Modification of Existing Signal Cycles by Incorporating Approach Road Width Loss in Saturation Flow Formula Using Webster's Method

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***Abstract*: The Saturation Flow is the flow which would be obtained if there was a continuous queue of vehicles and they were given a 100 per cent green time. It is generally expressed as P.C.U per hour of green time. Saturation flow depends on the layout of the intersection (especially the width of the approach road), the number of right turning vehicles and goods carrying (commercial) vehicles, the presence of parked vehicle on the road and other factors. The road width of approach is assumed to be constant for at least the length of the approach road which is defined as the length of road which will accommodate the queue which can just pass through the intersection during a fully saturated green period.**

In connection with the saturation flow formula for the change in approach road width, observations were held at three signalized intersections of Visakhapatnam city, they are, Asilmetta junction, RTC Complex Junction, and Sangam Sarath Junction. In this study, the approach road width loss due to vehicles parked near the Signal intersections at busy and major Visakhapatnam areas are considered and this loss is updated in the approach road width value to be used in the Saturation flow formula and consequently the empiricism of the Saturation flow formula is updated to suit the Visakhapatnam area Signal intersection designs.

Index Terms*: *Saturation Flow Approach road width, Intersections, Approach road width loss, Signal Design, Webster's Method.

I. Introduction

As the road traffic increases, more and more traffic signals are installed at the intersections. Since it has been estimated that queuing at traffic signals accounts for about100 million vehicle- hours each year it is clearly of the utmost importance to set the timings correctly so as to minimize the delay. Capacity of signal-controlled intersections is a very important subject and is of considerable concern, not only at design stage, but also when making economic assessments of different types of intersections and of value of improvements at signal-controlled junctions.

Saturation flow formula **S = 525w** is the commonly used in India for any width of road at signalized intersection [1]. In correction with the saturation flow formula for the change in approach road width, observations were held at three signalized intersections of Visakhapatnam city, they are, Asilmetta junction, RTC Complex Junction, and Sangam Sarath Junction. These signalized intersections have the width of approach roads varying from 9 to 12 meters.

The observations are done in the peak hours of the day i.e. in the morning, noon, and evening peak times to get the values of observed saturation flows for each approach road. The signal design is simple and is totally based on formulas laid down by Webster, in this method, the total cycle time of the signal is determined which forms total least delay occurring at signal.

A. *Traffic Engineering Studies*

The traffic engineering studies are carried out for collection of traffic volume data are also called as Traffic Surveys. Traffic engineering studies are carried out to analyze the traffic characteristics and used to deign geometric features and traffic control measures for the safe and efficient traffic movement. The analysis of results of the studies conducted is also useful for assessing the need of proposed road project with justifications. The different traffic surveys generally carried out are

1. Traffic Volume Studies
2. Spot Speed Studies
3. Speed and Delay Studies
4. Origin and Destination Studies
5. Parking Studies Accident Studies

The type of survey adopted for the project is "Traffic Volume Study" and the below describes about the same.

B. *Traffic Volume Studies*

Traffic volume is a measure of quantity of traffic flow and is expressed as the number of vehicles that pass across a given transverse line of the road during unit time. As the carriageway width may vary the volume is generally expressed as the number of vehicles per hour or per day, per traffic lane. Different class of vehicles makes use of the same roadway particularly in developing countries like India; thus the traffic streams consist of 'mixed traffic flow'. The vehicles of traffic stream may be classified into different vehicle classes. They consist of:

Fast moving vehicles such as

i. Passenger cars
ii. Busses
iii. Trucks or Heavy Commercial Vehicles (HCV)

iv. Light Commercial Vehicles (LCV)
v. Auto rickshaws
vi. Two wheelers

Slow moving vehicles or animal drawn vehicles:

In order to express the total traffic flows on a road per unit time. It becomes necessary to convert the flow of different classes of vehicles into one standard vehicle type, such as the 'Passenger Car'. Therefore the equivalency factor, called "Passenger Car Unit (PCU)". And all the vehicles are expressed in terms of Passenger Car Units.

C. Traffic Signals

At intersections where there are a large number of crossing and right turning vehicles, there is a possibility of several accidents as there cannot be orderly movements. The problems of conflicts at the intersection gains more significance as the traffic volume increases. In such a situation the earlier practice has been to control the traffic with the help of traffic police who stops the vehicles on one of the roads alternatively and allows the traffic stream of the other road to cross or take right turn. Thus the crossing streams of traffic flow are separated by 'time- segregation'. In bigger cities, a large number of police personnel are required simultaneously to control the traffic during peak hours at most of the junctions with heavy traffic flow. Therefore traffic signals are made use of to perform this function of traffic control at road intersections.

