The Use of Queuing Theory in the Management of Traffic Intensity

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Abstract: One of the major objectives of road transport policy is to minimize road congestion and road accidents in an area. An intense interruption of free movement on a road is known as traffic congestion. Traffic congestion is as a result of too many cars, buses, trucks in a road space at a particular time. It can occur almost on any road system. It is more dominant and severe around central business district, industrial areas and the like, during the morning and afternoon periods as a result of the influx of commuters and goods delivery around such areas. The impact of such traffic congestion includes delay in delivery of goods and services, excessive fuel consumption and pollution, frustration and inability to estimate travel time. Road transport which is popularly used as medium for mobility can be tiring, irritating and costly when congestion is encountered. This work contributes to the prediction of road traffic intensity of some areas in Lagos state, Nigeria by the application of queuing theory. The approach adopted in the paper describes traffic intensity as performance measure used in the prediction of the level of queue build-up at traffic light intersection in the selected area. The prediction may enhance proper traffic management devoid of undue delays.

Keywords: Queuing Process; Traffic Intensity; Traffic Management

Introduction

Traffic congestion occurs in busy and populated areas. It can be very frustrating because of the delay it causes on vehicular movement for commuters and item delivery. It is periodical and has several causative factors depending on the area. The causes of congestion include lack of internal route expansion, bad roads and many vehicles in transit, poor packing by commercial vehicles and the like. Traffic congestion is common in Lagos because it is heavily populated with a small land mass. Mala et al (2016) describes traffic congestion as a situation on road network which occurs as its use increases. It is characterized by slower speeds, increased trip times and queuing of vehicles. It is therefore necessary to apply the principle of queuing theory to optimize the waiting time in queuing system as experienced in traffic congestion.

The effect of traffic congestion includes commuters' frustration, vehicle collision and fuel wastage. Traffic congestion also has spill over effect from congested main routes to secondary roads and side-streets as alternative routes are sought. Such spill over effect results in delays which in turn leads to late arrivals for meetings and business activities in the locality. Mala et al (2016), assert that traffic congestion occurs when a mass of traffic requires space greater than the available road capacity.

According to Humphreys (1991) queuing theory is the mathematical study of waiting lines or queues. In queuing theory a model is constructed so that queue lengths and waiting times can be predicted. Generally, queuing theory is a branch of operations research because the results are used in making business decisions about resources required in the provision of services. A queue is a waiting line but queuing is used broadly to cover variety of problems usually for economic balance and optimization involving waiting and delay in serving people or servicing machines and equipment.

Queuing theory takes its origin from the research credited to Agner Krarup Erlang who created models to describe the Copenhagen telephone exchange. The idea has been extended to applications such as telecommunication, traffic engineering, computing and the design of factories, shops, offices and hospitals.

Intikhat et al (2008) assert that efficient transportation system plays an important role in the provision of daily necessities in the life of citizens because it assists in the smooth running of activities

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for optimal performance. Wane (2001) also points out that transportation is a crucial factor for urban development since it gives fluidity to economic activity, family life and helps in spinning social networks. Clearly the importance of free flowing road network cannot be overemphasized.

Some applications of queuing theory to road traffic congestion are cited to conclude the introduction of the paper.

