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A Markov Chain Approach to the Dynamics of Vehicular Traffic Characteristics in Abeokuta Metropolis

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Abstract: The study examined the traffic characteristics and management within Abeokuta metropolis. The daily traffic volume in the study locations was categorized into low, medium and high. Markov chain model and descriptive analysis were used for the analysis of data collected from the two locations. The short and long-term projections of the proportion of daily traffic volume for the three categorizations (low, medium and high) were carried out using Markov chain model. The result predicted 18.0 and 5.0% for high daily traffic volume (incoming) for Lafenwa and Ibara intersections respectively in 2009. In the long- run, moderate traffic at Lafenwa intersection (outgoing traffic) is expected to be 13.5% while 22.4% is predicted for Ibara intersection. Unlike Lafenwa intersection, Ibara intersection exceeded the average daily traffic volume for the incoming and outgoing traffics. Provision of terminal facilities, parking lots instead of on-street parking and adequate terminal facilities around the intersections are suggested traffic management options to reduce traffic congestion noticed at these intersections.

Key words: Traffic volume, Markov Chain model, management, probability and transition matrix

INTRODUCTION

In many of the major urban centers of developing countries today, considerable efforts have been given to transportation studies, in terms of traffic flow and its management in relation to level of service of the road. The evolution of transportation has generally led to changes in the urban form. The more radical the changes, the more the urban forms have been altered. Among the most fundamental change in the urban form is the emergence of new clusters expressing new urban activities and new relationships between elements of the urban system. In many cities, the Central Business District (CBD) is the primary destination of commuters serviced by public transportation.

In Nigeria, transportation demands in urban areas continue to increase rapidly as a result of increase in ownership and utilization of personalized motor vehicle as well as inefficiency in public transport system. Widespread automobile ownership has brought untold hardship and serious parking problems to all urban roads. Street congestions and parking problems have been particularly acute in the central business areas in big cities. Traffic congestion undermines the economic productivity and competitiveness, it contributes to air pollution which degrades the quality of life in our metropolitan areas (Greenzeback and Woodle, 1992). A few cities in developing countries have implemented traffic management scheme in an attempt to manage street traffic better. Lagos introduced a traffic management scheme in 1978, Singapore in 1975 and Kuala Lumpur in 1979 (Orikaye, 1983). Prior to 1950, motorized urban transportation and its attendant problems of congestion cost, environmental pollution, and damage to property were not known to most cities in developing countries. Current solutions to these problems include improved infrastructure, transport coordination programmes and more effective urban land-use planning in order to reduce the level of traffic congestion.

According to Cracknell (1989) traffic management schemes and policies should be designed to achieve increase urban transportation efficiency by:

- Increasing the capacity of the transport system for people and goods rather than for vehicles alone.
- Ensuring that full potential capacity of the existing system is realized
- Improving the quality of the transport system, particularly for public transport users and the transport disadvantaged-usually the urban poor.
- Improving the safety for all system users.

The overall objective of this research is to analyse the characteristics and management of traffic at Ibara and Lafenwa intersections. Specifically, this paper assessed the effectiveness and lapses in traffic management in the intersections by focusing on the following objectives:

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- To categorize the daily traffic volume in the study locations.
- To determine the variation in the incoming and outgoing of traffic in the intersections,
- To predict the traffic situation for both short and long terms.
- To identify problem (s) at each intersection and proffer necessary solutions(s)

Definition of Terms:
ADT: Average Daily Traffic
HTV: Hourly Traffic Volume
ANOVA: Analysis Of Variance
PTM: Probability Transition Matrix
CBD: Central Business District
PHV: Peak Hourly Volume
ENTRY: Incoming Traffic
EXIT: Outgoing Traffic

Background of the Study: Abeokuta is one of the major towns of the defunct Western region of Nigeria and later became a district council headquarters when the region was divided into two states (that is, West and Midwest) in 1967. Abeokuta became the seat of Ogun State government in 1976 and business activities have since become intensified within it. The recent astronomic increase in vehicular activities in Abeokuta Township may be due to mass movement of people with their business characteristics and the increase in the number of car owners as a result of increase in the salary of civil servants few years ago. Abeokuta road network was originally designed for 2 – Lane 2 way and 1- Lane 2 way travels without the provision for parking and pedestrian sidewalk. However, despite the upgrading of these roads to cope with increase in vehicular activities, problem of indiscriminate parking of vehicle and location of market along the highways still persist.