II. LITERATURE REVIEW

Analysis of Saturation Flow at Signalized Intersection in Urban Area: Surat (2016) [1] Mr. Sharukh. M. Marfani Mr. H. K. Dave. The authors through their works found that the saturation flow obtained through field studies is higher than the saturation flow obtained by generalized formula S = 525 * W of IRC Sp-41 they also found that with increasing proportion of two wheeler, saturation flow per meter width also tends to increase due to heterogeneity and filling of gaps by two wheelers, while increase in proportion of cars the saturation flow tend to decrease to more homogeneity.

Saturation Flow Model for Signalized Intersection under Mixed Traffic Condition (2018) [8]- Satish Chandra et.al The authors in the present study came up with a model of estimating saturation flow based on the composition of through traffic and percentage of right turning traffic in the approach. In this regard data from thirteen signalized intersections of four different cities where considered the validation showed that field observed saturation flow values were pretty much similar with the model estimated values. However, maximum difference was 8-10% which is in an acceptable limit. Therefore, I can be recommended that saturation flow measurement of an intersection approach can be successfully used for saturation flow measurement at intersection locations under mixed traffic conditions.

Saturation Flow at Signalized Intersection under Mixed Traffic Flow Condition (2016) [7]-Shaikh Nazneen Mustaq et.al, They considered that the Saturation flows, lost times and Passenger Car Units (PCU) are the significant parameters in the planning, design and control of signalized intersection. The accurate estimation of Saturation flow values is prime importance when determining the capacity of signalized intersection. Saturation flow is important for estimating signal green time. Their paper attempts to literature Review on the saturation flow of signalized intersections. A saturation flow and the proportion of mix traffic, which suggest that mix traffic flow have significant impact and should be considered in the capacity analysis of signalized intersections.

Modification of saturation flow formula by width of road approach (2011)[6]-Budi Hartanto Susiloa , Yanto Solihinb The authors proposed that the formula of saturation flow s=600*We is still in use for narrow and medium width of approach(3m to 8m)for wide approach (9m to 12m)is better used s=500*We+400 at least for Bandung city. To convince the formula is valid it has to be tried at other cities, other countries.

III. METHODOLOGY:

The entire project work is based on analyzing the identified research problem, by conducting traffic volume studies. The traffic volume data consisting of the traffic volume count is posted in data sheets. For the traffic samples obtained for the count is converted into PCU/hr. From this calculated PCU/hr values the saturation flow and signal timings are calculated. Using the volume count the width loss of the lane and the saturation flow and signal timings for the corrected approach widths is calculated. The methodology is provided in the form of flow chart.

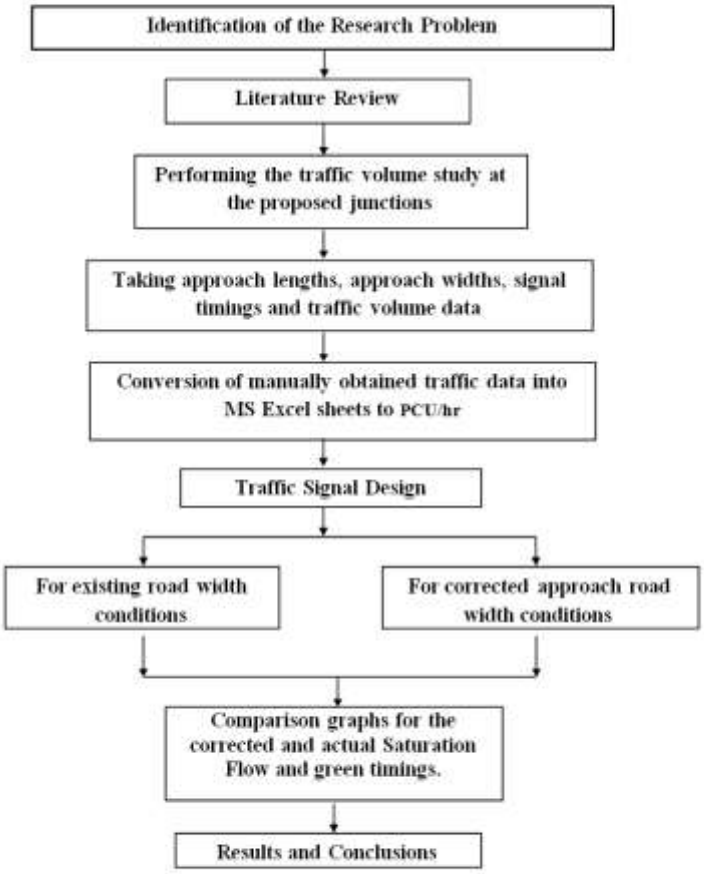

Fig 3.1: Flowchart for Methodology

Traffic signals are one of the most affective and flexible active control of traffic and is widely used in several cities worldwide. The conflicts arising from movement of traffic in different directions is addressed by time sharing principle. The advantages of traffic signal include an orderly movement of traffic, an increased capacity of the intersection and require only simple geometric design. However, the disadvantages of the signalized intersection are large stopped delays, and complexity in the design and implementation. Although the overall delay may be lesser than a rotary for a high volume, a user may experience relatively high stopped delay. The various design principles of traffic signal such as phase design, cycle length design, and green splitting and also the concept of saturation flow, capacity, and lost times are also presented below.

