International Refereed Journal of Engineering and Science (IRJES)
ISSN (Online) 2319-183X, (Print) 2319-1821
Volume 3, Issue 5(May 2014), PP.41-49

Passenger Car Unit Values for Urban Mixed Traffic Flow at Signalised Intersections on Two Lane Dual Carriageways in the Tamale Metropolis, Ghana

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Abstract:- In many west and east African cities, road traffic mix is characterised by high volumes of two wheeler motorcycles which traverse the roadway without lane discipline. For many years, the Transport Research Laboratory UK (TRL) provided guidelines and parameters for the design of transport facilities based on their research in some countries. In signalised intersection design and traffic operations on roadway facilities, passenger car unit values (PCU) and saturation flows are very important and can vary across cities owing to differences in traffic mix and vehicle characteristics as well as differences in driver behaviour, regulation and enforcement. Local values no matter how crude may be preferred. The traffic mix and performance characteristics on roads in the Tamale metropolis and other northern cities in northern Ghana differ from the other regions due to the high number of motorised two wheeler vehicles in the traffic stream as well as bicycles. Even though this is known, there has not been any research to quantify the Passenger Car Unit values for design. This study aimed to evaluate the local passenger car equivalent unit values which may be used in the design of traffic intersections in order to improve the performance of signalised intersections in Tamale. Two signalised intersections with fixed time control along one of the busiest corridors were studied. Manual counts were used to collect data from three hour video recordings of each intersection under saturation flow conditions played on a laptop computer. The passenger car unit values (PCU) were estimated using multiple regression analysis between the saturation times and vehicle types. PCU values for Motorcycles, Tricycles, Cars and Buses/trucks have been evaluated. It was recommended that a special area should be prepared in front of the signalised intersection stop lines in the metropolis to accommodate the high volumes of motorcycles in the traffic.

Keywords:- *Northern Ghana, Passenger Car Unit, Saturation Flow, Tamale*

I. INTRODUCTION

For many years, research publications from the overseas centre of the Transport Research Laboratory UK (TRL) formed the basis for design of most transport facilities such as pavements as well as traffic operations on roadway facilities including signalised intersection timing design. Traffic in most cities differ significantly due to differences in traffic mix and vehicle characteristics as well as driver behaviour, regulation and enforcement.

Traffic in the Tamale metropolis and other northern cities in Ghana; consist of a high number of motorised two wheeler vehicles in the traffic stream as well as bicycles. In Ghana there are no standardised passenger car unit values (PCU) for design, and research in this area is sparse. This study aimed to evaluate the local passenger car equivalent unit values which may be used in the design and operational analysis of signalised traffic intersections.

Vien et al. (2008) states that capacity is the major factor in the design of signalised intersections and saturation flow rate plays an important role in determining the capacity of individual approaches. Traffic operations at signalised intersections would be much easier to analyse if all vehicles in the traffic stream were identical. However, saturation flow is influenced by the proportion and type of vehicles in the traffic stream. Therefore, passenger car equivalent unit values are usually assigned to various categories of vehicle in order to normalise the saturation flow to a common base of passenger car units per hour (pcu/hr).

According to Minh and Sano (2003), more than 80% of the total transportation modes in Hanoi, Vietnam, are two-wheelers. In Malaysia, there are approximately 7.5 million registered motorcycles with an increase in motorcycle ownership from 0.13 in 1990 to 0.28 motorcycles per person in 2006. In Korea, authorities have prepared a special area in front of signalised intersection stop lines to accommodate the high volumes of motorcycles. Other countries like Taiwan have introduced a segregated flow concept to improve the performance of traffic mixed with motorcycles (Vien et al., 2008). In the city of Bangalore, India, two-wheelers constitute more than 70% of the total traffic volume, while cars comprise 15%, autos 4% and the remaining includes vehicles such as buses, vans and tempos (Anusha et al., 2012). In Nigeria, Uganda and Kenya motorcycles serve as a mode of paratransit service to deliver people and goods (Ajay, 2011; Olubomehin, 2012). Road side observations in these countries show a large proportion of motorcycles in the traffic stream.

