Saturation Flow Rate for Through-Traffic at Signalized Junctions in Kampala

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ABSTRACT
Capacity of signalized junctions is estimated based on two parameters; allocated green time and saturation flow rate in traffic engineering practice. The allocation of green time proportion is based on traffic demand, lane and phase configurations. However, the saturation flow rate is dependent on locality, traffic intensity and driving characteristics as spelt out in the Highway Capacity Manual [HCM] (2000). A study was conducted to determine saturation flow rate for through-traffic at two operational signalized junctions with minimal interference from traffic enforcement; Yard and Kampala-Entebbe Road Junctions in Kampala following HCM 2000 procedure. The estimated field saturation flow rate was compared with recommended value of 1900 vehicles per hour of green per lane [vphgpl] and adjusted values based on HCM 2000 model. The analysis yielded field saturation flow rates of 1579 and 1774 vphgpl at Yard Junction, and 1470 vphgpl at Kampala-Entebbe Road Junction. The adjusted saturation flow rate values were 1608 for Yard Junction and 1539 vphgpl at Kampala-Entebbe Road Junction. The findings showed that design using ideal saturation flow rate results in over estimation of capacity; whereas correct adjustments using HCM 2000 model results in capacity depicting the operating conditions.

Key Words: Capacity, saturation flow rate, signalized junctions, through-traffic.

1.0 INTRODUCTION
Poor signal timing, reflected from insufficient green time allocation and provision of very long cycle lengths can be traced back to using the wrong saturation flow rate which does not reflect the true driving characteristics of a given locality coupled with understanding of the dynamics that influence these factors. Saturation flow rate, unlike other engineering parameters is not a universal constant, but rather differs between countries owing to variations in driver behaviour and traffic composition. Its accurate determination for a given region is therefore of prime importance in signal timing design as it directly affects functionality of the signal.

Saturation flow rate is defined as the flow in vehicles per hour that can be accommodated by the lane group assuming unlimited green time and infinite queue. Design and operational analysis models presently in use require saturation flow rate as an input parameter. According to a special report by the Australian Road Research Board as reported by Long (2006), saturation flow rate is the most important single parameter in capacity and timing analysis of signalized junctions.

The Highway Capacity Manual (HCM [2000]), suggests an ideal saturation flow rate value of 1900 passenger cars per hour of green per lane (pcphgpl) for estimating a lane's saturation flow rate under ideal geometric and operational conditions. For non ideal conditions, this value is adjusted using a range of factors to account for reduced capacity. Whereas this approach can provide a quick alternative for estimating the saturation flow rate of a lane group, it must be used with caution as it may yield wrong values. HCM 2000 in fact, notes that the adjustment of the base saturation flow rate may not cater for some unique regional conditions such as weather and traffic stream composition; and therefore recommends estimating it directly from field study.

The idea behind defining a base saturation flow rate for a given region is to create a start point for estimating the maximum flow rate of a junction; existing or non-existing. Determination of the base saturation flow rate however requires area wide measurements on junctions with ideal geometric and operational conditions. In Uganda, the absence of junctions with uniform geometric and traffic attributes further complicates the determination of the base saturation flow rate.

The only option would be to have new signal designs based on a base value from another region, and later, after opening the junction to traffic, determine and adjust the timing to a more be-fitting saturation flow rate. The aim of this research was to determine the saturation flow rate for through traffic under prevailing local conditions. Two junctions were selected for the study; Jinja Road Yard Junction and Entebbe-Kampala Road Junction. These were identified as the only technically functioning junctions ideal for such research. Two approaches at Yard junction were selected; Yusuf Lule Road approach for Industrial Area bound traffic and Jinja Road approach for Nakawa bound traffic and on Entebbe-Kampala Road junction for City Square bound traffic.

2.0 JUNCTION ATTRIBUTES

The two study junctions are located in Kampala, Uganda's capital city in the central business district (CBD). The speed limit at both junctions is 50kph for built up areas in Uganda according to the Highway Code (2004). The cycle lengths were 230 and 90 seconds for Yard and Kampala-Entebbe Road Junctions respectively as shown in Table 1. Figure 1 shows the positions of camcorders at the two junctions.

