



Impact Assessment of Tricycle's Proportion on Saturation Flow Rate at Urban Signalized Intersections

^{1&2}Umar Dalhatu, ¹Muttaka Na'ya Ibrahim, ¹Murtala Umar

¹Department of Civil Engineering, Bayero University, Kano, Nigeria,

²Department of Civil Engineering, Federal University Dutsinma, Katsina, Nigeria

ABSTRACT

Tricycles constitute a substantial proportion of traffic in Kano and other cities in Nigeria. This study assesses the impact tricycle's proportion on saturation flow rate at six selected signalized intersections in Kano metropolis. Two methods; Highway Capacity Manual (HCM) model and empirical approaches were used to evaluate saturation flow rates at the selected intersections and results compared. Saturation flow rate was estimated using the HCM model approach based on intersection's geometric features and vehicle's adjustment factors, excluding tricycles. In the empirical approach, saturation flow rate per intersection's approach was estimated based on the number of vehicles (tricycles inclusive) that crossed the stop-line per effective green-time of an approach. Results obtained from the study showed that saturation flow rates from empirical approach ranges from 2,885 to 8,626 veh/hr, while that from the HCM model approach, it ranges from 3,906 to 10,891 veh/hr. On the average scale, saturation flow rates of 5,964 veh/hr and 7,446 veh/hr were recorded for the empirical and HCM model approaches, respectively. On the overall scale; 20 out of the 21 approaches of the 6 studied intersections recorded higher saturation flow rates based on the HCM model relative to those estimated based on the empirical method. A test of significance using independent t-test was performed at 95% confidence level to ascertain whether there is statistically significant difference between saturation flow rates values obtained from empirical and HCM model approaches. Results from this test revealed a P-value 0.04 ($P < 0.05$), which indicates that there is statistically significant difference between the results obtained from the two approaches. This implies that the HCM model overestimated the saturation flow rate relative to the empirical approach. The implication of this finding is that saturation flow rates based HCM model would lead to erroneous designation of an intersection's operational performance or level of service; specifically, denoting a premature operational failure of the facility. This would consequently suggest for a premature facility improvement with associated unjustified expenditures.

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INTRODUCTION

Right from ancient civilization, transportation has been a pivotal component of human existence as it primarily involves the movement of people and goods from one place to another. As human population increases, the need

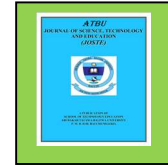
for transportation also increases. According to Fadare and Salami (2004), this growing need for mobility is borne out of the necessity for people to meet social and economic needs. The use of tricycle (Keke NAPEP or Adaitata Sahu) has in recent times become a common means of

Corresponding author: Muttaka Na'ya Ibrahim

✉ mnibrahim.civ@buk.edu.ng

Department of Civil Engineering, Bayero University, Kano, Nigeria

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transportation in many Nigerian cities with an ever increasing number on road segments and intersections. It is seen as a major intra-city transport in recent times, especially in cities where commercial motorcycles are banned or restricted (Saleh, 2011). Another reason for this as Galyuon et al., (2019), Ipingbemi and Adebayo, (2016) pointed out, in most developing countries like Nigeria, vehicle ownership is low and dependency on public transport is high. These have led to more problems associated with traffic flow on the roads and has added to the challenges within the domain of traffic studies.

This study assesses the impact of tricycle's proportion on saturation flow rate at urban signalized intersection. Saturation flow rate is the maximum number of vehicles that can pass the stop line per unit of time under one phase or lane with sufficient traffic demand at the intersection entrance. It is referred to as the maximum constant departure rate from the queue during the green period and it remains fairly constant until either the queue is exhausted or the green period ends (Agent and Crabtree, 1982). In other words, it means, the number of vehicles that passed an intersection for the period of one hour, if an intersection approach signal is indicating green for that one hour and the traffic is expected to be as dense as possible (Perera, 2018). Saturation flow rate is a fundamental value for the determination of an intersection capacity (Aoyama et al., 2020).