In 2010, the Driver Vehicle Licensing Authority (DVLA) Ghana, registered 102,330 motor vehicles out of which 36,097 were motorcycles representing about 35.3%, which was the highest in any vehicle category registered in 2010 (NRSC, 2010). Adams (2013) has also reported that motor cycle growth in vehicle registration data is alarmingly high and can have serious implications for road safety.

In the three northern regions of Ghana, motorcycle transportation constitutes a significant proportion of all modes and represents a large part of the vehicle population. In one study, motorcycles accounted for 44% of the total vehicles in the Tamale metropolis (BCEOM and Associated Consultants, 2003). The reason for the widespread use of this mode of transport is that; it is relatively inexpensive compared to a motor vehicle and is economical in terms of fuel consumption and maintenance, making it affordable to people from the lower income group. Therefore inappropriate maneuvering of motorcycles on the road especially at signalised intersections will not only lower the level of service of the intersection but may also lead to increase in road traffic accidents. The specific objectives of this research were to 1) Determine the characteristics of traffic at signalised intersections and 2) Estimate the passenger car equivalent unit values of different categories of vehicles at signalised intersections in Tamale including the motorcycle.

II. LITERATURE REVIEW

2.1 Passenger car units, headway and saturation flows

Hounsell (1989) and Leong (2004) found that the average headway method is the best for predicting saturation flows, lost times and passenger car unit (PCU) factors. The Road Note 34 also gives good estimates of saturation flows and lost times, although it sometimes underestimates the lost times. Though the Road Note 34 method requires data in simple classified vehicle count format, it does not allow one to calculate PCU values which are essential for saturation flow (in PCU) measurement. The regression method which gives saturation flow and PCU values simultaneously is therefore attractive. However, investigation by Kimber et al. (1986) revealed that while the synchronous regression method produced a good approximation of PCU factors as well as saturation flow, corresponding values produced by the asynchronous multiple regression method underestimate the true factors from those of the headway ratio method. Hence, the synchronous counting method was adopted for data collection and analysis.