The choice of Ibara and Lafenwa intersections is as a result of high vehicular movement due to concentration of public and private business activities along most of the routes that constitute these intersections. Also the intersections are the links to other parts of Abeokuta Township.

MATERIALS AND METHODS

A cross-sectional data collected using observation method is used for this study. Specifically, traffic volume data on hourly basis (12 h per day, 6:00 am-7:00 pm) were collected from Lafenwa and Ibara intersections. Lanfewa intersection consists of Ayetoro, Old Bridge and Ita-Oshin routes, while Ibara intersection is made up of Omida, Oke-Ilewo, Ita-Eko and Post Office routes. Hourly traffic volume data were collected four times per year for two consecutive years (2004 and 2005) from each of the seven routes.

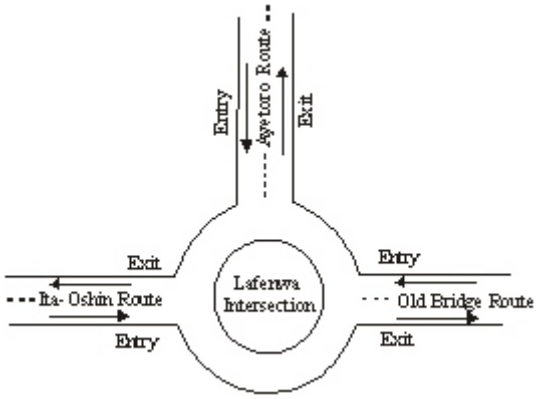

Fig 1: Schematic layout of Lafenwa intersection

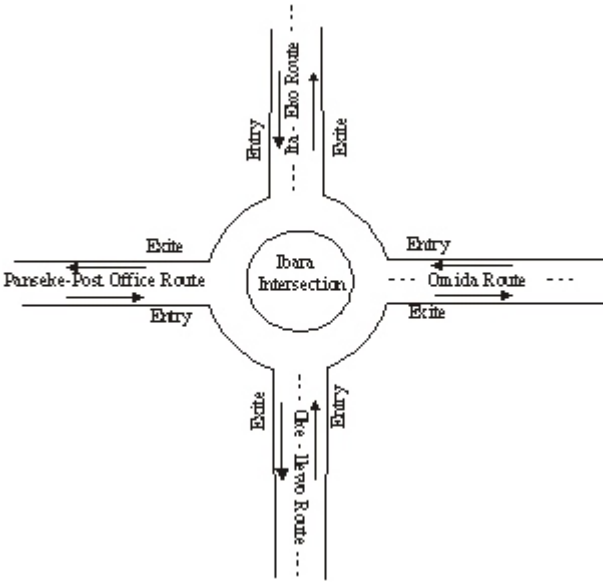

Fig 2: Schematic layout of Ibara intersection

Table 1: Categorisation of average traffic per hour:

Average Traffic Volume per Hour	Lafenwa Intersection		IbaraIntersection	
	Range	Percentage (%)	Range	Percentage (%)
Low	288 - 430	46.6	0 - 650	47.9
Moderate	431 - 580	43.1	651 - 780	25.0
High	580 & above	8.3	781 & above	27.1

Source: Survey Data (2004 & 2005)

The study considered entry and exit of vehicle in each of the routes. Daily traffic volume is categorized into low, moderate and high. The range of vehicles that belong to each of this categorization is higher in Ibara intersection compare to Lanfewa intersection.