Martin Anokye et al (2013) discuss the application of queuing theory to vehicle traffic at signalized intersection using a case study of Kumasi Ashati Region Ghana. Mala et al (2016) focus on the minimalism of traffic congestion by using queuing theory. Chao et al. (2009) and Quddus et al. (2010) argue that the level of traffic congestion does not affect the severity of road crashes on the M25 motorway. The impact of traffic flow on the severity of crashes, however, showed an interesting result. Yannis et al. (2010) develop ordered logic models to provide insight into the human-factors' aspect of the introduction of advanced technologies to the sensitive segments of driver population. Glen et al. (2003) show how congestion-reduction strategies can induce additional traffic as a result of economic benefits. Qingyu et al. (2007) suggest a base for the implementation of urban road congestion pricing and other travel management strategies after analysing the production mechanism of urban traffic congestion. They found that travellers overlook the negative externality of urban traffic congestion and join the congested queues. Jayaram and Lincoln (2007) identify two polar cases. In one case, the estimation of the number is trivial and therefore enables further analysis, including the quantification of the relative impact of congestion on distribution costs and the deduction of empirically testable hypotheses. The other case is considerably less tractable; a specific instance of this case is broadly relevant to one of the companies that participated in the research. Strasbourg et al. (2008) adopt laboratory experiments designed to study the impact of public information about past departure rates on congestion levels and travel costs. The design is based on a discrete version of Arnott et al. (1990) bottleneck model. In all treatments, congestion occurs and the observed travel costs are quite similar to the predicted ones. The capacity of subjects to coordinate is not affected by the availability of public information on past departure rates, by the number of drivers or by the relative cost of delay. This seemingly absence of treatment effects is confirmed by finding that a parameter-free reinforcement learning model best characterizes individual behaviour. Luke and Richard (2006) road traffic crash (RTC) details contain casualties, by severity, for each of the eight state and territory jurisdictions in Australia. They use these details to estimate and compare the economic impact of RTCs across these regions. Their paper makes two fundamental contributions; it provides a detailed breakdown of estimated RTC casualties and sub-national breakdown of RTC costs for Australia.

This work tries to investigate the problems of road congestion, predict and provide information which may engender free traffic flow. The investigation is based on traffic intensity on some areas in Victoria Island, Lagos. The investigation can be extended to densely populated areas in the Lagos mainland for comparison.
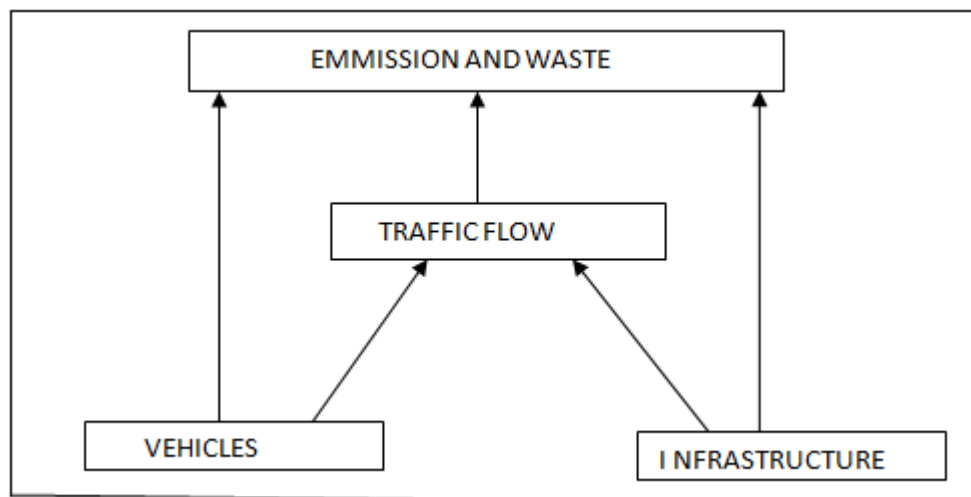

Figure 1: Static and dynamic impact of road traffic on emissions and waste.
SOURCE: Tom Van Woensel et al (2000)

METHODOLOGY

Typically any queuing system is composed of units, referred to as customers, needing some kind of service and who arrive at a service facility, join a queue if service is not immediately available, and eventually leave after receiving the service. A server refers to mechanism that delivers service(s) to the customer. If upon arrival a "customer" finds the server busy, then she/ he may form a queue, join it or leave the system without receiving any service even after waiting for some time. According to Lartey (2014), the following configurations of vehicular traffic flow as typical queuing system are possible. They are explored in this work.

