Estimating Base Saturation Flow Rate for Selected Signalized Intersections in Doha, Qatar

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***Abstract*—Base saturation flow rate is an important factor used for the timing of traffic signals. Although, the Highway Capacity Manual (HCM) suggests a value of 1,900 pc/h/ln, the base saturation flow rate is not necessarily a constant value as it varies from one city to another depending on the local driver behavior and traffic environment. Therefore, it is important to estimate under prevailing local conditions. This study attempts to estimate the base saturation flow rate in Doha, Qatar. Towards this end, the headways of 1,431 through-moving vehicles form 86 queues at three signalized intersections were used. The average saturation headway was measured to be 1.55 seconds; therefore, the corresponding base saturation flow rate was found to be 2,323 pc/h/ln. This is clearly higher than the 1,900 pc/h/ln suggested by the HCM. Nevertheless, it is close to the results reported in other studies conducted in the region with similar roadway and traffic conditions. This finding shows that adopting the HCM's default value will result in underestimation of the signal capacity in Doha.**

***Index Terms*—saturation flow rate, base saturation flow rate, Signalized intersections, doha, qatar.**

I. Introduction

Traffic signals are traffic control devices used to manage the flow of traffic through intersections in a safe and efficient manner. Whether it is for designing new timing plans (to allocate green times) or operational analysis (to determine level of service) of existing ones, traffic engineers require an accurate estimate of the capacity of the signal.

Capacity (c) is the maximum number of vehicles that can reasonably be expected to pass through the intersection under prevailing traffic, roadway, and signalization conditions during a 15-minute period [1]. Capacity is computed as follows:

$$c = s \cdot \frac{g}{C} \tag{1}$$

where:

c = Capacity (vehicle/hour)
s = Saturation flow rate (vehicle/hour)
g = Green interval time (second)
C = Cycle length (second)

Therefore, saturation flow rate (s) is a basic parameter used to derive a signalized intersection's capacity. The HCM defines saturation flow rate as the equivalent hourly rate at which previously queued vehicles can cross an intersection approach under prevailing conditions, assuming that a green signal is available at all times and no lost time is experienced [1]. Saturation flow rate can be estimated by first measuring average saturation headway in the field, then computed using:

$$s = \frac{3{,}600}{h} \tag{2}$$

where:

s = Saturation flow rate (vehicle/hour)
h = Saturation headway (second)

The saturation headway is the average headway (time gap) between vehicles occurring after the fourth or fifth vehicle in the queue and continuing until the last vehicle in the initial queue clears the intersection [1].

However, many engineers opt to follow the HCM procedure to estimating saturation flow rate using:

$$s = s_{\circ} \cdot N \cdot \prod_i f_i \tag{3}$$

where:

s = Saturation flow rate for subject lane group, expressed as a total for all lanes in lane group (vehicle/hour)
s_o = Base saturation flow rate at ideal condition (passenger car/hour/lane)
N = Number of lanes in a lane group
f_i = Adjustment factors to account for various non-ideal geometric, traffic, and environmental conditions that may influence the departure headway of vehicles in the subject lane group

The HCM suggests a base (ideal) saturation flow rate of 1,900 passenger cars per hour of green time per lane (pc/h/ln). However, this default value is not necessarily applicable at different local conditions around the world. This is due to different driver behavior, operational traffic conditions, and road characteristics between different

Manuscript received February 9, 2015; revised April 20, 2015.

doi: 10.12720/jtle.3.2.168-171

locations. The HCM clearly adds a disclaimer emphasizing the need for adapting locally measured values outside of North America [1].

The purpose of this paper is to summarize the procedure undertaken and results achieved of measuring base saturation flow rate in the field for a few selected signalized intersections in Doha, Qatar. This will assist local engineers to better estimate saturation flow and capacity of signalized intersections in Qatar and the region, which will ultimately improve functionality of signals and reduce delays for the vehicles.