The Table 1 shows that 46.6% of the hourly traffic volume at Lafenwa intersection was low while 8.3% of the hourly traffic volume was high at the same intersection. At Ibara intersection, 47.9% of the hourly traffic volume was low while 27.1% of the traffic volume was high.

Method of Analysis: The study combined descriptive and Markov chain model to achieve the objective of the study. Markov chain involves transition from one state to the other. P_{ij} is the probability of the traffic volume transiting from state i to j (Pfeifer and Carraway 2000). The probability of average daily traffic volume conditions in a year, given the traffic situation in the preceding year can be represented by a probability transition matrix as shown below:

Average Traffic Volume Per Day		2005		
		Low	Moderate	High
2004	Low	P_{11}	P_{12}	P_{13}
	Moderate	P_{21}	P_{22}	P_{23}
	High	P_{31}	P_{32}	P_{33}

To see how traffic volume will evolve in the intersections, the focus was on the probability of changing among the states of traffic volume (low, moderate and high). Fig. 1 and 2 show the flow of daily traffic volume in and out of the intersections for low, moderate and high traffic volumes. The movement of vehicle in and out of each traffic volume categorization can be summarized in a 3 by 3 "*Probability Transition Matrix*", (see equation (iii)). Each cell gives the probability of moving from one state (traffic volume category) in 2004 to another state (traffic volume category) in 2005. The proportion of traffic volume in each of the three categories in the succeeding years is obtained using equation (i) below:

$$P(k) = P(0)\, P_{ij}^{k} \qquad \text{(i)}$$

Where:

P(0) represents the initial traffic volume proportion (2005) for low, moderate and high vehicular movement.
P_{ij} represents the probability transition matrix
k represents period (k = 1 for 2006 , k = 2 for 2007, k = 3 for 2008, k = 1 for 2008 etc)

At equilibrium (long term projection) the change in the average hourly traffic volume of entering a particular traffic category (low, moderate and high) is expected to be equal to the average traffic volume of withdrawing from a particular traffic category. For a three – state (three categories of traffic volume). Markovian model (using fixed point theorem) equilibrium is reached when:

$$e = eP \qquad \text{(ii)}$$

where:
$e = (e_1 \;\; e_2 \;\; e_3)$ is the steady – state vector for a three – state Markovian model (White, 1993; Fingleton, 1998 and Wikipedia, 2006): (e_1 represents the long term projection for low daily traffic volume, e_2 represents the long term projection of moderate daily traffic volume and e_3 represents the long term projection for high daily traffic volume)

P_{ij} = is the probability transition matrix.

$$(e_1 \;\; e_2 \;\; e_3) = (e_1 \;\; e_2 \;\; e_3)\begin{pmatrix} P_{11} & P_{12} & P_{13} \\ P_{21} & P_{22} & P_{23} \\ P_{31} & P_{32} & P_{33} \end{pmatrix} \qquad \text{(iii)}$$

RESULTS AND DISCUSSION

Lafenwa Intersection: From the Fig. 3 and 4, the traffic volume for the incoming traffic increases gradually in the morning; reaches its peak between 10-11 am for the incoming and outgoing traffics. The lowest traffic volume is recorded between 6.00 and 7.00 pm. The figures show that Ita-Oshin route has the highest traffic volume to the Lafenwa intersection between 10-11am. This period coincides with the rush hour in the morning when workers and traders are leaving for their places of work while students also depart for their various schools located a couple of kilometers from the intersection. Furthermore, the vicinity of the intersection is a Motor Park for Lagos bound passengers. Also other subroutes such as new bridge and Olomore housing estate that linked the Ita – oshin route might have contributed to this heavy traffic volume.

The study shows that there is significant difference in the average hourly traffic volume of the incoming and outgoing traffics (Appendices A_1 and A_2). Also, the average hourly traffic volume of the incoming traffic (484.1) is greater than the outgoing traffic (431.3). The intersection's average daily traffic volume is less than the design capacity for the incoming (1465.4) and outgoing (1411.3) traffics (ADT = 1500). With the exception of old Lafenwa bridge route, other two routes lead to cities, towns and villages outside Abeokuta.