There are several methods that can be used to determine saturation flow rate all of which have been developed by western countries to suite their own traffic characteristics. According to (Karim et al., 2008), there are three principal methods available for estimating saturation flow. These include; Road Note 34, Average Headway and Multiple Linear Regression methods. The Highway Capacity Manual (TRB, 2010) is widely used to calculate saturation flow rate at urban signalized intersection. In that approach, the base saturation flow rate is multiplied by some adjustment factors to take into consideration the effect they have on saturation flow rate value. This approach is suitable for homogeneous traffic state, however, it is not suitable for a highly

heterogeneous traffic state (Biswas et al., 2018) which is the traffic state offered due to the presence of high number of tricycles with no lane discipline. This approach may not be suitable for use in Kano city's traffic condition, as the traffic is mostly non-lane disciplined and there is no established adjustment factor for the effect of tricycle. Due to this limitation, some researchers suggested for estimation of saturation flow rate using local traffic conditions.

Aoyama et al., (2020) who researched on the estimation of saturation flow rate at signalized intersection in Japan, Nguyen, (2016) based on local traffic settings. He examined saturation flow rate at signalized intersection for mixed traffic conditions in motorcycle dependent cities. ElSahly and Abdelfatah, (2021), insisted that despite the importance and the use of saturation flow rate, most of the transportation agencies do not collect data from the field. Instead, they use Highway Capacity Manual (HCM) suggested values, which are not necessarily applicable to different cities around the world.

Modibbo and Mary, (2017) studied tricycle operation from an economic point of view in their research when they looked at the impact of commercial tricycle operation on the income of youths in Mubi north local government Adamawa State, north east Nigeria. In Minna, Niger state, Ajiboye et al., (2020) assessed the operation and management of tricycle as a means of public transport. Transport services in Nigeria is inadequate both in qualitative and quantitative terms considering the rate of population growth (Ibelieve et al., 2020). Tricycles as a mode of public transport falls under the broader heading of Informal Public Transport of which (Hilling, 1996) stated that the mode has emerged spontaneously to fill the gaps in the conventional transport of the urban areas. Totally absent from Kano streets two decades ago, tricycles are now by far the dominant form of public transport in urban Kano. High level of tricycles importation began in 2012 when commercial motorcycles were banned in the state (Madugu, 2017).

Currently, there are some 45,000 registered tricycles operating in the state, and



about 15,000 unregistered ones (Kofar-Na'lsa et al., 2021). A lot of researchers have studied the effect of IPTs in traffic. (Anusha et al., 2013), studied the effect of two-wheelers on saturation flow rate at signalized intersection in Bangalore, India. Data collected from few intersections showed strong correlation between the measured saturation flow and proportion of two-wheelers in traffic which suggests that two-wheelers have significant impact and should be considered in the capacity analysis of signalized intersections. A study by Adams and Zambang, (2015) examined the effects of motorcycles on saturation flow rates of mixed traffic at signalized intersection in Ghana.

The study concluded that the higher the motorcycles on any approach, the lower the headway and the higher the saturation flow. How to accurately estimate saturation flow rate remains one of the most important tasks in transportation Engineering (Linhong et al., 2018). This is because Traffic in developing countries consist of both motorized and non-motorized vehicles. Shah and Chitaria, (2020), examined the effect traffic flow characteristics at signalized intersections and with reference to non-lane based traffic condition prevailing in India. In that study videography technique was used to get traffic data at signalized intersection of Ahmedabad city for the analysis. The study concluded that the proportion of two wheelers in traffic (61%) is maximum and leads to high heterogeneous traffic conditions. Suweda and Wedagama, (2021), discovered that the discharge headways between vehicles at signalized intersection were affected not only by the number of motorcycles in the traffic flow but also by the lack of motorcyclist compliance to lane discipline and given the fact that motorcycles take positions in front of and between vehicles in a variety of non-uniform ways.

The HCM model approach for calculating saturation flow rate is based on adjusting the base saturation flow rate value of

1900 pcu/hr/ln to reflect local traffic conditions individual intersection geometric properties like lane width, approach width, number of lanes, grade etc. This may lead to erroneous decisions which then leads to inaccurate results if used to for areas with different traffic characteristics. In reality, traffic characteristics differ from city to city. Al-Mosawi and Al-jameel, (2023) attempted to estimate the base saturation flow rate for Al-Najif city in Iraq. The mean headway from a total of 9931 through moving vehicles from 187 line ups was calculated to be 155. The basic saturation flow rate was therefore determined to be 2323 pcu/hr/ln. This result is substantially higher than the 1900 pcu/hr/ln proposed by the HCM2010, but is comparable to results from other nations with similar traffic conditions and driving habits.