II. Litruture Reivew

Several researchers have underlined the importance of estimating saturation flow rate under local traffic and roadway conditions. The following paragraphs summarize some of the recent research effort in this topic.

Mukwaya and Mwesige studied the saturation flow rate for through-traffic at signalized intersections in Kampala, Ughanda [2]. Data from 107 queues were collocated from three approaches of two signalized intersections in the CBD area. The mean discharge headway at the three sites were reported as 2.28, 2.03, and 2.45 seconds. The results yielded base saturation flow rates of 1,579, 1,774, and 1,470 pc/h/ln, respectively. These values are well below the values recommended by the HCM.

Jobair bin Alam et al. measured the saturation flow rate at signalized intersection in Makah, Saudi Arabia [3]. They selected five signalized intersections for this study. Traffic operation at the study sites were recorded using video camera. The sites were selected based on a range of criteria to satisfy the study requirements that included level terrain; no pedestrian crossing, parking nor bus stops. Data were collected for periods that reflect typical peak traffic periods at each study site during weekdays. The basic saturation flow rate was measured for through lanes during cycles containing only passenger cars and satisfying the criteria for ideal conditions. Using measured saturation headways from a total of 156 cycles, the results showed that the base saturation flow rate for Makah to be 2,500 pc/h/ln. This much higher than the value suggested by the HCM.

Shao et al. reported their findings on the saturation flow rates at signalized intersection in China [4]. They studied the influence of traffic composition, lane width and approach grade on saturation flow rates. Field data were collected from 18 cities in China using video cameras and field measurements. The base saturation flow rate of 1,800 pc/h/l was found and suggested to be adapted in China.

Bester and Meyers studied the saturation flow rate for through-traffic at six signalized intersections in Stellenbosch, South Africa [5]. The reported saturation flow rates ranged from 1,711 to 2,370 (with an average of 2,076) pc/h/ln. The study concluded that these values are much higher than in other countries, which could be an indication of the aggressiveness of local drivers.

Rahman et al. compared saturation headways and the corresponding saturation flow rates between Yokohama, Japan and Dhaka, Bangladesh [6]. From the observed data of 17 intersections in the two cities, they found that the headway values of passenger cars in the Dhaka were lower than those in Yokohama. This corresponds to an average saturation flow rate of 2,048 pc/h/ln in Dhaka, as opposed to an average of 1,900 pc/h/ln in Yokohama.

Finally, Dunlap conducted a study to measure in the field the ideal saturation flow rate in Pennsylvania [7]. To account for the less aggressive characteristics of the local drivers, engineers were using an ideal saturation flow rate of 1,800 pc/h/ln, which is less than the default value of 1,900 pc/h/ln provided by HCM. The objective of the study was to determine the appropriateness of the lower ideal saturation flow rate. The average ideal saturation flow rate was determined to be 1,701 pc/h/ln, which is clearly below suggested value in the HCM.

III. Methodolagy

To separate the effect of other factors that can affect the capacity of a signalized intersection, the following criteria were used to select sample intersections to be used in the study [1]:

- Lane with of 12 feet (3.65 m)
- No parking adjacent to a travel lane within 250 feet (75 m) of the stop line
- No disturbance from heavy vehicles
- No disturbance form right turning vehicles on the other approaching lane
- No disturbance form left turning vehicles on the other approaching lane
- No disturbance from pedestrians
- The approach's grade is level

After choosing the sample intersections, video recording cameras were carefully placed in the field at each intersection to record the through-moving (TH) lanes for the approach with highest percentage of through-moving traffic. Using the video recording available for the selected intersection, the time frame was selected that:

- Has the highest percentage of through traffic,
- Occurred during peak hours on weekdays, and
- Does not have weather disturbance.

After obtaining all the video recording for each intersection needed for the study, the following information were extracted from the video recordings:

- The number of through vehicles in the queue,
- The number of heavy vehicles (buses and trucks) making a TH movement in the queue, and
- The queue discharge time, which is measured when the 4th vehicle in the queue passes the stop line following the onset of the green interval and until the last previously queued vehicle crosses the stop line.