A. Definitions and Notations

i. Cycle:

A complete series of stages during which all traffic movements are served in turn is known as a cycle.

ii. 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. The cycle time is the sum of each of the stage times.

iii. Interval:

Thus it indicates the change from one stage to another. There are two types of intervals - change interval and clearance interval.

a. Change Interval is also called the yellow time indicates the interval between the green and red signal indications for an approach (Yi).

b. Clearance Interval is also called all red and is provided after each yellow interval indicating a period during which all signal faces show red and is used for clearing of the vehicles in the intersection.

iv. 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.

v. Red Interval:

It is the red indication for a particular 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.

vi. 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 halts the flow before the phase of another set of movements start.

vii. Lost Time:

It indicates the time during which the intersection is not effectively 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 before vehicle actually moves and gains speed.

B. Phase Design

The signal design procedure involves six major steps. They include:

i. Phase design,
ii. Determination of amber time and clearance time,
iii. Determination of cycle length,
iv. Apportioning of green time,
v. Pedestrian crossing requirements, and
vi. Performance evaluation of the design obtained in the previous steps.

The objective of phase design is to separate the conflicting movements in an intersection into various phases, so that movements in a phase should have no conflicts. If all the movements are to be separated with no conflicts, then a large number of phases are required. In such a situation, the objective is to design phases with minimum conflicts or with less severe conflicts. There is no precise methodology for the design of phases. This is often guided by the geometry of the intersection, the flow pattern especially the turning movements, and the relative magnitudes of flow. Therefore, a trial and error procedure is often adopted.

However, phase design is very important because it affects the further design steps. Further, it is easier to change the cycle time and green time when flow pattern changes, where as a drastic change in the flow pattern may cause considerable confusion to the drivers.

Two Phase Signal Design

Two phase system is usually adopted if through traffic is significant compared to the turning movements. Needless to say that such phasing is possible only if the turning movements are relatively low.

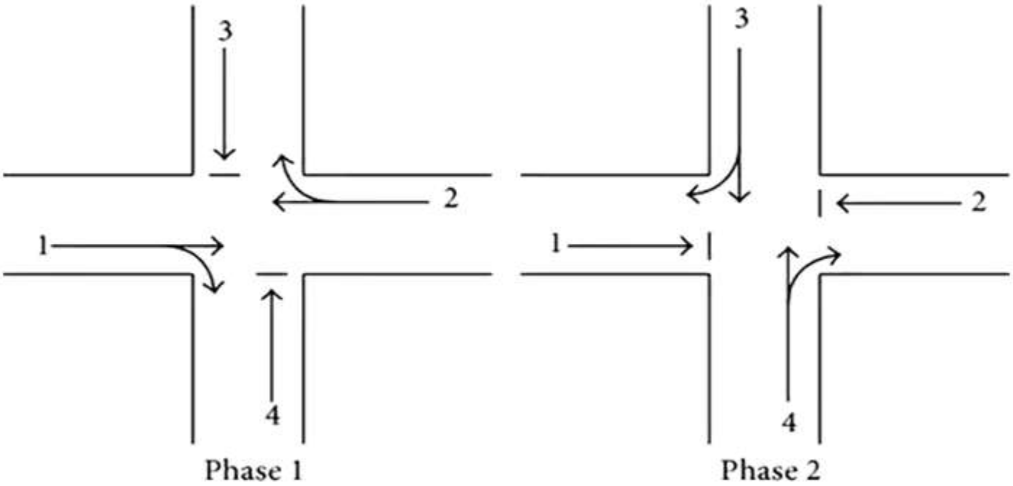

Fig 3.2 **2 – Phase Signal**

Three Phase Signal

Three phase signals are adopted for a three legged intersection, where there are two conflicting movements which are right turns for both the roads and two non conflicting movements which are through movements.

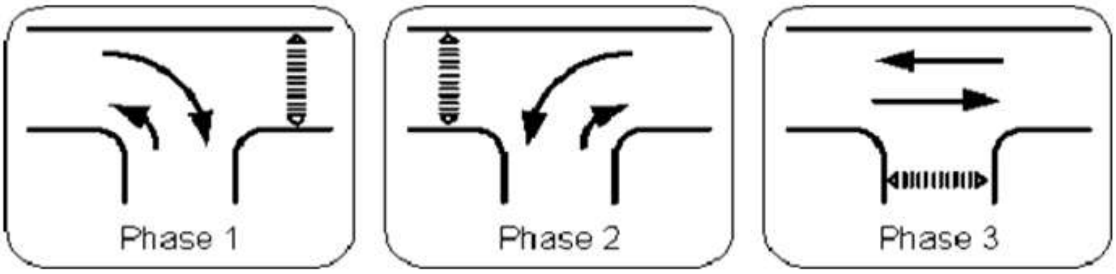

Fig 3.3: **3 – Phase Signal**

Four Phase Signal

This type of phase plan is ideally suited in urban areas where the turning movements are comparable with through movements and when through traffic and turning traffic need to share same lane. This phase plan could be very inefficient when turning movements are relatively low.

