrians with safe and comfortable facilities to cross the road.

Well-designed pedestrian crossings increase driver's awareness of pedestrians. Pedestrian crossings are the tool to ensure pedestrians can safely cross the street. In built-up areas different types of pedestrian crossings are functional, e.g. uncontrolled Zebra crossings, light control crossings, overhead bridges and Pedestrian underpasses. An important purpose of pedestrian crossings is to concentrate pedestrian movements to selected locations where the conflict between pedestrians and motor vehicles can be more effectively managed. Generally, the cost of installation and maintenance of pedestrian crossing needs to be balanced against associated benefits such as delay and safety. Therefore, installation of pedestrian crossing at a location of a road is being considered, delay is one of the major term that should be considered. In general, motor vehicles will experience delay due to pedestrians crossing the road as well as pedestrians will also experience delay and it will be significantly differ upon the type of crossing introduced to a particular location. Some time there would be additional delay by introducing crossing where it is not needed or inappropriate. An initial decision has to be made at a location whether a crosswalk is to be provided or not.

If it should be provided, what is the appropriate type of crossing for that location? There are warrants and guidelines developed by several researchers and traffic authorities to decide the installation of the appropriate pedestrian crossing based on various criteria. These developments are described in the Chapter 2 under the literature review.

In Sri Lanka, the practice of deciding where to install pedestrian crossing considerably differs from other countries, and Engineers have been got to use their judgment arbitrarily and sometimes influenced by political or pubic pressure in reaching decisions, because in Sri Lankan context, there is no guideline available.

1.3 SCOPE AND OBJECTIVES OF THE STUDY

Level of control of a pedestrian crossing is very useful in improving efficiency as well as safety at the pedestrian crossing. Goal of this study is, to prepare a background to develop set of guidelines to assist in determining the appropriate crossing facility for a given location of a road, based on the relationship between pedestrian and vehicle flow and their delays. These relationships help to develop a more efficient pedestrian crossing facility that minimizes total delay for both pedestrians and vehicles. Reaching this goal entails the fulfilling the following objectives:

1) Develop delay relationships between pedestrian and vehicle flow.
2) Obtain total delay for signalized crossings for different ranges of pedestrian and vehicle volumes using standard mathematical delay functions.
3) Compare total delay for uncontrolled and controlled pedestrian crossing.

1.4 STUDY OVERVIEW

This chapter described the significance of pedestrians crossing facility in the context of its accident profile, delays and defines research objectives and general approach.
Chapter 2 presents an in-depth literature review of various published pedestrian related studies, namely Classification of pedestrian crossing facilities, pedestrian and vehicular delay at a pedestrian crossing and past studies and current practices for installation of pedestrian crossing facilities

Chapter 3 describes the methodology adopted to collect data and general site description.

Chapter 4 presents analysis methodology and development of regression models for uncontrolled and signal controlled crossing and comparison of these relationships.

Chapter 5 includes conclusions and recommendations and discusses direction of future research.

Finally, the development of warrants is presented.

CHAPTER 2. REVIEW OF PEDESTRIAN RELATED LITERATURE

2.1 INTRODUCTION

Researchers and many Traffic Engineering organizations have developed various analytical approaches, innovative safety devises, as well as different types of pedestrian facilities to comfort the pedestrian activities.

In this chapter, followings are reviewed.

i) Classification of pedestrian crossing facilities.

ii) Pedestrian and vehicular delay at a pedestrian crossing.

iii) Past studies and current practices for installation of pedestrian crossing facilities.

2.2 CLASSIFICATION OF PEDESTRIAN CROSSING FACILITIES

The aim of introduction of pedestrian crossing facilities is to provide pedestrians to cross the road safely and comfortably. Well-designed pedestrian crossings increase driver's awareness of pedestrians. Pedestrian crossings have to be adjusted to pedestrian's needs and limitations.

Traffic engineering techniques which may be used to assist pedestrians to cross roads and to control pedestrian / vehicle interaction include

i) General crossing treatments.

ii) Time separation (traffic control) treatments.

iii) Grade (or spatial) separation.

iv) Integrated treatments. (AUSTROADS, 1995)

Objectives of providing General Crossing Treatments (Physical Pedestrian aids) are to increase the safety of pedestrians by use of physical aids within the roadway so as to reduce conflict or degree of hazard between vehicle and pedestrians and to simplify the decisions which both pedestrians and drivers have to make. Relevant general crossing treatments are Pedestrian refuge islands, Traffic islands, Medians, Footpath

(Kerb) extensions. Loading islands, Safety zones, Pedestrian fencing and Speed control devices. Time Separated (Controlled Traffic) Facilities are the commonly requested form of facility to assist pedestrians in crossing roadways. They offer higher degree of safety by requiring vehicular traffic to stop and or give away while pedestrians are crossing. There are several types of time separated facilities such as uncontrolled crossings (zebra crossings), signal controlled crossings.

Grade separated facilities are provided to increase the safety of pedestrians by eliminating conflict between vehicles and pedestrians. Relevant treatments are Pedestrian underpass and over head bridges.

Integrated facilities consist of pedestrian warning signs, Shared zones, School zones, Local Area traffic management schemes, and Lighting. These facilities provide an environment in which pedestrians and vehicles may share existing road space in a largely unsupervised manner. (AUSTROADS, 1995)

2.2.1 UNCONTROLLED CROSSING- ZEBRA CROSSINGS

Zebra crossing is the most widespread safety measure for pedestrians all over the world. Some studies, however, have shown that their influence on pedestrian safety is negative. Herms (1972) observed pedestrian accidents on 400 marked and 400 unmarked pedestrian crossings and found that relative to the numbers of pedestrians using the pedestrian crossings, approximately twice as many pedestrian accidents occurred in the marked crossings than in the unmarked ones. As Evans (1985) explained it, 'It would appear that the painted crosswalk induced a sense of security in the pedestrians using it that was in no way justified by any increase of caution on the part of the approaching drivers brought about by the appearance of the marked crossings.' Brundell-Freij and Ekman (1991) arrived at very similar results and conclusions using Swedish traffic conflict and behavioral studies, accidents and flow data.

Although most studies indicate a negative effect of zebra crossings, there are exceptions. Brundell-Freij and Ekman (1991) for instance referred to studies that showed quite positive effects of zebras in Norway and in the UK. The main reason for this difference is most probably that there is a distinct give way rule for car drivers in those two countries, while other countries (e.g. Sweden and the U.S.) do not have that rule. This rule seems to have a significant effect on the car driver, thus creating much more preparedness and actual stopping for pedestrians. Ekman (1983) has also showed in an earlier conflict study that the safety effect of zebra crossings can be largely improved also in Sweden by raising them and making them more conspicuous for the drivers. Part of the positive effect is, however, in this case that car drivers are forced to slow down before arriving at the zebra crossing.

Hydén, Gårder and Linderholm (1978) found in conflict studies that there was a strong relation between the location of the zebra crossings at non-signalised intersections (i.e. in principle the crossing location of the pedestrian) and pedestrian risk. Pedestrian risks were lowest when the distance between the extension of the right side of the parallel road and the zebra crossing was either less than 2 meters or more than 10 meters.

Broadly speaking, Zebra crossings are considered inappropriate on high speed or high motor traffic flow roads, particularly multi-lane roads. The DETR (The Department of the Environment, Transport and the Regions, UK) guidance recommends that Zebras should not be installed on roads where 85 percentile speeds is greater than 35 mi/h (56.35 km/h)

Zebra crossings generally cause far less delay to pedestrians than Pelican crossings. (Hunt, 1997). They are considerably cheaper to install and maintain than signal-controlled crossings. However, there has been a tendency for traffic engineers to replace Zebras with Pelicans and to choose Pelicans rather than Zebras when installing new pedestrian crossings.

There are some signs that the Zebra may be making a come-back, particularly within traffic calmed areas, because Zebra crossings give pedestrians greater priority and are less visually intrusive and less expensive. Also, it is argued that Pelican crossings encourage the driver to look for signals and not for pedestrians and that this can have a detrimental effect on pedestrian safety.

2.2.2 PELICAN CROSSINGS

Signal controlled Pelican crossings (the name "Pelican" is derived from PEdestrian LIght CONtrolled crossings) are used in some urban areas in Sri Lanka. Pedestrian demands for use of the crossing are registered on pushbuttons prominently positioned on both sides of the crossing and the signals display a continuous green aspect for vehicles in the absence of such demands. The sequence of signal aspects shown to pedestrian and drivers are indicated in **Fig.2.1**, f is the vehicle precedence period and pedestrian demands arising during time period k (d + e + f) are stored until the expiry of this period. The vehicle precedence period is normally set to a value of 20s to 30s to suit the requirements of the site, with an absolute maximum value of 40s.values of the remaining stages of the operational cycle shown in **Fig.2.1** are given in **Table 2.1**, variations in settings being depend on road with at a particular site.

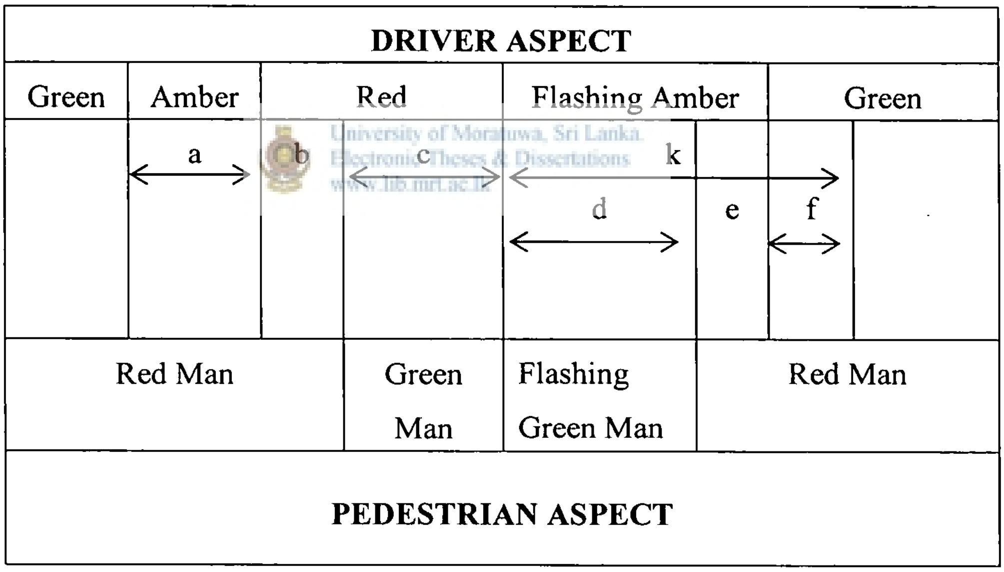

Fig.2.1 Operational Cycle of Pelican Crossing Signals

Source: Department of Transport. Pelican Crossings: Pelican Crossing Operation; Departmental Standard TD/4/79,London.

Signal to Pedestrians	Duration (seconds)	Signal to Drivers
Red standing man (meaning 'wait')		Steady green (meaning 'Proceed' if the way is clear)
Red standing man	a = 3s	Steady amber (meaning 'stop' unless unsafe to do so)
Red standing man	b= 1 s (possibly increased to 3s on roads not subject to 30 mile/h speed limit and also on a 'forced change 'where vehicle actuation is employed)	Steady red (meaning 'stop', wait behind the stop-line on the carriageway)
Green man (meaning 'cross with care')	c= 4s for crossings up to *7.5m* long 5s for crossings 7.5m-10.5m 6s for crossings 10.5m-12.5m 7s for crossing over 12.5m	Steady red
Flashing green man (meaning 'do not start to cross)	d= 6s plus 1 s for each 1 .2m over 6m length of crossing	Flashing amber (meaning ' give way to pedestrians on the crossing-they have priority')
Red standing man	e= 1s up to 10.5m length of crossing, 2s over 10.5m	Flashing amber
Red standing man		Steady green

Table.2.1 Duration of Stages in Pelican Crossing Cycle
Source: Department of Transport. Pelican Crossings; Pelican Crossing Operation. Departmental Standard TD/4/79,London.

Signal sequence used in Sri Lanka differs from presented above. Only difference is there is no flashing amber in Sri Lankan system. In calculation of delays at signalized crossings this difference is taken into account in the section 4.3 Delays at signalized crossings.

In general, observations suggest that while most pedestrians may press the push button at a Pelican they will cross the road as soon as they perceive a suitable gap in the traffic flow, irrespective of the pedestrian signal aspect. This applies particularly when a pedestrian phase has just ended, and pushing a pelican button will not activate another pedestrian phase promptly. Another observation at pelican crossing is after pushing button to activate Pedestrian phase, pedestrians often do not know whether the button has been pressed, they may believe that the button does not work and start crossing early, while the steady Don't Walk is being displayed.

2.2.3 GRADE SEPARATED CROSSINGS

Convenience is essential in designing overpass and underpass. Studies have shown that pedestrians can rarely be convinced to use a poorly located crossing and will almost never use an overpass if it takes fifty percent longer to cross than an at-grade crossing. Grade-separated crossings should be provided within the normal path of pedestrians wherever possible. Even for the most ideal overpass location, it may still be necessary to block pedestrian access to the at-grade crossing with fencing. A 1988 study concluded that state and local governments usually consider grade-separated crossings in the following situations:

- where there is moderate to high pedestrian demand to cross a freeway or expressway.

- where there is a large number of young children (i.e., particularly near schools) who must regularly cross a high-speed or high-volume roadway.
- on streets having high vehicle volumes, high pedestrian crossing volumes, and where there is an extreme hazard for pedestrians (e.g., on wide streets with high-speed traffic and poor sight distance).
- Where one or more of the conditions stated above exists in conjunction with a well-defined pedestrian origin and destination (e.g., a residential neighborhood across a busy street from a school, a parking structure affiliated with a university, or apartment complex near a shopping mall). (Zegeer et al, 1988)

The guidelines have been prepared for the use of Roads and Traffic Authority of New South Wales so that grade separated pedestrian facilities on arterial roads that meet a common criteria and allow the Road and Traffic Authority to identify priorities for future works funded through its works programs on the basis of their likely contribution to the improvement of traffic efficiency and safety. The guidelines says that grade separated pedestrian facility may be warranted if the following conditions are met for at least the three busiest hours of a normal weekday. . In the following criteria V is the volume of vehicular traffic (2 ways) in vehicles per hour, and P is the volume of pedestrian traffic in pedestrians per hour (Guidelines for Traffic Facilities, 1987)

i) Criteria for the General case:

These criteria apply where the proportion of pedestrians under 12 years and over 60 years of age is 40% of the total crossing sample or less.