Once this information is obtained, the average queue discharge headway for each queue was calculated using:

$$h = \frac{T}{N_{TH}} \tag{4}$$

where:

h = Average discharge headway (second)

T = Queue discharge time (second)

N_{TH} = Number of through moving vehicles in the queue minus the four vehicles at beginning of queue

To account for the presence of heavy vehicles, a passenger-car equivalent factor of 2.0 was used to convert the mix traffic with heavy vehicles into passenger-car only traffic. Finally, the base saturation flow rate was calculated using Eq. (2).

IV. Data Collection

To measure the saturation flow rate at signalized intersection, three signalized intersections in Doha, Qatar were selected. Fig. 1 shows the location of the study sites. These intersections have long queues for extended periods of time, especially during peak hours. All data were recorded during peak hours on weekdays, during the period from February 2013 to May 2013. Traffic data were collected via video with each video record was expected to capture all turning movements: left turning movement, through movement, and right turning movement. Ideally, the camera has to be placed in a way that enables the viewer to see the start and end of each phase, the end of the queue for each lane, and the stop line of the lane. Fig. 2 shows, for example, the location of the two video recording cameras used to collect the data needed at Al-Sadd intersection. Fig. 3 is a screenshot taken from one of the video recording at the same intersection. In a few cases where it was impossible to see the end of the queue, we assumed that the end of the queue happens when there was large time gap (more than 2 seconds) between two consecutive vehicles.

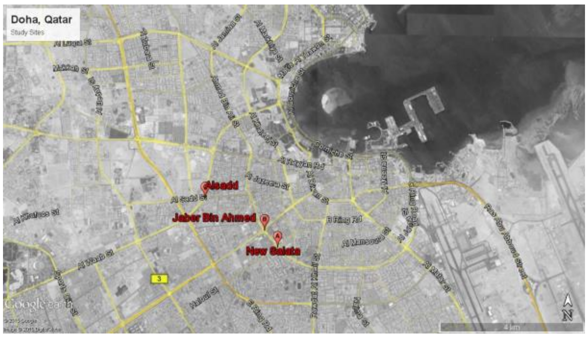

Figure 1. Location of Selected Sites.

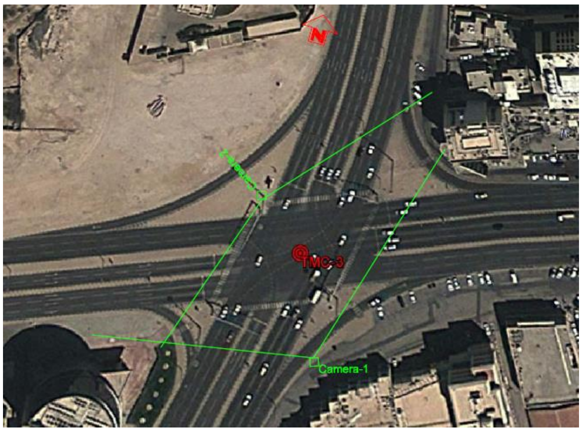

Figure 2. Placement of video cameras at Al Sadd Intersection.

Figure 3. Sample screen capture from the video recording.

Table I shows the sample size from the different intersections. The total number of queues considered from the three selected intersections combined was 86 and the total number of vehicles used was 1,431.

TABLE I. Chosen Intersection and Data Collected from Each Intersection

	New Salata	Jabr Bin Ahmed	Al Sadd	Total
Approach	South	West	North	
No. Queues	29	30	27	86
No. Vehicles	580	417	434	1,431

V. Results

For each of the 86 queues, the queue discharge time (T) was measured from the video recordings. Eq. (4) was then used to compute the saturation headway. Table II summarizes the saturation headway statistics from the three intersections individually and combined. The headways ranged from 1.38 to 1.77 seconds. The variations among the three intersections is negligible. The mean of the headway for all intersections combined was 1.55 seconds, as opposed to the 1.9 seconds recommended by HCM (a difference of -18 percent).

