Capacity and Level of Services for Signalized Intersections under Mix Traffic Conditions- A Global Scenario

Jayesh Rameshbhai Juremalani
Research Scholar, Civil Engineering Department, SVNIT, Surat, 395007, India
Juremalani_jayesh@gtu.edu.in

Dr. Krupesh A. Chauhan
Associate Professor, Civil Engineering Department, SVNIT, Surat, 395007, India
kac@ced.svnit.ac.in

ABSTRACT

Saturation flow rate and control delay are very important parameters for the calculation of capacity and level of service at signalized at grade intersections. While many methods are currently available to estimate the saturation flow rates and delays incurred at intersection approaches, very little research has been conducted to assess the consistency of these estimates as they are less suitable under mix traffic conditions.This paper is divided into two parts. First saturation flow rate is discussed and various modifications which are made by various researches in the developing countries to match as far as possible the theoretical values obtained from the models with the real field values have been discussed one by one. In the second part delay is at intersections is explained in details along with modification suggested.

1. Introduction of saturation flow rate at signalized intersections.

The Highway Capacity Manual defines the capacity as the maximum hourly rate at which persons or vehicle can be reasonably expected to traverse a point or a uniform segment of a lane or roadway during a given time period, under prevailing roadway, traffic and control conditions. Level-of-Service is introduced by HCM to denote the level of quality one can derive from a local under different operation characteristics and traffic volume.

The Chapter 16 of the 2000 Highway Capacity Manual (HCM) provides the procedure and equation for estimating saturation flow rate at signalized intersections. However, due to the difference in roadway conditions, transportation conditions, the drivers' behavior and cultures etc, the method provided by HCM is not applicable in developing countries like ours to estimate the saturation flow rate. It was found that the base condition suggested by the HCM are not suitable in developing countries and default saturation flow rate of 1900PC per hour per lane suggested in HCM is much higher than the value obtained from the surveyed data; and that the adjustment factors are not proper to be applied too. Furthermore, there is no one manual alike the Highway Capacity Manual 2000 based on the conditions of urban road and transportation for developing countries which can be applied in practice to determine saturation flow rate.

Some findings of the earlier research, especially about the saturation flow rates and some factors such as traffic composition, lane width, approach grade and turn radius influencing on the capacity of signalized intersections are discussed here. The methods discussed here did not take into account the potential impact of downstream congestion on intersection operation. Nor did the methodology detect and adjust for the impacts of turn-pocket overflows on through traffic and intersection operation.

Chang-qiao Shao et al.2011 conducted the study on saturation flow at signalized intersection of 18 cities in China for which the passenger car equivalents were computed using the time headway ratio method. The effects of lane width, approach grade and turn radius on the saturation flow rates were analyzed using regression method. In order to eliminate the estimate error interaction, the effect of influence factors on capacity was mostly studied one by one. Hence, for each influence factor, the saturation flow rate model was developed by them and compared to the base saturation.

The effect of lane width on saturation flow rates:

$$S = Sb \times fw \times fo + \varepsilon \qquad 1$$

Where, S =saturation flow rate, passenger car/h/lane;

Sb =base saturation flow rate, = 1800 b S passenger car/h/lane;

fw =adjustment factor for lane width.

ε =random error

$fw = 1 + (w - 3.50) / (5)$ 2

Where, w=width of the lane, m;

$fw = 1 + (w - 3.50) / 6.56$ 3

$2.80m \leq w \leq 3.90m$

The effect of lane approach grade on saturation flow rates: The linear regression model is developed as:

$S = -17.068G + 1787.7 , -8.0 \leq G\% \leq 8.0$ 4

Where, S =saturation flow rate, passenger car/h/lane; G =approach grade, %.

Effect of Lane Width and turn-radius on saturation flow rates:

By using the using PLS (partial least-square method) method, the left-turn saturation flow rates model on the exclusive lane was built by the authors.

$Sl=815.4+136.2w+11.3r$ 5

$2.7m<w<4$ m,

20 m $< r < 48$ m

Where,

Sl =saturation flow rate for exclusive left-turn lane, passenger car/h/lane;

w=width of exclusive left-turn lane the lane, m;

r =left-turn radius for the left movement vehicles, m;

Huayan Shang et. al. 2014 have analyzed the saturation flow rates at signalized intersections of Beijing city and found that the saturation headways approximately follow the normal distributions. They also calculated the saturation flow rates for three different movements: (I) Through movement (II) left turn movement (III) Right turn movement.

