Proceedings of the Eastern Asia Society for Transportation Studies, Vol. 5, pp. 959 - 966, 2005

COMPARISON OF SATURATION FLOW RATE AT SIGNALIZED INTERSECTIONS IN YOKOHAMA AND DHAKA

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Abstract: The evaluation of capacity at signalized intersections is an important component in the proper planning, design, operation, and management of urban road street network. A procedure for determining the saturation flow rates at signalized intersections is presented in this paper; the procedure differs substantially from the procedure as discussed in the Highway Capacity Manual (HCM). ANalysis of VAriance (ANOVA) was performed to determine the saturation flow region of the queue for different queue regions. Saturation headway was estimated by averaging the headways of all the vehicles in the saturation flow region. A comparative study was then made between these two methods for different signalized intersection approaches in two metropolises, namely Yokohama, Japan and Dhaka, the capital of Bangladesh. The findings of this study suggests that the procedure as discussed in the HCM overestimate saturation flow rates for some approaches and underestimate for the other approaches. From the observed data it was evidenced that the headway values of passenger cars in the Dhaka metropolis are lower than that of in Yokohama.

Key Words: Saturation flow rate, signalized intersections, highway capacity manual, saturation flow region,

1. INTRODUCTION

Traffic carrying capacity of signalized intersections is of fundamental importance in designing new intersections and modifying existing ones. The saturation flow is used as the basis for the determination of traffic signal timing and evaluation of intersection performance. One of the problems in estimating saturation flow from observed headway data is accurately defining the saturation flow region of the queue of vehicles. Stockes *et a*l. (1986) used regression model for double left-turn vehicles to determine the saturation flow region of the queue. They suggested that this model is also applicable to straight-through vehicles, although the headway values of left-turn vehicles and straight-through vehicles are not the same. According to the Highway Capacity Manual (HCM, 1994) the saturation flow region starts from the 5th queued vehicle position, although this may not be applicable to Asian cities because of differing road environment and operating characteristics. Branston (1979) investigated the effects of day time on saturation flow and found differences in saturation flows between peak and off-peak periods, as well as between day-time and darkness. The author suggested three parallel straight lines as a good representation of the observed variations in saturation flow at different times of day.

Fujiwara et al. (1994) investigated the effect of winter season on saturation flows. The results of this study suggested that the decrease in winter saturation flow rates is about 20% as compared to the observed non-winter saturation flow rates; at most the variation could be around 30% in comparison with the basic saturation flow rates. Mccoy and Heimann (1990) investigated the effect of driveway traffic on saturation flow rates at signalized intersections. The data for the study was gleaned from Lincoln and Nebraka. The authors concluded that driveway traffic can reduce the saturation flow rates on signalized intersections approaches. Stokes (1989) reviewed a study on the factors affecting signalized intersection capacity. A review of these research suggested that intersection capacity is affected by a number of physical and operational features at or in the vicinity of the intersections. An overall review of the studies suggested that past efforts were fragmented in terms of study methods, location characteristics, and technical objectives. No study was related to determination of saturation flow region except Strokes et al. (1986). However, that study was on double left-turn vehicles only.

2. DESCRIPTION OF RESEARCH DATA

All data were collected from the signalized intersections located in Yokohama city of Kanagawa prefecture of Japan and Dhaka, the capital metropolis of Bangladesh. Seventeen approaches of nine signalized intersections (fixed-time) were selected for this study. The selected intersections of Yokohama and Dhaka, and their associated characteristics are summarized in Table 1.

Table 1: Geometric and operating characteristics of data collection sites (Yokohama)

Intersection	Green time (sec)	Speed limit (Km/hr)	Number of lanes	Lane position	No. of cycles observed
Yokohama					
YIS-1	78	40	1	---	34
YIS-2	72	40	1	---	30
YIS-3	80 and 84	30 and 40	2 and 4	Inner-outer, middle	90
YIS-4	80	50	2	Inner-outer	57
YIS-5	72 and 68	50	3 and 2	Middle, inner-outer	83
YIS-6	84	50	3	Middle	66
YIS-7	84	50	4	Middle	87
Dhaka					
DIS-1	68	N/A	3	Middle	53
DIS-2	60	N/A	3	Inner-outer	48

For all of the selected intersection approaches in Yokohama, vehicle movements were recorded by using a portable digital video camera system. All field video tapings of traffic movements were conducted in August to December, 2002. All data were recorded during the morning peak and the evening peak. While filming, lane traffic movements, only the lane of interest was recorded. In case of Dhaka metropolis, data were collected manually by a group comprised of four people. In all, more than 100 cycles of traffic data were collected from Dhaka.

