International Journal of ChemTech Research
CODEN (USA): IJCRGG, ISSN: 0974-4290, ISSN(Online):2455-9555
Vol.10 No.8, pp 536-563, 2017

Modelling and Assessment of Traffic Safety at Urban Signalized Intersection

Adarsh Toppo[1]*, K J Justus Abhishek[2], P Guru Sai Charan[3], Prathibaa.K[3]

[1]Civil engineering Professor Karunya University, India.
[2,3,4]Civil Engineering, Karunya University, Coimbatore, Tamilnadu, India.

Abstract : The road intersections are two or more streets can be a point of conflict or meeting and a location to manage the movement of both vehicles and pedestrian to their desire direction. An intersection must accommodate and regulate both conflict and meeting effectively to ensure the safe traffic and pedestrian maneuvering[1]. In developing country like India, majority of the urban intersections are signalized with partially manual operation for safe and efficient movement of large volume of traffic on urban road network. The multitudinal challenges are observed in urban intersections like frequent collisions on high volume arterial, uncontrolled crosswalk, frequency of hit and runs, heavy right turn movements from a busy street on to a main street, conflicts involving vehicles maneuvering in and out of on-street parking, location of a transit stop on a main street just before an intersection. Different signalized urban intersections are screened at Coimbatore city for this study. The data collection based on the variety of prevailing conditions, including the amount and distribution of traffic movements, special and temporal components of intersection, sight triangles, crashes, traffic composition, details of signalization conditions, travel patterns, capacity needs and safety emphasis [2,3]. The methodology performing in this study to model and assess the intersection safety by analyse the capacity and level of service (LOS) of signalized intersection as per Highway Capacity Manual (HCM) approaches. The safety analysis at signalized intersection to be proceed with the details of crash frequency, crash rate and geometric issues. Simulate and analyse the behaviour of vehicles and road users at intersections with real time data observed from the study locations. The main contribution of this study is to understand the behaviour of existing signalized intersections and safety issues. The scientific approaches are identified to model and assess the safety and reducing the ill effects of its performance [4]. The suggestions to be framed based on the findings to improve existing signalized intersection design to facilitate the convenience, safe & comfort movement of motor vehicles, cyclists, and pedestrian. The micro simulation tool VISSIM is using to understand and compare the safety behaviour of existing and improved intersections.
Keywords : Sight triangles,capacity,LOS, HCM

1.0 Introduction

An intersection is an at- grade junction where two or more roads meet or cross. Intersection may be classified by number of road segments, traffic controls, and lane design.

Signalized intersections are critical elements of an urban road transportation system and maintaining these control systems at their optimal performance for different demand conditions has been the primary concern of the traffic engineers. Safety, which is the main concern of this project, is commonly measured in

terms of the number of traffic accidents and the consequences of accidents in relation to their severity and/or fatalities. In order to estimate and predict levels of traffic safety at different types of intersections, there is a distinct need for the development of newer and more detailed methods and models that can successively replace those in existence today. For study of this purpose three intersections are identified in the corridor of Avinashi Road in Coimbatore. The intersections are Esso Bunk, Anna Statue and Lakshmi mills. This assessment for safety predictions are important due to the growing number of vehicles and accident rates in India. Over 1, 37,000 people were killed in road accidents in 2013 alone. Tamil Nadu is the state with the maximum number of road crash injuries. The time-slot with highest rate of road accidents was 15:00 to 18:00. The conflicts arising from movements of traffic in diff erent directions is solved by time sharing of the principle. The advantages of traffic signal includes an orderly movement of traffic, an increased capacity of the intersection and requires only simple geometric design. However, the disadvantages of the signalized intersection are it aff ects larger stopped delays, and the design requires complex considerations. Although the overall delay may be lesser than a rotary for a high volume, a user is more concerned about the stopped delay.

A. Objective

The important objectives of this present study are

- To understand the behaviour of oversaturated traffic intersection with real time data collection.
- To analyse the capacity and level of service of the oversaturated intersection by using HCM 2000
- To assist and predict the intersection safety by quantifying congestion, analysis of geometric issues and road user behaviour.
- To simulate and analyse the behaviour of vehicle and road user at intersection.

B. Definations and notations

A number of definitions and notations need to be understood in signal design. They are discussed below:

- Cycle: A signal cycle is one complete rotation through all of the indications provided.
- Cycle length: Cycle length is the time in seconds that it takes a signal to complete one full cycle of indications. It indicates the time interval between the starting of green for one approach till the next time the green starts. It is denoted by C.
- Interval: Thus, it indicates the change from one stage to another. There are two types of intervals change interval and clearance interval. Change interval is also called the yellow time indicates the interval between the green and red signal indications for an approach. Clearance interval is also called all red is included after each yellow interval indicating a period during which all signal faces show red and is used for clearing off the vehicles in the intersection.
- Green interval: It is the green indication for a particular movement or set of movements and is denoted by (Gi). This is the actual duration the green light of a traffic signal is turned on.
- Red interval: It is the red indication for a movement or set of movements and is denoted by Ri. This is the actual duration the red light of a traffic signal is turned on.
- Phase: A phase is the green interval plus the change and clearance intervals that follow it. Thus, during green interval, non conflicting movements are assigned into each phase. It allows a set of movements to flow and safely halt the flow before the phase of another set of movements start.
- Lost time: It indicates the time during which the intersection is not eff ectively utilized for any movement. For example, when the signal for an approach turns from red to green, the driver of the vehicle which is in the front of the queue, will take some time to perceive the signal (usually called as reaction time) and some time will be lost here before he moves.

C. Definations and notations

1) **Human Factor:**

a) Driving habits
b) Ability to make decisions
c) Decisions and reaction time
d) Pedestrians behaviours

2) **Traffic considerations**

a) Design and actual capacities
b) Traffic mix (proportion of heavy and light vehicles, slow moving vehicles, cyclists etc.
c) Types of movement (diverging, converging, weaving, crossing)

3) **Road and environmental considerations**

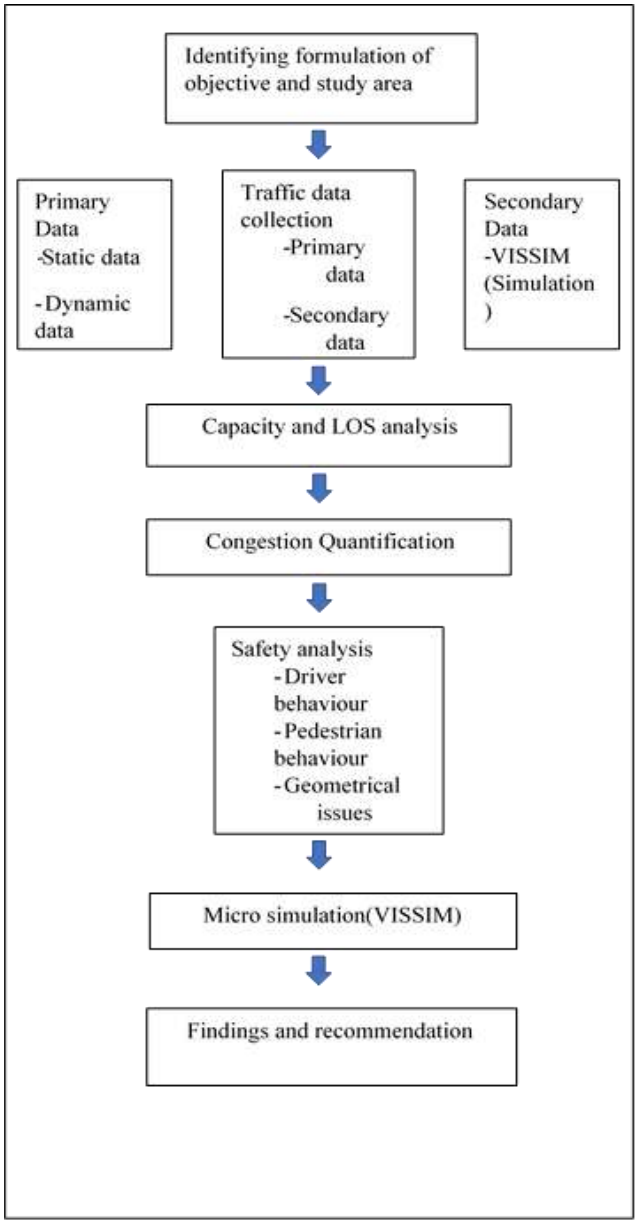
a) Sight distance
b) Conflict areas
c) Geometric features
d) Traffic control devices

4) **Economic factors**

a) Cost of improvement.

