Evaluating Level of Service on a Signalized Intersection by Various Methods

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ABSTRACT: This research paper is about the various methods and understandings related to measuring Level of Service on Signalized Intersections. The Signalized intersections form a crucial part of urban traffic congestion problem and lot of effort gets into designing them and coordinating them, to best fit the traffic demand of the area and reduce any stopped delay times on it. The measure of effectiveness of the signalized intersection is mainly its Level of Service, which is described in TRB HCM 2000 and now latest in Indo HCM 2017. This paper reviews the literature available in this context and tries to evaluate the LOS of a case study intersection by both approaches and compare the results to comment on the better approach suitable to Indian Heterogeneous traffic conditions.
KEYWORDS: Signalised Intersection, Level of Service, HCM 2000, Indo HCM 2017, Traffic, and Congestion.

I. INTRODUCTION

Urban areas of most developing nations have seen a surge in traffic, increasing many fold with increase in GDP of the nation. The growth of cities and rapid urbanization of suburbs have led to an immense pressure on road ways and related infrastructure in the cities. The urban streets and corridors are mostly under pressure to cater to over saturated traffic conditions and people and commuters face huge traffic jams on them. The travel time on any road is unpredictable in current scenario and it can become 100 to 500% more than as it is in normal conditions. One significant part of travel time is time spent on Intersections which one has to cross in its path. These intersections could be signalized or un-signalized or manually handled as per the demand traffic and road importance related to them. The most complex issue that arises for analysts and traffic planners is to how to measure the effectiveness of these signals. The delays at the signal, the queue lengths at it, or the comfort of

manoeuver what should be the correct criteria to determine level of service offered by a Signalized intersection. In this paper we will review, what the other authors have said in this regard, will also try to assess the Level of service of a sample intersection by way of noted methods,i.e the standardized approach of Traffic Research board (TRB) US,in its Highway Capacity Manual 2000 (HCM 2000) and how Indian scientists have summarized it as per Indian context in their latest publication of Indo HCM 2017.

Let us first begin with understanding some important technical terms as associated with Signalized intersection.

Any on-grade intersection of two or three cross roads, forming a T, Y or cross junction could be provided with suitable signals to control the conflicting streams of vehicular and pedestrian traffic. Such intersections are called Signalized intersections.

Signalized intersections provide various benefits to the traffic system like providing an orderly movement of traffic, they can increase traffic handling capacity of intersection, accidents frequency is reduced and totally altered especially at right-angle turns, they also give freedom to control and capture heavy traffic to give fine manoeuvre capability to lighter traffic and pedestrians, they reduce the economic expense associated with an intersection due to less manpower required to manage traffic streams.

The critics of Signalized intersections however bargain with many disadvantages aligned with them which include excessive delay to traffic, particularly in non-peak hours , un-necessary installation of signals increase the chances of public disobedience to them which may lead to fatal accidents to an innocent driver, drivers also get attracted to use less safer routes just to avoid signal interactions on route, any fault and breakdown of signal system leads to total chaos in the area , and needs lot of time and effort by

manual traffic controllers before the normalcy can be restored.

II.   LITERATURE REVIEW

The various important terms to be understood before trying to evaluate the level of service of any intersection are as follows, let's revisit them once:

Approach Capacity : It is referred to as the highest number of vehicles which any approach to an intersection can discharge ,with respect to prevailing site conditions of traffic, geometric characteristics of junctions and signal phase timings , this is generally measured in PCU/ hour, or passenger car units per hour. This is as per our Indian HCM 2017, however if we refer to TRB HCM 2000 , they express it in terms of vehicles per hour directly, without giving any weightage to the heterogeneous traffic nature and thus reducing all vehicles to a common size parameter.

Saturation Flow Rate: the steady state discharge rate of vehicles which are queued up at an approach of intersection, during the green phase of that approach. In simpler terms it can be essayed as number of vehicles crossing the stop line at intersection approach during its green phase under prevailing conditions of traffic and geometry. This is measured and put in PCU/hour of green time.