Undivided Road V>850 and P>250.

Criterion value of PV of 212,150 but the preferred value is 250,000.

Divided Road V> 1500 and P>250.

This criterion results in a minimum value of PV of 375,000 but the preferred value is > 400,000.

ii) Criteria for special cases:

These criteria apply where the proportion of pedestrians under 12 years and or over 60 years of age is greater than 40% of the total crossing sample.

Undivided Road V>750 and P>200.

This criterion results in a minimum value of PV of 150,500 but the preferred value is> 180,000.

Divided Road V>1,100 and P>200.

This criterion results in a minimum value of PV of 220,000 but the preferred value is> 280,000.

The guideline also stated that the meeting of the above numerical criteria does not solely justify the installation of a grade separated crossing, but there are non-numerical factors such as physical site suitability, future road hierarchy, appropriate traffic management solution, likely utilization, engineering feasibility and cost.

It is important to provide adequate lighting of the crossing to prevent crime and vandalism. Underpasses often need lighting 24 hours a day. Topography should be a major consideration in determining whether an underpass or overpass is more appropriate.

The general reasons include high capital cost of providing the structures, their generally poor patronage particularly on the roads where traffic is interrupted by traffic signals, and difficulties encountered by the aged and physically disabled due to the necessary level differences. In view of the above, the provision of this type of facility needs to be carefully evaluated considering each case on its merits, rather than set numerical warrants and guides.

The evaluation should include physical site suitability, future road hierarchy, alternative traffic management solutions, likely level of use, likely benefits of increased safety and reduced delay, engineering feasibility, and costs (including cost of relocating services where necessary and maintenance). (AUSTROADS, 1995)

2.3 PEDESTRIAN AND VEHICULAR DELAYS AT A PEDESTRIAN CROSSING

Delay is a complex measure and is depend on a number of variables, including quality of progression, traffic volumes, and pedestrian volume. For determining delay at pedestrian crossings, it can be clearly categorized into two types that are vehicular delay and pedestrian delay. Although researche[1]s have studied both pedestrian and vehicular delay, more emphasis has been given to vehicular delay.

Vehicular delay due to pedestrian crossing activity can be further divided into different parts.

a) Initially, there is a deceleration delay to stop at the pedestrian crossing.
b) Secondly, the stopped delay to allow pedestrians to cross the road.
c) Finally, acceleration delays to gain an original speed of the vehicle.

Generally, in delay studies in traffic engineering more concern is given to the stopped delay because it is difficult to measure deceleration and acceleration delay. Some time it is not essential or important depend on the requirements of particular studies.

2.4 COST OF DELAY

It is clear that waiting cost per unit time of pedestrians and vehicles could differ significantly. Reducing waiting time results in corresponding economic value of time. The vehicular cost is based on the average value of occupants' time for a representative traffic composition (80.8 per cent cars, 8.9 per cent vans, 8.7 per cent other commercial, and 1.6 per cent public service vehicles) and does not include allowance for vehicle operating or capital costs. On this basis a ratio of approximately 2-3 between pedestrian and vehicle cost is appropriate, but this is at best a rough estimate, which could in any case vary rapidly in the current situations. (Grffiths et al, 1976). Pillai (1974) also suggested that cost of delay to a vehicle is twice the cost to a pedestrian.

Therefore when deriving total delay, it has to be assign a figure to the relative cost between vehicle delay and pedestrian delay according to the value of time.

2.5 COMPUTING DELAY AT SIGNALIZED CROSSING

Numerous efforts have been devoted to the development of delay estimation. The purpose of reviewing delay function at signalized crossing is to decide installing signal by comparing delay due to introducing signal at pedestrian crossing.

In the Highway Capacity Manual 1994, the average stopped delay per vehicle for a given lane group, with stopped delay defined as completely immobilized vehicle, is computed using the following equation.

$$d = 0.38C\frac{\left(1-\frac{g}{C}\right)^2}{1-\left(\frac{g}{C}\right)X} + 173X^2\left\{(X-1)+\sqrt{(X-1)^2+16\frac{X}{c}}\right\}$$ **Eq.2.1**

Where,

D = Stopped delay per vehicle (seconds/vehicle),
C = cycle length (seconds),

g = effective green time for lane group (seconds),

X = volume to capacity ratio of lane group,

c = capacity of the lane group (vehicle per seconds)

Pedestrian delay at signalized crossings must often be considered when describing the quality of pedestrian flow. There are three pedestrian indications normally encountered.

1 .Walk- the time period when pedestrians are expected to leave the curb. Here, it is also referred to as pedestrian green or green.

2. Flashing Don't Walk- the clearance time for pedestrians equal to the crossing length divided by expected walking speed (normally 1.2m/s). Here, it is also referred to as pedestrian clearance time.

3. Don't Walk- the time period during which pedestrians do not have the right- of-way as assigned by the signal. Here, it is also referred to as pedestrian red.

A logical model of pedestrian delay might assume all the pedestrians who arrive during pedestrian clearance and pedestrian red will wait until the beginning of the pedestrian green interval and then immediately enter the crosswalk. Braun and Roddin (1978) gave the following equation, based on random arrivals, constant cycle length, no pedestrian actuation, and complete signal compliance.

$$D = \frac{(C-G)^2}{2C}$$ **Eq.2.2**

Where,

D = average delay per pedestrians,

C = cycle length,

G = duration of Walk signal.

2.6 PAST STUDIES AND CURRENT PRACTICES FOR INSTALLATION OF PEDESTRIAN CROSSING FACILITIES

Pedestrian delay at unsignalized intersection was first treated by Adams in 1936 in one of the earliest theoretical traffic papers. He assumed that pedestrian and vehicles are random and made field observations that generally justified the assumption. He assumed that the main street flow is q (vehicles/sec) and that an interval τ (the critical gap in seconds) is required between successive arrivals on the on the main street for a pedestrian to cross safely, the probability that a pedestrian will pass without delay is

$$P(h > \tau) = e^{-q\tau}$$ **Eq.2.3**

After several steps the amount of delay for all delayed pedestrians is

$$E_d(t) = \left[\frac{1}{qe^{-q\tau}} - \frac{(1-\tau)}{q}\right] \times \left[\frac{1}{1-e^{-q\tau}}\right]$$ **Eq.2.4**

Adams (1936)

Underwood (1957), in applying these formulas for pedestrian delay to determine warrants for installation of pedestrian crossings, considered three levels of pedestrian treatment:

i). no treatment zone

ii). a "walking legs" sign zone (pedestrian sign and crosswalk markings in U.S. practice)

iii). traffic control signal zone

His proposed method requires that three values be established.

a) minimum vehicular volume warrant

b) minimum pedestrian volume warrant

c) maximum pedestrian volume warrant

If the volume is less than that required by warrants a) or b), no treatment is required. In the case of warrant a), the delay to pedestrian would be acceptable; in the case of warrant b), because there are so few pedestrians delay would be acceptable. The "walking legs" sign zone (includes painted crosswalk) is used if warrants a) and b) are exceeded. If warrant c) is also exceeded, a traffic control signal is justified.

The minimum vehicular volume warrant is determined from the application of **Eq.2.4** which is plotted in **Fig.2.2** for values of r at 9, 12,15, and 18 sec. Line AA represents a point such that below the delay increase gradually; above it, increase at an accelerating rate. In each case V x τ is approximately 6,000, where V=hourly vehicular volume.

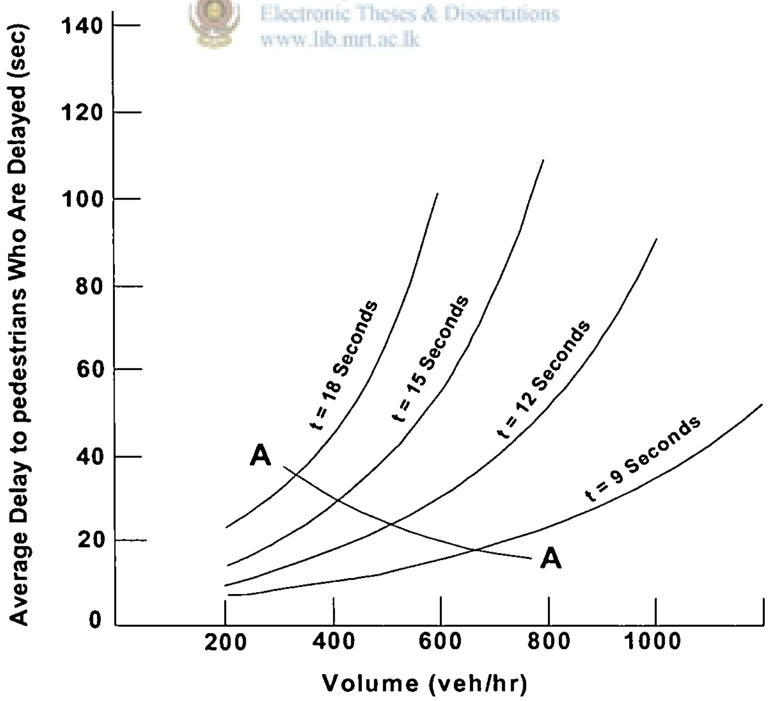

Fig 2.2 Pedestrian Delay vs. Vehicular Volume

Source: Daniel et.al (1975)

To attain the minimum

$$V = \frac{6000}{\tau}$$ **Eq.2.5**

Minimum pedestrian volume warrant is taken from

$$P_{\min} = \frac{V e^{-q\tau}}{1 - e^{-q\tau}}$$ **Eq.2.6**

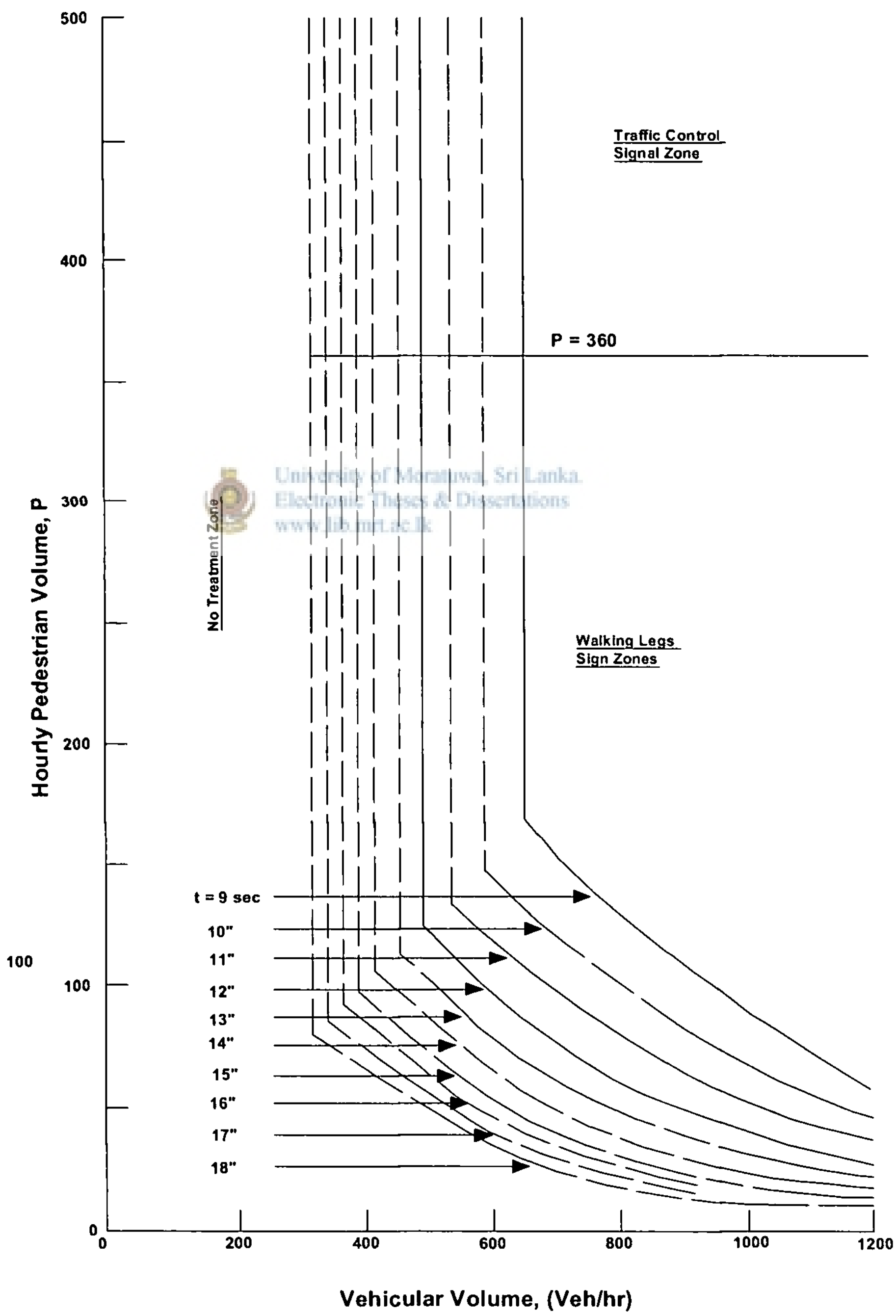

Fig.2.3 Warrants for Pedestrian Controls
Source: Daniel et.al (1975)

Underwood's study is based on certain assumptions: a minimum vehicular warrant, a Minimum pedestrian warrant and a maximum pedestrian warrant are developed based on certain assumptions. Such warrants for pedestrian and vehicle flows have not taken into account the combined effect of pedestrians and vehicles, but have considered them in isolation. Pilli (1975)

The U.K. Road Research Laboratory developed a criterion based on the investigations of Tanner (1951) and Smeed (1958) establishing an uncontrolled pedestrian crossing considering the economic feasibility (loss or gain). This criterion deepened on the relative importance between vehicle and pedestrian times and is given by the following:

$$\frac{0.75\left(e^{nI}\left(1-e^{-1.5n}\right)-1.5n-18Kn^{2}\right)}{3600n} \qquad \textbf{Eq.2.7}$$

Where,

P = pedestrian /h over100d of road including crossing site

n = veh/sec past the crossing site

I = gap, in sec in which a pedestrian will cross when not at crossing

K = relative importance of vehicle to pedestrian times

Flow levels are finally recommended for different values of K and I for installation of an uncontrolled pedestrian crossing.

