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Effect of Increasing Rate of Tricycles on Saturation Flows at Signalized Intersections in Uyo, Akwa Ibom State, Nigeria

I. N. Usanga*, R. K. Etim

Department of Civil Engineering, Akwa Ibom State University, Ikot Akpaden, Akwa Ibom State, NIGERIA.

Abstract

This study involves understanding the effect of tricycles on saturation flow rate at signalized intersections. The goal is to show that intersection dominated by tricycle experience congestion especially at peak periods (morning and evening). This was done by collecting vehicular traffic data, signal timing and geometric data from five (5) signalized intersections at ten (10) cycles. The period covered October, 2015 to June, 2016 for four working days of the week (Mondays, Tuesdays, Wednesdays, and Fridays), between the hours of 7:30 am–9:30 am and 4:30 pm–6:30 pm. The duration of data collected covered both rainy and dry seasons. Average vehicular departure time during green time was determined and saturation flow obtained through field measurement by the ratio of average vehicular departure time to green time. Highway Capacity Manual method was also used to obtain saturation flow at each study approach. Saturation flow obtained through field measurement and Highway Capacity Manual were compared using independent t-test having t-value of 4.239 and P-value of 0.000 at 20 degree of freedom were obtained. The analysis indicated that P-value is less than 0.05, hence the mean of Highway Capacity Manual 2000 Model (5918.60) was significantly higher than the field measurement (4687.50). The result indicated that the increasing rate of tricycle with non-lane discipline causes congestion at signalized intersection. The findings suggest that the widely used Highway Capacity Manual is not appropriate for determining saturation flow for a mixed traffic with increasing rate of tricycle coupled with non-lane discipline traffic condition. From the analysis, it is recommended that Government should give priority to use of buses as a means of mass transit system so that it can accommodate more commuters than tricycle.

Keywords: saturation flow, highway capacity manual 2000 model, tricycle, lane discipline, intersections

1. INTRODUCTION

Saturation flow rate plays a critical role in the road traffic performance evaluation. The movement at signalized intersections depends on saturation flow [1]. It is the maximum sustainable rate at which vehicles can depart an intersection during effective green time. Traffic movement at signalized intersection is rendered more complex to analyze due to the heterogeneous characteristics of the traffic stream. However, saturation flow is influenced by the number and type of vehicles in the traffic stream [2].

Heterogeneous traffic situation with high composition of tricycles without lane discipline is common in most urban areas of developing countries. In Bangladesh and India, tricycles constitute 31% of the total vehicle composition in most signalized intersections [3]. In Nigeria, tricycles serve as a mode of para transit service to convey people and goods [4]. Registered tricycles in Uyo have increased from 1,345 in 2012 to 26,998 in 2016 [5]. This represents 76% annual growth. The increasing number of these tricycles together with a large number of other motor vehicles in our urban area coupled with non-lane discipline affects the saturation flow at signalized intersection. In general, to improve the performance of the system, it is necessary to identify and study the factors affecting it. The saturation flow rate is a fundamental parameter to measure the capacity of signalized intersection as well as determining the green time of traffic signal [6, 7]. Highway Capacity Manual 2000 Model (HCM 2000) approach is widely used in estimating saturation flow at signalized intersections. This method assumes a lane based discipline and does not provide adjustment factor for the effect of the tricycles. Due to these fundamental differences, the highway capacity manual methods of estimating the values of saturation flow are not appropriate for estimating saturation flow in the study area. For correct estimation of saturation flow rate, the parameters should be based on the local prevailing traffic conditions and

*Corresponding author (**Tel:** +234 (0)703 918 0879)
Email addresses: usangaidy@gmail.com (I. N. Usanga), rolandetim@aksu.edu.ng (R. K. Etim)

hence requires a traditional approach. The traffic analysis studies conducted by [8] in Uyo Metropolis considered a non-lane based traffic, but failed to take into consideration the intersections that is dominated by tricycles. Study by [9] analyzed the behavior of cyclist at signalized intersections, thus, it presented a model for accidents between vehicles and bicycles and the effects of the bicycle on saturation flow rate. It presented new formulae for determining the bicycle adjustment factor for left turn and bicycle adjustment factor for right turn. The study concluded that when the traffic flow of the bicycle is high, the proposed model is very close to the field observation data and results showed better correspondence than the HCM result.