Base Saturation Flow rate: every approach will have its stated base saturation flow rate, which will be minimum as prevalent in its standard conditions of traffic, geometry and signal timing. This too is expressed as PCU /hour of green time. The base saturation flow rate can be co-related with the geometric and traffic characteristics of the approach road, this is well established in Indo HCM 2017, where they estimate the Unit Saturation flow as the saturation flow per unit width of road approaching intersection.

The Unit base saturation flow is represented as USFo, where USFo is equal to 630 , if width of approach is less than 7 m, USFo is given as 1140-60*width of approach , if width is between 7 m and 10.5 m and USFo= 500 for all widths more than 10.5 m.

In contrary to Indo HCM 2017, TRB HCM 2000 , gives a flat rate of 1900 Passenger cars per hour per lane of base saturation flow rate and thereafter gives adjustment factors to be applied to it, to match the site conditions to arrive at saturation flow rate.

Control Delay: Every vehicle experience an average delay due to presence of signal, this is termed as control delay. Control delay is also called total delay experienced by vehicle due to signal, as it includes the time lapse due to deceleration while stopping at signal, then slow speed while moving up in traffic queues and time taken again to accelerate back to normal speed after crossing the intersection. It is measured in terms of sec/vehicle as per HCM 2000, whereas as per Indo HCM it can be expressed in sec/PCU.

Level of Service: it is a qualitative measure which gives an idea of the operational efficiency of a traffic facility. Both HCM 2000 and Indo HCM 2017 accept Control delay as a service measure to determine level of service (LOS) offered by a signalized intersection. In addition to control delay, Indo HCM also states Volume to Capacity Ratio (v/c) ratio corresponding to various ranges of LOS. In general LOS is defined in 5 ranges from A to F, with "A" being the best situation of traffic with highest free flow movement and driving comfort to drivers, in least congestion, whereas "F" suggests situation of worst traffic jam where travel speeds are reduced to zero and vehicle just pass through in stream without any freedom of manoeuvring.

SurendranRaji and others [1], in their research about traffic study in Port Blair , have also tried to define LOS as a user perception index, in the research they have interviewed various drivers on a road facility and quantified their perception rating of the facility based on 5 factors of speed achieved, safety, sight distance, riding comfort and travel time. The satisfaction level of users being rated as highly satisfied to least satisfied in all these aspects and being summed up to give a User Perceived LOS to the road facility. In context of travel time reliability Indo HCM 2017 have also tried to categorize the road facilities and measure the travel time reliability approach but this study has been limited to the complete urban or interurban corridor and does not talk about individual signalized intersection on corridor.

ArpitaSaha and others [2] in their research have stated that HCM 2000 is based on Webster's delay model and these models, developed on the basis of homogeneous traffic conditions, yield erroneous results for developing countries where the traffic is highly heterogeneous with almost no lane discipline. SO they have presented a different model based on study of seven intersections under heterogeneous traffic across the country. They have successfully measured queue length and plotted the same with time and used Simpson's one-third rule to estimate the total delay in a cycle and average delay per vehicle. Their proposed model is validated by using the data of eight other intersections and the maximum difference between the observed delay and estimated delay is found to be less than 5%.

Parth M. Pande and others [3] in their work observe that for safe and efficient movement of large volumes of traffic on city road network, majority of the intersections are usually signalized. Operation and performance of signalized intersections is influenced by the roadway parameters, traffic condition, operating parameters and environmental conditions along with user's behavioural characteristics, which significantly differ among locations. They have used HCM 2000 to evaluate an important intersection in Ahmedabad city under severe traffic congestion with heterogeneous traffic mixes.