The probability transition Matrix (incoming traffic) in Table 2 shows that a moderate daily traffic volume in 2004 had 50% (1/2) chance of being moderate again in 2005 and 16.7% chance of changing to high daily traffic volume. Current daily traffic proportion P(0) is. $\left(\frac{3}{8} \;\; \frac{4}{9} \;\; \frac{1}{6}\right)$.

Table 3 shows that for the outgoing traffic, a low average traffic volume per day in 2004 had 87.5% $\left(\frac{7}{8}\right)$ chance of recording low traffic volume again and 12.5% $\left(\frac{1}{8}\right)$ chance of changing to moderate traffic volume in 2005. The current outgoing traffic volume proportion P(0) is $\left(\frac{28}{55} \;\; \frac{8}{19} \;\; \frac{2}{29}\right)$.

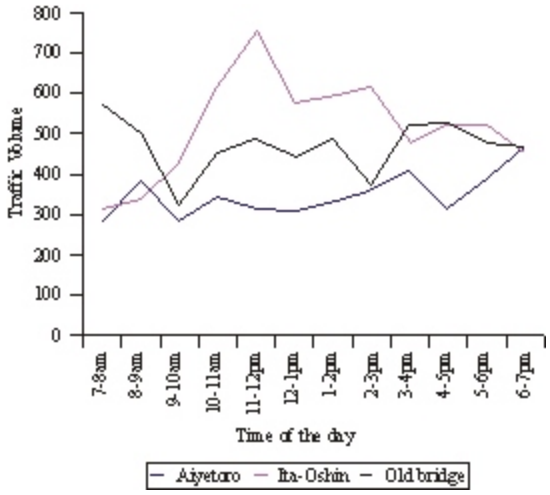

Fig 3: Incoming Hourly Traffic Volume Distribution for Lafenwa intersection

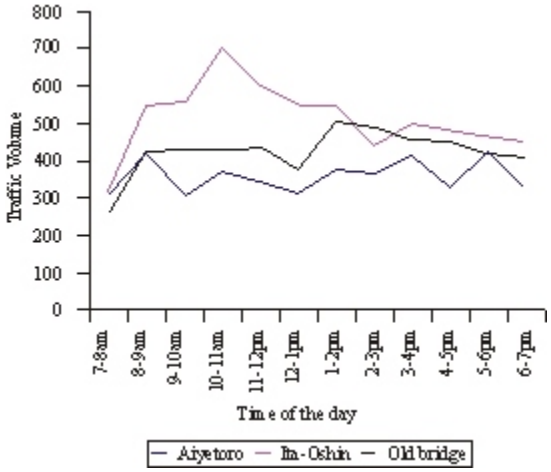

Fig 4: Outgoing Hourly traffic Volume Distribution of Lafenwa Intersection

Table 2: Probability Transition Matrix (Entry)

Average Traffic Volume Perday		2005 Low	Moderate	High
2004	Low	$\frac{9}{14}$	$\frac{2}{14}$	$\frac{3}{14}$
	Moderate	$\frac{4}{12}$	$\frac{6}{12}$	$\frac{2}{12}$
	High	$\frac{3}{15}$	$\frac{10}{15}$	$\frac{2}{15}$

Source: Survey Data (2004 & 2005)

The Markovian model result for Lafenwa intersection showed that for a long term projection, 46.8% of the total daily traffic volume for incoming traffic is expected to be low, 35.3% moderate and 17.9% for high daily traffic volume. The outgoing traffic is expected to be 84.8% low, 13.5% moderate and 1.7% for high daily traffic volume. This means that most daily vehicular traffic is expected to be low (288 - 430) for incoming (46%) and outgoing traffic (84%). The result revealed that low traffic volume is expected to be the highest in the long run. This may be attributed to the market located in the vicinity of the intersection which comes up every five days. It is only during the market day that the daily traffic volume is usually high because of buying and selling which attracts participants from far and near. With the exception of 2009, the projection (short and long term) shows a progressive increase in the average daily traffic volume (incoming and outgoing) for every succeeding years.