Study by [10] investigated and analyzed the effect of two-wheelers on the saturation flow of signalized intersections by collecting data at a few signalized intersections in Bangalore, India. The study showed a strong correlation between the measured saturation flow and the proportion of two-wheeler traffic. This suggested that the two-wheeler traffic has significant impact and should be considered in the capacity analysis of signalized intersections.

Study conducted by [11] investigated the effect of encroaching vehicles (Vehicles standing beyond the stop line when red is given to that particular approach) on saturation flow and capacity at signalized intersections in mixed traffic conditions. Two separate saturation flow models were developed using regression analysis. Significant variables considered in the study include, approach width, proportion of two-wheelers and cars, one with considering encroaching vehicles (considering vehicles passing through reference line 2) and another without considering encroaching vehicles. The data were collected from five signalized intersections: Suchitra, Malaparamba, University cross roads, Gandimaisamma and Kazipet railway station intersections in India. The model developed in this study showed variation in saturation flow with and without consideration of encroaching vehicles. The study concluded that model developed considering encroaching vehicle showed higher saturation flow value than the one without considering the encroaching vehicles.

The effects of the bicycles on the capacity of the intersections studied by [12], determined the crossing time of the bicycles turning left from the opposite direction through the vehicles and presented a model for them. They reached to these results that the capacity of the vehicles passing and turning left at the predicted model is less than capacity in the prediction model of HCM.

Study by [13] analyzed the role of motorcycle on saturation flow rates at signalized intersections in Gorgan. The study divided motorcycles at an intersection into two groups: inside flow motorcycles and outside flow motorcycles. Inside flow motorcycles represented those motorcycles located next to other vehicles and when the light becomes green, pass through the intersection with other vehicles, while outside flow motorcycles are those that are located in front of the stop line and are the first vehicles that exit the intersection after the light become green. Video camera were used to collect traffic data. Observed saturation flow rate was calculated and compared to estimated saturation flow rate by Malaysian HCM.

Evaluation and retiming of a pre-timed traffic signal in Benin City, Nigeria was studied by [14]. They reported that, the number of phases and cycle length required based on the prevalent volume of traffic making use of selected intersection should be three and 120 seconds respectively. They concluded that, the maximum volume to capacity ratio reduced from 1.06 to 0.68 while the overall intersection control delay reduced from 126.4 s/pcu to 29.7 s/pcu. However, the retiming and pre-timed signal is likely based on the saturation flow of various vehicles recorded in the period of the investigation.

However, the traffic in Uyo Metropolis consists of different classes of vehicles with increasing percentage of tricycles having non-lane discipline. Highway Capacity Manual is widely used in estimating saturation flow rate at signalized intersection. This approach assumed a homogenous and lane based discipline traffic condition. The prevailing traffic condition in Uyo is however characterised by non-lane based discipline with increasing rate of tricycles and other motorized vehicles. As a result of these fundamental differences, the widely used Highway Capacity Manuals are not appropriate in determining the values of saturation flow rate. Intersection dominated by tricycles with non-lane discipline considered in this study include: Udo Udoma Intersection, Four-lane Intersection, May Flower Intersection and Udo Eduok intersection. These intersections experience congestion especially at peak period between 6:30 – 9:30 AM and 4:30 – 6:30 PM. Understanding the effect of increasing rate of tricycles with non-lane discipline on saturation flow will indicate if the presence of tricycles with non-lane discipline causes congestion at these signalized intersection.

2. STUDY AREA

This study was carried out in Uyo (Fig. 1). Uyo is the capital of Akwa Ibom State created in 1987 and located at the south-south region of Nigeria, thus having tropical climate condition. The city lies between longitudes 37° 50' E and 37° 51' E and between latitudes 55°40' N and 54°59' N. Uyo has a total area of 188.035 km^2 and an estimated population of 3.920,208 [15–17]. In the past nine years, there has been massive increase in infrastructural growth in Uyo, leading to the city becoming a fast growing one in Nigeria.