Smith and Knoblauch (1987) developed criteria relating pedestrian and vehicle volumes for determining when zebra crossing may be beneficial. The chart takes into account road width and presence of children, elderly or disabled persons. Satisfaction of these criteria means that benefits of crosswalk outweigh economic costs and possible disadvantages.

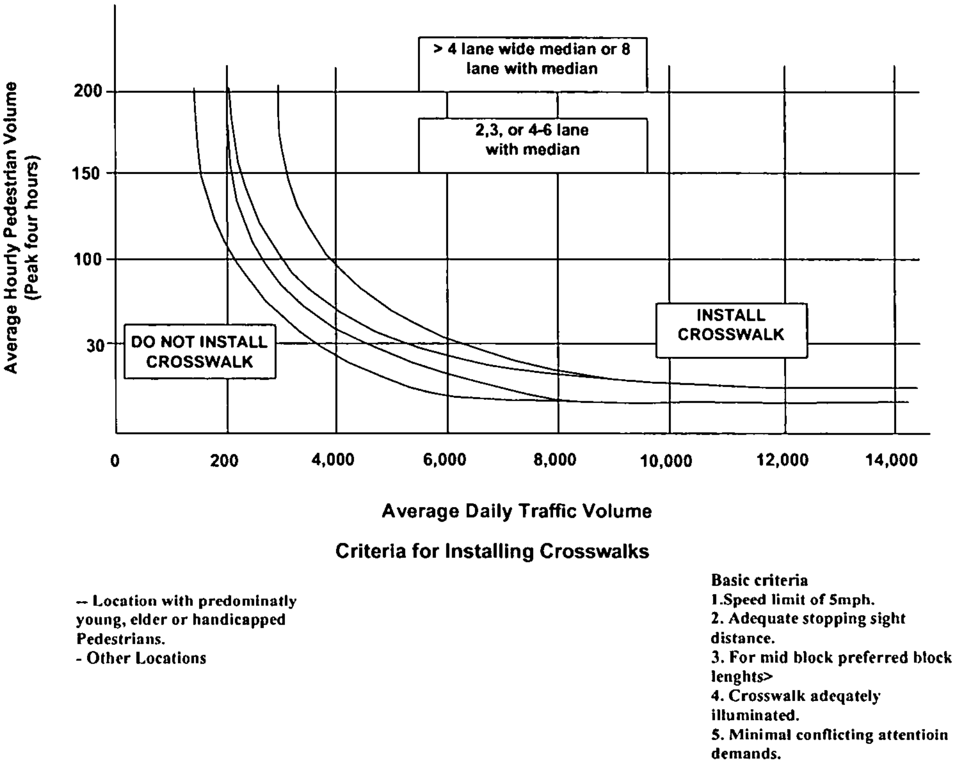

Fig.2.4 Criteria for Installing Crosswalks

Source: Manual on Uniform Traffic Control Devices, Washington, D.C.: US. Department of Transportation, 1988.

Füsser (1995) differentiate two approaches to solution of pedestrian safety problem. First one, "hard", represent clear separation of between pedestrian facilities and those for cars while "soft" approach relies on the road user's co-operation in conjunction with a low enforcement of low speed limit.

As Füsser further mentions, "soft", pedestrian-oriented designs for crossing facilities use the traffic calming and appear to function particularly well on collector road, (including local distributor roads) with a low speed level, especially in "30 km/h zones". "Hard", car-oriented designs for crossing facilities do not change the character of a roadway and are mostly limited to the installation of center isles. They function particularly well on major roads, even in case of a medium-to- high-speed level (about 50km/h), but the volume of crossing pedestrians is low and the complexity of the crossing arrangement is straightforward.

Based on these findings, pedestrian crossing measures depend on pedestrian and vehicle flow. Center islands are recommended for roads with high vehicle volume, but relatively small pedestrian volume. Traffic calming is useful for roads with high pedestrian volume and low vehicle volume. Use of traffic calming means to include insulation of the traffic sign "traffic calming" and high engineering measures ensuring very slow vehicle speeds and equal rights for pedestrians and drivers. This may be substituted by "30 km/h-zone" with a limited use of engineering measures. In case of both high pedestrian and high vehicle volumes, traffic lights are recommended.

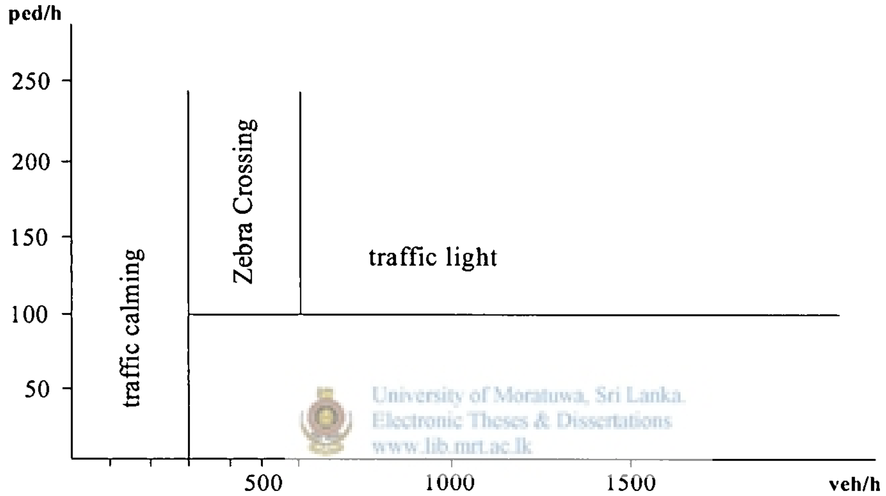

Fig.2.5 Useful Area of Application

Source : Füsser (1995)

Pillai (1975) suggested that warrants to establish a type of pedestrian crossing should depend on the acceptable delay to vehicles. At a time the importance of the pedestrian has become universally recognized, a more realistic approach would consider both pedestrian and vehicle delays. At a time when the importance of the pedestrian has become more universally recognized, a more realistic approach would consider both pedestrian and vehicle delays.

2.7 CURRENT PRACTICES

Several countries and many organizations have established their own guidelines to assist in determining the need of pedestrian facilities. In this section, few of them are briefly discussed

Actual numerical warrants as specified by Australian Standards AS 1742.10-1990 in determining Zebra crossings, generally should be installed when the following conditions are met:

(a) In two separate 1hour periods of a typical weekday, there are no fewer than 60 pedestrians and 600 vehicles pass the site, subject to the product of the number of pedestrians per hour and vehicles in the same hour exceeding 90,000.

(b) No more than four lanes of moving traffic (generally representing a 15 m carriageway) are to be encountered by the pedestrian in any one stage of the crossing

(c) There is adequate visibility of the crossing as well as of pedestrians on it

(d) The 85th percentile speed of traffic is not more than 80 km/h.

The development of criteria by Smith and Knoblauch (1987) is practicing as guidelines of the installation of marked crosswalks at uncontrolled crossing in USA **(Fig.2.4)**.

The Department for Transport in UK published 'Local Transport Notes 1/95 and 2/95' advice on the assessment and design of pedestrian crossings. Local Transport Note 1/95, The Assessment of Pedestrian Crossings recommends the practices to be followed when planning at-grade pedestrian crossings. It describes all types of crossings, including facilities shared with cyclists, other than those at signalized junctions. The Note recommends a framework method to encourage informed decisions to be made as to whether a crossing is necessary and if so which type should be used. Local Transport Note 2/95, The Design of Pedestrian Crossings recommends the design of pedestrian crossings in general and the operation of signal-controlled (Pelican, Puffin or Toucan) crossings in particular. Guidance is also given on the use of pedestrian refuge islands.

In Northern Ireland, carrying out assessment of the site the degree of conflict between pedestrians and vehicles is estimated by counting the number of vehicles passing the site in both directions, and the number of pedestrians crossing the road along a length extending at least 50m on each side of the proposed crossing site. The degree of conflict between pedestrians and vehicles is determined by PV^2 where V is the 2-way total hourly flow of vehicles and P is the 2-way total hourly flow of pedestrians crossing the road within 50m on either side of the site at busy times. The numerical criterion against which the requirement for a pedestrian crossing will be assessed is provided by the average of the four highest hourly rates of PV^2. An average value exceeding 10^8 for an undivided road or $2x10^8$ for a divided road will meet this criterion.

In most of the numerical guidelines developed to install pedestrian crossings, type of the crossing determines based on pedestrian and vehicle flow but there are some differences in basics such as delays, degree of conflict, accident profile, etc. In this study, delay to both pedestrians, vehicles and number of vehicle stopped at pedestrian crossing for pedestrians to cross the road have been considered as a basic factors to develop the guideline based on pedestrian and vehicle flow.

CHAPTER 3. DATA COLLECTION

3.1 INTRODUCTION

The study of the relationships between pedestrian flow, vehicle flow and their delays may help to identify an appropriate control mechanism to reduce delays and improve safety. Therefore to build up these relationships, data collection was carried out as describe in the Section 3.4. Survey Methodology.

Data collections were done at 10 uncontrolled pedestrian crossings in Colombo and Matara. Delays to motorists and pedestrians mainly depend on the volumes of these two groups and there will be relationships between delay and the vehicle flow and pedestrian flow, therefore these sites were selected to represent different traffics, pedestrian volumes to see whether there are relationships between delay and flow of these two parties.

Following are the sites that the data were collected.

i) Malian junction

ii) Bambalapitiya Kovil

iii) Mount Lavinia (near Hena Road)

iv) House of Fashion

iv) Papiliyana junction

v) Borralasgamuwa junction

vi) Matara bus stand

vii) Matara Hospital

viii) Matara Bo-tree

ix) Matara St.Thomas College

3.2 GENERAL METHODOLOGY

Data collection was carried out at different uncontrolled pedestrian crossings. Data was collected for 1 hour (8.00am To 9.00am) for each site and for each 5min time interval was considered. Data represents number of pedestrians from two sides of the crossing separately, number of vehicles in each direction so it represents the pedestrian and vehicle flow. Average pedestrian waiting time and average pedestrian crossing time was also represented in each 5min interval.

3.3 SITE DESCRIPTION

Maliban junction

This crossing is near to the Maliban Junction, which is a T-intersection with main traffic flow from Galle road. Galle road is four lane main arterial. There are shops, factories and bus stops which causes to high pedestrian mobility and people are frequently use this zebra crossing to cross the road.

Bambalpitiya Kovil

This is also situated in Galle road and near to the Bambalpitiya Kovil. This is area is enclosed with high rise office blocks, shops and vendors and Kovil also generate higher pedestrian volume.

Mount Laviniya (near Hena Road)

Relatively higher vehicle speeds than other selected crossing on' the Galle road. No median available, so pedestrians expose risk of accident at the middle of the road. Various types of shops and bus stop near to the crossing create pedestrian crossing activities.

House of Fashion

This crossing is on Duplication road in front of the House of Fashions, which is a main pedestrian generated shopping center throughout the day. The usual data collection period (i.e. 8.00am To 9.00am) was changed to 11.00am to 12.00 noon because the shopping center opens at 10.00am.

Papiliyana junction

This is a four-leg intersection, and crossing is on the Piliyandala-Colombo Road. There are shops, factories generate pedestrian crossing activities and also bus passengers who change their routes from Nugegoda- Rathmalana to Piliyandala-Colombo vise versa create other crossing activities.

Borralasgamuwa junction

Four-arm intersection with a roundabout and high pedestrian activities can be seen due to shopping, bus passengers who change their route. Crossing is on the Piliyandala-Colombo road.

Matara bus stand

Bus passengers create high crossing activities to and from the bus stand. The highest pedestrian crossing volume has been recorded here out of 10 sites surveyed.

Matara Hospital

Relatively high pedestrian activities are available in this area of the Matara town. Main pedestrian crossing activities are due to the Matara-hase hospital.

Matara Bo-tree

This crossing is on the Matara- Galle road and in front of the Matara bo tree. There is a bus halt that is crowded throughout the day. People to the bus halt and Bo tree create more pedestrian crossing activities.

Matara St.Thomas College

This is also on the Matara- Galle road and high pedestrian activities can be seen throughout day. School crossing operates the period before and after school hours. as this is a some extent of controlled type pedestrian crossing, the survey was carried out after the morning school opening hours.

3.4 SURVEY METHODOLOGY

There were four enumerators for data collection. Tally counters were used to count number of pedestrians and vehicles and stopwatches were used to measure waiting time and crossing time of the pedestrians.

In considering delay to motor vehicles, number of vehicles stopped for pedestrian to cross was recorded. During the early stages of the surveys, it was identified that some vehicles stopped only for a pedestrian to cross half width of the road and some of the vehicles stopped until a pedestrian cross the full width of the road. Considering these facts the survey form was modified to identify these two categories of vehicle and when calculating stopped delay of vehicles, stopped delay for a vehicle was taken as time for a pedestrian to cross half width of the road for a vehicle stopped only for a pedestrian to cross the half width of the road and time for a pedestrian to cross full width of the road is taken as stopped delay for a vehicle stopped until a pedestrian cross the full length of the road.

Pedestrian waiting time at curb was also examined, by stopwatch method. Waiting time was taken for randomly selected pedestrian during each 5min time interval.
The survey forms used are shown in Appendix 1, Appendix 2 and Appendix3.

CHAPTER 4. ANALYSIS

4.1 DATA ANALYSIS

Total delay at a pedestrian crossing consists of two parts, the vehicle delay and pedestrian delay. Vehicular delay due to pedestrian crossing activity can be further divided into three components as deceleration delay, stopped delay and acceleration delays. These are discussed in the Chapter 2. Acceleration and deceleration delays are not depend on the number of pedestrians cross the road but stopped delay mainly depend on pedestrian flow therefore in this study only stopped delay is considered.