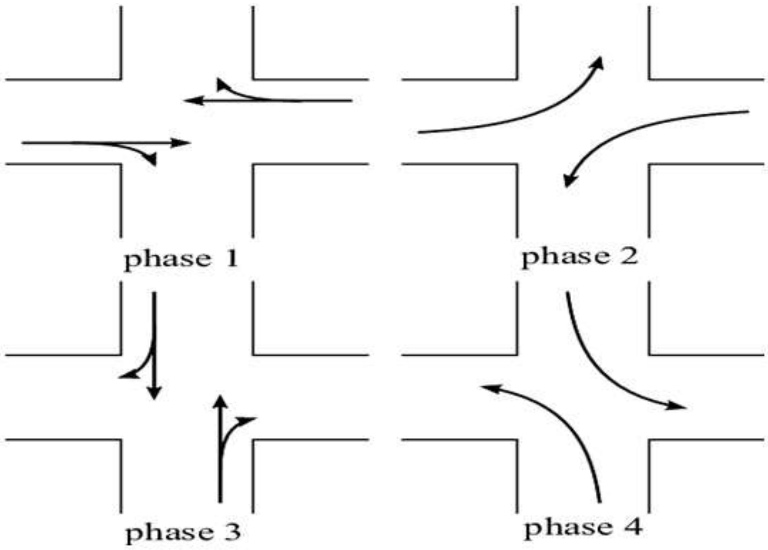

Fig 3.4 : **4 – Phase signal**

C. Types of Traffic Signals Available:
There are essentially two types of signals in general use:

1. Fixed-Time and
2. Vehicle Actuated signals.

Because signals permit traffic movements from any approach for only a proportion of the time, it is sometimes necessary for the intersection approaches, where queuing takes place, to be wider than the roads which feed these approaches in order to pass the flow. If the intersection already exists, the timing of the signals can be adjusted for a given flow pattern to make the best use of the layout. If the intersection is in its design stage, or if some adjustments can be made to the existing intersections, then a choice of approach width may be available, after selection of which the green times can be adjusted to give the correct capacities for those approaches.

The amount of vehicles that can pass through a signal-controlled intersection from a given approach depends on the green time available to the traffic and on the maximum flow vehicles pass the stop line during the green period is defined as the capacity of that particular intersection.

When the green period commences vehicles take some time to start and accelerate to normal running speed, but after a few seconds the queue discharges at a more or less constant rate called the **Saturation Flow** (Fig. 4).

The saturation flow is the flow which would obtained if they were given a 100 percent green time. It is generally expressed in vehicles per hour of green time or PCU/ hr of green time.

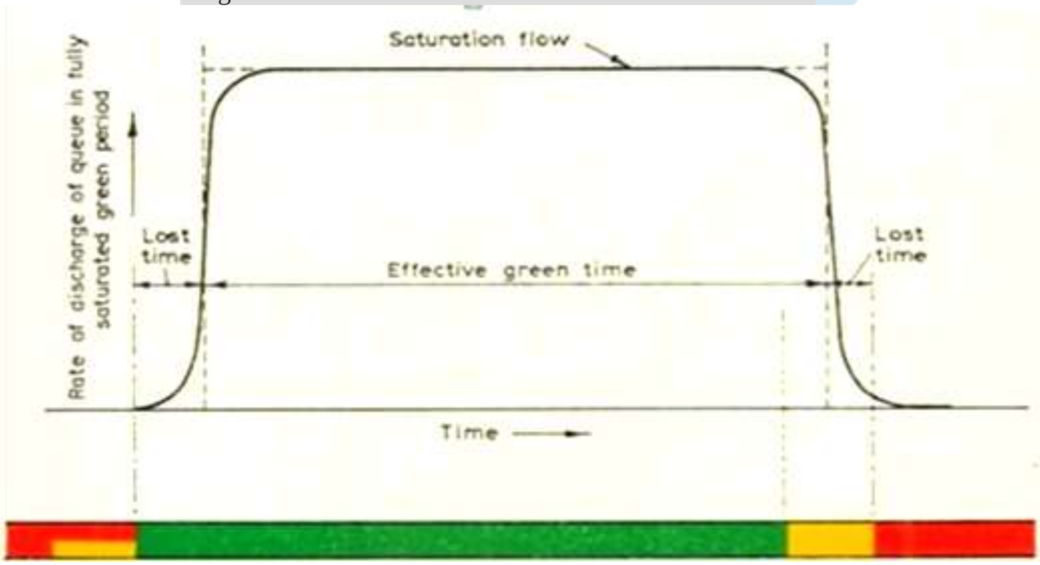

Fig 3.5: Variation with time of discharge rate of queue in a fully saturated green period.