The increase in land mass and population is evident in economic activities including daily trade in commodities carried out in a network of traditional and modern markets, hotels, guesthouse dotting the landscape of both inner and outskirts of the city [18]. These activities have increase in traffic volume in the city as people travel between

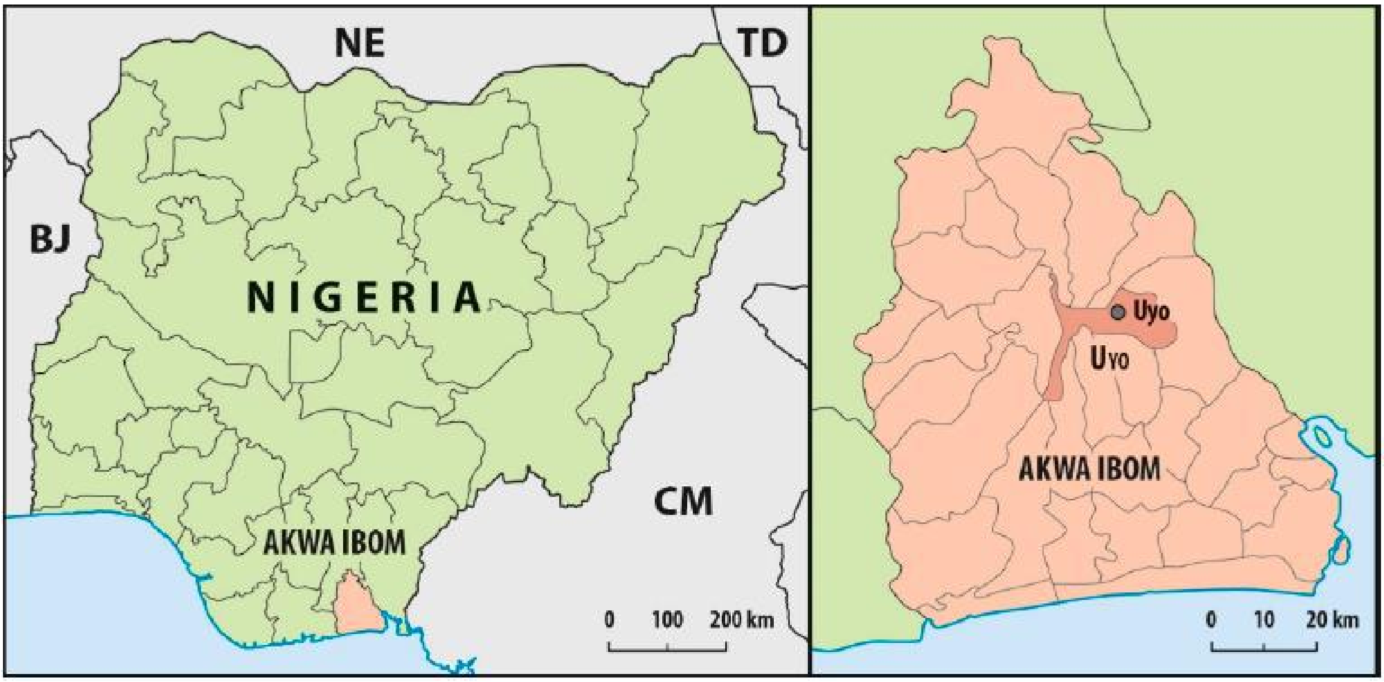

Figure 1: Map of Nigeria showing Akwa Ibom State, and map of Akwa Ibom State showing Uyo capital city (Source: Ministry of Land Surveying, Uyo).

their homes and jobs, get services, and so on, using tricycle vehicle as major means of intra-urban transportation system. There are nine (9) signalized intersections in Uyo out of which five (5) signalized intersections experience increasing rate of tricycle during morning and evening periods and are prone to traffic congestion. This study considered Udo Udoma Intersection, Four Lanes Intersection, Mayflower Intersection, Udo Umana Intersection and Udo Eduok Intersection.