III. CASE STUDY

The sample case study was done at BHEL Junction, on Infosys Avenue road in Electronic City Phase-1, Bangalore. It's a 3 Legged signalized intersection formed on confluence of three major roads, Infosys Drive on east, Erakdi road on West and Wipro Avenue in South .The junction was selected as it is a major junction in prime corridor passing through Electronic city phase –I. This corridor not only connects the high density residential and commercial area of E-city to the elevated flyover exit from E-city connecting it to whole of Bangalore, but also leads to NICE road (private ring road around Bangalore and connects to highway to Mysore city) and also NH-44 (Hosur Road) which connects Bangalore to Chennai via Hosur and other important towns of Tamil Nadu. The location of intersection is shown here in Picture 1.
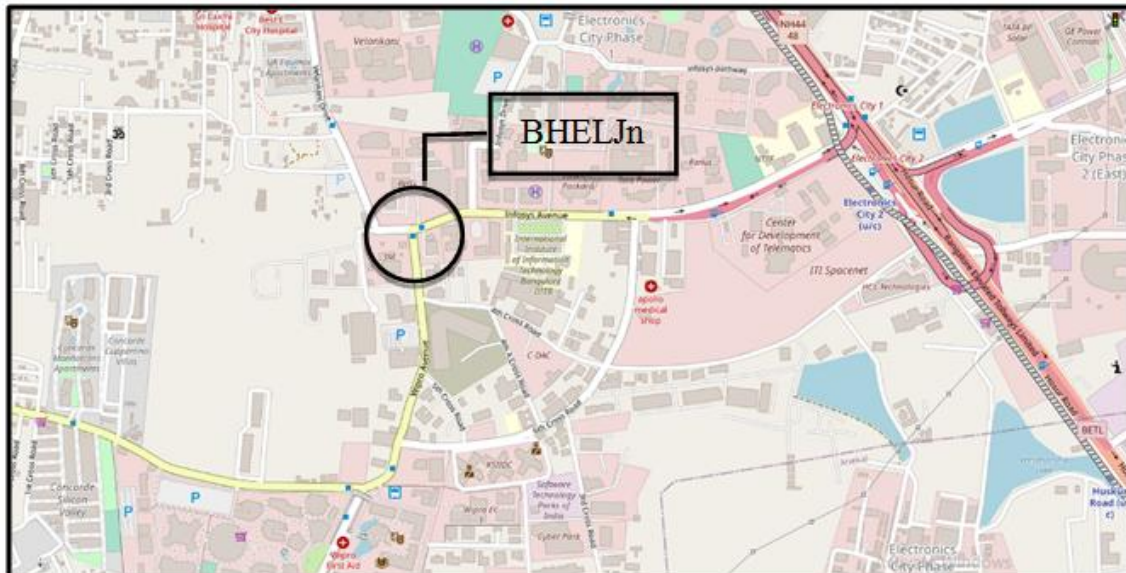
Picture 1: Location of Signalized Intersection under study.

Method adopted for data collection was to first go for a detailed reconnaissance survey to establish details about junction and assess the peak hours on it, thereafter the road inventory survey was done to measure and accurately map all dimensions of junction and approach widths. The signal timing and phasing was studied on site to get the cycle length and green time information. The classified traffic count was conducted for complete turning movement on intersection with help of videography technique, wherein the video feeds from the high resolution installed cameras by governing agency ElCITA have been taken and analysed manually to get the traffic counts. The view of intersection from one camera is shown in Picture 2 and 3.

Picture 2 and 3: Snapshots of videography done for Traffic study at intersection

IV. DATA COLLECTION AND ANALYSIS

The turning movement classified vehicular count (TMC) was done for the intersection during morning peak hour of 10 to 11AM to assess the various types of vehicles and their frequency on the intersection. The classified vehicular count is shown in Table 1 and the peak hour traffic flow is represented as Figure 1 hereunder.

The Indo HCM requires data evaluation based on equivalent Passenger car units (PCU) of vehicles however the HCM 2000 evaluates LOS based on vehicle numbers per hour directly, therefore to evaluate as per Indo HCM, use of dynamic PCU values for the purpose of Urban Intersection was done and the respective traffic flow in PCU /hour was determined as shown in Figure 1.

The dynamic PCU values for various categories of vehicles are enumerated as Two wheeler 0.4 , three wheeler 0.5, Car as 1, light commercial vehicles LCV as 1.1, Heavy commercial vehicles 1.6 , Buses 1.6 and Bicycle 0.3 . The dynamic PCU of Bus and HCV seems quite on lower side , but it is clarified in HCM that these values hold true only when their proportion in total traffic stream is not more than 15%.