3.0 LITERATURE REVIEW

In attempting to improve junction capacity, signals introduce interruptions in the flow of traffic during the red signal display, leading to a queue build up of vehicles on the affected lanes. At the onset of the green light, the queue discharges through the junction, initially at slow rate, but very quickly peaks up to a constant value called the saturation flow rate. The saturation flow rate is therefore the maximum discharge rate of vehicles through a junction after the onset of the green light and is assumed to start after the 4^{th} vehicle, and end shortly before the onset of the change interval HCM 2000.

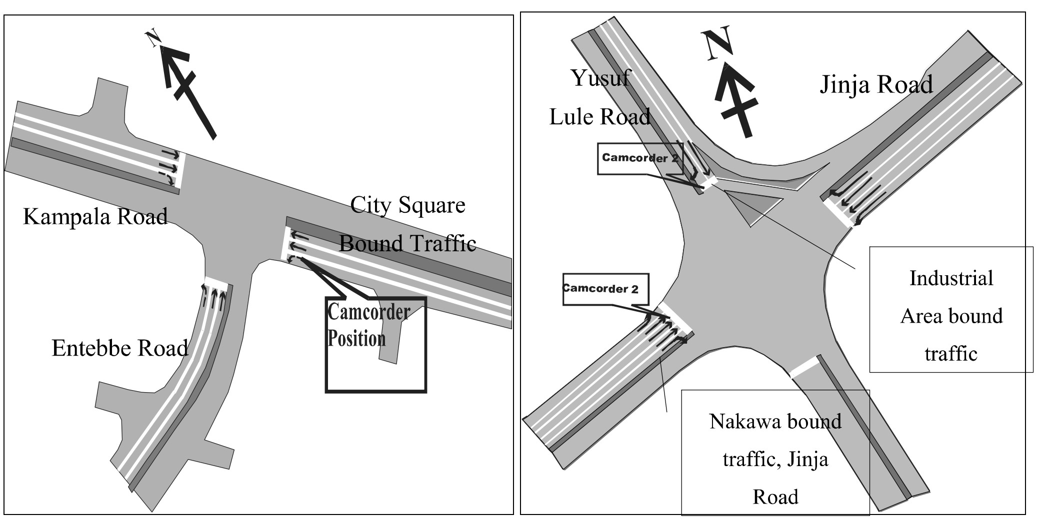
3.1 Theory on Saturation Flow Rate

At a junction, the maximum number of vehicles that can enter from an approach road is affected by the amount of green time available to that approach. When the green period commences, vehicles in the traffic queue take some time to accelerate to a constant running speed. This time/delay constitutes the start-up lost time, which is a function of perception and reaction time of drivers in the front of the queue.

Table 1: Geometric and Operational Attributes of the Junctions

Junction Name	Cycle length (s)	Phases	Approach	Movement	No. of Lanes	*Approach Grade (%)	Lane width, (m)
Yard	230	4	Industrial Area Bound Traffic	Through	1	-0.37	3.54
				Right turn	1		
				Left turn	1		
			Nakawa Bound Traffic	Through	2	-2.65	3.25
				Right turn	2		
				Left turn (shared)	1		
Kampala – Entebbe Road	90	4	City Centre Bound Traffic	Through	2	3.67	3.00
				Left turn	1		

* Negative grade means downgrade



(a) (b)

Figure 1: Position of the Camcorder at Junctions; (a) Kampala – Entebbe Road Junction, (b) Jinja Road Yard Junction

The Highway Capacity Manual (Appendix H, p.16-158) assumes that the start-up lost time is between10 to 14 seconds after the start of green, which corresponds to the crossing of the front axle of the 4th to 6th vehicle in the queue. The Traffic Signal Timing Manual (2009, Ch. 5) also assumes the same values. At the end of this time, the queue discharges into the intersection at a more or less constant rate. The constant time between successive vehicles entering an intersection is referred to as saturation headway. The saturation headway is attained between the 4th and 14th vehicle in the queue according to HCM (2000). At the end of the green period, some of the vehicles in the queue make use of the amber period to enter the intersection, and the discharge rate falls away to zero during this period. The usable amount of green time, that is, the duration of time between the end of the start-up delay and the end of the yellow extension, is referred to as the effective green time for the movement.