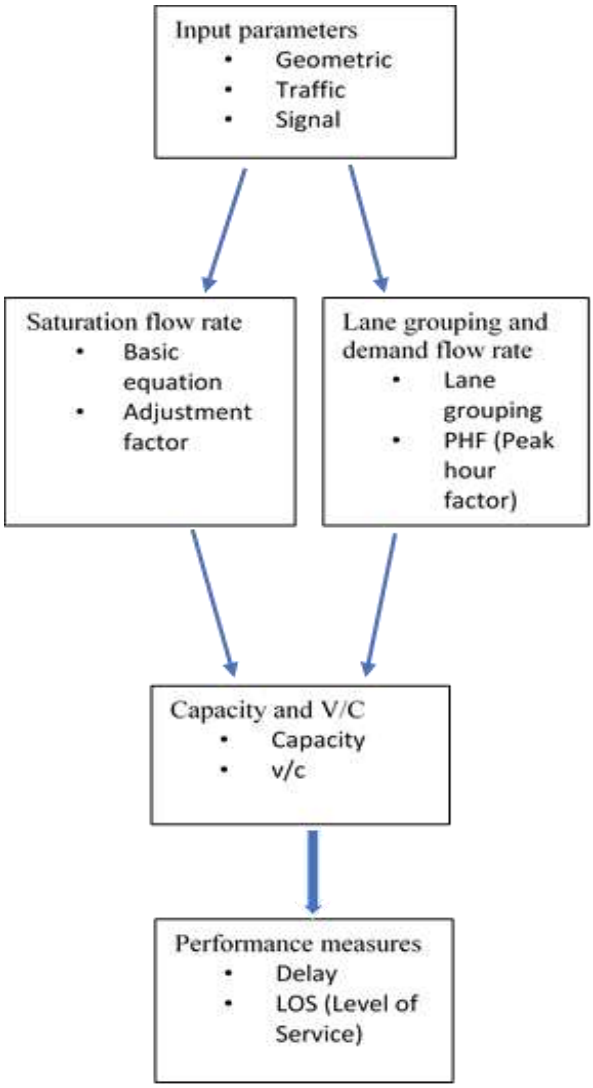
2.0 Study Methodology

2.1 Work methodology



2.2 Study methodology

Figure shows the input and the basic computation order for the method. The primary output of the method is level of service (LOS). This methodology covers a wide range of operational configurations, including combinations of phase plans, lane utilization, and left-turn treatment alternatives.



LOS (level of service):

The average control delay per vehicle is estimated for each lane group and aggregated for each approach and for the intersection as a whole. LOS is directly related to the control delay value. The criteria are listed below

Table 1. LOS Criteria for signalized intersection

LOS	Control delay per vehicle(s/veh)
A	≤10
B	>10-20
C	>20-35
D	>35-55
E	>55-80
F	>80

Input parameters

Table 2. Input data needs for each analysis lane group

Type of condition	Parameter
Geometric conditions	• Area type • Number of lanes, N • Average lane width, W (m) • Grade, G (%) • Existence of exclusive LT or RT lanes • Length of storage bay, LT or RT lane, Ls (m) • Parking
Traffic conditions	• Demand volume by movement, V (veh/h) • Base saturation flow rate, so (pc/h/ln) • Peak-hour factor, PHF • Percent heavy vehicles, HV (%) • Approach pedestrian flow rate, vped (p/h) • Local buses stopping at intersection, NB (buses/h) • Parking activity, Nm (maneuvers/h) • Arrival type, AT • Proportion of vehicles arriving on green, P • Approach speed, SA (km/h)
Signalisation condition	• Demand volume by movement, V (veh/h) • Base saturation flow rate, so (pc/h/ln) • Peak-hour factor, PHF • Percent heavy vehicles, HV (%) • Approach pedestrian flow rate, vped (p/h) • Local buses stopping at intersection, NB (buses/h) • Parking activity, Nm (maneuvers/h) • Arrival type, AT • Proportion of vehicles arriving on green, P • Approach speed, SA (km/h)

2.3 Study location

The following intersections are considered in Coimbatore, Tamil Nadu.

2.3.1 Esso Bunk
2.3.2 Anna Statue
2.3.3 Lakshmi mill

All are situated in Avinashi Road

Avinashi Road is an arterial road in Coimbatore, India. Running from east to west, the road starts at Uppilipalayam flyover and ends at Nilambur Junction.

1) Esso Bunk

2.3.3.1 It is a three-way intersection.
2.3.3.2 It consists of two major and one minor road
2.3.3.3 Six lane divided on all sides (major)
2.3.3.4 Two lane (minor)

Fig. 1. ESSO Bunk intersection

2) Anna Statue

a) It is a four-way intersection in which one leg is one-way
b) Two major road and two minor road
c) An exclusive left turn is given for the vehicle coming from Gandhipuram Road.

Fig. 2. Anna Statue Intersection.

3) Lakshmi Mills

a) It is a four-way intersection.
b) Two major and two minor Rd.
c) Six lane road (major)
d) Four lane road (minor)

Fig. 3. Lakshmi Mill Intersection

3.0 Data collection

3.1 Introduction

The data collection process is divided into two parts

3.1.1 Primary Data
3.1.2 Secondary Data

3.2 Primary data collection

It consists of following types

3.2.1 Static data

These are collected at the site

3.2.2 Dynamic data

These are collected by video graphic surveys and calculation through HCM2000

1) Static data

3.2.2.1 Esso Bunk

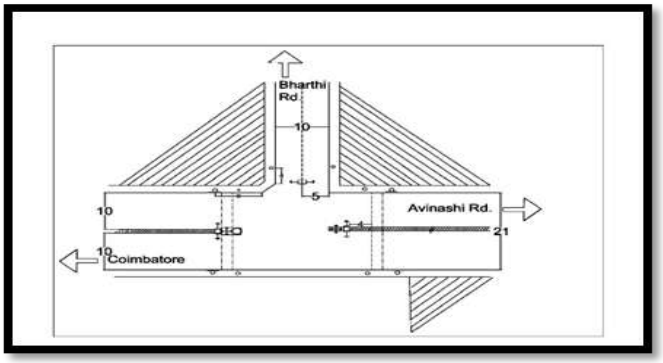


Fig. 4. Inventory diagram of Esso Bunk

- Roadway surface – Bituminous road

- Lane information – Six lane (Avinashi-Coimbatore Rd)
  Two lane (Bharthi Rd)
- Median – Avinashi Rd (Barrier median)
  Bharthi Rd (no median)
- Number of intersection leg – Three
- Median (Type and width) – Concrete, height -1m and width-1m
- Traffic control devices – Traffic signals, CCTV, traffic signs, all pavement margins in white.
- Avinashi Rd (zebra crossing)
  Bharthi Rd (no zebra crossing)