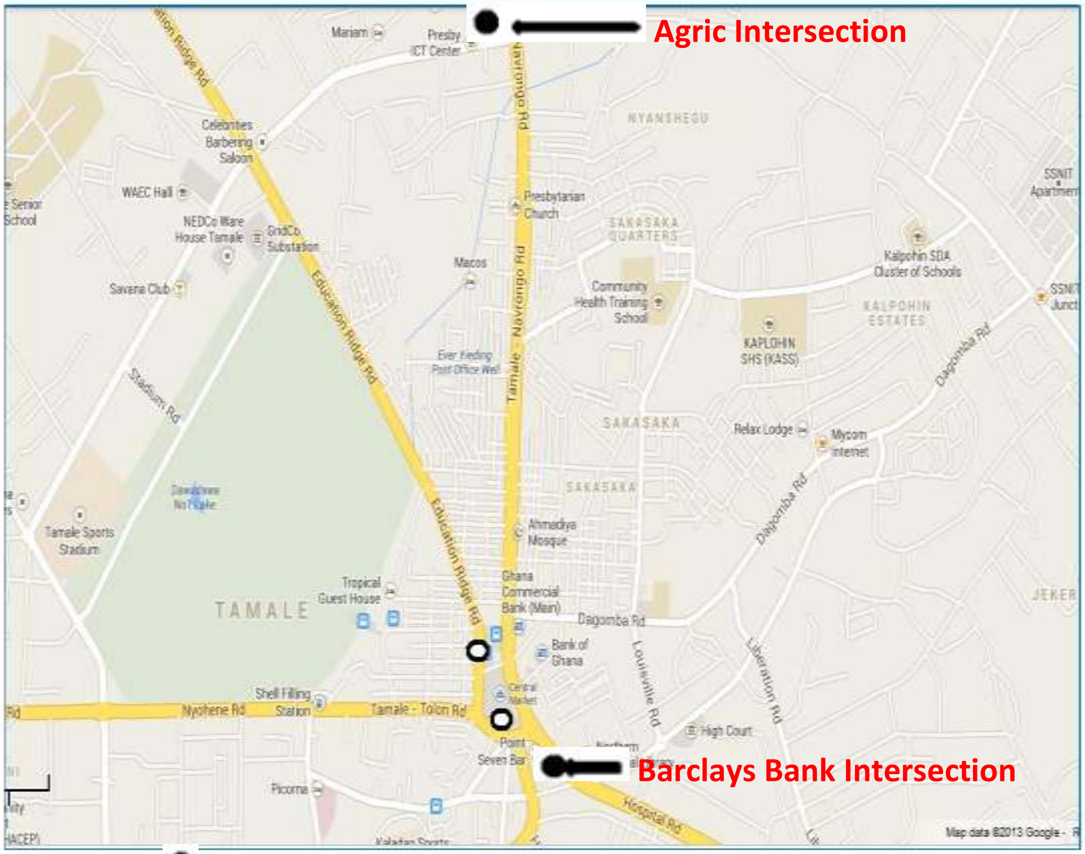
III. METHODOLOGY

3.1 Description of study sites

Two out of the four signalised intersections on the two lane dual carriageway Tamale - Navrongo trunk road were studied, namely the “Barclays bank” intersection located on the “Hospital road” link and the “Agric” intersection. These intersections are shown in Figure 1, which is a map of Tamale showing the signalised intersections in the metropolis. The Sites were selected based on consideration of several factors such as achievement of saturation queues during peak conditions, uninterrupted flow of the traffic during the green interval (main traffic approach) and adequate spacing between intersections to avoid offset measurement of the same platoon of vehicles. The study of these intersections was therefore expected to give correct passenger car units and saturation flow values.

The study approaches at both the “Barclays bank” and the “Agric” intersections were the North bound and the South bound approaches which were having the same total approach width of 7.5m as shown in Figures 2 and 3 respectively. The study approaches were selected due to their traffic flow which results in saturation queues during peak hours. The “Barclays bank” intersection is a staggered crossroad with the main road being a dual carriageway two lane road and the minor road is a single carriageway two lane road. The “Agric” intersection on the other hand is not staggered; it also has a two lane dual carriageway main road and a two lane single carriageway minor road.

All the intersections have a fixed – time signal control. An initial manual determination of signal timings yielded the following. The “Barclays bank” intersection has a cycle time of 126 sec consisting of 35 sec, 3 sec and 88 sec for green, yellow and red times respectively for both the north and south bound approaches, while the “Agric” intersection has a cycle time of 128 sec comprising of 50 sec, 3 sec and 75 sec for green, yellow and red times respectively for both the north and south bound approaches. The intersection markings at both the intersections have faded, therefore an imaginary stop line was adopted at each of the intersections.