In all, more than 28 hours of traffic data were recorded on videotapes for this study. The tapes were first examined in the laboratory to screen out the cases that were not suitable for use in this study, including the following: platoons of traffic within which vehicles did not stop before entering an intersection; vehicle platoons with turning vehicles; and platoons in which movements of vehicle were impeded by pedestrians, cross traffic, or turning vehicles were not included. In other words, only platoons of traffic containing uninterrupted, straight-through vehicles stopped before entering an intersection were considered as valid cases for the study. The valid cases were later viewed on a television screen to retrieve the headways of queued vehicles.

Time Code (TC) reader software was used to estimate the headways of vehicle entering the intersections. For the first vehicle of a queue, its entering headway was taken to be the time elapsed between the start of a green indication and the time at which the rear bumper of the vehicle cleared the stop line of the intersection. For other vehicles in the queue, the entering headways were taken to be the elapsed time, rear bumper to rear bumper, as successive vehicles passed an intersection stop line.

3. DETERMINATION OF SATURATION FLOW REGION

The first part of the analysis focuses on finding out the saturation flow region of the queued vehicles. Before finding the queue position from which saturation flow region started, it is necessary to establish that headways of vehicle at different queue positions are not the same. The saturation flow region started from the first queued vehicle if the headways of all queued vehicles are the same. Analysis of variance (ANOVA) was performed to establish this concept. Since the purpose of the test was to evaluate whether the queue storage positions of the vehicle had a significant impact on the headways, the statistical basis for ANOVA test was the hypothesis H_o that the queue storage position does not have a significant impact on the headways. A confidence level of 95% was set for the test.

ANOVA results of this analysis confirmed that the null hypothesis was rejected for all of the intersection approaches, so it could be concluded that queue storage positions had significant impact on the entering headways. In other words, headways at different queue positions were not the same. In order to determine the saturation flow region of queued vehicles ANOVA tests were also performed for various queue ranges. The null hypothesis H_o was that the headway of different queue region is the same. The concept was that the saturation flow region started from that queue position for which the null hypothesis would be accepted. ANOVA results for saturation flow region at different intersection approaches are shown in Table 2.

As shown in table 2, saturation flow region started from the 4^{th} queued vehicle position for the intersections having only one lane. The intersections having two lanes, the saturation flow region started from the 3rd queued vehicle position in case of the outer lane and the 5th queued vehicle position in case of the inner lane. For the intersections having three lanes, the starting position of the saturation flow region varied from intersection to intersection. For intersection approaches YIS-6A, YIS-6B and YIS-5 the saturation flow region started from the 3rd, 5th and 6th queued vehicle position respectively. This difference seems to occur due to the following reasons: the middle lane is surrounded by the inner lane and the outer lane; after starting of the green period some vehicles are yet changing lane which affect the movement of other vehicles in the middle lane and the headway value is varied; another reason is the different percentages of taxis present in the middle lane that also affected the headway. The length of the storage bay for right turning vehicles also affects the headway values. The relationship of headway value and percentage of taxis are discussed in next section. In the intersection having four lanes, the saturation flow region started from the 3rd queued vehicle position. So it could be concluded that the starting of the saturation flow region widely varied from intersection to intersection depending on the geometries of the intersections, lane configuration and intersection operation characteristics.

Table 2: ANOVA results for the saturation flow region at different intersection approaches

Approach	Lane number	Lane position	Basic vehicle (Passenger car)			
			Flow region	$F_{observed}$	$F_{critical}$	H_o
YIS-3A	4	Middle	3-14	0.78	1.91	Accepted
YIS-7A	4	Middle	3-13	1.57	1.91	Accepted
YIS-6B	3	Middle	5-14	1.67	1.91	Accepted
YIS-5	3	Middle	6-12	2.10	2.17	Accepted
YIS-6A	3	Middle	3-13	1.85	1.91	Accepted
YIS-3	2	Inner	5-13	1.62	1.91	Accepted
YIS-4	2	Outer	3-12	1.58	1.91	Accepted
YIS-4	2	Inner	5-13	1.59	1.91	Accepted
YIS-3	2	Outer	3-12	1.36	1.91	Accepted
YIS-1	1	---	4-12	1.69	1.91	Accepted
YIS-2	1	---	4-12	1.13	1.91	Accepted
DIS-1	3	Middle	5-13	1.58	1.91	Accepted
DIS-1	3	Middle	3-12	1.67	1.91	Accepted
DIS-2	3	Inner	5-13	1.36	1.91	Accepted
DIS-2	3	Outer	3-13	1.62	1.91	Accepted