S. No	Vehicle Type	2 Wheeler	3 Wheeler	Passenger Car	Mini Bus	Standard Bus (Govt)	Standard Bus (Pvt)	LCV : Freight	2-Axle	3-Axle	Bicycle	TOTAL Vehicles
1	WEST To EAST	182	66	60	0	4	0	5	2	0	18	337
2	WEST To SOUTH	913	166	351	12	0	4	29	16	0	26	1517
3	EAST TO WEST	165	89	156	2	2	3	9	5	0	1	432
4	EAST To SOUTH	555	251	359	8	61	2	25	17	0	7	1285
5	SOUTH To WEST	508	109	215	6	16	6	26	2	0	25	913
6	SOUTH To EAST	445	219	256	5	49	3	6	8	0	20	1011
	Total =	2768	900	1397	33	132	18	100	50	0	97	5495

Table 1: Classified Turning Movement Count of Vehicles on BHEL Junction
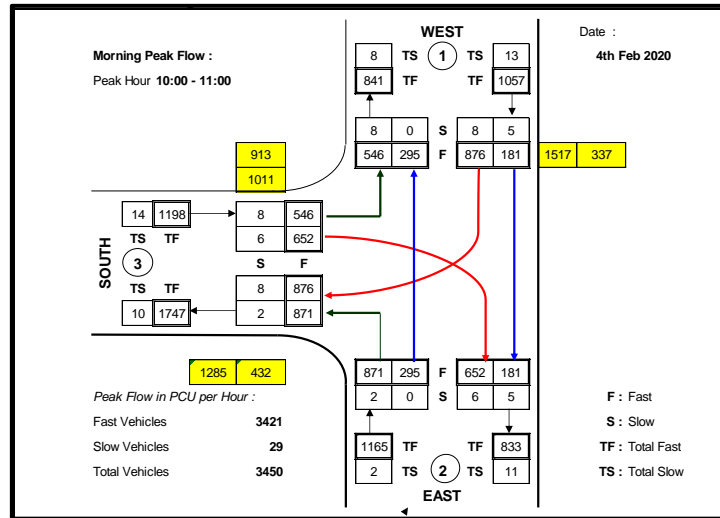
Figure 1: Peak Hour Traffic Flow Diagram in PCU

The signal timings and phases studied at the junction are presented in standard format used by local governing authority in Table 2. However the representation of same as per Indo HCM 2017 is done in Table 3.

S. No	Approach	Phase 1			Phase 2			Phase 3			Phase 4 Pedestrian
1	Northbound (Wipro Avenue)	*	*	*	Left	*	Right	Left	*	*	*
2	Eastbound (Erakdi Road)	*	*	*	*	*	*	*	Through	Right	*
3	Westbound (Infosys Avenue)	Left	Through	*	Left	*	*	*	*		*
	Green Time (s)	34s			46s			45s			10s
	Amber Time (s)	2s			2s			2s			
	Cycle Time (s)	141s									

Table header spanning: **Morning Peak Hour Week Days (Mon-Fri) BHEL Junction (3L-Jn)**

Table 2: Signal Phase Diagram at Junction

V.   CAPACITY AND LEVEL OF SERVICE ESTIMATION

Capacity and level of service calculation is done as per Indo HCM 2017 first, this needs enumerating the complete geometric characteristics of the intersection under study which is presented in Table 3 here.

Thereafter the saturation flow rate is to be evaluated, as per INDO HCM 2017, the base USFo of 630 is used for approach width being 5.18 m only. This base saturation flow is to be adjusted for suitable factors for any presence of Bus Blockage due to presence of bus stops within 75 m of intersection, which was not found in study area. Adjustment factor for blockage by standing right turn vehicles is also not observed on site, hence this reduction factor is also not considered. Adjustment factor initial surge of vehicles due to any approach flare effect of anticipation effect or both, is also not observed on any lane traffic, thus this factor is also considered 1 as stated in INDO HCM 2017. Hence the saturation Flow for each direction traffic lane of approach is given by 630 * available width for traffic stream in that direction, which is found to be only 2.59 m. The complete assessment of Capacity and LOS as per Indo HCM is given in Table 4.