Table 3: Probability Transition Matrix (Exirt

Average Traffic Volume Perday		2005 Low	Moderate	High
2004	Low	$\frac{7}{8}$	$\frac{1}{8}$	0
	Moderate	$\frac{8}{17}$	$\frac{7}{17}$	$\frac{2}{17}$
	High	$\frac{2}{11}$	$\frac{8}{11}$	$\frac{1}{11}$

Source: Survey Data (2004 & 2005)

The short term projection for the incoming traffic in 2009 (Table 4) showed that 44.9% of the total daily traffic volume is expected to be low, 36.8% to be moderate while 18.3% is expected to experience high traffic volume. On the other hand, the outgoing traffic is expected to be 76.5% low, 20.7% moderate and 2.9% high in 2009.

Ibara Intersection: The Fig. 5 and 6 show that Post office and Omida routes recorded the highest daily traffic volume at Ibara intersection from 1:00pm - 2:00pm and 5:00pm – 6:00pm. Ita – Eko route recorded the lowest traffic volume (161) at the intersection between 7:00am and 8:00am. Generally, traffic volume at Ibara intersection is heavier compared to Lafenwa Intersection.

Ibara intersection's vicinity is a Central Business District (CBS) where banks, eateries, shops and market, schools, government ministries and parastatals are located. 'Hold ups' early in the morning and late in the evening is a common phenomenon at Post office and Omida routes. Apart from the heavy traffic volume on these routes, indiscriminate parking is a common occurrence. Average daily traffics for the incoming and outgoing traffics are 2937.7 and 2911.2, respectively. These values almost double the standard average daily traffic (ADT = 1500). Unlike the Lafenwa intersection, there is no significant difference in the average hourly traffic volume for the incoming and outgoing traffics (Appendices B_1 and B_2).

Table 5 shows that for incoming traffic, a high traffic volume in 2004 had a chance of 23.5% of maintaining the high traffic volume in 2005. The

Table 4: Short term (2007-2009) and long term projections

Traffic Category (%)	2007 Traffic Incoming	2007 Traffic Outgoing	2008 Traffic Incoming	2008 Traffic Outgoing	2009 Traffic Incoming	2009 Traffic Outgoing	Steady State/Equilibrium Incoming	Steady State/Equilibrium Outgoing
Low	44.2	72	45.1	75	44.9	76.5	46.8	84.8
Moderate	37.8	24.1	37.2	21.8	36.8	20.7	35.3	13.5
High	18.1	3.9	17.1	32	18.3	2.9	17.9	1.7

Source: Survey Data (2004 & 2005)