They have chosen 36 signalized intersections of Beijins'5 th ring road for their survey. The method included the determining of start-up lost times, saturation headways and saturation flow rates of each observed vehicle queue at each intersection. This was done by recording the time from the start of green time to the time each vehicle's rear wheels crossed the stop line. This was done until green time or the queue ended. As for saturation flow, it describes the number of passenger car units (pcu) in a dense flow of traffic for a specific intersection lane group. In other words, if an intersection's approach signal were to stay green for an entire hour and the flow of traffic through this intersection were as dense as could be expected, the saturation flow rate would be the amount of passenger car units that passed through this intersection during that hour. So it can be calculated by:

$Soi = 3600 / hi$ 6

Where Soi is the saturation flow rate of the i th entrance lane of a signalized intersection and i h is the saturation headway of the i th lane. Let the green split of the i th entrance lane is ri, then the i th lane's capacity i C would be :

$Ci = Soi \times ri$ 7

By summing up all the entrance lanes' capacities, the intersection's capacity C can be obtained:

$C = 1Cn \times Ci$ 8

Where n indicates the total number of entrance lanes at the intersection

Jenish Joseph and Gang-Len Chang 2005 computed saturation flow rates and maximum critical lane volumes for, USA palling applications in Maryland. The objective was mainly to present observation results of start-up lost times and saturation flow headways of more than 3,800 drivers at 11 representative signalized intersections, and discussed the methods used to produce an average saturation flow rate and the maximum critical lane volume (MCLV)for a statewide intersection planning analysis.

C.S. Anusha et al.2 013analyzed the effect of two-wheelers on saturation flow rate and introduced a new adjustment factor for two-wheelers.

2. Introduction of Delay at signalized intersections.

There are a number of criteria to assess the performance and level of service of signalized intersections among which delay is used most widely. The reason is that the meaning of delay is generally well understood and drivers can experience it directly. There are a number of widely used delay models to determine the average delay per vehicle at a signalized intersection, all of which are developed in countries with car dominated traffic stream, where the road traffic condition is homogeneous and lane based

(Webster 1958 , Miller 1963, Akcelik 1993and Teply et al. 1989). Among these models, the oldest and the most popular one is the Webster's classical delay formula, which has been originated in UK.

Cronje W. B. 1983 analyzed existing formulas, namely, Webster's (1958) and Miller's (1963) equations for average delay, overflow, and average number of stops for under saturated conditions. These formulas were examined over a large variation of flows and cycle lengths. He concluded that the Miller formula (1963) gave the most accurate results.

Hagen L. T. and Kennneth G. G. 1989 compared the "Highway Capacity Manual" (HCM) ("Highway" 1985) delay model with the models used in the Australian Signal Operations Analysis Package (SOAP 1985) and the TRANSYT-7F Release 5 computer packages. They focused on the effect of the degree of saturation, the peak hour factor, the length of period of flow observation on delay computations, and the effect of straight-ahead traffic on right turning vehicles. The results of all these models agreed closely at volume levels below saturation point. When conditions became oversaturated, the models diverged.

Colyar and Rouphail 2003 studied the variability of control delay on an arterial corridor using field data. They tried to capture the variability of delay during the peak-hour period (morning and evening).

Park and Kamarajugadda 2007 proposed a method that estimates mean and variance of the HCM delay where demand volume is considered as a random variable. They used two different methods to estimate variance of delay for under saturated and oversaturated situations: Taylor approximation for under saturated and integration method for oversaturated condition. They assumed that capacity of the lane group is constant during the analysis period (implying the method was applicable only for protected movements). At the end, they proposed a genetic algorithm model that optimizes signal timing plan. To optimize signal timing plan they assumed that delay is normally distributed.

Levinson et al. 2006 used field data and examined the impact of day-to-day variation in peak-hour volume on intersection level of service. They estimated that the coefficient of variation of peak hour volume range from 0.048 to 0.155 with a mean of 0.089. By using HCM methodology, they computed the intersection delay for the mean peak-hour volume, 85th percentile volume, and the 97.5 percentile volume and concluded that a level of service based on the mean peak-hour volume is not a good representative for the performance of busy intersections.

Francois Dion et al. 2004 compared the delays that are estimated by a number of existing delay models for a signalized intersection approach controlled in fixed-time and operated in a range of conditions extending from under-saturated to highly saturated. Specifically, they compared the delay estimates from a deterministic queuing model, a model based on shock wave theory, the steady-state Webster model, the queue-based models defined in the 1981 Australian Capacity Guide, the 1995 Canadian Capacity Guide for Signalized Intersections, and the 1994 and 1997 versions of the Highway Capacity Manual (HCM), in addition to the delays estimated from the INTEGRATION microscopic traffic simulation software. The results of the comparisons indicate that all delay models produce similar results for signalized intersections with low traffic demand, but that increasing differences occur as the traffic demand approaches saturation.