3. METHODOLOGY

Vehicular traffic data, signal timing and geometric data, were conducted between October, 2015 and June, 2016 for four working days at 11 phases of the five (5) signalized intersection in Uyo metropolis. The duration of this data collection is to accommodate weather conditions (dry and wet season) in the study area and also to ensure accuracy of the data collected and cost effectiveness. This intersection is considered to experience traffic congestion due to percentage increase in tricycle during morning and evening peak periods. Observation point was selected at the stop line of each selected phase of the signalized intersection. Vehicular traffic counts were carried out through observation and direct counting method of vehicular traffic with the help of ten (10) enumerators at the 11 phases of the 5 selected intersection. Effective green time was obtained by using digital stopwatch to time the signal timing. The vehicular traffic count was conducted at 10 cycles of the effective green time of each intersection for two (2) time periods for duration of four working days of the week (Mondays, Tuesdays, Wednesdays, and Fridays) from October, 2015 to June, 2016. These times are as follows:

7:30 AM – 9:30 AM Morning peak

4:30 PM – 6:30 PM Evening peak

The study also involves the collection of geometric data at the selected intersections. The data include number of lanes, width of lanes, gradient, proportion of right turn and left turn. From the geometric data obtain, Highway Capacity Manual model method of saturation flow rate was calculated to compare with the field measurement of saturation flow rate to determine if the percentage increase in tricycle have effect on saturation flow rate. The study employs some basic statistical tools to analyze traffic data obtained at each intersection. These tools include mean, standard deviation, variance and independent t-test.

Independent t-test was used to compare the saturation flow obtained using HCM 2000 model and field measurement to ascertain if the increasing rate of tricycle has significant impact on saturation flow rate at signalized intersection. Table 1 shows traffic composition and geometric features at the study intersections shown in Fig. 2a – 2e while Fig. 3 – 7 indicates typical traffic situation at selected intersections.

3.1. Highway Capacity Manual 2000 Model and Field Measurement of Saturation Flow

Other methods of obtaining saturation flow including headway method are not suitable for a non-lane based traffic condition because in non-lane based traffic flow, headways are difficult to observe, as vehicles do not move in lanes. Traffic is analyzed on the basis of total width of approach and hence, the option of vehicular traffic count is