METHODOLOGY

Study Area

Kano metropolis consists of six Local Government Areas which include Dala, Kano Municipal, Gwale, Fagge, Nasarawa and Tarauni. It also includes parts of Ungogo and Kumbotso LGAs. Figure 1 shows a map of Kano metropolis. According to the 2006 general census in Nigeria, Kano has an estimated population of about 3,802,216 people with an estimated area of 212 square mile. There are a high volume commercial and industrial activities within Kano metropolis. This is because of the availability of both basic economic, social and industrial infrastructure. Kano metropolis has been playing a domineering role over the rest of the state in both administrative, commercial, economic, educational, industrial and all other sectors; Right from historical times, Kano metropolis enjoys strategic location in relation to the Trans-Sahara trade routes. This makes the city to continue to attract people from far and near distances (Saleh, 2011).

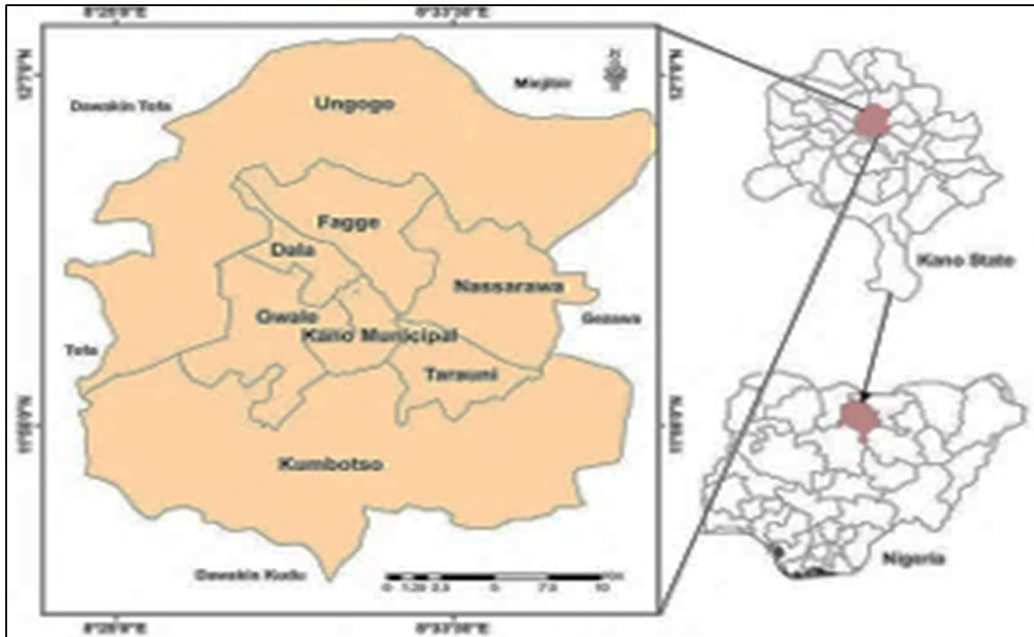


Figure 1: Map of Kano Metropolis

Six signalized intersections with considerable traffic volume within Kano metropolis were selected for this study. For ease of description, the intersections are designated as A, B, C, D, E and F, outlined as follows:

1. Miaduguri Road – Ahmed Musa Stadium Intersection
2. State Road – Audu Bako Secretariat Intersection

3. Katsina Road – Hajj Camp Intersection
4. Hadejia Road – Dakata Intersection
5. Zoo Road – Gidan Buhari Intersection
6. BUK Road – FRSC Intersection

Figure 2 shows a typical vehicular traffic at two representative studied intersections.