● Signalised intersections in Tamale metropolis selected for the study

Figure 1 Map of Tamale showing signalised intersections in the metropolis

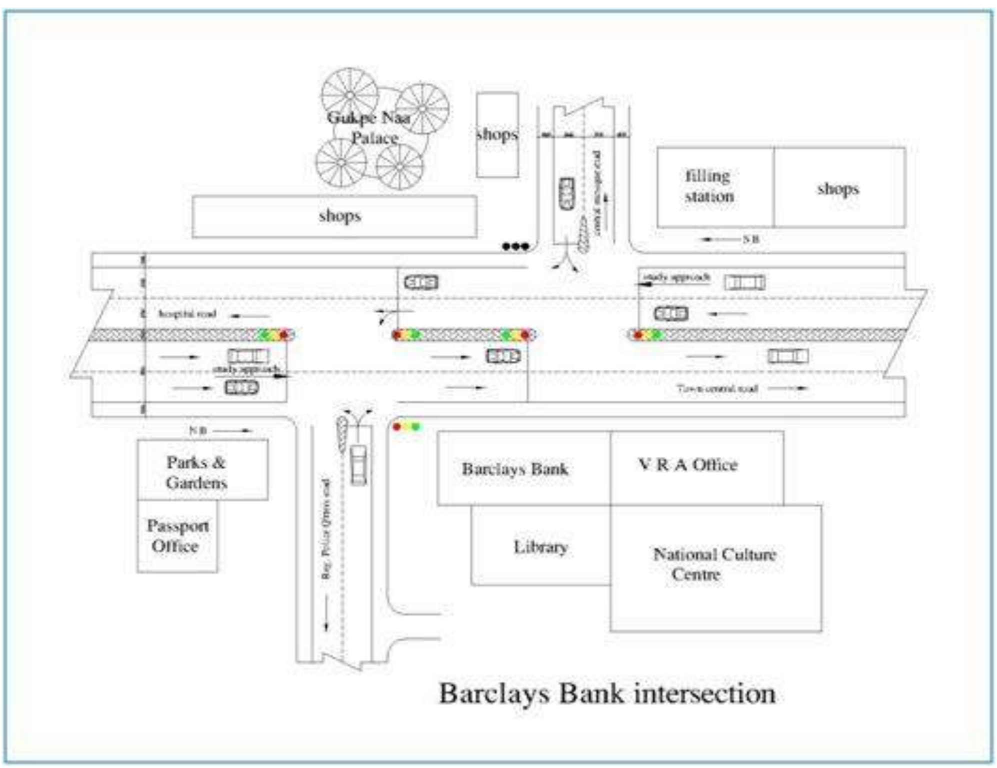


Figure 2 Barclays bank intersection

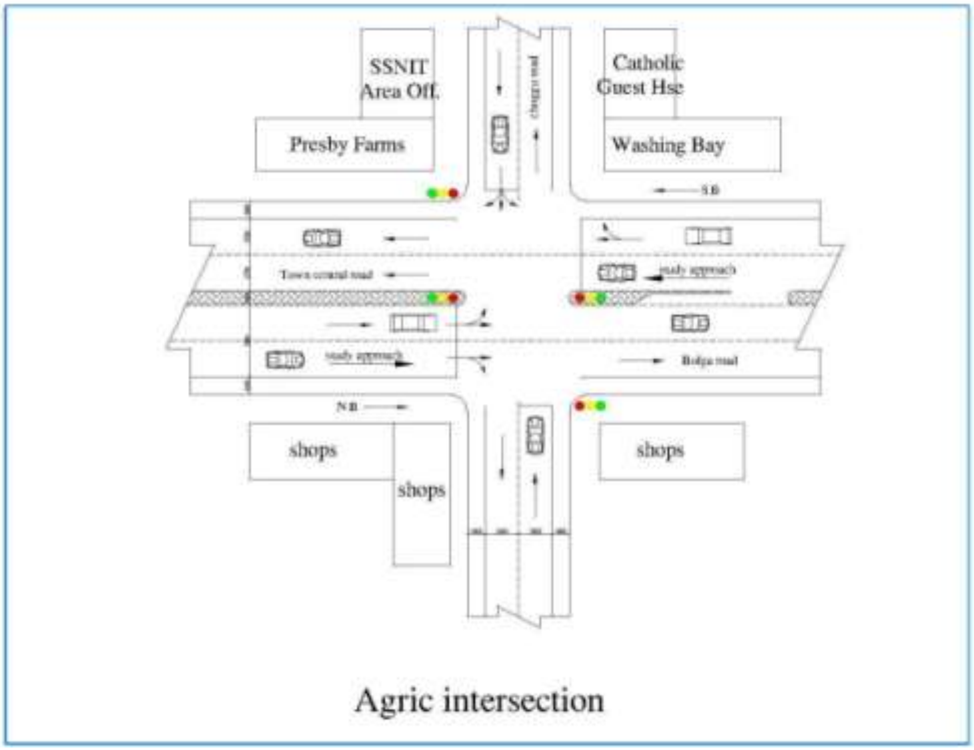


Figure 3 Agric intersection

3.2 Data collection

3.2.1 Video recordings, data extraction and analysis

During preliminary survey, it was observed that the queues at the selected intersections were denser and had longer lengths at morning peak from 7:00 am to 10:30 am. A digital video camera of 14 mega pixels was mounted on a tripod stand placed at a vantage point to capture every second of traffic movement at the intersection approaches. The camera was placed at a point such that the recording was done without interfering with the traffic flow. The video recording was done for three hours on the study approach at each of the intersections. All traffic events were recorded during the observed peak traffic hours. The camera was set-up at least 15 minutes before the start of each study period. The recording was done from Tuesday 17th July to Thursday 19th July 2013 for typical week day traffic under clear weather conditions. The video recording was then analysed manually on a computer by trained observers by dividing the green interval into 5 sec slices, since divisibility of time is easier with 5 sec. Classified counts were obtained for the vehicles discharging at the stop line during these slices throughout the green interval. As the intersection markings at the intersections had faded and in addition many of the motorcycles rarely stopped before an existing stop line where present, a virtual stop line was assumed. All vehicles that stood behind this stop line were considered in the analysis; they were counted as their rear axle/wheel crossed the virtual stop line.

3.3 Determination of Passenger Car Unit values

Data collection for saturation flow rate was conducted at the study approaches in several cycle times. The video camera recorded simultaneously, the traffic movement and the signalised control system. From the video films, vehicle types and passing time were captured and later extracted by trained observers on computer. The different types of vehicles in the traffic stream were classified into four groups for the traffic survey, namely, Motorcycles, Tricycles, Passenger cars/Taxis and Buses/Trucks. These observations with varying saturated green times (5–35 sec) were recorded to estimate the passenger car unit values (PCU) of the classified vehicle groups as well as average headway and saturation flow rate.