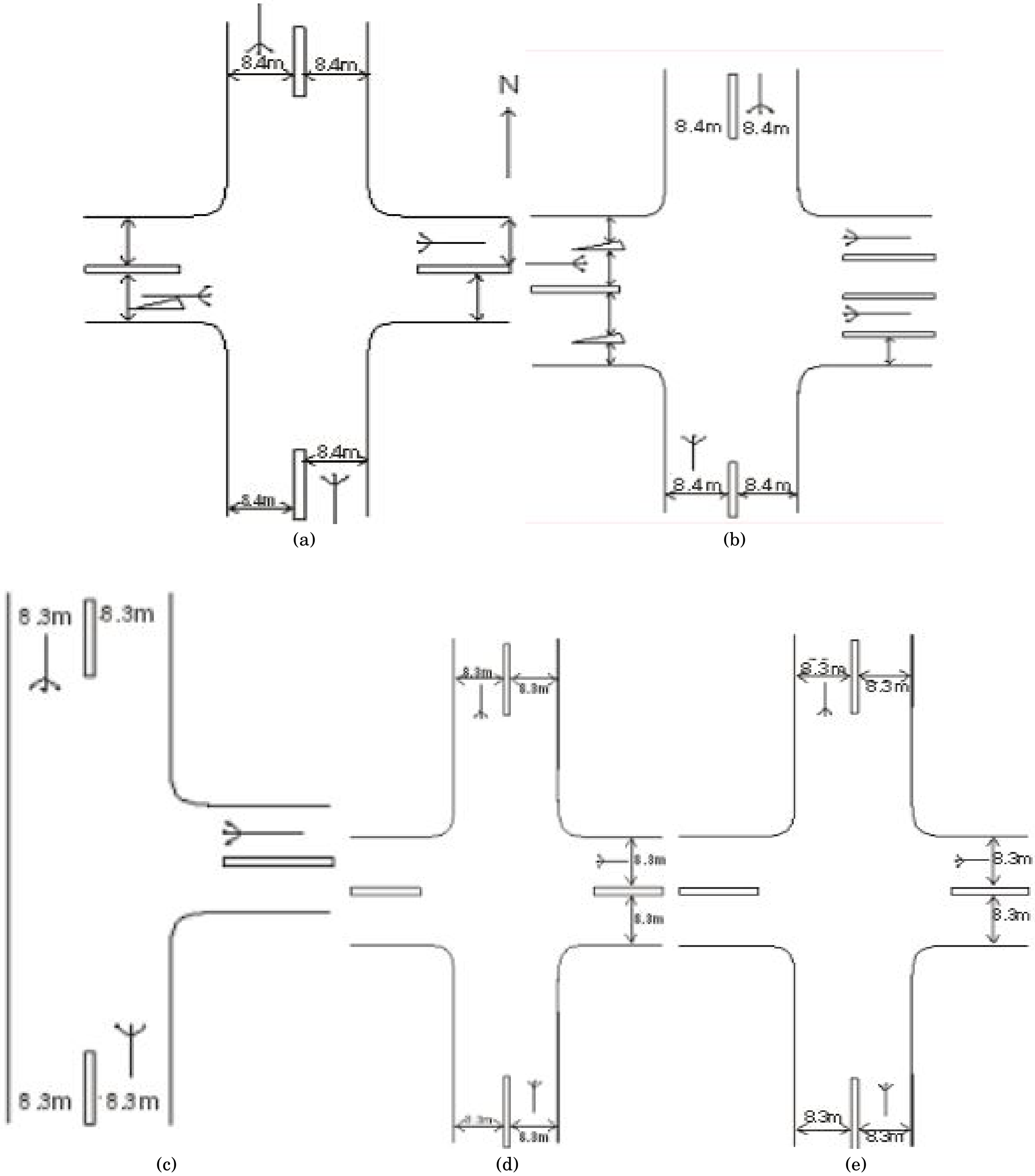

Figure 2: (a) Geometric features of Udo Udoma Intersection (b) Geometric features of four-lane Intersection (c) Geometric features of May Flower Intersection (d) Geometric features of Udo Umana Intersection (e) Geometric features of Udo-Eduok Intersection.

Table 1: Traffic composition and geometric features of the study intersections.

Intersections	TT	% Tricycle	% Car	% Truck (L& H)	Lane Number	Approach width (m)	Gradient (%)	LTT (%)	RTT (%)
Udo Udoma									
(a) North Approach	67	57	35	8	2	8.4	-0.42	55	26
(b) South Approach	62	53	40	7	2	8.4	-0.84	32	20
Four Lane									
(a) North Approach	56	56	38	6	2	8.4	-0.67	41	30
(b) South Approach	54	54	41	5	2	8.4	-1.4	25	17
May Flower									
(a) North Approach	43	53	42	5	2	8.7	+0.41	15	34
(b) South Approach	42	54	41	5	2	9	+0.73	37	0
Udo Umana									
(a) North Approach	60	61	39	4	2	8.3	-0.76	28	11
(b) South Approach	51	56	42	2	2	8.3	+0.62	22	12
(c) West Approach	34	56	42	2	2	8.3	-0.54	39	15
Abak Road-Udo Eduok									
(a) North Approach	40	55	42	3	2	8.3	-0.46	16	17
(b) South Approach	42	57	40	3	2	9.3	+0.70	27	18

TT-Total traffic; (L & H)- Light and Heavy; LTT- Left Turn Traffic; RTT- Right Turn Traffic.

Figure 3: Vehicular traffic concentration at Udo Udoma intersection.

Figure 4: Vehicular Traffic Concentration at Four-Lane Intersection.

Figure 5: Vehicular traffic concentration at Mayflower intersection.

Figure 6: Vehicular traffic concentration at Udo Umana intersection.