It can be seen from the above figure that the average rate of flow is lower during the first few seconds and during the amber time. It is convenient to replace the green and amber periods by an Effective Green period throughout which flow is assumed to take place at the saturation rate, and

a 'lost time' during which no flow take place. This is useful concept because capacity is directly proportional to the effective green time. Therefore from the figure it is evident that the height of the rectangle is equal to the average saturation flow and the base of the rectangle is called the effective green time and the difference between this and the combined green and amber period is 'lost time'.

D. Estimation of Saturation Flow

Width of Approach

The Road Research Technical Paper No. 56 suggested that the Saturation Flow (S) be expressed in terms of passenger car units (pcu's) per hour and with no turning traffic or parked vehicles;

Where, w is the width of the approach road in meters and 5.15 <w< 18.3m. For widths less than 5.15 m the following values may be used:

Table – 3.1: Values of saturation flow for widths less than 5.15m

Width *w* (m.)	2.70	3.00	4.00	4.50	5.15
Saturation flow S (PCU/hr)	1790	1850	1950	2250	2700

Research and experience has shown that S may be more accurately reflected by the number of lanes rather than the overall width of the approach - which tends to underestimate flows in situations where narrow lanes of, say, 2.70m are used.

IV. OBSERVATIONS AND CALCULATIONS

Step 1 – Identification of Traffic Flow Volumes

Traffic flow volumes are identified, including turning movements. The traffic volume surveys are performed at the proposed intersections and the resulting data obtained is further converted into PCU/hr values from vehicles /hr.

The following are the tables which show the observed traffic volume at the proposed intersections along with the PCU/hr conversion.

Step – 2 – Calculation of Pedestrian Crossing time (sec)

Step – 3 – Calculation of minimum Green time Step – 4 – Calculation of Revised Green Time Step – 5 – Check for Revised Green Time.

Table 4.1: List of tables for all three intersections

Table no.	Junction Name	Topic of the Tabular Form
6.1		List of tables at all three intersections
6.2		Field traffic census for phase 1 north
6.3		Field traffic census for phase 2 south
6.4		Field traffic census for phase 3 east
6.5		Field traffic census for phase 4 west
6.6	Sangam Sarath Junction	Cycle times of the Sangam Sarath junction for actual width
6.7		Cycle times of the Sangam Sarath junction for corrected width
6.8		Corrected Approach Road Width Values at Sangam Sarath Junction
6.9		Data sheet for maximum Y values for actual widths
6.10		Data sheet for maximum Y values for corrected widths
7.1		Field traffic census for phase 1 north
7.2		Field traffic census for phase 2 south
7.3		Field traffic census for phase 3 east
7.4		Field traffic census for phase 4 west
7.5	RTC Complex Junction	Cycle times of the RTC junction for actual width
7.6		Cycle times of the RTC junction for corrected width
7.7		Corrected Approach Road Width Values at RTC Junction
7.8		Data sheet for maximum Y values for actual widths
7.9		Data sheet for maximum Y values for corrected widths
8.1		Field traffic census for phase 1 north
8.2		Field traffic census for phase 2 south
8.3		Field traffic census for phase 3 east
8.4		Field traffic census for phase 4 west
8.5	Asilmetta Junction	Cycle times of the Asilmetta junction for actual width
8.6		Cycle times of the Asilmetta junction for corrected width
8.7		Corrected Approach Road Width Values at Asilmetta ss Junction
8.8		Data sheet for maximum Y values for actual widths
8.9		Data sheet for maximum Y values for corrected widths

Table 4.2: Field Details.

Area	Sangam Sarath Junction	**Day:**	Friday
Date:	20/09/2019	**Weather:**	Sunny
Location:	Sangam Sarath Junction	**Direction & Phase :**	North & 1

Table 4.3: Field Data Sheet for Traffic Census

Time		**Cars**				**Buses**				**Three Wheelers**				**Two Wheelers**				**Total**
From	To	L	S	R	T	L	S	R	T	L	S	R	T	L	S	R	T	PCU
08:00	08:30	2	8	19	29	0	21	28	49	0	43	25	68	2	47	32	81	227
08:30	09:00	2	32	17	51	0	63	18	81	11	80	16	107	3	43	32	78	210
09:00	09:30	0	47	20	67	0	53	14	67	4	103	17	124	4	106	36	146	404
09:30	10:00	1	40	27	68	0	49	25	74	0	82	29	111	4	72	51	127	380
12:00	12:30	0	91	7	98	0	56	4	60	0	128	10	138	3	163	7	173	469
12:30	13:00	10	29	51	90	0	49	21	70	13	100	36	149	23	16	115	154	463
13:00	13:30	16	65	29	110	11	14	60	85	16	52	14	82	19	141	46	206	483
13:30	14:00	20	72	19	111	4	25	84	113	20	58	20	98	21	112	49	182	504
16:00	16:30	18	69	40	127	7	28	53	88	19	52	82	153	23	10	45	78	446
16:30	17:00	21	56	38	115	28	11	41	80	28	41	52	121	18	85	62	165	481
17:00	17:30	38	64	41	143	21	14	60	95	18	60	64	142	17	102	75	194	574
17:30	**18:00**	**29**	**68**	**72**	**169**	**14**	**47**	**58**	**119**	**35**	**58**	**116**	**209**	**24**	**115**	**122**	**261**	**758**
19:00	19:00	20	72	50	142	7	7	50	64	29	50	90	169	21	137	119	277	652
19:30	20:00	26	52	76	154	14	7	44	65	24	44	6	74	16	115	77	208	501
20:00	20:30	22	74	42	138	7	14	76	97	31	76	56	163	19	154	79	252	650
20:30	21:00	20	62	54	136	7	14	50	71	28	50	66	144	17	116	89	222	573