3.2.2.2 Anna Statue

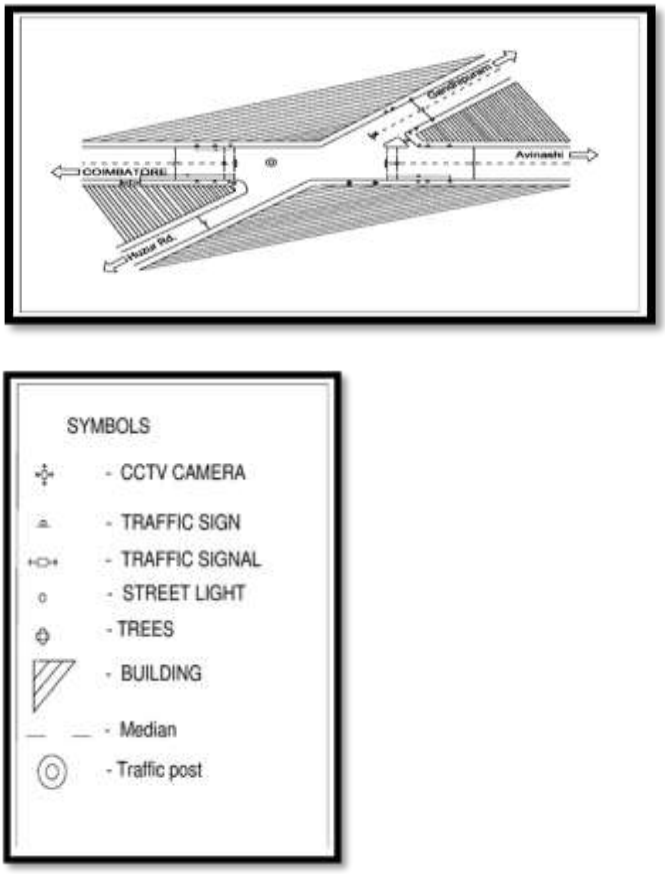


Fig. 5. Inventory diagram of Anna Statue

- Roadway surface – Bituminous road
- Lane information – Six lane (Avinashi-Coimbatore Rd)
  Four lane (Gandhipuram Rd)
  Two lane (Huzur Rd) one-way Rd
- Median – Avinashi-Coimbatore Rd (Barrier median)
  Gandhipuram Rd (Barrier median)
  Huzur Rd (No median)
- Number of intersection leg – Four (one leg is one-way)
- Median (Type and width) – Concrete, height -1m and width-1m
- Traffic control devices – Traffic signals, CCTV, traffic signs, all pavement margins in white.
- Avinashi Rd (zebra crossing)
  Gandhipuram Rd (zebra crossing)
  Huzur Rd (No zebra crossing) .

3.2.2.3 Lakshmi Mills

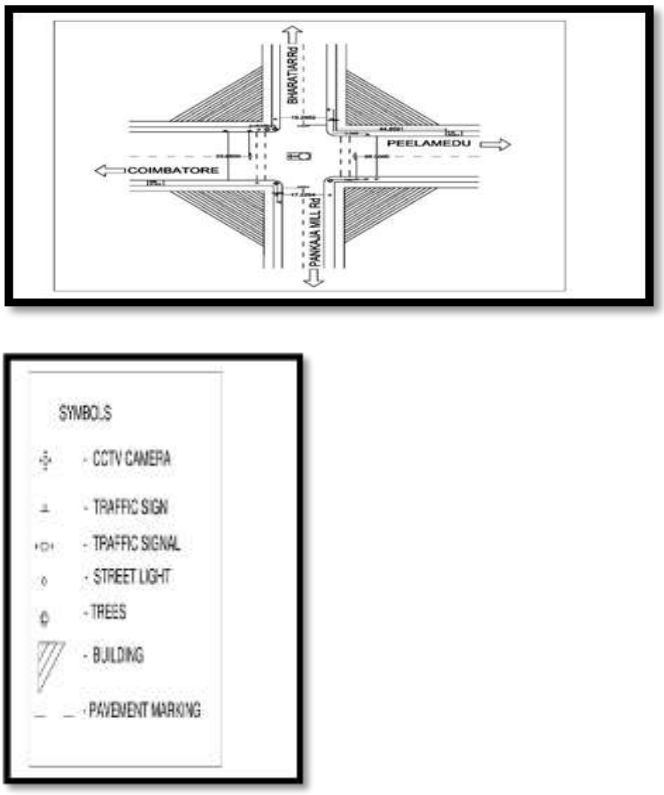


Fig. 6. Inventory diagram of Lakshmi mills

- Roadway surface – Bituminous road
- Lane information – Six lane (Avinashi-Coimbatore Rd)
  Four lane (Bharatiar Rd)
  Four lane (Pankaja mill Rd)
- Median – Avinashi-Coimbatore Rd (Barrier median)
  Bharatiar Rd (Barrier median)
  Pankaja mill Rd (Barrier median)
- Number of intersection leg – Four
- Median (Type and width) – Concrete, height -1m and width-1m
- Traffic control devices – Traffic signals, CCTV, traffic signs, all pavement margins in white.
- Avinashi-Coimbatore Rd (zebra crossing)
  Bharatiar Rd (No zebra crossing)
  Pankaja Rd (No zebra crossing)

3.2.3 Dynamic data

It consists of following data

- Traffic volume
- Composition
- Percentage of heavy vehicle
- Arrival type (percentage of vehicle arriving in green time)
- Cycle length
- Green time available in each movement
- Others such as buses stops at intersection, parking maneuverers per hour
- Actual saturation flow and field delays.

3.3 Video graphic survey

Video graphic survey was conducted at Esso bunk on 13.02.2017, Anna Statue on 17.02.2017 and Lakshmi mill on 22.02.2017

- Morning 9AM to 11AM (Peak hour)
- Evening 4PM to 6PM (Peak hour)
- From the video the number of vehicles are counted and peak hour factor (PHF) is determined for each direction of the intersection.
- Cycle length is determined by using HCM2000
- Saturation flow rate is determined followed by the total delay.
- Based on the above calculation LOS (Level of Service) is determined.

3.3.1 Esso Bunk

Fig. 7. Video at Esso Bunk

3.3.2 Anna Statue

Fig. 8. Video at Anna Statue

3.3.3 Lakshmi Mills

Fig. 9. Video at Lakshmi Mills

3.4 Volume count survey

The aim of this traffic survey is to find the prevailing traffic flow during peak hour and giving solutions to decrease the traffic congestions followed by easy flow of traffic [5,6]. Through the survey the composition of vehicles, the classified volume count by recording the volume of various vehicle types for 15 minutes' interval, the vehicle composition and peak hour volume were found for each and every direction.

3.4.1 Esso Bunk.

Six directions are identified in Esso Bunk intersection.

3.4.1.1 Coimbatore to Avinashi
3.4.1.2 Avinashi to Coimbatore
3.4.1.3 Bharathi to free left
3.4.1.4 Coimbatore to free left
3.4.1.5 Bharathi to Coimbatore
3.4.1.6 Avinashi to Bharathi

a) **Layout of Esso Bunk**

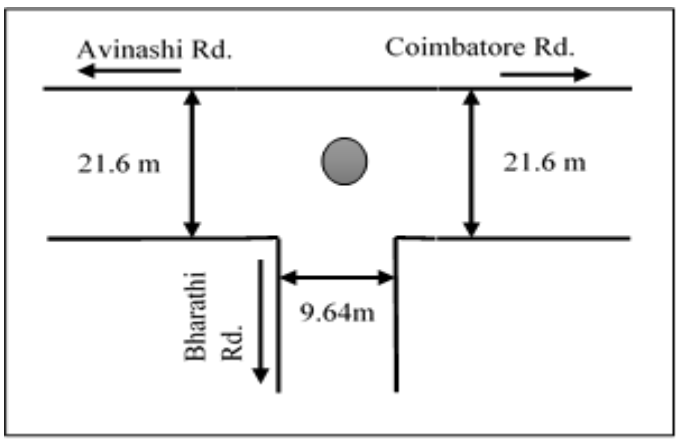


Fig. 10. Layout of Esso Bunk

b) **Conflict point at Esso Bunk**

Any location having merging, diverging or crossing manoeuvres of two vehicles is a potential conflict point.