Figure 2: Approach Vehicular Traffic at BUK and State Roads' Intersections

Corresponding author: Muttaka Na'ya Ibrahim

✉ mnibrahim.civ@buk.edu.ng

Department of Civil Engineering, Bayero University, Kano, Nigeria

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Data Collection

The research methodologies adopted for the determination of saturation flow rate are; the empirical and HCM model approaches at six signalized intersections in Kano metropolis. The saturation flow rates derived from the duo methodologies were subsequently compared to examine the effect tricycle's proportion. Data were collected on traffic volume and composition, signal timing and intersection geometric features. Vehicular traffic count was carried out through classified vehicular traffic count using of digital counters. Four people stood by the stop line and press the counter each time a vehicle crosses the stop line during the effective green time. The vehicular traffic count was conducted at three cycles of the effective green time for each approach.

Signal timing data specifically the effective green time was obtained by the use of digital stop watch. One person records the signal timing by pressing the stop watch at the start of green time and stops the watch the moment the red light shows. The geometric features of the signalized intersections such as lane widths were measured using measuring tape. Number of lanes per approach was also noted. The geometric data was used with the HCM 2010 model equation for saturation flow. All data were collected during the evening peak periods; 17:00 – 19:30 on Mondays, Tuesdays and Thursdays.

HCM Model Saturation Flow Rate

The HCM2000 (TRB, 2000) provided guideline which is widely used to estimate the saturation flow rate at signalized intersections based on Equation 3.2. The HCM2010 (TRB, 2010) and HCM2016 ((TRB, 2016) provided a more advanced procedure for calculating saturation flow rate based on average headway method. This method, although more advanced than the HCM2000 approach is not suitable for non-lane based traffic, as the case with the study locations in this work. The HCM2000 method

involves multiplying the base saturation flow rate of 1900 veh/hr/green-time by adjustment factors provided to adjust the base condition's saturation flow rate. The prevailing condition saturation flow rate is determined based on Equation 3.1.

$$S = S_o N f_w f_{HV} f_g f_p f_{bb} f_a f_{LU} f_{LT} f_{RT} f_{Lpb} f_{Rpb} \quad (3.1)$$

Where, S = Saturation flow rate, S_o = Base saturation flow rate, N = Number of lanes, f_w = Adjustment factor for lane width, f_{HV} = Adjustment factor for heavy vehicles, f_g = Adjustment factor approach grade, f_p = Adjustment factor for parking activity, f_{bb} = Adjustment factor for bus blockage, f_a = Adjustment factor for area type, f_{LU} = Adjustment factor for lane utilization, f_{RT} = Adjustment factor right turns, f_{LT} = Adjustment factor for left turns, f_{Lpb} = Pedestrian-bicycle adjustment factor, for left-turn movements, f_{Rpb} = Pedestrian-bicycle adjustment factor for left-turn movements. Geometric features of the studied intersections were used for the determination of the adjustment factors. All intersections have flat grade; hence, the grade adjustment factor is considered as zero. The studied intersections have 2 – 3 approach and circulating lanes.

Empirical Saturation Flow Rate

For each of the six studied intersections, average vehicular departure per average effective green time was determined. Also, the number of vehicles crossing the stop line during an effective green time were recorded. Likewise, the effective green time over this period was observed and recorded with the aid of a stop clock. Subsequently, the saturation flow rate is then computed for each approach based on total vehicular departure per approach within the effective green time using Equation 3.2.

$$\text{Saturation flow rate} = \frac{\text{Total vehicle departure}}{\text{Effective green time}} \times 3600 \quad (3.2)$$

RESULTS AND DISCUSSIONS

Traffic Composition

To define the state of traffic condition at the studied intersections, traffic composition in terms of mean proportion of different vehicles' categories was first established. To establish the traffic composition for each of passenger cars, tricycles, motorcycles, buses and trucks categories per intersection approach, the individual vehicle's category volume is related to the total traffic volume, expressed as percentage. The mean traffic composition for the different vehicle's categories is depicted in Figure 3.