The PCU values were evaluated using multiple linear regression analysis, in which the saturated green time is a function of vehicles passing the stop line during that green time. It was assumed that the relationship between dependent and independent variables is linear and the regression function can be represented in a general form as given in equation (1).

_ = _ + _ _ + _ _ + _ + _ _(1)

Where _ is the saturated green time which is defined as the time the traffic flow is saturated. __ is a constant, __ is the coefficient of motorcycles, _ is the coefficient of tricycles, _ is the coefficient of cars/taxis and __ is the coefficient of buses/trucks. __ is the number of motorcycles passing the stop line in time _ for the subject approach, _ is the number of tricycles, _ and __ is the number of cars/taxis and buses/trucks respectively, all passing the stop line in time _.

To determine when the traffic was saturated in mixed traffic, all vehicles passing the stop line at each 5 sec interval were converted into passenger car equivalent by using the passenger car unit values adopted from the Indian Road Congress (IRC) as shown in Table 1.

Table 1 Passenger car unit values recommended by the Indian Road Congress (IRC)

Vehicle Type	Passenger Car Units
Motorcycle	0.5
Tricycles	0.7
Buses	2.0

Source IRC

These values were adopted because the traffic situation in the Tamale metropolis is similar to that of India. The values in Table 1 were used in determining saturated flow conditions and saturated green times only. If more than three passenger car units (PCU) passed through the stop line at an approach in any 5 sec in the green time during the survey, then that time was considered as saturated green time (Minh and Sano, 2003), and the total saturated green time for each cycle was obtained by adding saturated 5 sec in the cycle. The saturated green time in this study varied from 5 sec – 35 sec. From the regression analysis, the PCU values of each vehicle group were obtained by the ratio of the coefficient of each group to the coefficient of the car group as shown below.

__ ___________ = (2)__

__ _________ = (3)

__ ____/____!_ = (4) __

IV. RESULTS AND DISCUSSION

This section primarily deals with development of the regression model for saturated green time and estimation of passenger car unit values (PCU).

4.1 Traffic composition

The study approaches at both the "Barclays Bank" and the "Agric" intersections were the North bound and the South bound approaches. The Approaches were selected based on their existing traffic flows which result in saturation queues during peak hours. Table 2 shows the directional distribution and classification of vehicles traversing each study approach at the respective intersections.