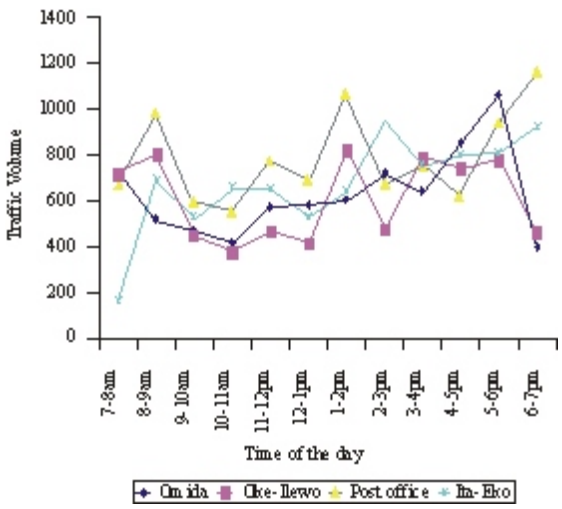

Fig 5: Incoming Hourly Traffic Volume Distribution for Ibara Insection

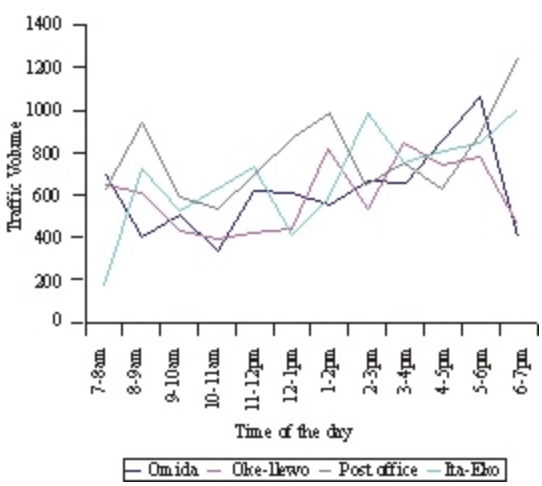

Fig 6: Outgoing Hourly Traffic Volume Distribution for Ibara Intersection

possibility of the traffic volume changing to low and moderate traffic volumes is 65% and 11.8, respectively. Current traffic proportion is $\left(\frac{19}{39}\ \frac{13}{48}\ \frac{15}{62}\right)$ for the incoming traffic.

Table 6 (probability transition matrix) shows that for the outgoing traffic, a moderate traffic volume in 2004 had 15.4% chance of maintaining the statuesque in 2005,

Table 5: Probability Transition Matrix (Entry)

Average Traffic Volume Perday		2005 Low	2005 Moderate	2005 High
2004	Low	$\frac{3}{6}$	$\frac{1}{6}$	$\frac{2}{6}$
	Moderate	$\frac{2}{7}$	$\frac{7}{17}$	$\frac{1}{7}$
	High	$\frac{11}{17}$	$\frac{2}{17}$	$\frac{4}{17}$

Source: Survey Data (2004 & 2005)

Table 6: Probability Transition Matrix (Exit)

Average Traffic Volume Perday		2005 Low	2005 Moderate	2005 High
2004	Low	$\frac{2}{4}$	$\frac{1}{4}$	$\frac{1}{4}$
	Moderate	$\frac{8}{13}$	$\frac{2}{13}$	$\frac{3}{13}$
	High	$\frac{6}{13}$	$\frac{3}{13}$	$\frac{4}{13}$

Source: Survey Data (2004 & 2005)

62% chance of changing to low in 2005. Current traffic proportion for the outgoing traffic is $\left(\frac{41}{78}\ \frac{11}{52}\ \frac{5}{19}\right)$.

The Ibara intersection's Markov result for long term projection of incoming traffic showed that 43.8% of the total traffic volume per day is expected to be low, 32.7% moderate while 43.8% is expected to be high. For the outgoing traffics 51.6% is expected to be low, 26.1.4% moderate and 26% high traffic volume. The short term projection as shown in Table 7 for the outgoing (exit) traffic in this intersection showed that 51.3% of the total traffic volume per day is expected to be low, 22.5% is expected to be moderate while 26.2% is expected to experience high traffic volume.

Traffic Management: In Markov chain result for Lafenwa intersection, the incoming traffic volume for the year 2009 is expected to be 44.9% low and 36.8 % for moderate traffic volumes. That is, the peak daily traffic volume along this intersection is expected to be from 288-430. The average daily traffic at this intersection is less than the highway manual standard of 1500 (ADT = 1500 Highway Manual). The average daily traffic of the incoming traffic was 1465.4 while that of outgoing traffic was 1411.3. This means that the road has not exceeded its design capacity but conflicts at this intersection most

Table 7: Short term (2007 - 2009) and long term projections

Traffic Category (%)	2007 Traffic		2008 Traffic		2009 Traffic		Steady State/Equilibrium	
	Incoming	Outgoing	Incoming	Outgoing	Incoming	Outgoing	Incoming	Outgoing
Low	48.1	51.6	47.8	50.2	49.3	52.3	43.8	51.6
Moderate	26.1	22.2	25.3	19.7	27.2	22.4	32.7	22.4
High	25.8	26.1	26.9	30.1	23.5	25.3	23.5	26.1

Source: Survey Data (2004 & 2005)

especially on the market days can be reduced through the following traffic management options:

- Provision if terminal facilities – for loading and unloading of passengers
- On-street parking should be discouraged and parking lots should be provided.