The conflict point that identified at Esso Bunk intersection are shown in figure

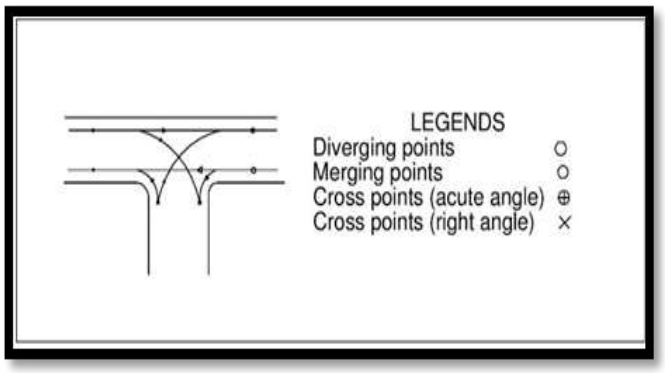


Fig. 11. Conflict point at Esso Bunk

c) **Peak hour factor of Esso Bunk**

Peak hour factor is the hourly volume during the maximum volume hour of the day divided by the peak 15 minutes' flow rate within the peak hour, a measure of traffic demand fluctuations within the peak hour.Number of vehicles passing are counted for each and every direction. Vehicles are classified as fast moving and slow moving vehicles. Number of vehicles are counted for 15 minutes for the two hour in morning as well as in evening[7,8,9] .Individual vehicle composition is calculated by dividing the total number of a particular vehicle and overall number of vehicle.

Count of the vehicle is converted into PCU unit that is Passenger Capacity Unit.PCU is calculated as follows: -

$$PCU = Total\ no.of\ vehicles\ in\ 15\ min \times PCU\ value\ of\ vehicle\ type \quad (1)$$

Peak hour factor is calculated as follows: -

$$\frac{V}{4 \times v15} \quad (2)$$

2) **Esso Bunk.**

Nine directions are identified in Anna Statue

- Coimbatore to Avinashi
- Avinashi to Coimbatore
- Avinashi to Huzur
- Coimbatore to Huzur
- Coimbatore to Gandhipuram
- Gandhipuram to Huzur
- Avinashi to Gandhipuram
- Gandhipuram to Avinashi
- Gandhipuram to Coimbatore

a) **Layout of Esso Bunk**

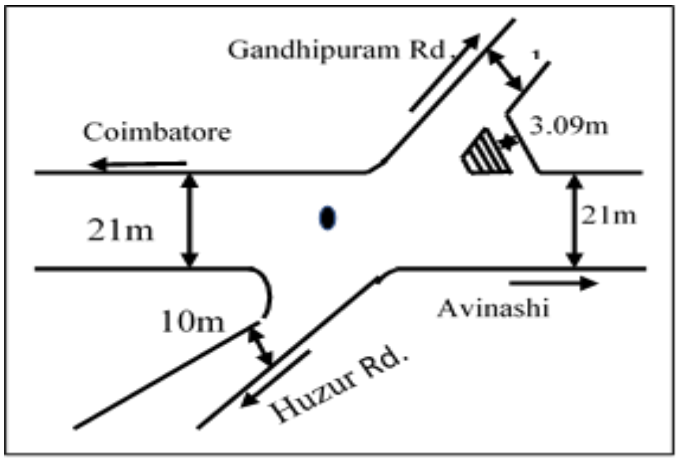


Fig. 12. Layout of Anna Statue.

b) **Conflict point at Anna Statue**

Any location having merging, diverging or crossing manoeuvres of two vehicles is a potential conflict point. Conflict point at Anna Statue is shown in figure

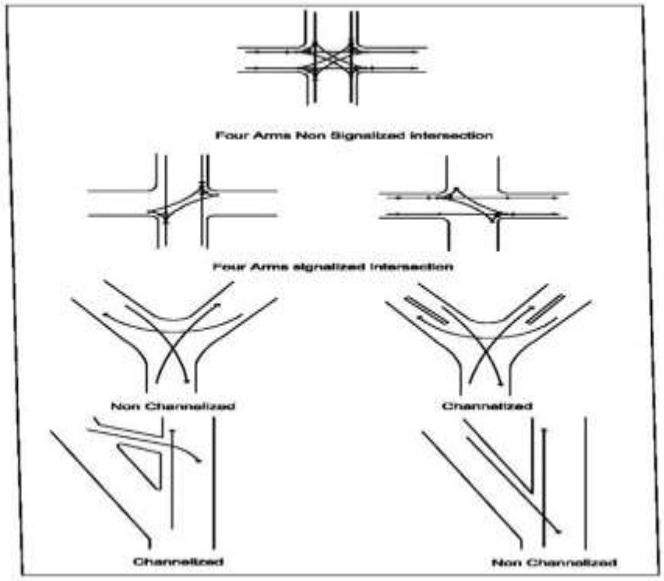


Fig. 13. Conflict point at Anna Statue

c) **Peak hour factor of Anna Statue**

Peak hour factor is the hourly volume during the maximum volume hour of the day divided by the peak 15 minutes' flow rate within the peak hour, a measure of traffic demand fluctuations within the peak hour. Number of vehicles passing are counted for each and every direction. Vehicles are classified as fast moving and slow moving vehicles. Number of vehicles are counted for 15 minutes for the two hour in morning as well as in evening. Individual vehicle composition is calculated by dividing the total number of a particular vehicle and overall number of vehicle.

Count of the vehicle is converted into PCU unit that is Passenger Capacity Unit.PCU is calculated as follows: -

$$PCU = Total\ no.of\ vehicles\ in\ 15\ min \times PCU\ value\ of\ vehicle\ type \quad (3)$$

Peak hour factor is calculated as follows: -

$$\frac{V}{4 \times v15} \qquad (4)$$

3) **Lakshmi Mills**

Twelve directions are identified at Lakshmi Mills

- Coimbatore to Avinashi
- Coimbatore to Bharatiar (free left)
- Coimbatore to Pankaja mill
- Avinashi to Bharatiar
- Avinashi to Pankaja mill (free left)
- Avinashi to Coimbatore
- Pankaja to Avinashi
- Pankaja to Coimbatore (free left)
- Pankaja to Bharatiar
- Bharatiar to Coimbatore
- Bharatiar to Avinashi (free left)
- Bharatiar to Pankaja

a) **Layout of Lakshmi Mills**

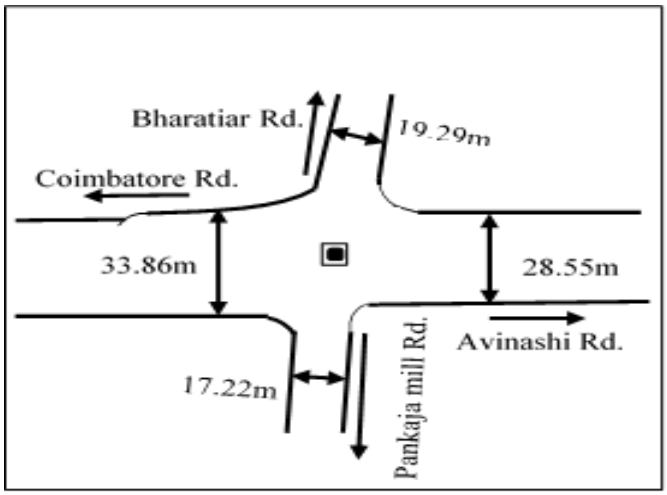


Fig. 14. Layout of Lakshmi Mills

b) **Conflict point at Lakshmi Mills**

Any location having merging, diverging or crossing manoeuvres of two vehicles is a potential conflict point. Conflict points at Lakshmi Mills are shown in figure.