The Time period that vehicle stopped to allow pedestrians to cross the road may vary depends on the crossing time of the pedestrians. It has been examined during the field surveys some vehicle stopped to cross full width of the road section and others to allow only half width of the road. Therefore, during the field survey these two categories have been counted separately. Crossing time also differs from site to site depending on the width and condition of the road and also it may differ from person to person depending on his or her age and physical condition. In this study, crossing time of a particular site has been taken pedestrians who are in good physical condition and cross the road without hesitation. Crossing time has been taken for number of pedestrians and average has been taken as an average crossing time for the particular site.

Therefore, total Stopped delay experienced by Vehicles that are stopped in each minute d_v is calculated as follow,

For vehicles that stopped to cross full width of the road

$$d_v = \text{number of Vehicles stopped during 1min period} \times \text{Average crossing time(s)}$$

For vehicles that stopped to cross half width of the road

$$= \text{number of Vehicles stopped during 1min period} \times \frac{\text{Average crossing time(s)}}{2}$$

Pedestrian delay dp is taken as

d_p=Average waiting time(s)×Total Pedestrian Flow per min

Average waiting time is taken as

$$= \frac{\text{Sum of waiting time}}{\text{Number of Pedestrians}}$$

It is clear that waiting cost per unit time of pedestrians and vehicles could differ significantly. Reducing waiting time results in corresponding economic value of time. Therefore when deriving total delay, it has to be assign a figure to the relative cost between vehicle delay and pedestrian delay according to the value of time. This criterion discussed in section 2.4.under the Cost of delay.

Values of times must be adjusted to reflect the appropriate value for the study year. If income surveys are not available, values must be adjusted using indices and the most rational index would be based on changes in per capita income. But in this case, relative value of time is derived; it is not needed to adjust VOT.

User Group	Urban	Rural	Intercity
Car	100.06	78.62	135.81
Van	51.15	37.62	51.15
Motor Cycle	19.05	27.00	14.29
Public Transport	10.83	12.41	12.41
Non Motorized Modes	6.78	8.62	0.00
All Motorized Modes(AV)*	24.61	23.01	28.81

Table 4.1 VOT for Transport User Groups (In 1999 Rs/Hour)

Source:Assessing Public Investment in the Transport Sector, Department of National Planning Ministry of Finance & Planning Colombo, Sri Lanka, September 2001.

**Assumed as being composed of 10% share for cars, vans and motorcycles respectively and 70% for public transport.*

Non-Motorized groups and All motorized Modes (AV) in urban area are considered when calculating relative cost from Table **Table 4.1.**

$$\text{Relative Cost between vehicle and pedestrian delay} = \frac{24.61}{6.78}$$

$$= 3.6$$

Accordingly, the pedestrian waiting times d_p obtained from the field survey were costed at nominal values of 1 unit / s and the vehicle delay d_v at a value of 3.6 unit /s. Therefore in this study, total delay is taken as Total delay d_{tot} is taken as,

$$d_{tot} = d_p + 3.6 d_v \qquad \textbf{Eq.4.1}$$

4.2 REGRESSION ANALYSIS

4.2.1 NUMBER OF VEHICLES STOPPED AND VOLUME OF PEDESTRIANS AND VEHICLES

The number of times vehicles are stopped by pedestrians at the crossing should be interaction between pedestrians and vehicles. In the study of traffic behavior at a pedestrian crossing, by Pillai (1972) following relationship was found in his study.

$$K = b_1 \times \sqrt{PV} + b_0 \qquad \textbf{Eq.4.2}$$

Where

K = The number of times vehicles are stopped by pedestrians while crossing the stream.

P= pedestrian volume per min (both side)

V = vehicle volume per min (both side)

b_1 and b_0 are constants.

Pillai's (1972) equation is dimensionless. In this study following dimensionless relationships were considered and regression analysis was carried out between PV and K for all the data collected from the sites. Data used to analysis is given in

Appendix 4.

Relationship	Equation	R-Squared Value
Linear	$K = 0.1085\,(pv)^{0.5} - 0.3412$	0.7293
Logarithmic	$K = 1.7355Ln(pv)^{0.5} - 3.2878$	0.7163
Power	$K = 0.0233\{(pv)^{0.5}\}^{1.4494}$	0.7276
Exponential	$K = 0.3032e^{0.0838(pv)0.5}$	0.6333

Table 4.2 Regression Results: Number of vehicles stopped and Volume of pedestrians and vehicles

Table 4.2 shows the results of regression analysis and the best-fit regression line is shown in **Fig4.1**

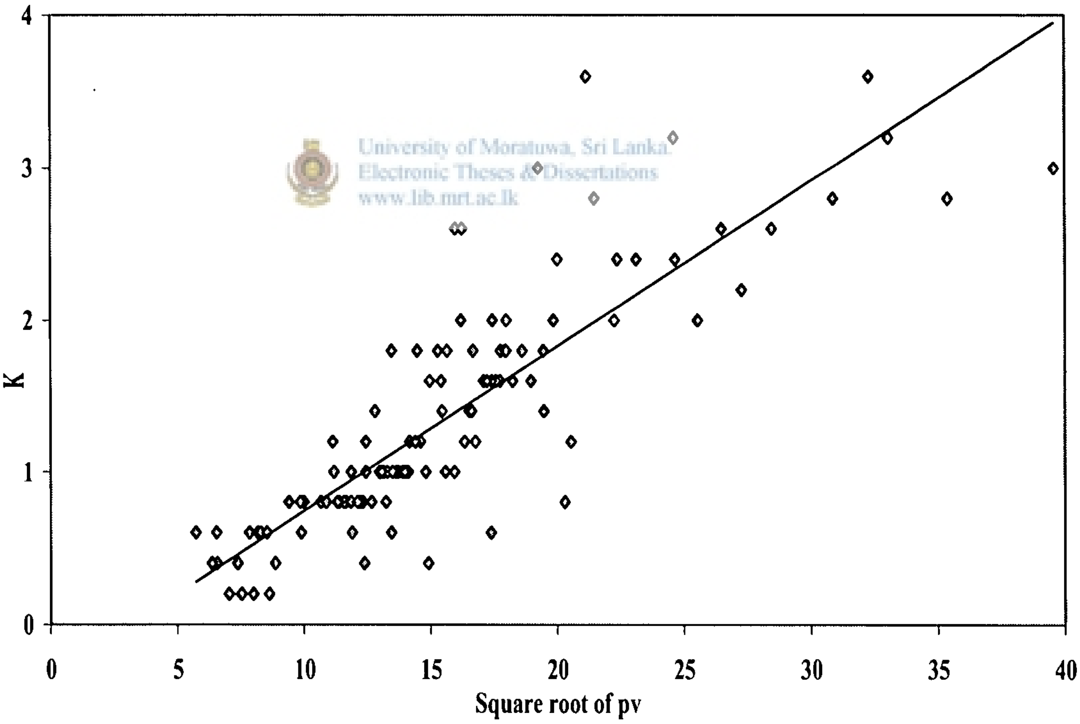

Fig. 4.1 Graph of Number of Times Vehicle Stopped Vs Square root of pv

The following equation was yielded from the field data

$$K = 0.1085\sqrt{PV} - 0.3412 \qquad \textbf{Eq.4.3}$$

"No special treatment zone".

This is a situation when, for the conditions of flows at the site, no conflict exits between a vehicle and a pedestrian. It means that the value of K will tends to zero and

$K \rightarrow 0$

$PV \rightarrow$ 10 ped/min. veh/min

4.2.2 TOTAL COST OF DELAY VS VOLUME OF PEDESTRIAN AND VEHICLES.

According to the study done by the Pillai (1972), there is a correlation between number of times vehicles are stopped by pedestrians at the crossing and square root of pedestrian into vehicle flow (**Eq.4.2**). This correlation is also taken into account in this section as total cost of delay is one-dimensional parameter therefore the squarer root of PV term should be PV. A regression analysis was carried out between total delay and PV, following results was obtained. Data used to analysis is given in Appendix 5.

Relationship	Equation	R-Squared Value
Linear	$y = 0.6971pv + 22.735$	0.6306
Logarithmic	$y = 54.871Ln(pv) - 138.19$	0.5275
Power	$y = 1.7719(pv)^{0.8491}$	0.5584
Exponential	$y = 25.624e^{0.0082pv}$	0.385

Table 4.3 Regression Results: Total Cost of Delay Vs Volume of Pedestrian and Vehicle.

Where,

P = pedestrian volume that affected particular direction of vehicle flow per mm

V = one directional vehicle volume per mm

A significant correlation (r = 0.6306), which is linear, has been found and it is plotted in **Fig.4.2**.and following best fit regression line is obtained.

$$d_{tot} = 0.6971\ PV + 22.735 \quad \textbf{Eq.4.4}$$

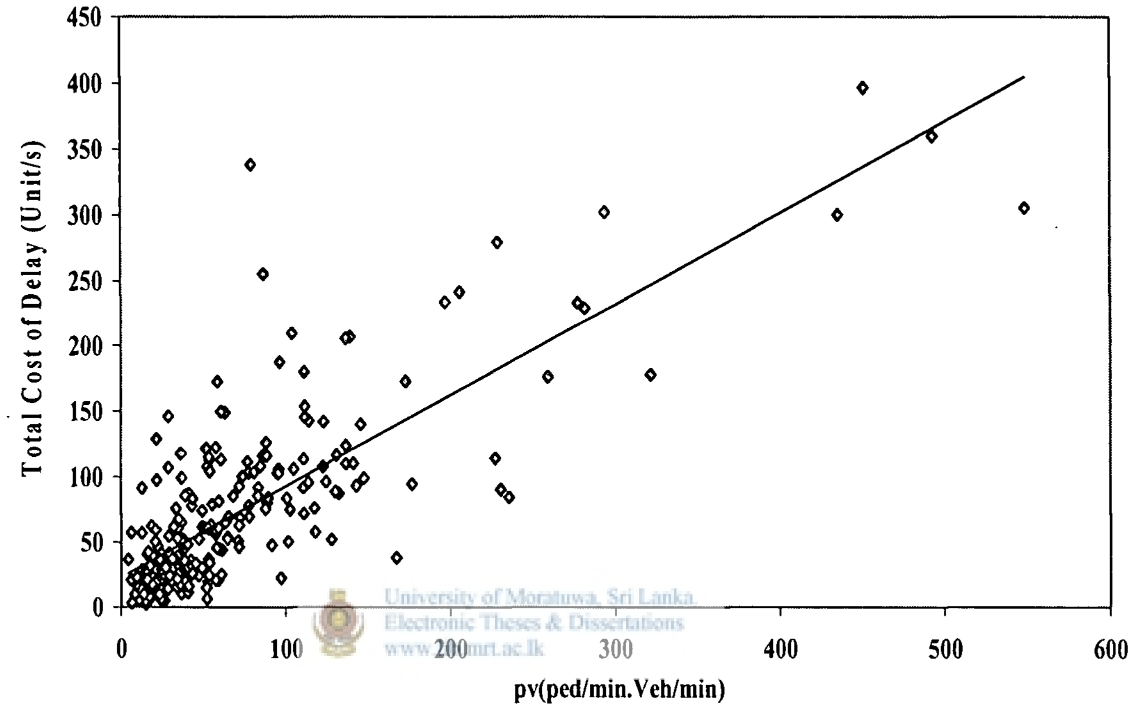

Fig. 4.2 Total Cost of Delay Vs pv

4.3 DELAYS AT SIGNALIZED CROSSINGS

Considering a two phase signal that is one phase allocated for the vehicles and other is allocated for the pedestrians, maximum and minimum cycle times were calculated by referring the **Table 2.1** assuming width of the road is greater than 12.5m for signal sequence used in Sri Lanka and maximum and minimum cycle times of 45 seconds and 67 seconds.

Pedestrian Aspect	Time Setting		Driver Aspect	Time Setting	
	Min	Max		Min	Max
Red man	-	-	Amber	3s	3s
Red man	1s	3s	Red	1s	3s
Green man	7s	7s	Red	7s	7s
Flashing green man	12s	12s	Red	12s	12s
Red man	2s	2s	Red	2s	2s
Red man	20s	40s	Green	20s	40s

Table 4.4 The Time Settings Assigned to the 'Fixed Time' Hypothetical Pelican Crossing.

The total cycle time C this case is 45seconds. Hence if one assume that pedestrians traverse during the 'steady green man' period of 7seconds and the following 6seconds of the flashing green man flashing amber period, then the average stopped delay per pedestrian is given by **Eq.2.2**

$$D_P = \frac{(C-G)^2}{2C}$$

$$= \frac{(45-7-6)^2}{2 \times 45}$$

$$= 11 seconds$$

The total delay for a sample of say 7 pedestrians per min is

D_{ptot} = 77 pedestrian seconds per min

If the vehicle volume of the road is 1200vehicles per hour and capacity of the road section is 1800 vehicles per hour.

Then

d = stopped delay per vehicle (seconds/vehicle), is given by **Eq.2.1**

$$d = 0.38C\frac{\left(1-\frac{g}{C}\right)^2}{1-\left(\frac{g}{C}\right)X} + 173X^2\left\{(X-1)+\sqrt{(X-1)^2+16\frac{X}{c}}\right\}$$

$$X = \frac{1200}{1800}$$
$$= 0.67$$

$c = 1800$ *vehicles per hour*

$$\frac{g}{C} = \frac{20}{45}$$
$$= 0.44$$

$$d_v = 0.38 \times 45 \times \frac{(1-0.44)^2}{1-0.44\times0.67} + 173\times0.67^2\left\{(0.67-1)+\sqrt{(0.67-1)^2+16\times\frac{0.67}{1800}}\right\}$$

$$D_{vtot} = 9\times\frac{1200}{60}\ vehicle\ \sec\ per\ \min$$
$$= 180\ vehicle\ \sec\ per\ \min$$

Therefore total cost for delay due to signalizing, **Eq.4.1**

$$d_{sig} = D_{ptot} + 3.6D_{vtot}$$

$$= 77 + 3.6\times180$$
$$= 725\ unit\ per\ \sec$$

Total cost for delay due to signalizing is examined for the different value of vehicle and pedestrian flow that were collected from the sites.