TABLE II. Through Moving Vehicle's Headway

	New Salata	Jabr Bin Ahmed	Al Sadd	Combined
Mean	1.55	1.55	1.54	1.55
Median	1.57	1.56	1.50	1.55
Mode	1.50	1.56	1.50	1.50
Minimum	1.41	1.38	1.40	1.38
Maximum	1.64	1.71	1.77	1.77

To compute the base saturation flow rate, the average discharge headway of 1.55 seconds for all intersections and Eq. (2) were used as follows:

$$S_o = 3{,}600/1.55 = 2{,}323 \text{ pc/h/ln}$$

The resulting base saturation flow rate was 2,323 pc/h/ln, which is clearly higher (almost +22 percent) than the 1,900 pc/h/ln value suggested by the HCM. This finding shows that adopting the HCM default value will result in underestimation of the signal capacity in Doha.

When comparing this value to the value found in countries with similar traffic condition, we find that the results are similar. For example, Md. Jobair Bin Alam *et* *al.* found the base saturation flow rate for Makkah in Saudi Arabia to be 2,500 pc/h/ln (a difference of only 7 percent) [4]. This is due to the aggressive driving in Doha and other cities in this region as compared to the USA and other parts of the World. Finally, Fig. 4 shows a comparison of the base saturation flow rates discussed in the literature review. Among the eight cities reported, the base saturation flow rate found in this study for Doha, Qatar is the second largest value.

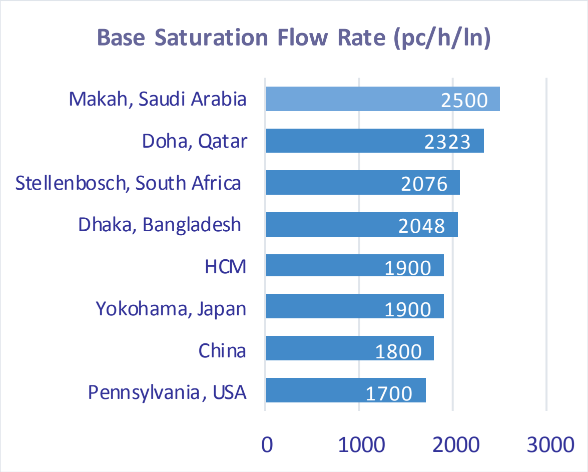

Figure 4. Comparison of base saturation flow rates cited in literature review.

VI. Conclusion

The saturation flow rate has been suggested by the HCM, however, the HCM also advices that the local traffic conditions/driver behavior, affects the estimation of the capacity of a signalized intersection and therefor it should be measured at the local level. Its accurate determination for a given region is of prime importance in signal timing design as it directly affects signal timing.

In this study attempted to calculate the base saturation flow rate in Doha, Qatar. This was accomplished using data collected from three different signalized intersections. From a total of 1,431 through moving vehicles from 86 queues, the mean headway was calculated as 1.55. Consequently, the base saturation flow rate was found to be 2,323 pc/h/ln. Even though, this result is significantly higher than the 1,900 pc/h/ln suggested by the HCM, it was similar to those from countries with similar driver behavior and traffic environment.

The results found in this study, will help local engineers to have better estimate of the capacity at signalized intersections. Eventually, this will benefit the road users as there will be less delay at traffic signals and, therefore, they will reach their destination quicker. Nevertheless, the finding of this study resulted from analyzing only three selected signalized intersections in Doha, Qatar. Prior to generalizing these results, verifying these results using a larger sample size may be necessary.

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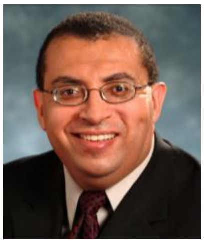

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