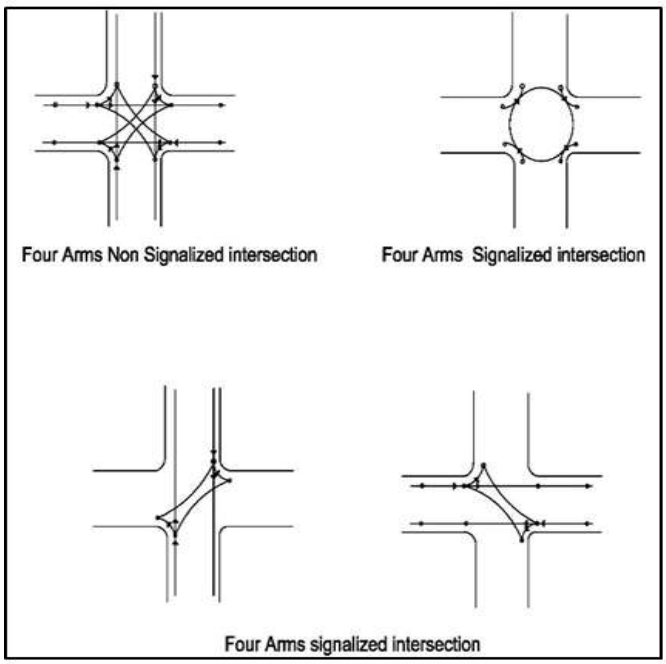


Fig. 15. Conflict point at Lakshmi Mills

c) **Peak hour factor of Lakshmi mills**

Peak hour factor is the hourly volume during the maximum volume hour of the day divided by the peak 15 minutes' flow rate within the peak hour, a measure of traffic demand fluctuations within the peak hour. Number of vehicles passing are counted for each and every direction. Vehicles are classified as fast moving and slow moving vehicles. Number of vehicles are counted for 15 minutes for the two hour in morning as well as in evening. Individual vehicle composition is calculated by dividing the total number of a particular vehicle and overall number of vehicle.

Count of the vehicle is converted into PCU unit that is Passenger Capacity Unit.PCU is calculated as follows: -

$$PCU = Total\ no.of\ vehicles\ in\ 15\ min \times PCU\ value\ of\ vehicle\ type \quad (5)$$

Peak hour factor is calculated as follows: -

$$\frac{V}{4 \times v15} \quad (6)$$

4.0 Result and Discussion

4.1 Introduction

The Highway Capacity Manual 2000 is used for calculating following data

4.1.1 Saturation Flow Rate
4.1.2 Capacity and V/C ratio
4.1.3 Delays
4.1.4 Level of Service

Volume count of vehicles are calculated by video graphic survey at different intersections. Percentage composition of vehicle is determined by volume count of vehicle. All the primary data are collected by video graphic survey and secondary data from pre-existing data of the site (intersection).

4.2 Percentage composition of vehicle

4.2.1 Esso bunk

4.2.1.1 Morning

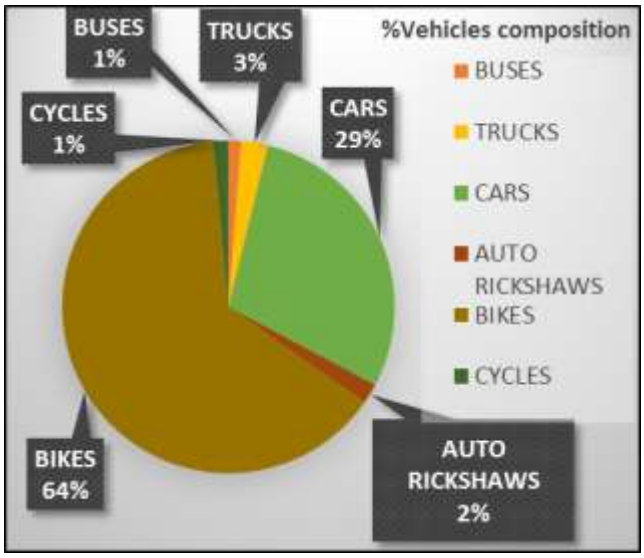


Fig. 16. % composition of Esso Bunk (morning)

4.2.1.2 Evening

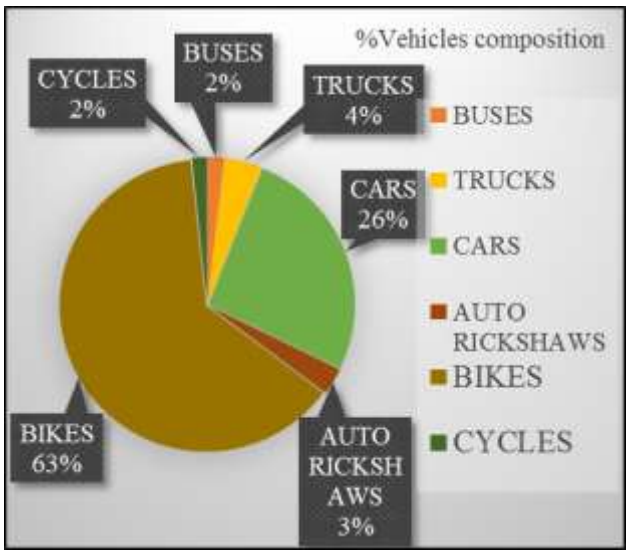


Fig. 17. % composition of Esso Bunk (evening)

4.2.2 Anna statue Morning

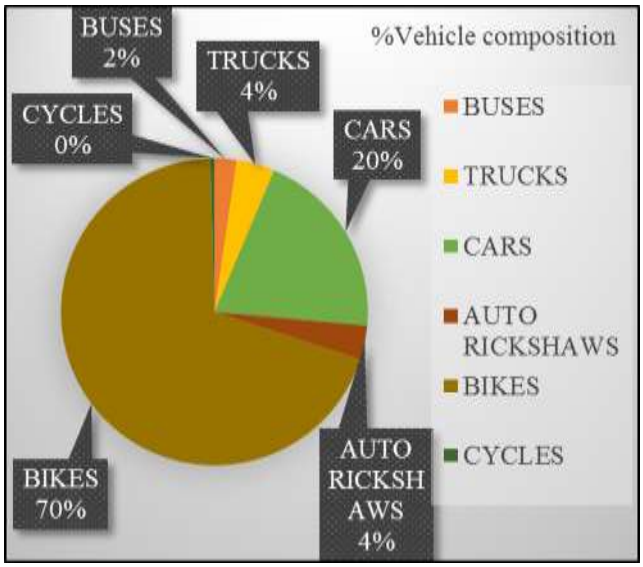


Fig. 18. % composition of Anna Statue (morning)

4.2.2.1 Evening

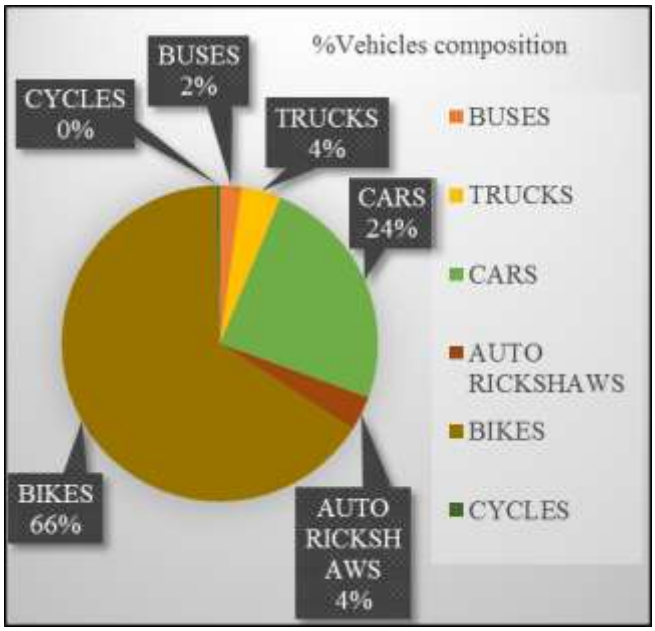


Fig. 19. % composition of Anna Statue (evening)

4.2.3 Esso bunk

Morning and evening peak hour factor is calculated for every direction at the intersection. Peak hour is also determined with the help of volume count.