Total cost for delay at uncontrolled crossing is examined using the **Eq.4.4**

$$d_{tot} = 0.6971\ PV + 22.735$$

4.4 COMPARISON OF TOTAL COST FOR DELAY UNDER DIFFERENT CONTROLLED CROSSINGS

Pedestrian flow (P) and vehicle flow (V) in this equation represent for the one directional, and total cost for delay is calculated for both way flows as follows.

Assume P_1, V_1 and P_2, V_2 are pedestrian and vehicle flows from each direction respectively.

Then,

Total cost for delay at each direction,

$$d_1 = 0.6971\ P_1 V_1 + 22.735$$

And

$$d_2 = 0.6971\ P_2 V_2 + 22.735$$

Total cost for delay on both way flows are taken as sum of d_1 and d_2.

Comparison is done between uncontrolled and signalized crossing under the different vehicle flow value and the maximum and minimum cycle time.

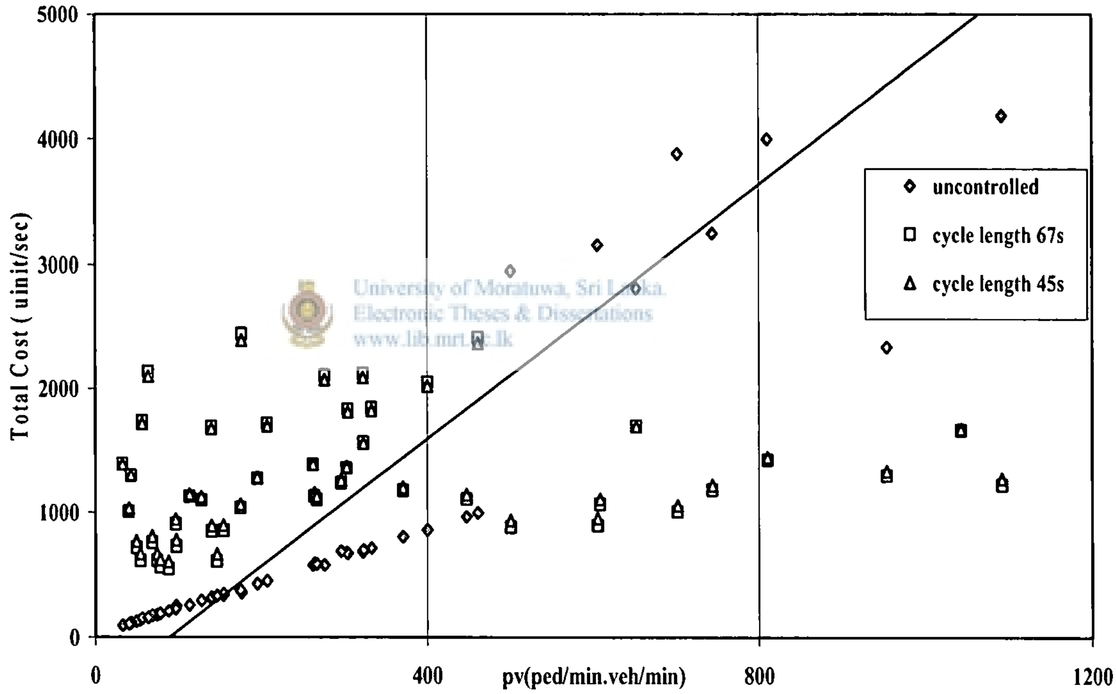

Fig.4.3 Comparison of Total Cost for Delay between Controlled and Uncontrolled Crossing at Vehicle Flow less than 30veh/min

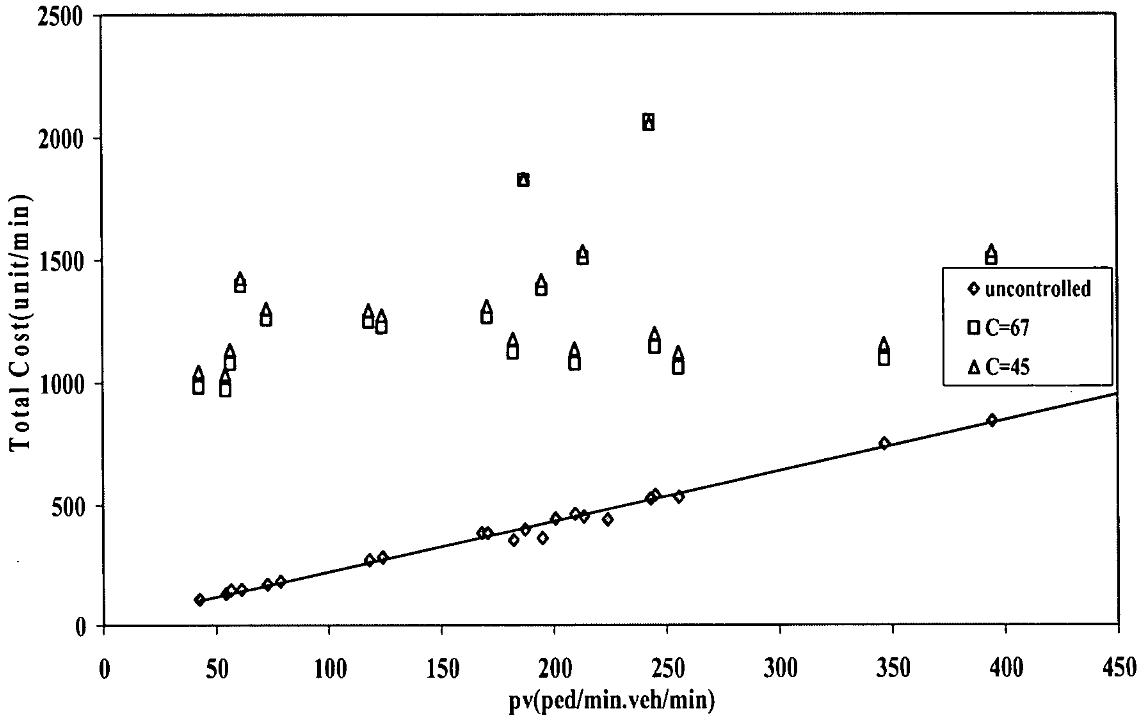

Fig.4.4.Comparison of Total Cost for Delay between Controlled and Uncontrolled Crossing at Vehicle Flow between 40veh/min and 30veh/min

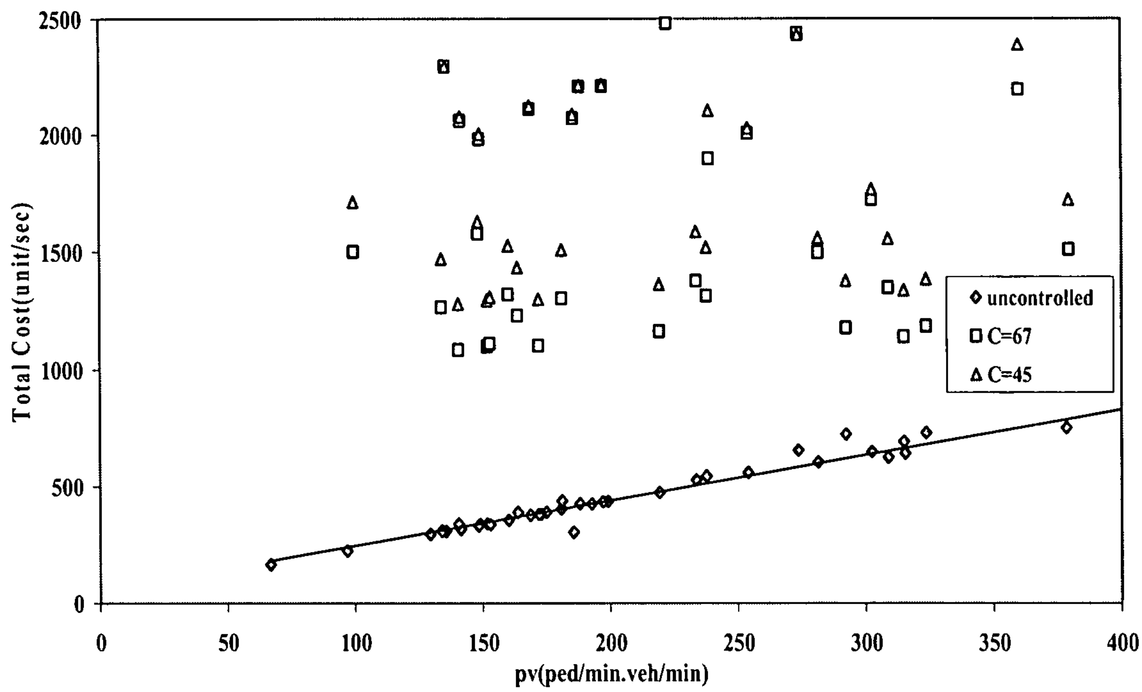

Fig.4.5.Comparison of Total Cost for Delay between Controlled and Uncontrolled Crossing at Vehicle Flow above 40veh/min

Fig.4.3 shows that comparison of total costs for delay between controlled and uncontrolled crossing at vehicle flow 30veh/min. Data which used in analysis is shown in Appendix 6. Total cost for delay at controlled crossing is higher than uncontrolled crossing below the pv value at about 400 ped/min.veh/min. when the pv value increases total cost for delay at controlled crossing is lesser than uncontrolled crossing. It also shows that total cost for delay for cycle length at 45s is lesser than that value for cycle length at 67s.

Fig.4.4 shows that comparison of total cost for delay between controlled and uncontrolled crossing at vehicle flow between 30vehlmin to 40vehlmin and used data is given in Appendix 7. Total cost for delay at controlled crossing is higher than uncontrolled crossing and variation is not appeared as above case.

Fig.4.5 shows that comparison of total cost for delay between controlled and uncontrolled crossing at vehicle flow above 40 veh/min and relevant data is given in Appendix 8. This graph also shows the same characteristics as above.

Therefore, no reduction in total delay by introducing signal controlled crossing to uncontrolled crossing when the vehicle flow is greater than 30 veh/min and there is significant reduction of total cost where vehicle flow is less than 30 veh/min and pv is greater than 400 ped/min.veh/min.

4.5 WARRANTS FOR UNCONTROLLED AND CONTROLLED CROSSINGS

'No special treatment zone' this is a situation when, the PV value is not greater than 10 ped/min.veh/min (total both direction) there does not exit any conflict and there are sufficient gaps available for pedestrians to cross the road. As such, no special treatment is required.A location where PV value exceeds 10 ped/min.veh/min then an uncontrolled crossing (Zebra) may be required.

Total cost for delay on signal controlled crossing is lesser than that of uncontrolled crossing when the vehicle flow is lesser than 30 veh/min and for higher value of pv

400 ped/min.veh/min (**Fig.4.3**) and vehicle flow exceed 30vehlmin total cost for delay is higher than that of uncontrolled crossing. (**Fig.4.4, Fig.4.5**)

Therefore, signal controlled crossing is feasible where vehicle volume on the road not exceeds 30 veh/min (total both direction) and pv value exceeds 400 ped/min.veh/min under the consideration of total cost of delay and it is not feasible vehicle flow is on the road exceeds 30veh/min.

The relationship between total cost for delay and pv **Eq.4.4** can be used as decision making tool when limited resources available to installation of signal controlled crossing among the several places.

If the signal-controlled location is considered, cycle length and time duration for vehicle can be designed according to vehicle flow and pedestrian flow at that location. Vehicle and pedestrian delay can be calculated due to introducing signal-controlled crossing. Total cost for delay due to signalizing dsig can be taken as sum of pedestrian and 3.6 times into vehicle delay **Eq.4.1**

$$d_{tot} = d_p + 3.6d_v$$

If vehicle flow in each direction V_1 and V_2 and pedestrian flow P_1 and P_2 respectively, then total cost for delay at uncontrolled crossing in each direction will be d_{t1} and d_{t2} according to **Eq.4.4**

Then total delay at the particular location when it is uncontrolled crossing is.

$$d_{tot} = d_{t1} + d_{t2}$$

Comparing d_{sig} and d_{tot} for all locations that are considered for signalizing, decision can be made which place would be the best to install signal control crossing or uncontrolled crossing.

CHAPTER 5. CONCLUSION AND RECOMMENDATIONS

5.1 INTRODUCTION

Objective of this study has been develop numerical guidelines to assist in determining the appropriate crossing facility for a given location of a road based on the relationship between pedestrian and vehicle flow and their delays. In order to accomplish this objective, the study was carried out following way. First, delay relationships were developed between pedestrian and vehicle flow based on survey data obtained from different uncontrolled crossings. Second, total delays were obtained for controlled crossing using standard mathematical delay functions for different ranges of pedestrian and vehicle volumes. Third, these total delay relationships were analyzed to appropriate crossing facilities for given pedestrian and vehicle volumes. The findings of this study are summarized as the following conclusions and recommendations:

5.2 CONCLUSION

a) There are number of alternative methods of crossing facilities which are uncontrolled crossings (Zebra), signal controlled crossings and complete segregation of pedestrians and vehicles by means of under-passes or overpasses and there should be a criteria to decide which of these methods can be applied to individual sites.

b) When a pedestrian crossing installation is being determined the extent of pedestrian traffic flow has to be taken into account as well as that of vehicular traffic whilst exercising due care and attention, with the minimum delay to both parties.

c) If the pv value does not exceed 10 ped/min.veh/min there are sufficient gaps available to cross the road without any conflict, as such situation 'no special treatment' is required. A location where PV value exceeds 10 ped/min.veh/min then an uncontrolled crossing (Zebra) may be required.

d) Signal controlled crossing may be provided where vehicle volume on the road not exceeds 30 veh/min (total both direction) and pv value exceeds 400 ped/min.veh/min under the consideration of total cost of delay and it is not feasible vehicle flow is on the road exceeds 30veh/min.

e) Although the segregation of pedestrian and vehicles by means of under-passes or overpasses can provide the safest mean of achieving the crossing the roads, it may not be sufficient to consider cost of delay in justifying grade separation crossings, as the generally highest capital cost of providing the structures.

f) The total cost for delay vs pv function **Eq.4.4** and signal delay functions for pedestrians and vehicles can be used as decision making tool when limited resources available to installation of signal controlled crossing at several places.

e) Priority should be given for providing of crossing on a location where direct route to/from a significant generator of pedestrian traffic such as schools, hospitals, markets and shopping malls

5.3 RECOMMENDATIONS

The following recommendations are based upon the analysis and conclusions. They are intended to point out needed future research.

a) In special circumstances where there is an above average number of inform of handicapped pedestrians, school children, then the criteria of determining crossing facility may differ and innovative crossing facilities may be required.

b) In addition to numerical warrants, a careful engineering study should be conducted before installation of pedestrian crossing facility such as grade separated, rather than set numerical warrants and guides.