Table 2 indicates that of all vehicles observed during the three hour study period at the intersections, the proportion of motorcycles on the approaches ranged from 43% to 52%, equaling the percentage range also observed for cars/taxis. This underscores the importance we have to place with regards to motorcycles and their effect on the performance of traffic facilities such as intersections in the metropolis. The percentage of tricycles were observed to be higher than that of buses/trucks by a maximum difference of 2% on either approaches at the Barclays bank intersection, the situation is reversed by the same margin however at the Agric intersection which saw a higher percentage of buses/trucks compared to tricycles. Considering both intersections, we can say that the percentage of tricycles in the traffic stream at the intersections is equal to that of buses/trucks.

Table 2 Vehicular composition at intersection approaches

Vehicle Type	Barclays Bank intersection		Agric Intersection	
	North bound	South bound	North bound	South bound
No of Lanes	2	2	2	2
Motorcycles	802 (52%)	708 (46%)	697 (43%)	689 (43%)
Tricycles	46 (3%)	48 (3%)	27 (2%)	34 (2%)
Cars/taxis	664 (43%)	773 (50%)	855 (52%)	814 (51%)
Buses/trucks	31 (2%)	15 (1%)	53 (3%)	55 (4%)

4.2 Estimation of Passenger Car Unit values (PCU)

Table 3 gives a summary of the statistics of data captured on video during saturation flow on green for vehicles traversing the Barclays bank intersection. Out of 76 cycles, the mean saturation time was 24 sec with a mean number of 16 motorcycles, 1 tricycle, 15 cars/ taxis and 1 bus/ truck crossing the stop line in that time. The modal and median saturation times were both 25 sec, this indicates the uniformity of vehicular arrivals at the stop line during the green interval.

Table 3 Descriptive statistics of saturated green time and the number of vehicles at the Barclays bank intersection

Statistics	Saturated Time	Motorcycle	Tricycle	Cars/Taxis	Buses/Trucks
Mean	23.6	15.5	1.0	15.2	0.5
Standard Error	0.7	0.5	0.1	0.7	0.1
Median	25.0	15.0	1.0	14.5	0.0
Mode	25.0	14.0	1.0	20.0	0.0
Standard Deviation	6.4	4.6	0.8	5.7	0.7
Sample Variance	40.4	21.0	0.6	32.9	0.4
Kurtosis	0.1	1.0	1.8	0.1	0.2
Skewness	-0.1	0.3	0.9	0.2	1.2
Range	30	28	4	29	2
Minimum	5	3	0	2	0
Maximum	35	31	4	31	2
Sum	1795	1176	78	1155	34
Count	76	76	76	76	76

The saturated green time was regressed against the number of vehicles in each vehicle group by the enter method of multiple regression analysis using the statistical package for social sciences software (SPSS). The result of the statistical significance test is shown in Table 4. The significance of each vehicle group was checked at 95% confidence level and the signs and coefficients were also assessed for their reasonableness and contribution to the saturation time.

Table 4 Statistical significance of vehicle groups in saturated green time regression at the Barclays bank intersection

Model		Unstandardized Coefficients		t	Sig.
		B	Std. Error		
	Constant	**2.777**	**1.254**	**2.214**	**0.030**
	Motorcycles	**0.295**	**0.067**	**4.423**	**0.000**
	Tricycles	**0.727**	**0.373**	**1.952**	**0.055**
	Cars/Taxis	**0.973**	**0.052**	**18.605**	**0.000**
	Buses/Trucks	**1.476**	**0.448**	**3.292**	**0.002**

The _-static computed in Table 4 for each vehicle category gives us information as to whether the individual partial regression coefficient for each vehicle category can be said to have an influence on the saturation time when the coefficients of the other vehicle categories is held constant. Since all the computed _-values with the exception of that of tricycles, exceeds the critical _-value of 2 at the 95% confidence level for a two tailed test, we can say that with the exception of tricycles, each of the vehicle categories has a significant positive effect on the saturation time when the other coefficients of the other vehicle categories are kept constant. This is further attested to by the p-values of the vehicle categories also given in Table 4, with the exception of tricycles, all the p-values are smaller than 5% level of significance, indicating that if the coefficients of the individual vehicle categories were not influencing the saturation time, then the probability of obtaining a _-value equal to or greater than the _-values computed for each category is smaller than 5%, which is indeed a small probability. Furthermore, the influence of the individual regression coefficients for all the vehicle categories with the exception of that of tricycles are still significant even at the 99% confidence level with a two tailed critical t-value of 2.7.