Table 1 PHF of Esso Bunk

Directions	Peak hour factor	
	Morning	Evening
Coimbatore - Avinashi	0.97	0.96
Avinashi –	0.90	0.92

Coimbatore		
Bharathi to free left	0.92	0.95
Coimbatore to free left	0.92	0.95
Bharathi to Coimbatore	0.83	0.95
Avinashi to Bharathi	0.88	0.78

The average peak hour factor of esso bunk in morning session is 0.90 and for evening session is 0.92.

4.2.3.1 Peak time

Peak time is calculated according to more number of vehicle in each direction. Table IV shows the peak time of each direction.

Table 2 Peak Time Of Esso Bunk

Directions	**Peak Hour**	
	Morning time	**Evening time**
Coimbatore - Avinashi	10:15AM-10:30	4:45PM-5:00PM
Avinashi – Coimbatore	9:45AM-10:00AM	4:45PM-5:00PM
Bharathi to free left	9:45AM-10:00AM	5:45PM-6:00PM
Coimbatore to free left	10:00AM-10:15AM	5:45PM-6:00PM
Bharathi to Coimbatore	10:15AM-10:30AM	5:45PM-6:00PM
Avinashi to Bharathi	9:45AM-10:00AM	5:45PM-6:00PM

The Average Peak hour determined for morning session is 9:45 AM-10:45PM and for evening session is 5:45AM-6:00PM.

4.2.4 Anna statue

Table 3 PHF of Anna Statue

Directions	**Peak hour factor**	
	Morning	**Evening**
Coimbatore - Avinashi	0.94	1.02
Coimbatore - Gandhipuram road	0.96	0.94
Coimbatore-Huzur road	0.92	0.95
Avinashi - coimbatore	0.99	0.98
Avinashi - Gandhipuram road	1.17	0.91

Avinashi-Huzur road	0.92	0.95
Gandhipuram road - Huzur road	0.96	0.96
Gandhipuram road - Avinashi	0.99	1.07
Gandhipuram road-Coimbatore	1.27	0.78

The average peak hour factor of esso bunk in morning session is 1.01 and for evening session is 0.95.

4.2.4.1 Peak time

Table 4 Peak Time of Anna Statue

Directions	Peak Time	
	Morning	Evening
Coimbatore - Avinashi	10:30AM-10:45AM	4:45PM-5:00PM
Coimbatore - Gandhipuram road	10:45AM-11:00AM	5:45PM-6:00PM
Coimbatore - Huzur road	10:30AM-10:45AM	5:45PM-6:00PM
Avinashi - Coimbatore	10:45AM-11:00AM	4:45PM-5:00PM
Avinashi - Gandhipuram road	10:30AM-10:45AM	4:45PM-5:00PM
Avinashi - Huzur road	09:45AM-10:00AM	4:45PM-5:00PM
Gandhipuram road - Huzur road	09:45AM-10:00AM	4:45PM-5:00PM
Gandhipuram road - Avinashi	10:45AM-11:00AM	5:45PM-6:00PM
Gandhipuram road - Coimbatore	10:30AM-10:45AM	5:45PM-6:00PM

The Average Peak hour determined for morning session is 10:45AM-11:00AM and for evening session is 4:45PM-5:00PM.

4.3 Saturation flow rate

A saturation flow rate for each lane group is computed according to Equation given below. The saturation flow rate is the flow in vehicle per hour that can be accommodate by the lane group assuming that the green phase were displayed 100 of the time.

$$S = so\ N\ fw\ fHV\ fg\ fp\ fbb\ fa\ fLU\ fLT\ fRT\ fLpb\ fRpb \quad (7)$$

where

S = saturation flow rate
S_o = base saturation flow rate per lane (pc/h/ln)
N = number of lanes in lane group
f_w = adjustment factor for lane width
f_{HV} = adjustment factor for heavy vehicles in traffic stream

f_g = adjustment factor for approach grade
f_p = adjustment factor for existence of a parking lane
f_{bb} = adjustment factor for blocking effect of local buses that stop within intersection area
f_a = adjustment factor for area type
f_{LU} = adjustment factor for lane utilization
f_{LT} = adjustment factor for left turns in lane group
f_{RT} = adjustment factor for right turns in lane group
f_{Lpb} = pedestrian adjustment factor for left-turn movements
f_{Rpb} = pedestrian-bicycle adjustment factor for right-turn movements.

4.4 Formulas for calculation saturation flow rate

Table 5 Formulas

Factor	Formula	Definition of Variables	Notes
Lane width	$fw = 1 + \frac{(W-3.6)}{9}$	W=lane width	W≥2.4 If W > 4.8, a two-lane analysis may be considered
Heavy vehicles	$f_{HV} = \frac{100}{100 + \%HV(E_T - 1)}$	% HV = % heavy vehicles for lane group volume	ET = 2.0 pc/HV
Grade	$f_f = 1 - \frac{\%G}{100}$	% G = % grade on a lane group approach	-6 ≤ % G ≤ +10 Negative is downhill
Parking	$f_p = \frac{N - 0.1 - (18N_m/3600)}{N}$	N = number of lanes in lane group Nm = number of parking manoeuvres/h	0 ≤ Nm ≤ 180 fp ≥ 0.050 fp = 1.000 for no parking
Bus blockage	$f_{bb} = \frac{N - (14.4N_B/3600)}{N}$	N = number of lanes in lane group N_B = number of buses stopping/h	0 ≤ NB ≤ 250 fbb ≥ 0.050
Type of area	fa = 0.900 in CBD fa = 1.000 in all other areas		
Lane utilization	$f_{LU} = {V_g}/{(V_{g1}N)}$	v_g=unadjusted demand flow rate for the lane group, veh/h v_{g1}=unadjusted demand flow rate on the single lane in the lane group with the highest volume N = number of lanes in the lane group	
Left turns	Protected phasing: Exclusive lane: f_{LT} = 0.95 Shared lane: $f_{LT} = 1/(1.0 + 0.05P_{LT})$	P_{LT} = proportion of LTs in lane group	
Right turns	Exclusive lane: f_{RT} = 0.85 Shared lane: $f_{RT} = 1.0 - (0.15)P_{RT}$ Single lane: $f_{RT} = 1.0 - (0.135)P_{RT}$	P_{RT} = proportion of RTs in lane group	f_{RT} ≥ 0.050
Pedestrian -bicycle blockage	LT adjustment: $f_{Lpb} = 1.0 - P_{LT}(1 - A_{pbT})(1 - P_{Lb})$	P_{LT} = proportion of LTs in lane group A_{pbT} = permitted phase	

	RT adjustment: $f_{Rpb} = 1.0 - P_{RT}(1 - A_{pbT})(1 - P_{RTA})$	adjustment P_{LTA} = proportion of LT protected green over total LT green P_{RT} = proportion of RTs in lane group P_{RTA} = proportion of RT protected green over total RT green	

4.5 Capacity and v/c ratio

4.5.1 Capacity

Capacity at signalised intersection is based on the concept of saturation flow and saturation flow rate. The flow ratio for a given lane group is defined as the ratio of the actual or projected demand flow rate for the lane group (Vi) and the saturation flow rate (Si). The flow ratio is given the symbol (V/S)i for lane group i. The capacity of a given lane group may be shown in Equation

$$C_i = \frac{S_i g_i}{C} \quad (8)$$

where

Ci = capacity of lane group i (veh/h)
Si = saturation flow rate for lane group i (veh/h)
gi /C = effective green ratio for lane group i.

4.5.2 V/c ratio

The ratio of flow rate to capacity (v/c), often called the volume to capacity ratio, is given the symbol X in intersection analysis. It is typically referred to as degree of saturation. For a given lane group i, Xi is computed using Equation.

$$X_i = \frac{V_i C}{S_i g_i} \quad (9)$$

where

Xi = (v/c) i = ratio for lane group i
vi = actual or projected demand flow rate for lane group i (veh/h)
si = saturation flow rate for lane group i (veh/h)
gi = effective green time for lane group i (s)
C = cycle length (s).