Shamsul Hoque and Md. Asif Imran 2007 has modified the F. V. Webster delay formula. The Webster's delay formula has been modified to suit the road traffic situation of Bangladesh. For this purpose, data have been collected using video camera at different signalized intersections of Dhaka city to measure average delay per vehicle at each cycle. Based on these data, a model in the form of multiple linear regression has been developed, which attempts to keep the first and second terms of Webster's delay formula as it is but to modify the adjustment term. The model has been calibrated to form a 'Modified Webster's Delay Formula', which is subsequently validated by comparing the expected delays with observed delays. The model provided a coefficient of correlation of 0.68 and all the independent variables were found to be statistically significant. Following is the modified model for delay at signalized intersections for Dhaka city.

$$d = \{c(1-\lambda)^2/ 2 (1- \lambda x)\} + \{x^2/2q(1-x)\}+46.93-46.04*q-37.32*x-36.08*pnmv. \qquad 9$$

Where:

d = average delay per vehicle on the particular lane group of the intersection, sec/veh;

c = cycle length, sec;

q = flow, vehicles/sec;

λ = proportion of the effective green with respect to cycle length (i.e. g/c and g is

effective green, sec); and

x = the degree of saturation. This is the ratio of the actual flow to the maximum flow

which can be passed through the intersection from this lane group, and is given by x

= g/λs, where s is the saturation flow in vehicles per second.

c = Cycle length (seconds).

x = Degree of saturation.

pnmv = Percentage NMV in traffic.

3. Conclusion

The first and foremost difference between the developed countries and undeveloped countries is the nature of traffic. In former countries the nature of traffic is homogenous while in later countries traffic is of heterogeneous nature. Saturation flow rates are found using different methods including HCM 2000 method and various researchers suggested some modifications according to their area of research in undeveloped countries Delay estimated from a deterministic queuing model, a model based on shock wave theory, the steady-state Webster model, the queue-based are compared. The results of the comparisons indicate that all delay models produce similar results for signalized intersections with low traffic demand(v/c ratio <1), but that increasing differences occur as the traffic demand approaches saturation,(v/c ratio > 1) so more research is required to be done in this area to make these models more reliable. From the above reviews it could be concluded that the consistency of delay models should be evaluated for multi-lane approaches, intersections controlled by actuated controllers, and intersections where non-random vehicle arrivals occurs as a result of signal coordination with upstream intersections. The impact of varying driver behavior should also be investigated, as this may impact the saturation flows used in the various delay models, as well as the approach speeds and amount of time lost every cycle due to driver reaction time.

References:

Akcelik, R., and Nagui, M. R. ,1993. "Estimation of delays at traffic signals for variable demand conditions." Transp. Res. Part B, 27B(2), 109-131.

C.S. Anusha, Ashish Verma and G.Kavitha ,2013 " Effects of two wheelers on saturation flow at signalized intersections in developing countries." Journal of Transportation Engineering, ASCE, May 2013, 448-457.

Chang-qiao Shao, Jain Rong and Xiao ming Liu.,2011."Study on the saturation flow rate and its influence factors at signalized intersections in China." 6th International sumposium on the highway capacity and quality of service Stockholm, Sweden.

Colyar, J. D., and Rouphail, N. M., 2003. "Measured distributions of control delay on signalized arterials." Transportation Research Record 1852, Transportation Research Board, Washington, DC, 1–9.

Cronje, W. B.,1983. "Analysis of existing formulae for delay, overflow and stops." Transp. Res. Rec. 905, Transp. Res, Board, Washington, D.C., 89-95.

Francois Dion, Hesham Rakha and Youn-Soo Kang.,2004. "Comparison of delay estimates at under-saturated and over-saturated pre-timed signalized intersections." Transportation Research Part B 99–122.

Hagen, L. T., and Kenneth, G. G.,1989. "Comparison of microscopic models for signalized intersection analysis." Transp. Res. Rec. 1225, Transp. Res. Board, Washington, D.C., 33-44.

HCM (TRB), 2000. Chapter 16.

Huayan shang, yiming Zhang and Lang Fan., 2014. "Heterogeneous lane's saturation flow rates at signalized intersections." 9th international conference on traffic and transportation studies.

Jenish Joseph and Gang-Len Chang (2005) " Saturation flow rates and maximum critical lane volumes for planning applications in Maryland." Journal of Transportation Engineering, ASCE, December 2005, 946-952.

Levinson, H. S., Sullivan, D., and Bryson, R. W. (2006). "Effects of urban traffic volume variations on service levels." 85th Annual Meeting of the Transportation Research Board, Washington, DC.

Miller, A. J. (1963). "Settings for fixed cycle traffic signals." Operations Res. Quarterly, 14(4).

Park, B., and Kamarajugadda, A.,2007. "Development and evaluation of a stochastic traffic signal optimization method." Int. J. Sustainable Trans., 1(3), 193–207.

Shamsul Hoque and Md. Asif Imran., 2007. " Modification of Webster's delay formula under non-lane based heterogeneous road traffic condition." Journal of Civil Engineering (IEB), 35 (2) 81-92.

Teply, S.,1989. "Accuracy of delay surveys at signalized intersections." Transp. Res. Rec. 1225, Transp. Res. Board, Washington, D.C., 2432.

Tom Methew (NEPTEL), lectures.

Webster, F. V.,1958. "Traffic signal settings." RRL-Tech. Paper No. 39, Her Majesty's Stationary Ofc. (HMSO), London, England.