4. COMPARATIVE STUDY OF SATURATION FLOW

Saturation flow rate is the reciprocal of saturation headway. In the HCM, saturation headway is calculated by averaging the discharging headway from the fifth queued vehicle to the last queued vehicle as follows:

$$Hs = \frac{\sum_{i=1}^{m}\sum_{j5}^{ni} Hij}{\sum_{i=1}^{m}(ni-4)} \tag{1}$$

Where,
Hs = saturation headway (sec)
Hij = discharge headway of jth queued vehicle in cycle i (sec)
n_i = number of vehicles in queue of cycle i, n_i>4; and
m = total number of cycles during an observation period

For this study, firstly the starting of saturation flow region is determined then saturation headway is calculated by averaging the discharging headway of all vehicles in the saturation flow region as follows:

$$hs = \frac{\sum_{j=n}^{l} hj}{(l-n)} \qquad (2)$$

Where,
h_s = saturation headway (sec)
h_j = discharge headway of jth queued vehicle (sec)
n = position of queued vehicle from where saturation flow region started
l = last queued vehicle position

Saturation flow is calculated as follows:

$$s = \frac{3600}{h_s} \qquad (3)$$

Where,
s = saturation flow rate (ppghpl)
h_s = saturation headway (sec)

The comparative study of saturation flow rate for different intersection approaches is presented in table 3.

Table 3: Comparative study of saturation flow rate

Approach	Saturation headway (sec)		Saturation flow (ppghpl)		Difference (%)
	This study (Yokohama)	HCM	This study (Yokohama)	HCM	
YIS-3A	1.86	1.84	1935	1956	+ 1.1
YIS-6A	1.89	1.83	1905	1967	+ 3.25
YIS-6B	1.78	1.78	2022	2022	0
YIS-5	1.90	1.92	1895	1875	- 1.1
YIS-7A	1.90	1.82	1895	1978	+ 4.38
YIS-3 (inner)	1.72	1.72	2093	2093	0
YIS-3 (outer)	2.01	1.99	1791	1809	+ 1
YIS-4 (inner)	1.91	1.91	1885	1885	0
YIS-4 (outer)	2.01	1.96	1791	1837	+ 2.57
YIS-1	2.09	2.04	1722	1784	+ 2.43
YIS-2	2.2	2.13	1636	1690	+ 3.3
	Dhaka	HCM	Dhaka	HCM	
DIS-1	1.79	1.72	2006	2091	+ 4.24
DIS-2	1.72	1.72	2091	2091	0

As shown in table 3, the HCM overestimate the saturation flow rate for most of the intersection approaches. The overestimation is as high as 4.38% for the YIS-7A approach. The saturation flow rates of some intersection approaches are the same as for this study and the HCM. The headway value of queued vehicles decreases as position of vehicles in the queue increases; so when saturation flow started from the 3rd or the 4th queue position saturation headway is relatively greater for this study and saturation headway as calculated by the HCM is relatively smaller. This causes the overestimation of saturation flow.

5. COMPARISON OF HEADWAYS OF BASIC VEHICLES

A comparative study of headway values of the basic vehicle that is the passenger car between Yokohama and Dhaka is discussed in this section. Figure 1 shows the comparison of headways between two cities. As shown in figure 1, headway values of passenger car in Dhaka metropolis is found to be smaller than that in Yokohama city.