D. Delays

The values derived from the delay calculations represent the average control delay experienced by all vehicles that arrive in the analysis period, including delays incurred beyond the analysis period when the lane group is oversaturated. Control delays includes queue position or slow down upstream of an intersection. The average control delay per vehicle for a given lane group is given by Equation.

$$d = d_1(PF) + d_2 + d_3 \quad (10)$$

Where

d = control delay per vehicle (s/veh)
d1 = uniform control delay assuming uniform arrivals (s/veh)
PF = uniform delay progression adjustment factor, which accounts for effects of signal progression

d2 = incremental delay to account for effect of random arrivals and oversaturation queues, adjusted for duration of analysis period and type of signal control; this delay component assumes that there is no initial queue for lane group at start of analysis period (s/veh)
d3 = initial queue delay, which accounts for delay to all vehicles in analysis period due to initial queue at start of analysis period (s/veh)

4.5.3 Uniform delay

$$d_1 = \frac{0.5(1 - g/c)2}{1 - (\min(1, X)\, g/c)} \qquad (11)$$

where

d1 = uniform control delay assuming uniform arrivals (s/veh)
C = cycle length (s); cycle length used in pretimed signal control, or average cycle length for actuated control (see Appendix B for signal timing estimation of actuated control parameters)
g = effective green time for lane group (s); green time used in pretimed signal control, or average lane group effective green time for actuated control
X = v/c ratio or degree of saturation for lane group.

4.5.4 Incremental delay

$$d_2 = 900(X - 1) + \sqrt{([X - 1]^2 + \frac{8KIX}{cT}} \qquad (12)$$

where

d2 = incremental delay to account for effect of random and oversaturation queues, adjusted for duration of analysis period and type of signal control (s/veh); this delay component assumes that there is no initial queue for lane group at start of analysis period
T = duration of analysis period (h)
k = incremental delay factor that is dependent on controller settings
I = upstream filtering/metering adjustment factor
c = lane group capacity (veh/h)
X = lane group v/c ratio or degree of saturation.

4.6 Level of service

The average control delay per vehicle is estimated for each lane group and aggregated for each approach and for the intersection as a whole. LOS is directly related to the control delay value.

Based on the value of saturation flow rate, capacity, v/c ratio and delay LOS is determined.

Table 6 Formulas

LOS	Control delay per vehicle(s/veh)
A	≤10
B	>10-20
C	>20-35
D	>35-55
E	>55-80
F	>80

5.0 Summary and Conclusion

5.1 Summary

The computation discussed results in an estimation of the average delay per vehicle in each lane group for each approach and for the intersection as a whole. LOS is directly related to delay value and is assigned on that basis. Los is a measure of the acceptability of delay levels to motorists at a given intersection.

Capacity and level of service are two important terms applied to traffic operation and are given suitable definition by HCM. Capacity represents the ability of the system to handle whereas level of service looks at the system from the driver's perspective. The fundamental diagrams of traffic flow can be used in the representation of level of service. Level of service ranges from A to F, representing the free flow conditions and F representing the worst traffic condition like less speed, high density etc.

5.2 Conclusion

The conclusions are summarized in the following tables:

5.2.1 Esso bunk data analysis

5.2.1.1 Morning session

i) Phase I - Coimbatore to Avinashi

- The Saturation(s) flow rate of the lane group is 3591 veh/h
- The Capacity(c) of the given lane group is 1556 veh/h
- The ratio of flow rate to capacity or volume to capacity ratio(X) is 3.09.
- The time delay(d) per vehicle for a lane group is 15 min 50 sec.
- The level of service(LOS) for the lane group is F.
- The Zone classification of the lane group is Over Saturated Zone.

ii) Phase I - Avinashi to Coimbatore

- The Saturation(s) flow rate of the lane group is 4341 veh/h
- The Capacity(c) of the given lane group is 1881 veh/h
- The ratio of flow rate to capacity or volume to capacity ratio(X) is 2.78.
- The time delay(d) per vehicle for a lane group is 13 min 52 sec.
- The level of service(LOS) for the lane group is F.
- The Zone classification of the lane group is Over Saturated Zone.

iii) Phase II - Avinashi to Coimbatore

- The Saturation(s) flow rate of the lane group is 4341 veh/h
- The Capacity(c) of the given lane group is 1881 veh/h
- The ratio of flow rate to capacity or volume to capacity ratio(X) is 2.78.
- The time delay(d) per vehicle for a lane group is 13 min 52 sec.
- The level of service(LOS) for the lane group is F.
- The Zone classification of the lane group is Over Saturated Zone.

iv) Phase II – Avinashi to Bharathi road

- The Saturation(s) flow rate of the lane group is 3561 veh/h
- The Capacity(c) of the given lane group is 801 veh/h
- The ratio of flow rate to capacity or volume to capacity ratio(X) is 0.61.
- The time delay(d) per vehicle for a lane group is 49 sec.
- The level of service(LOS) for the lane group is D.
- The Zone classification of the lane group is Saturated Zone.

v) Phase III – Bharathi road to Coimbatore

- The Saturation(s) flow rate of the lane group is 1752 veh/h
- The Capacity(c) of the given lane group is 378 veh/h
- The ratio of flow rate to capacity or volume to capacity ratio(X) is 2.30.
- The time delay(d) per vehicle for a lane group is 2 min 18 sec.
- The level of service(LOS) for the lane group is F.
- The Zone classification of the lane group is Over Saturated Zone.

5.2.1.2 Evening session

i) Phase I - Coimbatore to Avinashi

- The Saturation(s) flow rate of the lane group is 3639 veh/h
- The Capacity(c) of the given lane group is 1577 veh/h
- The ratio of flow rate to capacity or volume to capacity ratio(X) is 3.22.
- The time delay(d) per vehicle for a lane group is 19 min 5 sec.
- The level of service(LOS) for the lane group is F.
- The Zone classification of the lane group is Over Saturated Zone.

ii) Phase I - Avinashi to Coimbatore

- The Saturation(s) flow rate of the lane group is 4389 veh/h
- The Capacity(c) of the given lane group is 1902 veh/h
- The ratio of flow rate to capacity or volume to capacity ratio(X) is 2.83.
- The time delay(d) per vehicle for a lane group is 14 min 19 sec.
- The level of service(LOS) for the lane group is F.
- The Zone classification of the lane group is Over Saturated Zone.

iii) Phase II - Avinashi to Coimbatore

- The Saturation(s) flow rate of the lane group is 4389 veh/h
- The Capacity(c) of the given lane group is 1881 veh/h
- The ratio of flow rate to capacity or volume to capacity ratio(X) is 2.83.
- The time delay(d) per vehicle for a lane group is 14 min 19 sec.
- The level of service(LOS) for the lane group is F.
- The Zone classification of the lane group is Over Saturated Zone.

iv) Phase II – Avinashi to Bharathi road

The Saturation(s) flow rate of the lane group is 3601 veh/h

- The Capacity(c) of the given lane group is 801 veh/h
- The ratio of flow rate to capacity or volume to capacity ratio(X) is 0.59.
- The time delay(d) per vehicle for a lane group is 49 sec.
- The level of service(LOS) for the lane group is D.
- The Zone classification of the lane group is Saturated Zone.

v) Phase III – Bharathi road to Coimbatore

- The Saturation(s) flow rate of the lane group is 1801 veh/h
- The Capacity(c) of the given lane group is 390 veh/h
- The ratio of flow rate to capacity or volume to capacity ratio(X) is 1.24.
- The time delay(d) per vehicle for a lane group is 2 min 51 sec.
- The level of service(LOS) for the lane group is F.
- The Zone classification of the lane group is Over Saturated Zone.