The coefficient for tricycles however, though not significant at the 95% confidence level when considered on its own, is significant at the 90% confidence level. This indicates that the level of contribution of tricycles to the saturated green time is less than that of the other vehicle categories (motorcycles, cars/taxis and buses/trucks) but not necessarily irrelevant or to be ignored. Equation (5) thus describes the regression between the saturated green time _ as the dependent variable and the vehicle categories at the Barclays bank intersection, where _ is the number of motorcycles, _ is the number of tricycles, _ and _ is the number of cars/taxis and buses/trucks respectively.

t = 2.777 + 0.295n_ + 0.727n + 0.973n + 1.476n_ (5)

The coefficient of determination / obtained for the regression in equation (5) was 0.834 or 83.4% which tells us that the regression line is a good fit of the data with small residuals around the regression line. Meaning that 83.4% of the variations in the saturation time is explained by the regression model. While the _-test investigates the individual significance of the coefficients of the vehicle categories, the / value just like the F-value obtained through analysis of variance, tests the overall significance of the regression by considering whether all the coefficients considered together can be said to be simultaneously equal to zero or not significant. The / is directly related to the F-value, when / is zero F is zero and when / is one F is infinite, thus an / of 0.834 indicates that the F-value is large, F being 183.38 was far larger than the F-critical value of 3.65 even for a 1% significance level (99% confidence level). Thus all the coefficients of the vehicle categories considered simultaneously have an impact on the saturation time.

Table 5 also gives the summary of the descriptive statistics of the saturated green time and the number of vehicles traversing the stop line during the saturated green time at the Agric intersection.

Table 5 Descriptive statistics of saturated green time and the number of vehicles at the Agric intersection

Statistics	Saturated Time	Motorcycle	Tricycle	Cars/Taxis	Buses/Trucks
Mean	26	14	1	17	1
Standard Error	1	0.43	0.07	0.60	0.10
Median	25	14	1	17	1
Mode	30	14	0	20	1
Standard Deviation	8	4	1	6	1
Sample Variance	56.77	18.11	0.48	35.20	1.00
Kurtosis	-0.06	0.02	0.30	-0.42	0.10
Skewness	-0.44	0.23	0.87	-0.02	0.75
Range	35.00	22.00	3.00	29.00	4.00
Minimum	5	6	0	1	0
Maximum	40	28	3	30	4
Sum	2580	1385	61	1669	108
Count	99	99	99	99	99

Table 5 shows that out of 99 cycles, the mean saturation time at the Agric intersection was 26 sec, with a mode of 30 sec and median of 25 sec. The standard deviation for the saturated green time was 7.53 sec. A mean number of 14 motorcycles, 1 tricycle, 17 cars/taxis and 1 bus/truck crossed the stop line during the mean saturation green time. The mean, median and modal saturation times also depicts uniform arrivals but with slightly skewed higher saturation times when compared to those obtained for the Barclays bank intersection.

To estimate the passenger car unit values (PCU), the saturated green time at the Agric intersection was also regressed against the number of vehicles by the enter method using the statistical package for social sciences software (SPSS). The result of the statistical significance test is shown in Table 6.

Table 6 Statistical significance of vehicle groups in saturated green time regression at the Agric intersection

Model		Unstandardized Coefficients		t	Sig.
		B	Std. Error		
	Constant	**2.664**	**1.183**	**2.253**	**0.027**
	Motorcycles	**0.364**	**0.075**	**4.826**	**0.000**
	Tricycles	**0.639**	**0.447**	**1.430**	**0.156**
	Cars/Taxis	**0.958**	**0.056**	**17.224**	**0.000**
	Buses/Trucks	**1.612**	**0.308**	**5.230**	**0.000**

The _-values given in Table 6 indicates that when considered individually with the other partial regression coefficients held constant, the partial regression coefficients for motorcycles, cars/taxis and buses/trucks have a significant effect on the saturation time at 99% level of confidence, since their _-values are greater than the 1% two tailed critical _-value of 2.7, furthermore, the p-values of these vehicle categories are all smaller than the 1% significance level. The Partial regression coefficient for tricycles however was not significant on its own at the 99% nor 95% confidence level, but rather significant at the 85% confidence level. Thus the level of contribution of tricycles to the saturated green time is less than that of the other vehicle categories (motorcycles, cars/taxis and buses/trucks).