REFERENCES:

Adams, W.F. "Road traffic considered as a random series:" J. Inst. Civil Eng. 4:1936, pp 121-130.

AUSTROADS "Guide to Traffic Engineering Practice Pedestrians, Part 13". The National Association of Road Transport and Traffic Authorities in Australia, 1995.

Braun, R. and M. Roddin. NCHRP Report 189: "Quantifying the benefits of separating pedestrians and vehicle. TRB, National Research Council, Washington, D.C. 1978

Brundell-Freij, K. & Ekman, L., "Flow and safety -Some aspects on the relationship with special respect to unprotected road users", Paper presented at TRB Annual Meeting, Washington D.C. 1991

C.V. Zegeer, S.F. Zegeer, "Pedestrians and Traffic Control Measures", Washington, D.C.: Transportation Research Board, 1988

Daniel L, Gerlough, Matthew J.Huber, "Traffic Flow Theory", TRB Special Report 165, Transportation Research Board, National Research Council, Washington, D.C.1975

Department of Transport., "Pelican crossings: Pelican crossing operation." Departmental Standard TD/4/79, London, 1979.

Ekman, L., Farthinder på Boråsvägen i Kinna, "Speed reducing measures on the Borås road in Kinna". Inst. för Trafikteknik, LTH. Lund 1983

Evans, L., "Human behavior feedback and traffic safety. Human Factors", 1985 Vol.27, 5 55-576.

Füsser.K, "New Concept for Pedestrian Crossing Facilities, Safety and Design". 1995,

Griffiths, J.D, Hunt, J.G, and Cresswell, C., "Warrants for zebra and pelican crossings using minimum cost criterion", Traffic Engineering and Control, 1979.

Guidelines for Traffic Facilities, part 4.3, Grade Separated Pedestrian Facilities, Roads and Traffic Authority of New South Wales, 1987.

Herms, B.F., "Pedestrian crosswalk study accidents in painted and unpainted crosswalks." Highway Research Records, 1972, pp406, 1-13.

Hydén, C., Gårder, P. & Linderholm, L., Samband mellan olycksrisk och olika förklaringsvariabler. "Relation between accident risk and different explaining variables". LTH Bulletin 27, 1978.

Pillai,K.S.,"A study of traffic behavior at a pedestrian crossing. PhD Thesis. University of Birmingham, September1972.

Pillai, K.S., "Warrants for different types of pedestrian crossing based on delay to vehicles", Traffic Engineering and Control, 16(3), March 1975, 118-120

Smeed, R.J., "Theoretical studies and operational research of traffic and t traffic congestion." Bull. Int.Stat.36 (4), 1958

Tanner. J.C. "The delay to pedestrians crossing a road", Biometrica, 1951, pp38.

Underwood, R.T., "Tentative warrants for the installation of pedestrian crossings." Res. Memo. No 13. Country Roads Board, Victoria l95'7, p.1819Lv

Smeed, R.J., "Theoretical studies and operational research of traffic and traffic congestion." Bull. Int.Stat.36 (4), 1958

Tanner. J.C. "The delay to pedestrians crossing a road", Biometrica, 1951, pp38.

Underwood, R.T., "Tentative warrants for the installation of pedestrian crossings." Res. Memo. No 13. Country Roads Board, Victoria l95'7, p.1819Lv

Appendix 1

University of Moratuwa

Pedestrian and Vehicle Count at Pedestrian Crossing

Location :
Date :
Time : to

Vehicle Flow

Time Interval (min)	5	10	15	20	25	30	35	40	45	50	55	60
No. of Vehicles towards ----------------												
No. of Vehicles towards ----------------												

Pedestrian Flow

Time Interval (min)	5	10	15	20	25	30	35	40	45	50	55	60
No. of Pedestrians from ----------------												
No. of Pedestrians from ----------------												

Crossing Time (sec)												

Appendix 2

University of Moratuwa

Pedestrian and Stoppped Vehicle Count at Pedestrian Crossing

Location :
Date :
Time : to

Vehicle Flow towards -------------------------------

Time	# of Pedestrians who cross the road by stopping vehicles		# of Stopped Vehicles	
	to	from	Half width of the road	Full width of the road

Appendix 3

University of Moratuwa
Pedestrian Waiting time at Pedestrian Crossing

Location :
Date :
Time : to

Vehicle Flow towards ------------------------------

Pedestrian waiting time (sec)											
5	10	15	20	25	30	35	40	45	50	55	60

Appendix 4

Location	Pedestrian Flow per min (P)	Vehicle Flow per min (V)	Number of Stoppings permin (K)
Maliban	3.6	48.6	0.8
Maliban	3.8	47.6	0.6
Maliban	2	48.4	0.8
Maliban	5.8	43.8	1
Maliban	6.2	50.8	1.6
Maliban	4.2	47.4	1
Maliban	2.8	79.4	0.4
Maliban	4.2	52.2	1
Maliban	3	45.2	0.8
Maliban	4.2	44.8	1
Maliban	3.6	48	1
Maliban	2.4	55.8	0.8
Mount Lavinia	3	50.6	0.8
Mount Lavinia	2.8	46.2	0.8
Mount Lavinia	4	48.2	1
Mount Lavinia	3	51	0.4
Mount Lavinia	3.2	44.2	0.6
Mount Lavinia	4.4	44.8	1
Mount Lavinia	7.2	42	0.6
Mount Lavinia	3.4	43.8	0.8
Mount Lavinia	3.6	41.2	0.8
Mount Lavinia	1.4	47.6	0.6
Mount Lavinia	2	39.2	0.4
Mount Lavinia	3.4	50.6	1
House of fashion	6	29.4	1
House of fashion	3.8	32.6	1.2
House of fashion	5.2	24	1
House of fashion	5.2	36	1
House of fashion	6.2	61.2	1.4
House of fashion	7	40.2	1.2
House of fashion	3.8	44.4	1
House of fashion	5.4	57.2	1.6
House of fashion	8.8	60.8	2.4
House of fashion	7.6	49.8	1.8
House of fashion	6.6	47.8	1.8

House of fashion	4.8	75	1.6
Matara bus stand	31	24	2.2
Matara bus stand	23.8	27.4	2
Matara bus stand	26	23.4	2.4
Matara bus stand	39.4	24.2	2.8
Matara bus stand	31.4	25.8	2.6
Matara bus stand	23.4	21.4	2.4
Matara bus stand	32.2	21.8	2.6
Matara bus stand	49.2	22.2	3.2
Matara bus stand	53.6	29.2	3
Matara bus stand	29.4	20.6	3.2
Matara bus stand	52.6	23.8	2.8
Matara bus stand	39.2	26.6	3.6
Matara Hospital	11.6	34	2
Matara Hospital	15.8	29.2	2.8
Matara Hospital	16.4	30.2	2
Matara Hospital	14	28.6	2.4
Matara Hospital	9.8	26.8	2
Matara Hospital	7.8	31.4	1.8
Matara Hospital	8.4	30.4	2.6
Matara Hospital	10.8	28.2	2
Matara Hospital	10.4	25.4	2.6
Matara Hospital	18.2	24.6	3.6
Matara Hospital	14.6	25.4	3
Matara Hospital	6.8	30.8	1.8
Bambalapitiya Kovil	9	45.8	0.8
Bambalapitiya Kovil	5.8	38.6	1.6
Bambalapitiya Kovil	6	45.6	1.4
Bambalapitiya Kovil	6.6	36.8	1
Bambalapitiya Kovil	4.2	44.2	1
Bambalapitiya Kovil	5.2	81.2	1.2
Bambalapitiya Kovil	5.8	31.4	1
Bambalapitiya Kovil	4.4	22.2	0.6
Bambalapitiya Kovil	7	25	0.8
Bambalapitiya Kovil	6.2	34.4	1.2
Bambalapitiya Kovil	5.8	33.6	1
Bambalapitiya Kovil	4.2	40	1
Borralasgarnuwa	6.2	52.2	2
Borralasgarnuwa	3.2	56.6	1.8
Borralasgarnuwa	5.6	52.2	1.6

Borralasgarnuwa	3.4	81.8	1.8
Borralasgarnuwa	5.2	38.6	1.2
Borralasgarnuwa	2.8	50.2	1
Borralasgarnuwa	4.2	56.6	1.6
Borralasgarnuwa	3	54.6	1.4
Borralasgarnuwa	1.6	62.2	0.8
Borralasgarnuwa	3.4	70.2	1.4
Borralasgarnuwa	2.8	57.2	0.8
Borralasgarnuwa	4	58.4	1.8
Botree	5	28	0.8
Botree	11.4	26.6	1.6
Botree	9.6	28.8	1.4
Botree	6.6	23.4	1
Botree	11.2	28.8	1.8
Botree	11.4	30.4	1.8
Botree	7.4	28	1.2
Botree	11.4	26	1.6
Botree	7.4	26.4	1
Botree	10.6	25.2	1.2
Botree	11.8	28.2	1.6
Botree	11.8	27.4	1.8
Matara St.Thomas	3.6	20.6	0.2
Matara St.Thomas	6	23.4	0.8
Matara St.Thomas	4	19.6	0.4
Matara St.Thomas	4	24.2	0.8
Matara St.Thomas	6.6	23.4	1.2
Matara St.Thomas	5	25.6	0.8
Matara St.Thomas	7.4	19.8	0.8
Matara St.Thomas	4.4	25.8	0.8
Matara St.Thomas	2.6	20.8	0.4
Matara St.Thomas	2.2	22.4	0.2
Matara St.Thomas	4.6	19.2	0.8
Matara St.Thomas	3	22.8	0.6
Papiliyana	2	28.2	0.2
Papiliyana	1.8	30.2	0.4
Papiliyana	1.8	31.4	0.2
Papiliyana	1.2	27.2	0.6
Papiliyana	1.6	26.8	0.4
Papiliyana	2.2	29	0.2
Papiliyana	1.6	25.2	0.4

Papiliyana	5.2	32.8	1
Papiliyana	1.8	34	0.6
Papiliyana	1.4	30.4	0.6
Papiliyana	3.6	32.8	0.8
Papiliyana	2.2	33	0.6

Appendix 5

Location	Pedestrian Flow per min (P)	Vehicle Flow per min (V)	Number of Stopped Vehicles in		Average Crossing Time	Stopped Delay (s) during 5min	Average Waiting Time (s)	Pedestrian Waiting Cost (unit/s)	Vehicle Stopped Delay Cost	Total Cost of Delay (unit/s)
			During 1/2 width to	During full width to						
Maliban	2.0	26.4	1	0	11.72	5.86	7.57	15.14	4.22	19.36
Maliban	1.6	24.0	8	0	11.72	46.88	7.23	11.57	33.75	45.32
Maliban	1.2	28.0	16	0	11.72	93.76	6.79	8.15	67.51	75.66
Maliban	2.6	23.6	6	0	11.72	35.16	7.13	18.54	25.32	43.85
Maliban	2.8	29.8	17	0	11.72	99.62	6.99	19.57	71.73	91.30
Maliban	2.4	27.0	8	0	11.72	46.88	8.17	19.61	33.75	53.36
Maliban	2.0	29.6	1	0	11.72	5.86	8.22	16.44	4.22	20.66
Maliban	3.2	27.8	13	0	11.72	76.18	7.78	24.90	54.85	79.75
Maliban	1.4	22.0	4	0	11.72	23.44	7.48	10.47	16.88	27.35
Maliban	2.8	20.6	1	0	11.72	5.86	5.91	16.55	4.22	20.77
Maliban	1.4	21.0	3	0	11.72	17.58	6.21	8.69	12.66	21.35
Maliban	0.8	29.4	0	0	11.72	0.00	8.23	6.58	0.00	6.58
Maliban	1.6	22.2	10	0	11.72	58.60	6.88	11.01	42.19	53.20
Maliban	2.2	23.6	0	0	11.72	0.00	6.75	14.85	0.00	14.85
Maliban	0.8	20.4	0	0	11.72	0.00	5.68	4.54	0.00	4.54
Maliban	3.2	20.2	8	0	11.72	46.88	5.87	18.78	33.75	52.54
Maliban	3.4	21.0	7	0	11.72	41.02	6.17	20.98	29.53	50.51
Maliban	1.8	20.4	0	0	11.72	0.00	5.64	10.15	0.00	10.15
Maliban	0.8	49.8	4	0	11.72	23.44	7.68	6.14	16.88	23.02
Maliban	1.0	24.4	8	0	11.72	46.88	7.24	7.24	33.75	40.99
Maliban	1.6	23.2	4	0	11.72	23.44	6.41	10.26	16.88	27.13
Maliban	1.4	24.2	6	0	11.72	35.16	7.60	10.64	25.32	35.96
Maliban	2.2	27.0	7	0	11.72	41.02	6.92	15.22	29.53	44.76
Maliban	1.6	26.4	6	0	11.72	35.16	6.50	10.40	25.32	35.72
MountLavinia	1.8	27.6	4	0	11.29	22.58	6.23	11.21	16.26	27.47
Mount Lavinia	2.0	23.6	10	0	11.29	56.45	5.83	11.66	40.64	52.30
Mount Lavinia	1.6	22.8	14	0	11.29	79.03	4.91	7.86	56.90	64.76
Mount Lavinia	1.4	25.6	5	0	11.29	28.23	5.27	7.38	20.32	27.70