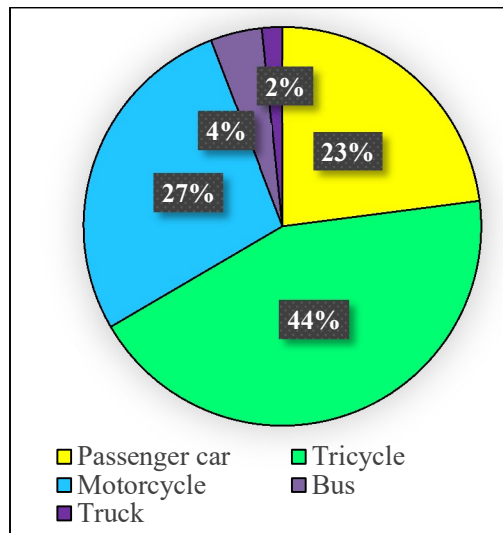


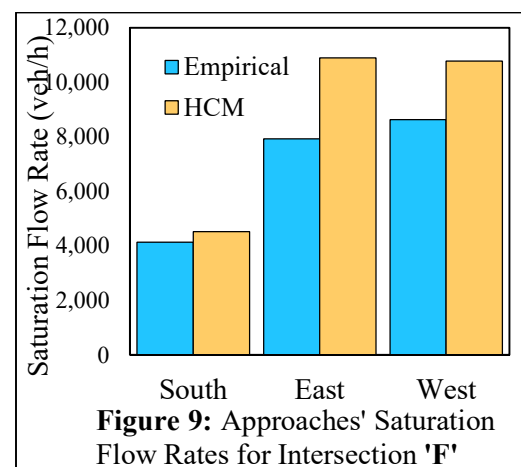
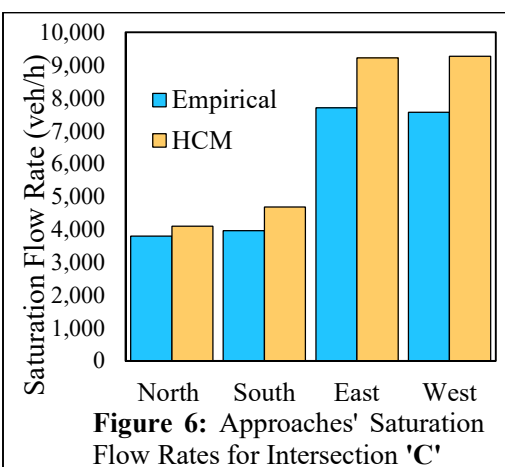
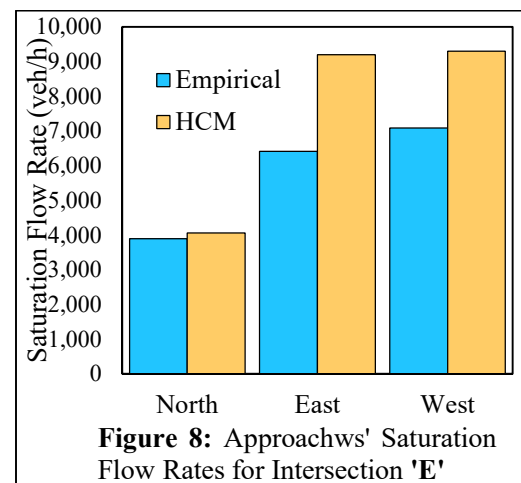
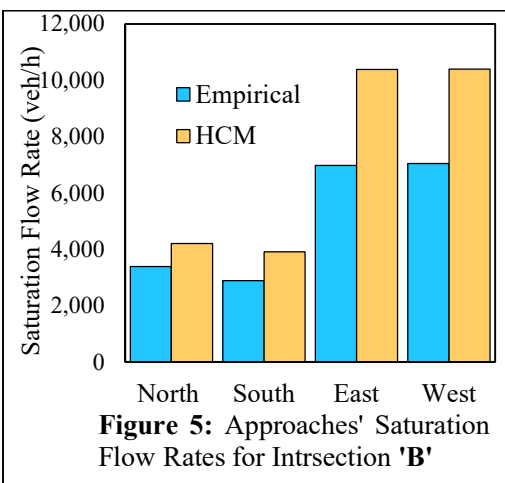
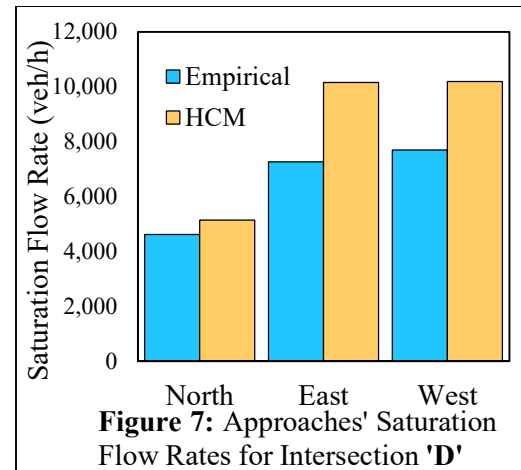
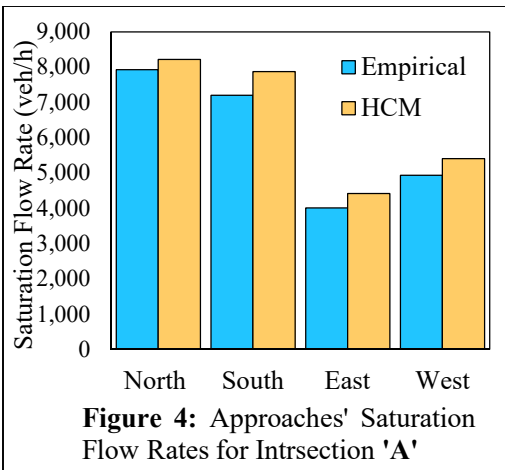
Figure 3: Aggregated Mean Traffic Composition for All Study Sites