Peak Hour Factor (PHF) = peak hourly volume (2 x peak 30 min volume) = (758+574)/ (2 x 758) = 0.88 PCU/hr of peak traffic volume = (peak hour traffic)/PHF = (758+574)/ 0.88 = **1513 PCU/hr**

Considered in Sunny Season also and tabulated RTC Complex Junction and Asilmetta Junction areas of Field Data Sheet For Traffic Census.

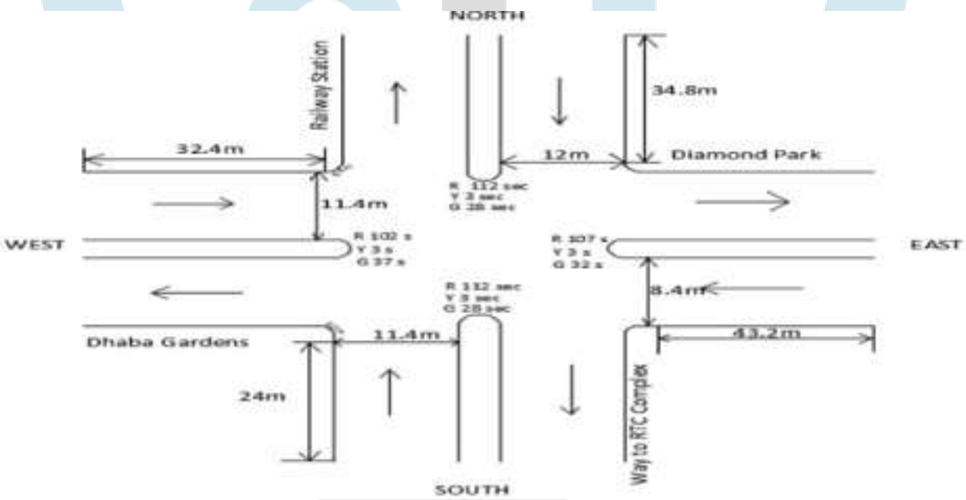

Fig 4.1: Existing Traffic Signal Timings at Sangam Sarath Junction

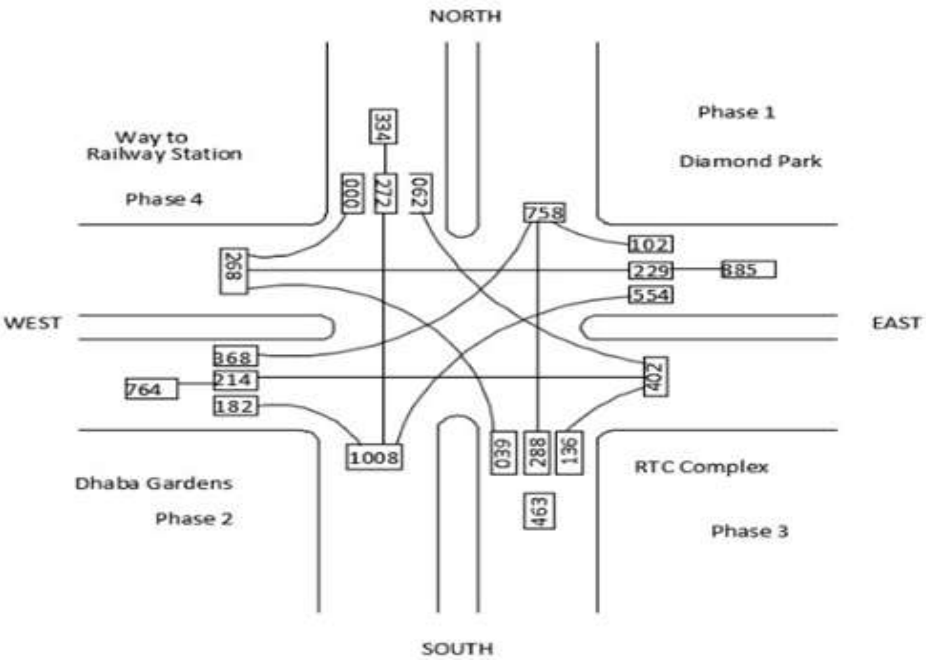

Fig 4.2: Traffic Volume Data and Traffic Flow at Sangam Sarath Junction.