The Canadian Capacity Guide [CCG] (2006) by Teply *et al* however explains Saturation flow rate using the modified model. The flow is determined every 6 seconds after the start of the green time. Saturation flow rate is assumed to be achieved within 25 to 50 seconds of the green time and it is not constant as assumed in the HCM 2000 also confirmed by a research by Lin and Tseng (2005). However, no comparison has been made on loss of accuracy for assuming constant as opposed to stochastic discharge. This study therefore followed the HCM 2000 procedure that assumes constant saturation discharge headway after the fourth vehicle in the queue.

3.2 Base Saturation Flow Rate

The base saturation flow is defined as the departure rate of straight-through vehicular traffic flow at the stop line of a signalized intersection approach lane during the green interval under ideal geometric, pavement surface, traffic, and weather conditions in a given community (CCG 2006). HCM 2000 assumes the following ideal conditions: twelve feet (3.66 metre) lanes, through traffic, consists only of passenger car, zero grade, no adjacent parking permitted, no bus blockages and located in a non CBD area. Base saturation flow varies from region to region because of variations in traffic stream composition and driver behaviour; without the fore mentioned variables, Base saturation flow rate would be a universal constant.

With reference to the saturation flow concept, the base saturation flow should be constant for a given community. However, some researchers like Long (2006) have refuted this assertion. The base saturation flow derived for a region can either be used in the operational analysis of existing intersections, or in the design of new signals. It should be adjusted to suite the prevailing local conditions. Both HCM 2000 and CCG (2006) define a range of adjustment factors for the different conditions affecting saturation flow. The effect of the adjustment factors is to reduce the base saturation flow so as to account for local variability. HCM (2000) proposes a model used to adjust the base saturation flow rate adjustment factors in Exhibit 16-7 of HCM (2000). The adjustment factors include; lane width, proportion of heavy vehicles, approach grade, number of lanes, existence of parking, bus blockage, area type, lane utilization, right turns, and pedestrian activity.

3.3 Prevailing Saturation Flow Rate

The Base Saturation Flow Rate is only an estimate of the prevailing field Saturation Flow Rate. Severe weather conditions, unusual traffic mixes, or other special local conditions can yield saturation flow rates that differ markedly from those estimated using the Base Saturation Flow Rate. The true value of the saturation flow rate can only be accurately determined after opening the junction to traffic. HCM (2000) and CCG (2006) therefore recommend that for performance analysis, the prevailing saturation flow rate should be computed from observed data.

4.0 RESEARCH METHODOLOGY

The methodology adopted involved recording vehicles with a camcorder as they discharged the intersection during green interval with the stop line as the reference for computing discharge headway between successive vehicles. The discharge headways, h_i, seconds after fourth queued vehicle were determined for n cycles and used to compute the mean discharge headway in seconds as shown in Equation 1. The mean discharge headway (h-bar) was then used to compute the saturation flow rate (S) in vehicles per hour of green per lane (vphgpl) for respective approaches using Equation 2.

$$\bar{h} = \frac{\sum_{i=1}^{n} h_i}{n} \tag{1}$$

$$S = \frac{3600}{\bar{h}} \tag{2}$$

Data was collected during the afternoon off-peak between 2:30 and 5:00 PM in February 2010. The choice of off-peak period was to collect discharge data when the junctions have no interference from traffic enforcement officers. In the peak period, the junctions are oversaturated that traffic police takes over the control of the junctions' operation. The study required that data collected under normal operation without any external interference. Approach grade and lane width were also measured and used to compute adjustment factors for HCM's base saturation flow rate. Data reduction involved reading videos and recording time the front axle of the vehicle crossed the stop line in hours, minutes, seconds and microseconds for several cycles and entered into spreadsheets. A total of 98 cycles about 6.50 hours were recorded at the two study approaches of Yard Junction and 75 out of the 98 cycles were considered for analysis. The remaining 23 cycles were discarded because of: very short queues less than seven vehicles, interference from traffic police, and ambulances driving through to Yusuf Lule Road, as well as cycles with learner drivers in driving school cars.