The traffic composition was derived from a total of 21 intersection approaches from the six study locations. On the average scale, tricycles recorded the highest traffic composition of 42% of

the total number of vehicles that crossed the stop line during the effective green time. Motorcycles also constituted a significant proportion of the total number of vehicles that were recorded with 27% followed by passenger car with 23%. Buses and trucks constituted the least traffic composition, with an approximate respective contribution of 2%. Based on the illustration in Figure 1, it is obvious that tricycles appear as the dominant vehicle category, as it recorded the highest proportion of traffic at all the studied intersections. This finding is consistent with the theoretical background that tricycles are becoming an acceptable means of urban transport and also constitute a significant proportion of traffic.

HCM Model and Empirical Saturation Flow Rates

As described earlier, this study estimated saturation flow rate based on HCM model and empirical approaches, compared the estimates from the two methodologies and evaluate the impact of tricycle's proportion on the saturation flow rate. The HCM model saturation flow rate was determined based on intersection geometric features and base condition adjustment factors on the basis of Equation 3.1. On the other hand, the empirical saturation flow rate was estimated based on number of vehicles crossing the stop line at the intersections within the signal effective green time. These inputs were then used to compute the empirical saturation flow rate using Equation 3.2. subsequent to the determination of the saturation flow rate from the two methodologies, the two sets of estimates were compared. The graphical comparisons are shown in Figures 4 to 9 for the six respective study locations.





Generally, findings from a comparative analysis of saturation flow rate estimates from HCM model and empirical approaches for the six study locations as depicted in Figures 4 to 9 showed that the former methodology recorded higher values of saturation flow rate for all the 21 intersection approaches. This is irrespective of geometric features, traffic volume and composition as well as effective green time duration for all the intersections considered.

For all the intersections, HCM model estimates ranges from 3,906 to 10,981 veh/hr/green time, while the empirical approach values ranges from 2,885 to 8,626 veh/hr/green time. Further analysis revealed that empirical saturation flow rates for the 21 approaches of the six signalized intersections are in most instances much lower than those based on HCM model approach. Fourteen (14) out of the 21 intersection approaches' saturation flow rates based on empirical approach are lower than those of HCM model values by more than 10%. This implies that fewer vehicles passed the stop line within the effective green time compared to the number that should have passed based on the HCM model. This finding is well consistent with the theoretical background that estimating saturation flow rate based on the HCM model approach for a heterogeneous traffic condition coupled with lack of proper lane discipline leads to over estimation.