Traffic Signal Design for the Corrected Width:

Data Obtained from Traffic Volume Studies

- Width of road 1, 2, 3, and 4 = 9 m (two lanes each of 4.5 m)
- Approach road volume of road 1 = 1513 PCU/hr
- Approach road volume of road 2 = 2021 PCU/hr
- Approach road volume of road 3 = 803 PCU/hr
- Approach road volume of road 4 = 540 PCU/hr
- Pedestrian walking speed = 1.2 m/sec
- Design traffic on road 1 = 1513/2 = 756.5 PCU/hr
- Design traffic on road 1 = 2021/2 = 1011 PCU/hr
- Design traffic on road 1 = 803/2 = 402 PCU/hr
- Design traffic on road 2 = 540/2 = 270 PCU/hr

Step 2: Pedestrian Crossing Time

(The pedestrian green time is equal to initial walk time of 7.0 sec plus walking speed of 1.2 m/sec) [as per clause 2.2.4 (i)]

- Pedestrian green time for road 1 and 2 = 91.2+ 7 = 14.5 = 15 sec
- Pedestrian green time for road 3 and 4 = 91.2+ 7 = 15 sec

Step 3: Minimum Green Time for Traffic
Step 4: Revised Green Time or Traffic Signals
Step 5: Check for Clearing the Vehicles Arrived During the Green Phase
Step 6: Check for Optimum Signal Cycle by Webster's Method

Table 4.4: Cycle Times of the Sangam Sarath Junction for Corrected Width

Road	Green Phase, G sec	Amber Phase time, sec	Red phase time, sec	Cycle time, C0 sec
Road 1	50	2	36+28+20+2	85
Road 2	32	2	54+28+20+2	85
Road 3	24	2	20+36+54+2	40
Road 4	16	2	28+36+54+2	40

Table 4.5: Cycle Times of the Sangam Sarath Junction for Actual Width

Road	Green Phase, G sec	Amber Phase time, sec	Red phase time, sec	Cycle time, C0 sec
Road 1	28	2	32+36+41+2	75
Road 2	28	2	36+41+32+2	75
Road 3	32	2	41+32+32+2	40
Road 4	37	2	32+32+36+2	40

Sangam Sarath Junction

Table 4.6: Corrected Approach Road Width Values at Sangam Sarath Junction

Corrected approach road width values at Sangam Sarath Junction				
Phase	**Actual width (z, m.)**	**Green time (g, sec.)**	**correction for width = (1.68-(0.9*(z-7.62))/g)**	**corrected width (w*)**
Phase 1	9	24	1.63	7.37
Phase 2	9	32	1.64	7.36
Phase 3	9	26	1.63	7.37
Phase 4	9	37	1.65	7.35

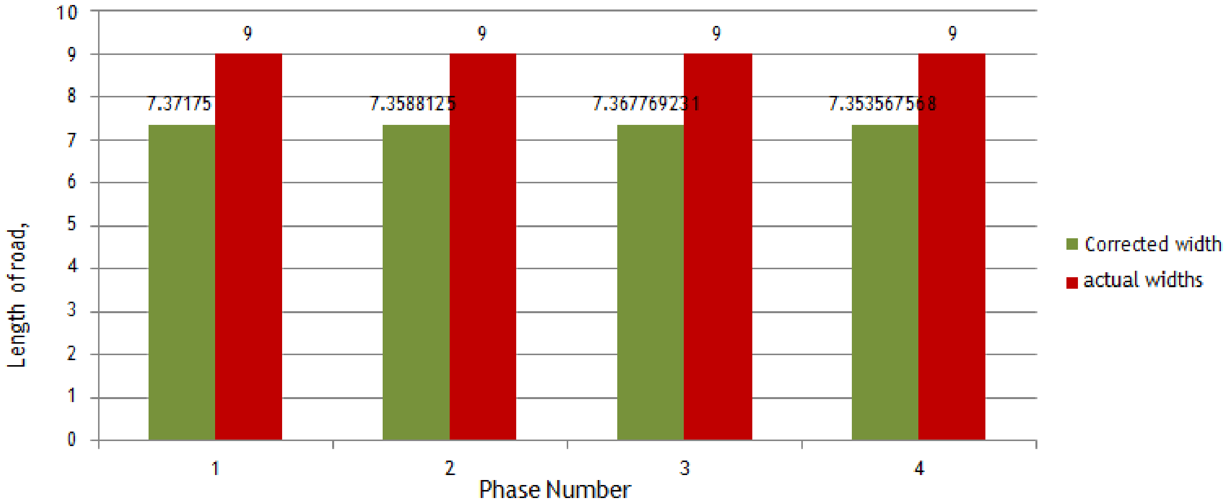

Fig 4.3 Comparison between Actual road width and corrected width as per calculations