MountLavinia	2.0	24.6	5	0	11.29	28.23	4.84	9.68	20.32	30.00
MountLavinia	2.6	23.4	24	0	11.29	135.48	5.95	15.47	97.55	113.02
MountLavinia	4.2	24.2	6	0	11.29	33.87	6.15	25.83	24.39	50.22
MountLavinia	1.6	21.6	15	0	11.29	84.68	3.67	5.87	60.97	66.84
MountLavinia	2.2	22.4	12	0	11.29	67.74	5.77	12.69	48.77	61.47
MountLavinia	0.6	24.4	0	0	11.29	0.00	4.66	2.80	0.00	2.80
Mount Lavinia	1.2	20.4	6	0	11.29	33.87	3.70	4.44	24.39	28.83
MountLavinia	2.4	26.4	33	0	11.29	186.29	6.20	14.88	134.13	149.01
MountLavinia	1.2	23.0	3	0	11.29	16.94	5.73	6.88	12.19	19.07
MountLavinia	0.8	22.6	5	0	11.29	28.23	5.16	4.13	20.32	24.45
Mount Lavinia	2.4	25.4	3	0	11.29	16.94	5.34	12.82	12.19	25.01
MountLavinia	1.6	25.4	0	0	11.29	0.00	6.99	11.18	0.00	11.18
MountLavinia	1.2	19.6	4	0	11.29	22.58	3.24	3.89	16.26	20.15
MountLavinia	1.8	21.4	6	0	11.29	33.87	6.34	11.41	24.39	35.80
MountLavinia	3.0	17.8	3	0	11.29	16.94	4.09	12.27	12.19	24.46
MountLavinia	1.8	22.2	2	0	11.29	11.29	5.31	9.56	8.13	17.69
MountLavinia	1.4	18.8	0	0	11.29	0.00	3.43	4.80	0.00	4.80
MountLavinia	0.8	23.2	14	0	11.29	79.03	6.55	5.24	56.90	62.14
MountLavinia	0.8	18.8	0	0	11.29	0.00	2.38	1.90	0.00	1.90
Mount Lavinia	1.0	24.2	0	0	11.29	0.00	5.70	5.70	0.00	5.70
House of fashion	4.4	19.6	4	12	8.87	124.18	6.03	26.53	89.41	115.94
House of fashion	2.4	15.6	8	2	8.87	53.22	5.70	13.68	38.32	52.00
House of fashion	4.4	16.4	7	3	8.87	57.66	6.16	27.10	41.51	68.62
House of fashion	3.8	20.4	8	8	8.87	106.44	6.95	26.41	76.64	103.05
House of fashion	4.8	27.6	12	2	8.87	70.96	7.54	36.19	51.09	87.28
House of fashion	5.6	21.0	3	5	8.87	57.66	6.16	34.50	41.51	76.01
House of fashion	2.2	23.0	14	0	8.87	62.09	7.31	16.08	44.70	60.79
House of fashion	4.4	33.6	16	2	8.87	88.70	7.96	35.02	63.86	98.89
House of fashion	6.6	34.4	12	5	8.87	97.57	6.63	43.76	70.25	114.01
House of fashion	5.6	31.6	17	0	8.87	75.40	7.18	40.21	54.28	94.49
House of fashion	5.0	28.6	17	0	8.87	75.40	7.76	38.80	54.28	93.08
House of fashion	4.0	32.6	15	2	8.87	84.27	6.99	27.96	60.67	88.63
House of fashion	1.6	9.8	0	5	8.87	44.35	5.31	8.50	31.93	40.43

House of fashion	1.4	17.0	4	2	8.87	35.48	5.01	7.01	25.55	32.56
House of fashion	0.8	7.6	5	0	8.87	22.18	6.08	4.86	15.97	20.83
House of fashion	1.4	15.6	4	0	8.87	17.74	6.37	8.92	12.77	21.69
House of fashion	1.4	33.6	5	0	8.87	22.18	5.83	8.16	15.97	24.13
House of fashion	1.4	19.2	2	3	8.87	35.48	5.88	8.23	25.55	33.78
House of fashion	1.6	21.4	6	0	8.87	26.61	6.43	10.29	19.16	29.45
House of fashion	1.0	23.6	8	0	8.87	35.48	7.90	7.90	25.55	33.45
House of fashion	2.2	26.4	9	0	8.87	39.92	7.60	16.72	28.74	45.46
House of fashion	2.0	18.2	4	0	8.87	17.74	6.00	12.00	12.77	24.77
House of fashion	1.6	19.2	6	0	8.87	26.61	6.12	9.79	19.16	28.95
House of fashion	0.8	42.4	2	0	8.87	8.87	11.18	8.94	6.39	15.33
Matarabusstand	22.0	12.8	19	0	13.39	127.21	6.24	137.28	91.59	228.87
Matarabusstand	15.8	16.4	18	0	13.39	120.51	5.65	89.27	86.77	176.04
Matara bus stand	14.0	4.2	20	0	13.39	133.90	5.43	76.02	96.41	172.43
Matara bus stand	25.4	21.6	27	0	13.39	180.77	6.90	175.26	130.15	305.41
Matarabusstand	19.8	14.0	24	0	13.39	160.68	5.93	117.41	115.69	233.10
Matarabusstand	12.0	11.6	29	0	13.39	194.16	5.57	66.84	139.79	206.63
Matara bus stand	19.8	10.4	26	0	13.39	174.07	5.86	116.03	125.33	241.36
Matarabus stand	38.2	11.8	38	0	13.39	254.41	5.58	213.16	183.18	396.33
Matarabusstand	34.0	12.8	22	0	13.39	147.29	5.71	194.14	106.05	300.19
Matarabusstand	16.4	12.0	30	0	13.39	200.85	5.43	89.05	144.61	233.66
Matarabusstand	32.0	15.4	33	0	13.39	220.94	6.27	200.64	159.07	359.71
Matarabusstand	21.6	13.6	39	0	13.39	261.11	5.29	114.26	188.00	302.26
Matarabusstand	9.0	11.2	6	0	13.39	40.17	6.07	54.63	28.92	83.55
Matarabusstand	8.0	11.0	4	0	13.39	26.78	7.00	56.00	19.28	75.28
Matara bus stand	12.0	19.2	3	0	13.39	20.09	6.32	75.84	14.46	90.30
Matarabusstand	14.0	2.6	12	0	13.39	80.34	4.27	59.78	57.84	117.62
Matarabusstand	11.6	11.8	6	0	13.39	40.17	6.98	80.97	28.92	109.89
Matarabusstand	11.4	9.8	19	0	13.39	127.21	5.44	62.02	91.59	153.60
Matarabusstand	12.4	11.4	7	0	13.39	46.87	6.16	76.38	33.74	110.13
Matara bus stand	11.0	10.4	16	0	13.39	107.12	5.95	65.45	77.13	142.58
Matarabusstand	19.6	16.4	9	0	13.39	60.26	6.86	134.46	43.38	177.84
Matara bus stand	13.0	8.6	14	0	13.39	93.73	5.97	77.61	67.49	145.10

Matara bus stand	20.6	8.4	10	0	13.39	66.95	6.04	124.42	48.20	172.63
Matarabusstand	17.6	13.0	34	0	13.39	227.63	6.55	115.28	163.89	279.17
Matara Hospital	6.4	19.2	15	3	9.30	97.65	5.88	37.63	70.31	107.94
Matara Hospital	7.6	16.4	15	0	9.30	69.75	6.08	46.21	50.22	96.43
MataraHospital	9.0	15.2	11	4	9.30	88.35	6.66	59.94	63.61	123.55
Matara Hospital	6.2	12.8	20	36	9.30	427.80	4.91	30.44	308.02	338.46
Matara Hospital	5.8	13.4	9	3	9.30	69.75	4.71	27.32	50.22	77.54
Matara Hospital	3.4	17.0	17	7	9.30	144.15	5.40	18.36	103.79	122.15
Matara Hospital	5.6	18.6	41	6	9.30	246.45	5.68	31.81	177.44	209.25
Matara Hospital	4.2	15.6	14	0	9.30	65.10	5.28	22.18	46.87	69.05
MataraHospital	3.8	14.2	28	0	9.30	130.20	4.98	18.92	93.74	112.67
Matara Hospital	7.0	12.4	28	19	9.30	306.90	4.86	34.02	220.97	254.99
Matara Hospital	7.8	12.4	21	12	9.30	209.25	4.69	36.58	150.66	187.24
Matara Hospital	3.6	14.6	16	5	9.30	120.90	5.75	20.70	87.05	107.75
MataraHospital	5.2	14.8	23	0	9.30	106.95	6.62	34.42	77.00	111.43
Matara Hospital	8.2	12.8	17	0	9.30	79.05	5.96	48.87	56.92	105.79
Matara Hospital	7.4	15.0	10	5	9.30	93.00	6.29	46.55	66.96	113.51
NiataraHospital	7.8	15.8	28	0	9.30	130.20	6.17	48.13	93.74	141.87
MataraHospital	4.0	13.4	18	5	9.30	130.20	5.31	21.24	93.74	114.98
MataraHospital	4.4	14.4	5	3	9.30	51.15	6.33	27.85	36.83	64.68
MataraHospital	2.8	11.8	14	0	9.30	65.10	4.06	11.37	46.87	58.24
Matara Hospital	6.6	12.6	16	0	9.30	74.40	4.82	31.81	53.57	85.38
MataraHospital	6.6	11.2	17	2	9.30	97.65	4.52	29.83	70.31	100.14
MataraHospital	11.2	12.2	39	2	9.30	199.95	5.51	61.71	143.96	205.68
MataraHospital	6.8	13.0	24	0	9.30	111.60	6.71	45.63	80.35	125.98
Matara Hospital	3.2	16.2	30	0	9.30	139.50	6.56	20.99	100.44	121.43
Bambalapitiya Kovil	6.4	36.8	10	0	12.78	63.90	5.97	38.21	46.01	84.22
BambalapitiyaKovil	3.6	32.8	8	0	12.78	51.12	5.83	20.99	36.81	57.79
Bambalapitiya Kovil	2.4	39.6	7	6	12.78	121.41	6.33	15.19	87.42	102.61
BambalapitiyaKovil	3.4	30.2	12	0	12.78	76.68	5.77	19.62	55.21	74.83
BambalapitiyaKovil	3.2	40.0	7	0	12.78	44.73	6.18	19.78	32.21	51.98
BambalapitiyaKovil	2.2	76.0	5	0	12.78	31.95	6.83	15.03	23.00	38.03
BambalapitiyaKovil	3.8	25.6	0	0	12.78	0.00	5.88	22.34	0.00	22.34

l3ambalapitiyaKovil	1.6	17.8	3	0	12.78	19.17	4.22	6.75	13.80	20.55
BambalapitiyaKovil	4.0	18.0	16	0	12.78	102.24	4.71	18.84	73.61	92.45
Bambalapitiya Kovil	3.4	28.2	19	0	12.78	121.41	5.36	18.22	87.42	105.64
BambalapitiyaKovil	4.0	27.8	11	0	12.78	70.29	5.35	21.40	50.61	72.01
BambalapitiyaKovil	2.0	35.8	8	0	12.78	51.12	4.60	9.20	36.81	46.01
Bambalapitiya Kovil	2.6	9.0	4	0	12.78	25.56	6.91	17.97	18.40	36.37
Bambalapitiya Kovil	2.2	5.8	3	7	12.78	108.63	6.00	13.20	78.21	91.41
BambalapitiyaKovil	3.6	6.0	15	4	12.78	146.97	6.31	22.72	105.82	128.53
Bambalapitiya Kovil	3.2	6.6	0	0	12.78	0.00	5.89	18.85	0.00	18.85
Bambalapitiya Kovil	1.0	4.2	7	0	12.78	44.73	4.26	4.26	32.21	36.47
Bambalapitiya Kovil	3.0	5.2	2	0	12.78	12.78	5.58	16.74	9.20	25.94
BambalapitiyaKovil	2.0	5.8	0	0	12.78	0.00	5.59	11.18	0.00	11.18
BambalapitiyaKovil	2.8	4.4	3	0	12.78	19.17	5.23	14.64	13.80	28.45
BambalapitiyaKovil	3.0	7.0	9	0	12.78	57.51	6.00	18.00	41.41	59.41
Bambalapitiya Kovil	2.8	6.2	0	0	12.78	0.00	5.84	16.35	0.00	16.35
BambalapitiyaKovil	1.8	5.8	0	0	12.78	0.00	5.58	10.04	0.00	10.04
BambalapitiyaKovil	2.2	4.2	0	0	12.78	0.00	5.17	11.37	0.00	11.37
Borralasgamuwa	2.0	30.4	43	0	8.99	193.29	5.24	10.48	139.17	149.65
Borralasgamuwa	0.8	36.0	22	11	8.99	197.78	4.33	3.46	142.40	145.87
Borralasgamuwa	1.0	34.6	17	0	8.99	76.42	5.44	5.44	55.02	60.46
Borralasgamuwa	1.2	65.0	19	0	8.99	85.41	6.46	7.75	61.49	69.24
Borralasgamuwa	2.2	18.8	24	0	8.99	107.88	4.21	9.26	77.67	86.94
Borralasgamuwa	1.0	34.2	15	0	8.99	67.43	4.08	4.08	48.55	52.63
Borralasgamuwa	1.6	35.8	15	0	8.99	67.43	4.64	7.42	48.55	55.97
Borralasgamuwa	1.0	35.0	19	0	8.99	85.41	5.94	5.94	61.49	67.43
Borralasgamuwa	0.4	38.0	8	0	8.99	35.96	5.06	2.02	25.89	27.92
Borralasgamuwa	1.0	52.2	0	0	8.99	0.00	6.34	6.34	0.00	6.34
Borralasgamuwa	1.6	33.2	9	0	8.99	40.46	4.96	7.94	29.13	37.06
Borralasgamuwa	1.6	35.6	12	2	8.99	71.92	5.01	8.02	51.78	59.80
Borralasgamuwa	4.2	21.8	7	0	8.99	31.47	5.89	24.74	22.65	47.39
Borralasgamuwa	2.4	20.6	6	6	8.99	80.91	6.42	15.41	58.26	73.66
Borralasgamuwa	4.6	17.6	8	8	8.99	107.88	5.55	25.53	77.67	103.20
Borralasgamuwa	2.2	16.8	18	4	8.99	116.87	6.81	14.98	84.15	99.13