Theoretically, the difference between the saturation flow rate values obtained using the empirical approach and the HCM model approach can be explained by considering the methodologies used in both approaches. The HCM model approach adjusted the base saturation flow rate of 1,900 veh/hr/green time. This base saturation flow rate is supposed to be for an ideal condition (homogeneous traffic). However, the base saturation flow rate is not ideal for the traffic condition in Kano metropolis being a heterogeneous traffic due to the presence of different vehicle mix, coupled with non-lane discipline. Adjustment factors given in HCM2010 are supposed to take into consideration all the factors that would affect the base saturation flow rate. The HCM model does not provide any adjustment factor for tricycles as it was designed

based on foreign countries, where traffic varies significantly with that of developing countries like Nigeria. The empirical approach on the other hand estimated the saturation flow rate based on local prevailing conditions. The difference is also in line with the study that presented that traffic composition, lane width and approach grade influences saturation flow at signalized intersection. This differences in saturation flow rate values for the 21 intersection approaches further stresses the need for estimating saturation flow rate values at urban signalized intersections based on prevailing traffic condition rather than adopting methodologies best suited for foreign countries with different traffic characteristics.

A test of significance using independent t-test was performed at 95% confidence level to ascertain whether there is statistically significant difference between saturation flow rates values obtained from empirical and HCM model approaches. The test revealed a mean saturation flow rates of 7,445 veh/hr/green time and 5,598 veh/hr/green time based on HCM model and empirical approaches, respectively. Further finding from this test revealed a P-value 0.04 ($P < 0.05$), which indicates that there is statistically significant difference between the results obtained from the two approaches. This implies that saturation flow rate estimates based on HCM model are significantly higher than those of empirical approach. This is because the HCM model approach is most suitable for a homogeneous traffic condition and where lane discipline is adhered to.

This further highlights the need for traffic engineers to work with methodologies that reflects our local traffic conditions. This implies that the HCM model substantially overestimates the saturation flow rate relative to the empirical approach. A key implication of this finding is that saturation flow rates based HCM model would lead to erroneous designation of an intersection's operational performance or level of service; specifically, denoting a premature operational failure of the facility. This would consequently suggest for a premature facility improvement with associated unjustified expenses.

Corresponding author: Muttaka Na'ya Ibrahim

✉ mnibrahim.civ@buk.edu.ng

Department of Civil Engineering, Bayero University, Kano, Nigeria

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CONCLUSIONS

This study discovered that tricycles constitute a significant proportion of traffic at the studied urban signalized intersections. Traffic records from the study showed that tricycles constituted the highest proportion of traffic of 44% at Maiduguri road – Ahmed Musa stadium intersection, 39% at Hadejia road – Dakata intersection, 40% at Zoo road – Gidan Buhari intersection and 39% at Katsina road – Hajj Camp intersection. On the average scale and for different vehicle's classes, tricycles recorded the highest proportion of traffic composition of 42%, followed by motorcycles with 27%. Passenger cars recorded 23%, while Buses and trucks constituted the least traffic composition, with an approximate respective proportion of 2%.

For all the intersections, HCM model's estimates ranges from 3,906 to 10,981 veh/hr/green time, while the empirical approach values ranges from 2,885 to 8,626 veh/hr/green time. Further analysis revealed that empirical saturation flow rates for the 21 approaches of the six signalized intersections are in most instances much lower than those based on HCM model approach. Fourteen (14) out of the 21 intersection approaches' saturation flow rates based on empirical approach are lower than those of HCM model values by more than 10%.

A test of significance using independent t-test was performed at 95% confidence level to ascertain whether there is statistically significant difference between saturation flow rates values obtained from empirical and HCM model approaches. Results from this test revealed a P-value 0.04 ($P < 0.05$), which indicates that there is statistically significant difference between the results obtained from the two approaches. This implies that the HCM model overestimated the saturation flow rate relative to the empirical approach. The implication of this finding is that saturation flow rates based HCM model would lead to erroneous designation of an intersection's operational performance or level of service; specifically, denoting a premature operational failure of the facility. This would consequently suggest for a premature facility improvement with associated unjustified expenditures.

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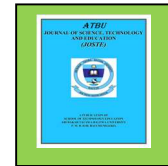
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Corresponding author: Muttaka Na'iyah Ibrahim

✉ mnibrahim.civ@buk.edu.ng

Department of Civil Engineering, Bayero University, Kano, Nigeria

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