5.2.2 Anna statue data analysis

5.2.2.1 Morning session

i) Phase I – Coimbatore to Avinashi

- The Saturation(s) flow rate of the lane group is 4883 veh/h
- The Capacity(c) of the given lane group is 2034 veh/h
- The ratio of flow rate to capacity or volume to capacity ratio(X) is 2.06.
- The time delay(d) per vehicle for a lane group is 4 min 49 sec.
- The level of service(LOS) for the lane group is F.
- The Zone classification of the lane group is Over Saturated Zone.

ii) Phase I – Avinashi to Coimbatore

- The Saturation(s) flow rate of the lane group is 4119 veh/h
- The Capacity(c) of the given lane group is 1716 veh/h
- The ratio of flow rate to capacity or volume to capacity ratio(X) is 2.82.
- The time delay(d) per vehicle for a lane group is 14 min 15 sec.
- The level of service(LOS) for the lane group is F.
- The Zone classification of the lane group is Over Saturated Zone.

iii) Phase II– Avinashi to Gandhipuram Road

- The Saturation(s) flow rate of the lane group is 4063 veh/h
- The Capacity(c) of the given lane group is 1286 veh/h
- The ratio of flow rate to capacity or volume to capacity ratio(X) is 0.26.
- The time delay(d) per vehicle for a lane group is 44 sec.
- The level of service(LOS) for the lane group is D.
- The Zone classification of the lane group is Saturated Zone.

iv) Phase II– Coimbatore to Huzur Road

- The Saturation(s) flow rate of the lane group is 3388 veh/h
- The Capacity(c) of the given lane group is 1072 veh/h
- The ratio of flow rate to capacity or volume to capacity ratio(X) is 0.89.
- The time delay(d) per vehicle for a lane group is 52 sec.
- The level of service(LOS) for the lane group is D.
- The Zone classification of the lane group is Saturated Zone.

v) Phase III– Gandhipuram Road to Huzur Road

- The Saturation(s) flow rate of the lane group is 3857 veh/h
- The Capacity(c) of the given lane group is 642 veh/h
- The ratio of flow rate to capacity or volume to capacity ratio(X) is 3.2.
- The time delay(d) per vehicle for a lane group is 17 min 24 sec.
- The level of service(LOS) for the lane group is F.
- The Zone classification of the lane group is Over Saturated Zone.

vi) Phase III– Gandhipuram Road to Coimbatore

- The Saturation(s) flow rate of the lane group is 4979 veh/h
- The Capacity(c) of the given lane group is 829 veh/h
- The ratio of flow rate to capacity or volume to capacity ratio(X) is 0.36.
- The time delay(d) per vehicle for a lane group is 51 sec.
- The level of service(LOS) for the lane group is D.
- The Zone classification of the lane group is Saturated Zone.

5.2.2.2 Evening session

i) Phase I - Coimbatore to Avinashi

- The Saturation(s) flow rate of the lane group is 4780 veh/h
- The Capacity(c) of the given lane group is 1992 veh/h
- The ratio of flow rate to capacity or volume to capacity ratio(X) is 2.06.
- The time delay(d) per vehicle for a lane group is 8 min 34 sec.
- The level of service(LOS) for the lane group is F.
- The Zone classification of the lane group is Over Saturated Zone.

ii) Phase I - Avinashi to Coimbatore

- The Saturation(s) flow rate of the lane group is 2822 veh/h
- The Capacity(c) of the given lane group is 1175 veh/h
- The ratio of flow rate to capacity or volume to capacity ratio(X) is 3.40.
- The time delay(d) per vehicle for a lane group is 18 min 36 sec.
- The level of service(LOS) for the lane group is F.
- The Zone classification of the lane group is Over Saturated Zone.

iii) Phase II– Avinashi to Gandhipuram Road

- The Saturation(s) flow rate of the lane group is 2346 veh/h
- The Capacity(c) of the given lane group is 742 veh/h
- The ratio of flow rate to capacity or volume to capacity ratio(X) is 1.14.
- The time delay(d) per vehicle for a lane group is 1 min 59 sec.
- The level of service(LOS) for the lane group is F.
- The Zone classification of the lane group is Over Saturated Zone.

iv) Phase II– Coimbatore to Huzur Road

- The Saturation(s) flow rate of the lane group is 3976 veh/h
- The Capacity(c) of the given lane group is 1259 veh/h
- The ratio of flow rate to capacity or volume to capacity ratio(X) is 0.38.
- The time delay(d) per vehicle for a lane group is 42 sec.
- The level of service(LOS) for the lane group is D.
- The Zone classification of the lane group is Saturated Zone.

v) Phase III– Gandhipuram Road to Huzur Road

- The Saturation(s) flow rate of the lane group is 3658 veh/h
- The Capacity(c) of the given lane group is 610 veh/h
- The ratio of flow rate to capacity or volume to capacity ratio(X) is 3.24.
- The time delay(d) per vehicle for a lane group is 17 min 42 sec.
- The level of service(LOS) for the lane group is F.
- The Zone classification of the lane group is Over Saturated Zone.

vi) Phase III– Gandhipuram Road to Coimbatore

- The Saturation(s) flow rate of the lane group is 4979 veh/h
- The Capacity(c) of the given lane group is 829 veh/h
- The ratio of flow rate to capacity or volume to capacity ratio(X) is 0.58.
- The time delay(d) per vehicle for a lane group is 53 sec.
- The level of service(LOS) for the lane group is D.
- The Zone classification of the lane group is Saturated Zone.

5.3 Safety issues

- Changing the priority of the crossing by introducing the GIVEWAY or STOP signs for the traffic entering the junctions from minor. By this way traffic that the conflict can be reduced.
- By providing a provision for U-turn at 40m from intersection reduce the accumulation of traffic at intersection.
- Rules to be strictly followed by vehicles at intersection while waiting for signal.
- Vehicles should be stopped before the zebra-crossing in order for free movement of pedestrians.
- Pedestrians should use zebra-crossing for crossing the road which results in minimization of accidents.
- Illegal movement of vehicles before green signal and after red signal to be arrested.
- Blocking of the free left for vehicles movement should be avoided.
- Accumulation of more buses should be avoided in order to have a stable flow condition.
- Vehicle movement should be in a defined path which doesn't disturb the behind vehicles movement.
- Proper usage of vehicle indicators must be done in order to avoid conflict while turning.
- Proper working delineators should be placed on the roads.
- Proper road signs should be mentioned for convenience and free movement of vehicle and for caution purpose.
- Creating the awareness of speed maintenance at the intersection to avoid any type of inconvenience.

5.4 Suggested phase time

The Suggested phase time of Esso Bunk

Table 7 Phase time of esso bunk

Phases	Red time (sec)	Green time(sec)
Phase-1	64	52
Phase-2	56	27
Phase-3	89	25

Note: - Amber time 2s

The suggested phase time of Anna Statue

Table 8 Phase Time of Anna Statue

Phases	Red time (sec)	Green time(sec)
Phase-1	66	50
Phase-2	78	38
Phase-3	96	20

Note: - Amber time 2s

5.5 Scope for further study

Further study should be directed at analyzing the intersection, drivers behaviour, pedestrian behaviour, conflict points. These analyses enable us to better understand the flow of traffic at intersection with real time data, to analyse the capacity and level of service and to predict the intersection safety.

6.0 References

1. A guide to Road Safety Auditing, Ministry of Infrastructure Development, Safety and Environment Unit, United Republic of Tanzania, January (2009).
2. Impediments to Road Safety Audits in India by Dr. Nishi Mittal, Head, Traffic Engineering and safety, Central Road Research Institute, New Delhi, India
3. Manual on Road Safety Audit, IRC: SP:88-2010

4. Transport Engineering & Planning by C.S Papacostas& P.D Prevedouros, University of Hawaii at Manoa, Honolulu, Hawaii.
5. Traffic Engineering and Transportation Engineering by Dr. L.R. Kadiyali
6. National Highway Authority of India, consultancy service for feasibility study and detailed project report for 4/6 laning of Karur- Madurai section of NH-7 from Km 305/8 to 426/6 in the state of Tamil Nadu, January (2005)
7. Manual for survey, investigation ans preparation of road projects, IRC: SP: 19-2001
8. Guidelines for the design of at- grade intersection in Rural & Urban areas, IRC : SP: 41-1994
9. Coimbatore corporation report on model road.

*****