Ibara intersection the situation is different in that the incoming and the outgoing traffic volume as regard the ADT has been exceeded (ADT>1500, see Highway Manual Part 1, 1973). The average daily traffic volumes are 2937.7 and 2911.2 for incoming and outgoing traffics respectively. In projecting, 26.0% of the total traffic volume is expected to be moderate (651-780) for the incoming traffic in the year 2009 as against 26.0% for the current year (2008). Therefore the solution that will be provided must be sensitive to accommodate the change at any hour of the day. In views of this, the following should also be provided.

- The terminal facility around the intersections is not adequate therefore effort should be geared toward upgrading the facility.
- Since the ADT (design) has been exceeded the road should be redesign to accommodate the traffic.
- On- street parking should be completely discouraged and parking facilities should be provided along this route.
- Bus-stop on the intersection should be discouraged.

CONCLUSION AND RECOMMENDATION

Markov chain and analysis of variance were used to analyse the traffic characteristic of the Lafenwa and Ibara intersections and also to predict the short and long term daily traffic situation for the incoming and outgoing traffics. The range of daily traffic volume categorizations (low, moderate and high) was higher for Ibara intersection because of the data collected at the different routes that make up the intersection. From the study the incoming daily traffic proportion is expected to be 44.9% and 49.3% for low traffic volumes for Lafenwa and Ibara intersections respectively in year 2009. The study has been able to identify that Ibara intersection is busier in terms of vehicular traffic. Many business activities (markets, banks eateries and other retail outlets), government offices, schools and links to other towns may be attributed for the higher vehicular movement. The variation in average hourly traffic volume was significant for the incoming and outgoing traffics at Lafenwa intersection ($p < 0.05$) and insignificant at Ibara intersections ($p > 0.05$). The Ita-Oshin route recorded the highest average daily traffic volume at Lafenwa intersection.

Moreover, the Ibara intersection usually experience heavy traffic congestion and "hold ups' in most part of the day. Lafenwa intersection the other hand experience traffic congestion and 'hold ups' during market days and festive periods. On-street parking, indiscriminate picking of passengers by commercial taxi operators and inadequate bus–stop are the identified problems of these intersections. The following solutions are suggested for identified problems:

- Open-up other road outlet to reduce pressure on the intersections most especially Ibara intersection.
- Provision of parking facilities and bus stop at a opriate locations.
- Traffic officers should be empowered to prosecute traffic offenders.

Appendices:

Appendix A1
Test for Outgoing traffics (Lafenwa Intersection)

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	142881.1667	2	71440.58333	14.61771665	2.84353E-05	3.284917651
Within Groups	161279.5833	33	4887.260101			
Total	304160.75	35				

Appendix A2
Test for Incoming Traffics (Lafenwa Intersection)

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	178514.0556	2	89257.02778	11.58297084	0.000154588	3.284917651
Within Groups	254294.1667	33	7705.883838			
Total	432808.2222	35				

Appendix B1

Test for Outgoing traffics (Ibara Intersection)

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	239885.7292	3	79961.90972	2.10627289	0.113076251	2.816465827
Within Groups	1670402.75	44	37963.69886			
Total	1910288.479	47				

Appendix B2

Test for Incoming Traffics (Ibara Intersection)

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	270666.2292	3	90222.07639	2.149217249	0.107603441	2.816465827
Within Groups	1847077.754	44	1979.03977			
Total	2117743.979	47				

- Location of bus stops close to the intersection should be discouraged.
- On street parking and indiscriminate picking of passengers should be discouraged.
- Towing vehicles should be made available for prompt removal of breakdown vehicle in any of the routes that make up the intersections.

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