Figure 7: Vehicular traffic concentration at Abak road – Udo Eduok intersection.

adopted. Field measurement saturation flow is calculated independently for each phase of the selected intersection by obtaining vehicular traffic count for 154 days at 10 cycles of each phase of the signalized intersection selected for this study as shown in Table 2. All vehicular traffic is added and then average over observed period. The average vehicular departure is divided by the effective green time to obtain field measured saturation flow in vehicles per hour green.

Table 2: Average number of vehicular departure during green time.

Intersections	**Effective green time (G)**	**No. of Vehicular Departure (DT)**
Udo Udoma		
(a) North Approach	45	67
(b) South Approach	45	62
Four-Lane		
(a) North Approach	40	56
(b) South Approach	40	54
May-Flower		
(a) North Approach	35	43
(b) South Approach	35	42
Udo Umana		
(a) North Approach	42	60
(b) East Approach	35	51
(c) West Approach	30	34
Abak Road		
(a) North Approach	35	40
(b) South Approach	35	42

Highway Capacity Manual 2000 Model is widely used in estimating saturation flow at signalized intersection. This model showed that certain factors affect saturation flow and developed equation for each adjustment factors. The saturation flow rate for each lane group is computed using Eq. (1). The saturation flow rate is the flow in vehicles per hour that could be accommodated by the lane group assuming that the green phase was always available to the lane group.

$$s = s_0 N f_w f_{HV} f_g f_p f_{bb} f_a f_{LU} f_{LT} f_{RT} f_{Lpb} f_{Rpb} \quad (1)$$

where s is saturated flow rate for the subject lane group, expressed as a total for all lanes in the lane group under prevailing conditions (vphg), s_0 is base saturation flow rate per lane, usually 1900 (pcu/hr green/hr), N is number of lanes in the lane group, f_w is adjustment factor for lane width; 12ft lanes are standard, f_{HV} is adjustment factor for heavy vehicles in the traffic stream, fg is the adjustment factor for approach grade, fp is adjustment factor for parking activity, f_{bb} is adjustment factor for the blocking effect of local buses stopping within the intersection area, f_a is adjustment factor for area type, f_{LU} is adjustment factor for lane utilization, f_{RT} is adjustment factor for right turns in the lane group, f_{LT} is adjustment factor for left turns in the lane group, f_{Lpb} is pedestrian-bicycle adjustment factor for left-turn movements and f_{Rpb} is pedestrian-bicycle adjustment factor for right-turn movements.

The HCM 2000 model saturation flow values were obtained by calculating the parameters for the model after necessary information were obtained at the approach intersection as stated in data collection and procedure. The parameters calculated were fitted into the HCM 2000 model in equation 1 to determine saturation flow values for each phase of the selected intersection. Table 3 gives the values of the parameters needed in the HCM 2000 model to determine saturation flow values for each phase of intersection.

4. RESULTS AND DISCUSSION

Table 4 provides the result of saturation flow in vehicles per hour of green time (Vphg) for field measurement and HCM 2000 model. The proportion of vehicles that would pass through North approach of Udo Udoma intersection for an hour of green time using HCM 2000 model is higher than the proportion of vehicles that passed the intersection during field measurement under prevailing traffic condition (higher percentage of tricycle with non-lane discipline). In every one hour of green time, the number of vehicles that would have passed this approach intersection will be reduce by 34 vehicles (0.63%). Similarly, saturation flow obtained using HCM 2000 model is higher than field measurement by (9%) at south approach of the same intersection. All the approaches of the selected intersections except North approach of Udo Udoma intersection, had higher value of saturation flow using HCM 2000 model than field measurement. South approach of Udo Eduok intersection had the highest percentage difference in the number of vehicles passing the intersection using HCM 2000 model as compared to field measurement saturation flow (22%). also, North approach of Udo Udoma intersection had the least percentage difference in the number of vehicles passing the intersection (0.63%). The highest and lowest percentage difference could be attributed to the fact that South approach of Udo Eduok intersection had the highest percentage of tricycle (61%) in traffic composition at peak periods, while the North approach of Udo Udoma intersection

Table 3: Parameters for determination of Saturation using HCM 2000 model.