Details	WB (Infosys Avenue Road)	EB (Erakdi Road)	NB (Wipro Avenue)
Total Approach Width ,w(m)	5.18	5.18	5.18
Demand Volume , PCU/hr	1168	1070	1212
Peak Hour Factor	0.9	0.9	0.9
Peak Hour Volume , PCU/h	1051.2	963	1090.8
Presence of exclusive lanes for an exclusive right phase	AB	AB	AB
Presence / absence of Busbays	AB	AB	AB
Number of Buses stopping at intersections , n_b (buses/h)	AB	AB	AB
Initial Surge	NO	NO	NO
(A) Anticipation effect	NO	NO	NO
(B) Approach Flare Effect	NO	NO	NO
(C) Surge Ratio (as per table 6.5 of Indo HCM 2017)	1	0	0

Summary of Capacity Estimation of 3 L-Jn						
Phase	Phase 1 WB (Infosys Drive)		Phase 2 NB (Wipro Avenue)		Phase 3 EB (Erakdi Road)	
Approach	TH	LT	RT	LT	TH	RT
Approach Width ,w(m)	2.59	2.59	2.59	2.59	2.59	2.59
Volume of Movement Group (PCU/Hr)	295	873	658	554	187	885
Green Time ,g(secs)	34	80	46	91	45	45
Total Cycle Time , C (secs)	141	141	141	141	141	141
Unit Base Saturation Flow Rate in PCU/hr/m, USF_0	630	630	630	630	630	630
Adjustment Factors for bus blockage due to downstreambus stops ,f_{bb}	1	1	1	1	1	1
Adjustment Factors for blockage by right turning vehicles in case of exclusive right turns,f_{br}	1	1	1	1	1	1
Adjustment Factor for initial 5-second surge of vehicles, f_{is}	1	1	1	1	1	1
Adjusted Saturation Flow rate in PCU/hour/m, $SF_{adjusted}$	1632	1632	1632	1632	1632	1632
Effective Green Time (g) (in sec)	32	78	44	89	43	43
g/C ratio ,λ	0.227	0.553	0.312	0.631	0.305	0.305
Capacity in PCU/hour , = $Sf_{adjusted}$ * λ	370	903	509	1030	498	498
Degree of saturation, X	0.80	0.97	1.29	0.54	0.38	1.78
Uniform delay, d1 = (s/veh) $$d1 = \frac{0.50\,C\left[1-\left(\frac{g}{C}\right)\right]^2}{1-\left[\frac{\min(1,X)\,g}{C}\right]}$$	51.43	30.27	48.50	14.52	38.46	49.00
Incremental delay, d2 (s/veh) $$d2 = 900\,T\left[(X-1)+\sqrt{((X-1)^2+\frac{4X}{cT})}\right]$$	16.18	22.98	145.64	2.01	2.16	358.40
Initial queue delay, d3 (s/veh)	0	0	0	0	0	0
Control Delay, d =0.9* d1 + d2 + d3 (s/veh)	62.47	50.23	189.29	15.08	36.78	402.50
Approach Delay in sec/PCU, d_a	53.32		109.66		338.71	
Approach LOS	**C**		**E**		**F**	
Intersection Delay in sec/PCU, D	161.62					
Intersection LOS based on Delay	**F**					

Table 3: Geometric, Traffic and Control Characteristics of intersection
Table 4: Level of Service Estimation as per Indo HCM 2017

The Assessment of Capacity and LOS as per TRB HCM 2000 is also done and is presented in Table 5. The key difference in TRB HCM and Indo HCM lies in considering direct vehicle count as flow measure versus using PCU as the flow measure of traffic. This small change has made lot of difference in whole analysis. The base saturation capacity is considered as 1900 passenger cars per hour per lane here, which is been given appropriate adjustments for the variation in approach width on site as per given methodology in HCM. The same is given as: $fw = 1 + (W - 3.6)/9$, the available width for each traffic lane was just 2.59 m, and thus this factor came out to be 0.8877, thus saturation flow rate is adjusted to 1684 Vehicles per hour.