Borralasgamuwa	3.0	19.8	13	0	8.99	58.44	6.03	18.09	42.07	60.16
Borralasgamuwa	1.8	16.0	2	14	8.99	134.85	5.39	9.70	97.09	106.79
Borralasgamuwa	2.6	20.8	20	3	8.99	116.87	7.62	19.81	84.15	103.96
Borralasgamuwa	2.0	19.6	3	10	8.99	103.39	5.59	11.18	74.44	85.62
Borralasgamuwa	1.2	24.2	10	0	8.99	44.95	7.59	9.11	32.36	41.47
Borralasgamuwa	2.4	18.0	12	4	8.99	89.90	5.38	12.91	64.73	77.64
Borralasgamuwa	1.2	24.0	14	0	8.99	62.93	7.68	9.22	45.31	54.53
Borralasgamuwa	2.4	22.8	10	2	8.99	62.93	7.24	17.38	45.31	62.69
Botree	1.6	12.2	7	0	12.05	42.18	5.26	8.42	30.37	38.78
Botree	2.4	14.2	6	0	12.05	36.15	5.47	13.13	26.03	39.16
Botree	1.2	13.2	5	0	12.05	30.13	4.43	5.32	21.69	27.01
Botree	2.4	9.2	8	0	12.05	48.20	5.01	12.02	34.70	46.73
Botree	1.6	13.6	20	0	12.05	120.50	6.58	10.53	86.76	97.29
Botree	5.6	15.8	10	4	12.05	108.45	6.78	37.97	78.08	116.05
Botree	2.8	12.4	3	0	12.05	18.08	4.45	12.46	13.01	25.47
Botree	2.8	15.6	15	0	12.05	90.38	6.53	18.28	65.07	83.35
Botree	2.6	12.2	11	0	12.05	66.28	5.34	13.88	47.72	61.60
Botree	3.0	12.6	8	0	12.05	48.20	4.80	14.40	34.70	49.10
Botree	4.2	13.2	12	0	12.05	72.30	6.36	26.71	52.06	78.77
Botree	7.8	14.2	10	0	12.05	60.25	6.21	48.44	43.38	91.82
Botree	3.4	15.8	2	0	12.05	12.05	7.36	25.02	8.68	33.70
Botree	9.0	12.4	28	0	12.05	168.70	6.51	58.59	121.46	180.05
Botree	8.4	15.6	13	0	12.05	78.33	7.15	60.06	56.39	116.45
Botree	4.2	14.2	12	0	12.05	72.30	6.93	29.11	52.06	81.16
Botree	9.6	15.2	17	0	12.05	102.43	6.88	66.05	73.75	139.79
Botree	5.8	14.6	14	0	12.05	84.35	8.13	47.15	60.73	107.89
Botree	4.6	15.6	6	0	12.05	36.15	7.92	36.43	26.03	62.46
Botree	8.6	10.4	7	0	12.05	42.18	6.21	53.41	30.37	83.77
Botree	4.8	14.2	10	0	12.05	60.25	8.69	41.71	43.38	85.09
Botree	7.6	12.6	12	0	12.05	72.30	6.65	50.54	52.06	102.60
Botree	7.6	15.0	9	0	12.05	54.23	7.43	56.47	39.04	95.51
Botree	4.0	13.2	7	0	12.05	42.18	7.45	29.80	30.37	60.17
MataraSt.Thomas	1.6	8.4	0	0	6.00	0.00	3.41	5.46	0.00	5.46

MataraSt.Thomas	2.4	11.4	1	0	6.00	3.00	5.40	12.96	2.16	15.12
MataraSt.Thomas	1.6	10.0	4	0	6.00	12.00	2.66	4.26	8.64	12.90
MataraSt.Thomas	2.2	13.8	4	0	6.00	12.00	5.01	11.02	8.64	19.66
MataraSt.Thomas	3.0	10.8	9	1	6.00	33.00	4.36	13.08	23.76	36.84
MataraSt.Thomas	2.6	13.8	2	0	6.00	6.00	4.77	12.40	4.32	16.72
MataraSt.Thomas	4.0	9.8	0	0	6.00	0.00	4.83	19.32	0.00	19.32
Matara St.Thomas	2.8	14.6	0	0	6.00	0.00	5.73	16.04	0.00	16.04
MataraSt.Thomas	1.2	10.4	8	0	6.00	24.00	2.50	3.00	17.28	20.28
MataraSt.Thomas	1.2	11.4	0	0	6.00	0.00	5.10	6.12	0.00	6.12
MataraSt.Thomas	1.6	9.4	0	0	6.00	0.00	4.46	7.14	0.00	7.14
MataraSt.Thomas	2.2	9.8	0	0	6.00	0.00	4.80	10.56	0.00	10.56
MataraSt.Thomas	2.0	12.2	1	0	6.00	3.00	5.59	11.18	2.16	13.34
MataraSt.Thomas	3.6	12.0	1	2	6.00	15.00	5.59	20.12	10.80	30.92
Matara St.Thomas	2.4	9.6	0	0	6.00	0.00	4.03	9.67	0.00	9.67
MataraSt.Thomas	1.8	10.4	5	0	6.00	15.00	3.50	6.30	10.80	17.10
MataraSt.Thomas	3.6	12.6	5	0	6.00	15.00	6.31	22.72	10.80	33.52
Matara St.Thomas	2.4	11.8	0	1	6.00	6.00	3.98	9.55	4.32	13.87
MataraSt.Thomas	3.4	10.0	3	0	6.00	9.00	4.41	14.99	6.48	21.47
MataraSt.Thomas	1.6	11.2	0	0	6.00	0.00	4.49	7.18	0.00	7.18
MataraSt.Thomas	1.4	10.4	0	0	6.00	0.00	3.42	4.79	0.00	4.79
MataraSt.Thomas	1.0	11.0	1	0	6.00	3.00	5.32	5.32	2.16	7.48
MataraSt.Thomas	3.0	9.8	5	0	6.00	15.00	4.46	13.38	10.80	24.18
MataraSt.Thomas	0.8	13.0	3	0	6.00	9.00	4.79	3.83	6.48	10.31
Papiliyana	0.8	20.2	2	0	9.02	9.02	7.66	6.13	6.49	12.62
Papiliyana	1.0	17.6	8	0	9.02	36.08	5.62	5.62	25.98	31.60
Papiliyana	0.6	21.0	6	5	9.02	72.16	8.72	5.23	51.96	57.19
Papiliyana	0.4	15.6	7	5	9.02	76.67	5.34	2.14	55.20	57.34
Papiliyana	0.8	13.8	5	0	9.02	22.55	6.90	5.52	16.24	21.76
Papiliyana	1.0	14.8	3	0	9.02	13.53	4.52	4.52	9.74	14.26
Papiliyana	1.0	14.4	1	2	9.02	22.55	4.47	4.47	16.24	20.71
Papiliyana	2.2	18.4	2	4	9.02	45.10	7.20	15.84	32.47	48.31
Papiliyana	0.8	20.4	5	3	9.02	49.61	8.25	6.60	35.72	42.32
Papiliyana	0.8	16.8	3	0	9.02	13.53	5.02	4.02	9.74	13.76

Papiliyana	1.6	19.4	2	3	9.02	36.08	6.98	11.17	25.98	37.15
Papiliyana	1.0	15.8	4	0	9.02	18.04	7.98	7.98	12.99	20.97
Papiliyana	1.2	8.0	0	0	9.02	0.00	4.63	5.56	0.00	5.56
Papiliyana	0.8	12.6	3	0	9.02	13.53	5.51	4.41	9.74	14.15
Papiliyana	1.2	10.4	2	0	9.02	9.02	5.53	6.64	6.49	13.13
Papiliyana	0.8	11.6	0	3	9.02	27.06	4.15	3.32	19.48	22.80
Papiliyana	0.8	13.0	0	0	9.02	0.00	6.26	5.01	0.00	5.01
Papiliyana	1.2	14.2	0	0	9.02	0.00	6.71	8.05	0.00	8.05
Papiliyana	0.6	10.8	0	0	9.02	0.00	5.30	3.18	0.00	3.18
Papiliyana	3.0	14.4	2	0	9.02	9.02	6.36	19.08	6.49	25.57
Papiliyana	1.0	13.6	1	0	9.02	4.51	6.42	6.42	3.25	9.67
Papiliyana	0.6	13.6	2	0	9.02	9.02	5.43	3.26	6.49	9.75
Papiliyana	2.0	13.4	5	0	9.02	22.55	7.04	14.08	16.24	30.32
Papiliyana	1.2	17.2	13	0	9.02	58.63	6.78	8.14	42.21	50.35

Appendix 6

Pedestrian Flow per min (p)	Vehicle Flow per min (v)	pv	Total cost @ C=45s	Total cost @ C=67s	Total cost @ uncontrolled
6.00	29.40	176	2391	2439	355
31.00	24.00	744	1219	1181	3250
23.80	27.40	652	1692	1697	2812
26.00	23.40	608	1109	1066	5213
39.40	24.20	953	1332	1295	2334
31.40	25.80	810	1444	1425	3999
23.40	21.40	501	933	880	2950
32.20	21.80	702	1056	1004	3882
49.20	22.20	1092	1270	1220	4185
53.60	29.20	1565	2783	2827	8783
29.40	20.60	606	951	895	3157
52.60	23.80	1252	1438	1398	5447
39.20	26.60	1043	1672	1664	6053
15.80	29.20	461	2367	2411	995
14.00	28.60	400	2020	2049	857
9.80	26.80	263	1391	1385	575
10.80	28.20	305	1813	1833	673
10.40	25.40	264	1155	1130	589
18.20	24.60	448	1141	1108	964
14.60	25.40	371	1201	1177	803
4.40	22.20	98	777	727	251
7.00	25.00	175	1065	1036	375
5.00	28.00	140	1674	1690	308
11.40	26.60	303	1366	1358	676
9.60	28.80	276	2071	2105	579
6.60	23.40	154	895	853	335
11.20	28.80	323	2089	2122	682
7.40	28.00	207	1701	1717	450
11.40	26.00	296	1257	1240	688
7.40	26.40	195	1283	1272	427
10.60	25.20	267	1130	1104	584
11.80	28.20	333	1824	1844	713
11.80	27.40	323	1560	1565	697
3.60	20.60	74	667	611	177
6.00	23.40	140	889	846	317
4.00	19.60	78	618	560	188
4.00	24.20	97	942	906	224
6.60	23.40	154	895	853	346
5.00	25.60	128	1124	1102	291
7.40	19.80	147	666	608	331
4.40	25.80	114	1147	1128	256
2.60	20.80	54	668	612	137
2.20	22.40	49	768	719	126
4.60	19.20	88	605	546	208
3.00	22.80	68	807	760	173
2.00	28.20	56	1716	1736	148
1.20	27.20	33	1390	1392	94
1.60	26.80	43	1301	1295	113
2.20	29.00	64	2098	2137	157
1.60	25.20	40	1031	1005	106

Appendix 7

Pedestrian Flow per min (p)	Vehicle Flow per min (v)	pv	Total cost @ C=45s	Total cost @ C=67s	Total cost @ uncontrolled
2.00	39.20	78	3122	3186	187
3.80	32.60	124	1274	1229	285
5.20	36.00	187	1828	1825	400
11.60	34.00	394	1534	1503	844
16.40	30.20	495	1196	1133	1063
7.80	31.40	245	1201	1145	541
8.40	30.40	255	1124	1062	533
6.80	30.80	209	1138	1078	464
5.80	38.60	224	2792	2841	440
6.60	36.80	243	2056	2067	526
5.80	31.40	182	1179	1123	356
6.20	34.40	213	1534	1508	452
5.80	33.60	195	1415	1380	364
4.20	40.00	168	3774	3861	385
5.20	38.60	201	2785	2835	443
11.40	30.40	347	1157	1095	751
1.80	30.20	54	1036	972	136
1.80	31.40	57	1135	1079	151
5.20	32.80	171	1312	1268	386
1.80	34.00	61	1426	1395	153
1.40	30.40	43	1047	985	111
3.60	32.80	118	1294	1250	274
2.20	33.00	73	1302	1260	175

Appendix 8

Pedestrian Flow per min (p)	Vehicle Flow per min (v)	pv	Total cost @ C=45s	Total cost @ C=67s	Total cost @ uncontrolled
3.60	48.60	175	3654	3725	388
3.80	47.60	181	3121	3168	403
2.00	48.40	97	3517	3583	222
5.80	43.80	254	2030	2008	559
4.20	47.40	199	3036	3078	436
3.00	45.20	136	2295	2295	307
4.20	44.80	188	2214	2207	425
3.60	48.00	173	3315	3371	379
2.80	46.20	129	2572	2590	293
4.00	48.20	193	3426	3487	425
3.20	44.20	141	2077	2061	314
4.40	44.80	197	2216	2209	435
7.20	42.00	302	1769	1724	647
3.40	43.80	149	2003	1982	336
3.60	41.20	148	1631	1578	330
1.40	47.60	67	3095	3141	163
7.00	40.20	281	1560	1498	603
3.80	44.40	169	2124	2111	376
7.60	49.80	378	4570	4673	750
6.60	47.80	315	3247	3299	641
9.00	45.80	412	2520	2530	741
6.00	45.60	274	2432	2438	654
4.20	44.20	186	2088	2072	303
6.20	50.80	315	1338	1140	692
2.80	79.40	222	2656	2481	
4.20	52.20	219	1363	1163	473
2.40	55.80	134	1472	1265	308
3.00	50.60	152	1296	1099	338
3.00	51.00	153	1309	1111	334
3.40	50.60	172	1300	1103	380
6.20	61.20	379	1723	1511	
5.40	57.20	309	1557	1349	624
8.80	60.80	535	1735	1524	
4.80	75.00	360	2388	2194	
5.20	81.20	422	2818	2653	
6.20	52.20	324	1385	1185	729
3.20	56.60	181	1510	1303	438
5.60	52.20	292	1379	1178	723
3.40	81.80	278	2846	2684	
2.80	50.20	141	1280	1084	339
4.20	56.60	238	1521	1314	543
3.00	54.60	164	1435	1230	389
1.60	62.20	100	1714	1502	
3.40	70.20	239	2105	1899	
2.80	57.20	160	1528	1320	354
4.00	58.40	234	1587	1378	528