5.0 FINDINGS

5.1 Saturation Headway and Saturation Flow Rate

Equation 1 was used to compute the mean discharge headway under saturated conditions also known as mean saturation headway. The mean saturation headway per cycle was computed by averaging headways after the 4th queued vehicle and saturation flow rate computed per approach using Equation 2, and the results are summarised in Table 2.

Table 2: Mean saturation headway and prevailing saturation flow rate values

Junction	Approach	Mean Saturation Headway, (s)	Saturation flow rate (vphgpl)	Standard deviation, (s)	Sample Size
Yard	Nakawa bound traffic	2.28	1579	0.29	40
	Industrial Area bound traffic	2.03	1774	0.26	35
Kampala - Entebbe Road	City Square bound traffic	2.45	1470	0.23	32

5.2 Comparison with HCM [2000] Estimation Model

Ideal saturation flow rate of 1900 pcphgpl given in HCM 2000 was multiplied by 13 adjustment factors, to obtain the adjusted saturation flow rate for each of the study approaches and compared with field saturation flow rate as shown in Table 3.

Table 3: Comparison of prevailing and adjusted saturation flow rate for the different study approaches

Junction Name	Approach	Field saturation flow rate (vphgpl)	Adjusted saturation flow rate (vphgpl)	Heavy vehicles (%)	95% Confidence level	
					Lower Bound	Upper Bound
Yard	Nakawa bound traffic	1579	1608	0.83	1541	1668
	Industrial Area bound traffic	1774	1608	5.41	1731	1890
Kampala-Entebbe Road	City Square bound traffic	1470	1539	1.79	1421	1560

5.3 Discussion

The average discharge headways at the two junctions were found to be; 2.28, 2.03 and 2.45 seconds indicating longer discharge times by drivers at the junctions. This has implications on the capacity and operation of the junctions. Field saturation flow rates on the two approaches of Yard junction were 1579 and 1774 vphgpl compared to 1470 vphgpl at Kampala-Entebbe Road Junction. The values are well below the recommended base saturation flow rate of 1900 pcphgpl. The adjusted saturation flow rates are not different than field flow rates, however, the adjustment must account for pertinent factors for accuracy. The traffic engineer must carryout correct adjustments. The low value of saturation flow rate at Kampala- Entebbe Road Junction is explained by the fact that traffic goes through a 3.67% upgrade which impacts significantly on the discharge characteristics. The percentage grade on industrial area bound traffic is -0.37% (downgrade) which explains higher saturation flow rate value computed.

The discharge characteristics of drivers at the junctions were characterized by improper lane changing, slow discharge speeds, occasional interference by traffic police and improper pedestrian crossing. The research recommends a check on the behaviour of pedestrian and motor cyclists in order to improve junction capacity, future research should focus on determining the effect of motorcycles on saturation flow rate and start-up lost time.

6.0 CONCLUSION

Field saturation flow rates for through traffic at the two signalized junctions were 1579 and 1774 vphgpl at Yard Junction and 1470 vphgpl at Kampala- Entebbe Road Junction. The adjusted saturation flow rate was 1608 vphgpl for Yard Junction and 1539 vphgpl. The variability in computed values was attributed to the proportion of heavy vehicles and grade at the discharge point. For operation and design of traffic signals, saturation flow rates between 1470 and 1774 vphgpl are recommended. However, future research is recommended to cover other junctions when they become operational so as to determine the mean saturation flow rate based on several junction studies. Future research is also necessary to determine the effect of motorcycle mix on the discharge characteristics of vehicles especially in terms of start-up lost time.

7.0 REFERENCES

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