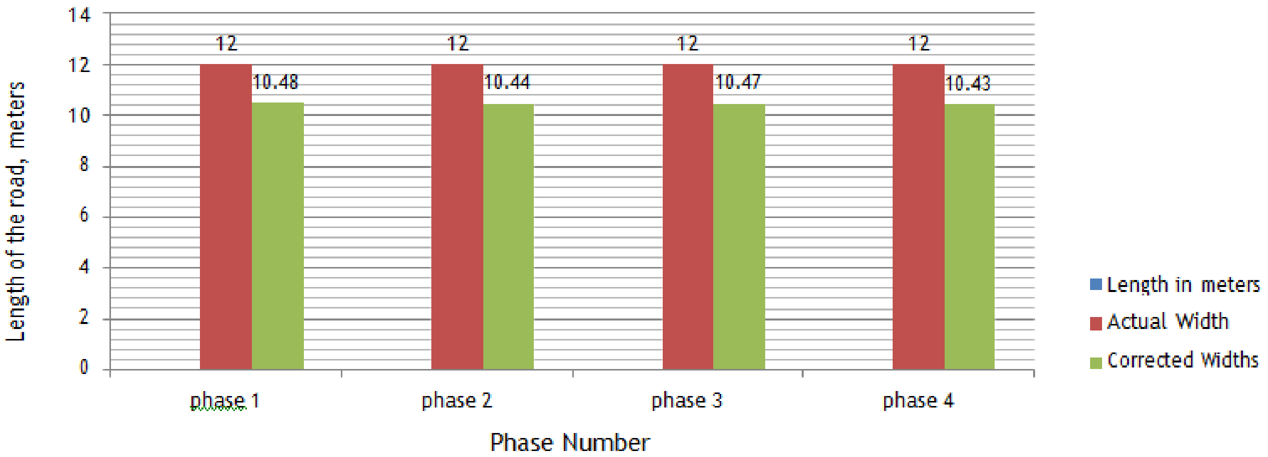

Fig 4.6 Comparison between Actual road width and corrected width as per calculations

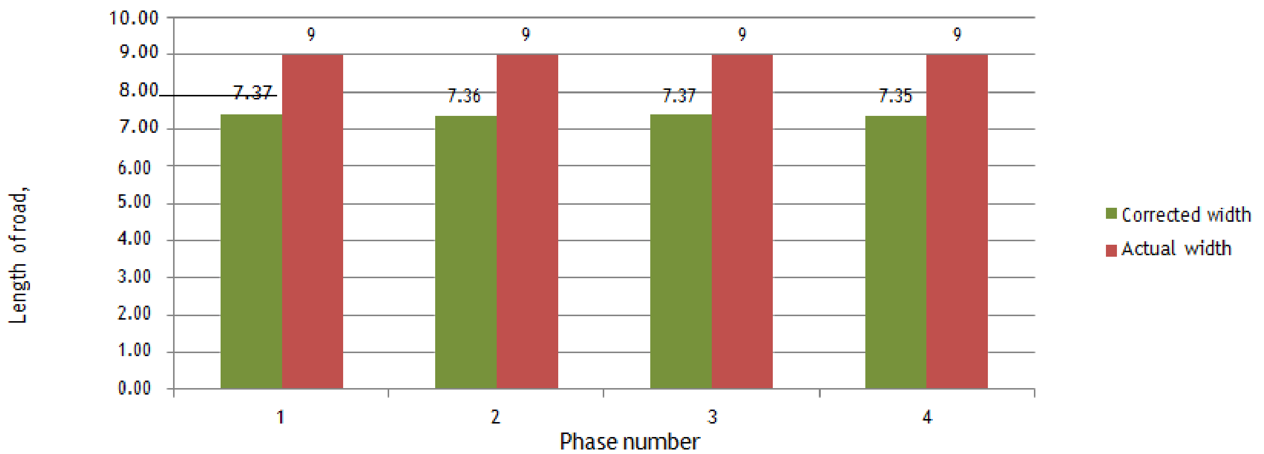

Fig 4.9: Comparison between Actual road width and corrected width as per calculations

V. RESULTS AND CONCLUSION

Table 5.1 Existing Green Times

Road	Green Phase, G sec Asilmetta	Green Phase, G sec RTC Complex	Green Phase, G sec Sangam Sarath
Road 1	30	24	28
Road 2	26	24	28
Road 3	24	35	32
Road 4	32	28	37

Table 5.2 Corrected Green Times

Road	Green Phase, G sec Asilmetta	Green Phase, G sec RTC Complex Junction	Green Phase, G sec Sangam Sarath
Road 1	33	30	50
Road 2	26	48	32
Road 3	43	48	34
Road 4	40	49	40

From the performed observation and calculations we found that to compensate the width loss of Approach roads, the cycle timings should be increased by 5 sec, which is caused due to the parking, waiting and bus stops.

The corrected signal cycles could be used as operating signals to provide a free flow conditions to the traffic with much reduced number of conflicts in the flow.

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