Lane Group Capacity , Control Delay and LOS Determination						
	WB (Infosys Drive)		NB (Wipro Avenue)		EB (Erakdi Arm)	
Lane Group	**TH**	**LT**	**RT**	**LT**	**Th**	**RT**
Cycle Length (seconds), C	141	141	141	141	141	141
Volume as Counted (veh/h)	432	1285	1011	913	337	1517
Peak Hour Factor (PHF)	0.9	0.9	0.9	0.9	0.9	0.9
Adjusted flow rate, v (veh/h)	480	1428	1123	1014	374	1686
Saturation flow rate, s (veh/h)	1684	1684	1684	1684	1684	1684
Effective green time, g (s)	34	80	46	91	45	45
Green ratio, g/C	0.24	0.57	0.33	0.65	0.32	0.32
Lane group capacity, c = s(g/C), (veh/h)	406	955	549	1087	537	537
v/c ratio, X	1.18	1.49	2.04	0.93	0.70	3.14
Uniform delay, d1 = (s/veh) $d1 = \dfrac{0.50\,C\,\left[1 - \left(\frac{g}{C}\right)\right]^2}{1 - \left[\frac{\min(1,X)\,g}{C}\right]}$	53.50	30.50	47.50	22.30	42.03	48.00
Incremental delay calibration, k	0.5	0.5	0.5	0.5	0.5	0.5
Incremental delay, d2 (s/veh) $d2 = 900\,T\,[(X-1) + \sqrt{((X-1)^2 + \frac{8KIX}{cT})}]^{\square}$	104.49	228.01	476.44	15.35	7.30	966.19
Initial queue delay, d3 (s/veh)	0	0	0	0	0	0
Uniform delay, d1 (s/veh)	53.50	30.50	47.50	22.30	42.03	48.00
Progression adjustment factor, PF	1	1	1	1	1	1
Delay, d = d1(PF) + d2 + d3 (s/veh)	157.99	258.51	523.94	37.65	49.33	1014.19
LOS by lane group	**F**	**F**	**F**	**D**	**D**	**F**
Delay by approach, dA = (s/veh) dA=∑(d)(v)/∑v	233.22		293.18		838.81	
LOS by approach	**F**		**F**		**F**	
Approach flow rate, vA (veh/h)	1908		2138		2060	
Intersection delay, dI = (s/veh) dI=∑(dA)(vA)/∑vA	458.54					
INTERSECTION LOS	**F**					

Table 5: Evaluation as per TRB HCM 2000

VI. CONCLUSION

After analysing delay as per both methods we can derive the following inference:

1)   The formula used to evaluate control delay is similar in TRB HCM and INDO HCM, however the change the final results vary a lot.

2)   Indo HCM uses well planned Dynamic PCU values, which are being evaluated by thorough research on heterogeneous traffic mixes found commonly on India urban roads and hence give desired cognizance to the effect of heavy vehicles and major chunk of two wheelers in the traffic stream count.

3)   The dynamic PCU considered in Indo HCM, also consider the poor lane discipline and criss- crossing manoeuvres of traffic on Indian roads and is more appropriate for use by researchers in India.

4)   TRB HCM considers traffic as Vehicle per hour and saturation flow is given in Passenger Car per hour per lane, thus Indian road capacity could be quite more in actual because 50% vehicle composition is of two wheelers which acquire half the space acquired by car on road.

5)   The low g/C ratio in Indian signals is planned considering less time required by Two wheeler traffic to cross over and thus does not reflect the true capacity as per TRB HCM , thus giving poor v/c ratio and in turn giving very high Delay estimations.

6)   The Total Control Delay when estimated as per Indo HCM was found only 2.68 minutes whereas TRB HCM evaluate it to 7.60 minutes.

7)   The level of service is found to be F for overall intersection by both the methods and Erakdi road Right turning traffic was found to be most critical group because of very less green time provided to it compared to the heavy traffic flow on approach.

This paper has attempted thereby to give clear understanding of both methods for evaluation of level of service and its concluded hereby that Indo HCM 2017, holds better for analysis in Indian traffic context and can be widely used and appreciated by researchers in India. The implication of same should also be studied for other developing nations like ours and can be widely accepted there too.

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