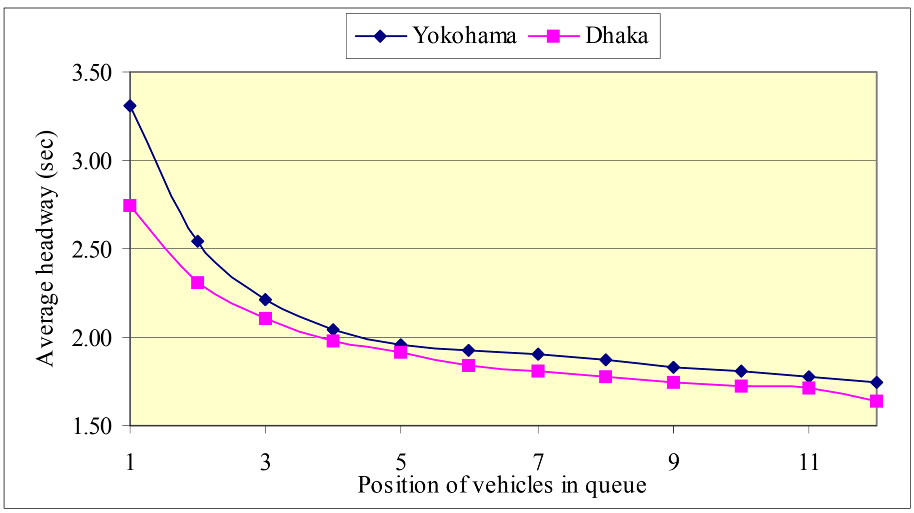

Figure 1. Comparison of headway values in Dhaka and Yokohama

From the observed data it was evidenced that the queued vehicles were closely spaced during the red interval at intersections in Dhaka city. On the other hand the gaps between queued vehicles at intersections in Yokohama city were more as compared to than Dhaka metropolis. This comparison is shown in Figure 2. So this is one of the major reasons of small headway of passenger cars in Dhaka city. Other factors, such as: varied sizes of the passenger cars, attitude of drivers, and level of congestion are also involved.

From figure 2, it is observed that the 13th queued vehicle (for Yokohama) stops at 40 meters from the stop line, which means that the average headway in jam density is 3 meters. However, that is generally varies from 5 to 6 meters in Japan. The observations were made only at few intersection approaches in this study, which located at CBD area, which may lead smaller headway in jam density. The results found in this study can be used for effective signal timing design in Dhaka metropolis.

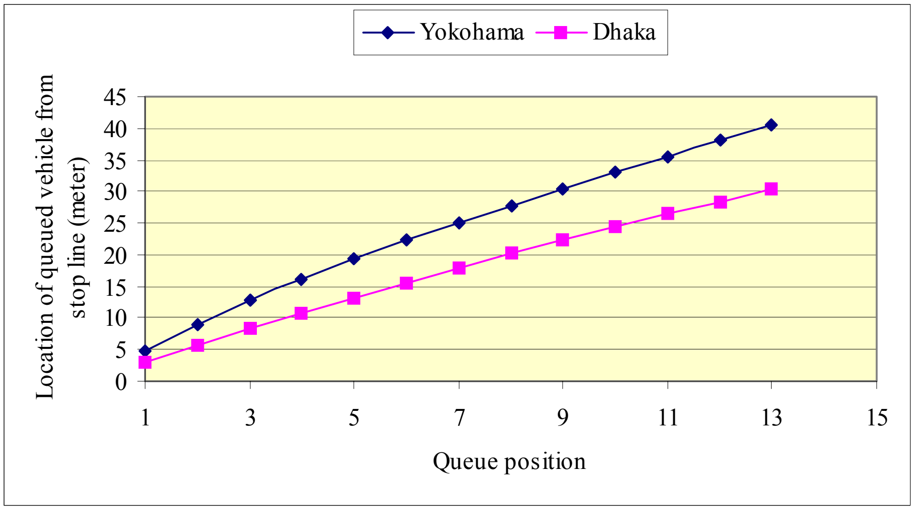

Figure 2. Comparison of location of queued vehicles in Dhaka and Yokohama

6. CONCLUSIONS

A procedure for determining the saturation flow rates at signalized intersections is presented, which differs from the procedure as discussed in the Highway Capacity Manual (HCM). This comparative study shows that the HCM procedure overestimates the saturation flow rates for the observed intersection approaches. For a few intersection approaches this value appears as high as 4.4%.

In case of basic vehicle type, namely passenger car the headway values varied significantly between Dhaka and Yokohama. In case of Dhaka city, queued vehicles were more closely spaced than those in Yokohama which produce smaller headway values. Moreover, the average wheel base of the passenger car in Dhaka city is smaller than that in Yokohama. In addition to this a few other factors, such as congestion level, attitude and socio-economic status of drivers are also responsible for the observed variations. As a result further comprehensive studies are required to identify those factors and their influences on the traffic flow at signalized intersections of metropolitan street networks.

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