Intersections	s_o	N	f_w	f_{Hv}	f_g	f_p	f_a	f_{bb}	f_{LU}	f_{RT}	f_{LT}	f_{Lpb}	f_{Rpb}
Udo Udoma													
(a) North approach	1900	2	1.533	0.925	0.998	1	1	1	1	–	–	–	–
(b) South approach	1900	2	1.488	0.935	0.996	1	1	1	1	–	–	–	–
Four-Lane													
(a) North approach	1900	2	1.488	0.943	0.977	1	1	1	1	–	–	–	–
(b) South approach	1900	2	1.488	0.952	0.933	1	1	1	1	–	–	–	–
May-Flower													
(a) North approach	1900	2	1.566	0.952	0.998	1	0.9	1	1	–	–	–	–
(b) South approach	1900	2	1.600	0.952	0.996	1	0.9	1	1	–	–	–	–
Udo Umana													
(a) North approach	1900	2	1.522	0.962	0.998	1	0.9	1	1	–	–	–	–
(b) East approach	1900	2	1.522	0.980	0.996	1	0.9	1	1	–	–	–	–
(c) West approach	1900	2	1.522	0.980	0.997	1	0.9	1	1	–	–	–	–
Udo Eduok– Abak Road													
(a) North approach	1900	2	1.522	0.971	0.998	1	0.9	1	1	–	–	–	–
(b) South approach	1900	2	1.633	0.971	0.996	1	0.9	1	1	–	–	–	–

Table 4: Field saturation flow in vehicles per hour(vph).

Intersections	Field measurement (vph)	HCM 2000 model (vph)	% Difference
Udo Udoma			
(a) North Approach	5360	5360	0.63%
(b) South Approach	4960	5947	9.0%
Four-Lane			
(a) North Approach	5040	5477	8.3%
(b) South Approach	4860	5507	12.5%
May-Flower			
(a) North Approach	4422	5088	14.0%
(b) South Approach	4320	5209	18.7%
Udo Umana			
(a) North Approach	5142	4997	1.4
(b) South Approach	4371	5181	17.0%
(c) West Approach	4080	5086	21.9%
Udo Eduok-Abak Road			
(a) North Approach	4114	5044	20.0%
(b) South Approach	4320	5401	22.0%

Table 5: Independent samples Test of the difference between HCM and Field measurement.

Group	N	Mean	Standard Deviation	t	df	P-value
Field	11	4635.36	446.76	4.239	20	0.000
HCM	11	5255.55	189.24			

Source: Researcher's Computation from SPSS 25.

had the lowest percentage of tricycle in traffic composition (52%) at peak periods. This is in line with the study that presented that traffic composition, lane width and approach grade influence saturation flow at signalized intersections [19].

Table 5 shows the descriptive statistics for the independent t-test. The result suggested that saturation flow in HCM 2000 model (Mean = 5255.55, SD = 189.24) is more than saturation flow measured in the field (Mean = 4635.36, SD = 446.76, t (20) = 4.239, p = 0.000, d = 1.81, 95% confidence interval (Cl) [294,946]. This further implies that intersections dominated by tricycle with non-lane discipline, affects saturation flow in Uyo. This agrees with the study that indicated that saturation flow should be measured based on prevailing traffic condition in developing countries rather than HCM method [10].

5. CONCLUSIONS

From the results of the study, it can be found that there is a strong relationship between the number of tricycle with non-lane discipline and saturation flow at signalized intersection. Seven (7) out of the eleven (11) considered signalized approaches had 10% and above percentage difference in saturation when modelled using HCM 2000 as compared to field measurement. This shows that fewer number of vehicles traverse these intersections compared to the number of vehicles that would traverse the intersections using HCM. This is due to increasing rate of tricycle coupled with non-lane discipline traffic condition at these intersections. For correct estimation of saturation flow rate for signal design, the parameters should be based on prevailing traffic conditions and hence field measurement approach should be adopted. The evidence in this study is essential for reliable planning, designing and maintenance of pre-timed traffic signal with respect to saturation flow of tricycle in Uyo metropolis. This is very important because if not properly managed, will end up with blocking and congestion at signalized intersections as well as cause bottleneck on adjoining streets. The longer duration at the intersections will in turn pose severe health and environmental problems to the area.

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