Equation (6) thus describes the regression between the saturated green time _ as the dependent variable and the vehicle categories at the Agric intersection, where __ is the number of motorcycles, _ is the number of tricycles, _ and __ is the number of cars/taxis and buses/trucks respectively.

t = 2.664 + 0.364n_ + 0.639n + 0.958n + 1.612n_ (6)

The regression in equation (6) highly correlates with the saturation time as indicated by an / value of 0.845. That is, 84.5% of the variations in the saturation time can be explained by the regression equation, the / value as previously discussed, tests the overall significance of the regression by considering whether all the coefficients considered together can be said to be simultaneously equal to zero, or not significant. The / value of 0.845 is approaching a value of one which indicates that the F-value is large, thus all the coefficients of the vehicle categories considered simultaneously have an impact on the saturation time.

We can say from the regression analysis discussed, that the findings at the Agric bank intersection is consistent with those found at the Barclays bank intersection. The passenger car unit value (PCU) of each vehicle group or category was obtained when the regression coefficient of that group was divided by the coefficient of the car/taxi group as given in Table 7.

Table 7 Passenger car unit values of vehicle groups

Intersection	Motorcycle	Tricycle	Car/Taxis	Bus/Truck
Barclays bank	0.30	0.75	1.00	1.52
Agric	0.38	0.67	1.00	1.68

The estimated PCU values presented in Table 7 for the two intersections are different but close considering the nature of the traffic and the non-lane based conditions at the intersections. It is clear that the PCU value for any type of vehicle group was not constant for the different intersections. Similar results have been reported by other researchers in mixed traffic conditions like Minh et al. (2010), Minh and Sano (2003) and Saha et al. (2009).

The motorcycle PCU values are less than one because their small size enables them to form a compact pack and occupy less space and also cause less hindrance to surrounding vehicles. The tricycles are a little bigger than the motorcycles but smaller than cars and therefore produce a lager hindrance effect compared to motorcycles, thus tricycles have larger PCU values than motorcycles. The Large PCU values for the buses/trucks are attributed to their low speed, large size and their relatively difficult manoeuvrability in the non-lane based conditions. The PCU values obtained is different from that of the Indian Road Congress values used in the initial determination of the saturation time. This is attributed to the different vehicle mix, driver characteristics and the intersection geometry. This supports the fact that PCU values from similar traffic situations does not apply to the traffic in the Tamale metropolis and for that matter the whole of Ghana.

V. CONCLUSION AND RECOMMENDATION

5.1 Conclusions

The PCU values have been estimated for vehicles types in Tamale. The traffic mix derived from this study shows that there are as much motorcycles in the traffic stream as there are cars/taxis. The proportion of tricycles though smaller than those of motorcycles or cars/taxis were also equal to the proportion of buses/trucks. PCU values for motorcycles, tricycles and buses/trucks were 0.3, 0.75 and 1.52 respectively for the Barclays bank intersection and 0.38, 0.67 and 1.68 respectively for the Agric intersection. Most motorcyclists stop ahead of the intersection stop line because no proper demarcation has been made for them at all intersection sites studied.

5.2 Recommendations

a) Provision for motorcycle queue storage at the stop line should be made due to the high percentage of motorcycles at the intersections to prevent them from stopping beyond the motor vehicle stop line at the intersections.

b) Passenger car unit values (PCU) have been derived for the mixed traffic conditions in the Tamale metropolis. This should be confirmed and adopted for design.

c) The Passenger car unit values (PCU) obtained were not the same at the various intersections, therefore it can be concluded that unified PCU values for different vehicles does not hold good for non-lane based traffic conditions.

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