- Customers are vehicles using the road infrastructure at the signalized intersection for which the traffic light (server) is used to regulate vehicular flow through the intersection.
- Vehicles arrive randomly as units and form a single file of waiting line until they are served by a server.
- Vehicles are served individually in parallel, according to the order in which they arrived.
- The Arrival Pattern: This is the manner in which arrivals occur, indicted by the inter-arrival time between any two consecutive arrivals. For our stochastic modelling framework, the inter-arrival time may vary and may be described by a specific probability distribution that best describes the arrival pattern observed.
- Arrival Rate λ : This is the average number of vehicles arriving per unit time.
- The Service Pattern: This is the manner in which the service is rendered and is specified by the time taken to complete a service. Similar to the arrival pattern, distribution of the service time must be specified under stochastic modelling considerations.
- Service Rate μ : This gives the average number of vehicles served per unit time.
- Server Utilization ρ: This gives the average utilisation of the server, given by $\lambda = \rho.\mu$

- Mean Service Time τ : The time to serve a designated customer.
- Mean Waiting Time T: The average time spent in the queue by a customer who receives a service.
- Mean Queue Size N: The Average number of customers in the system for service. The quality of service one receives could be judged, at least in part, by the length of time one waits in the queue for service and this is very much influenced by what constitutes the configurations of the system.

We can indicate this configuration as A/B/C/X/Y/Z, in accordance with Kendall-Lee notation, where the symbols A, B, C, X, Y, and Z respectively indicate the inter-arrival time distribution, the service time distribution, the number of servers, the system capacity, the population size and the queue discipline.

Mean Performance Parameter Forth model (M/M/1: ∞/FIF0)
Traffic Intensity ρ: The average number of customers being served is the ratio of arrival and service rate ($\rho = \lambda/\mu$). For a stable system the service rate μ should always exceed the arrival rate λ and thus ρ should always be less than unity. Therefore, it is also known as utilization factor of the server.

Average Number of Customer in the System: The average number of customer in the system is equal to the average number of customer in the queue together with those being serviced.
$$Ls = \lambda / \mu - \lambda$$
Average Number of Customer in Queue: It can be viewed as average queue length that is, the average number of customers who are waiting in the queue. It is defined as
$$Lq = \lambda 2 /\mu (\mu - \lambda)$$
Average Time Spent in the System: The average time spent in the system is equal to the total time that a customer spends in a system i.e. waiting time plus the service time. It is given by $Ws = 1/ (\mu - \lambda)$
Average Waiting Time in Queue: The average waiting time in queue is the average time a customer waits in queue for getting service. It is expressed as
$Wq = \lambda / \mu (\mu - \lambda)$

TABLE 1: Tabular presentation of the traffic situation showing traffic intensity of some channels in Victoria Island, Lagos.

Location/Channel	Session	Arrival Veh.	Arrival Time	Service Veh.	Service Time	Arrival Rate	Service Rate	Traffic Intensity
Ahmadu-Bello way-Victoria Island	Morning	25	1.20	34	1.04	21	32	0.6875
	Afternoon	23	2.56	18	1.08	9	17	0.5294
	Evening	32	1.20	30	1.05	26	28	0.9285
Awolowo Rd - Victoria Island	Morning	27	2.34	18	1.42	12	13	0.9230
	Afternoon	21	1.32	24	1.03	16	23	0.6956
	Evening	25	1.34	26	1.02	19	25	0.7600
Akin Adesola Rd - Victoria Island	Morning	21	2.05	18	1.08	10	16	0.6250
	Afternoon	27	1.50	29	1.07	18	27	0.5925
	Evening	51	8.09	43	1.45	7	31	0.2258
1st/ 2nd gate - Victoria Island	Morning	26	1.23	35	1.03	21	33	0.6363
	Afternoon	30	2.32	50	1.20	13	42	0.3095
	Evening	56	4.6	60	2.19	12	27	0.4444

TABLE 2: Tabular presentation indicating mean system waiting L_S, queue waiting L_q, system time W_s and queue time W_q of some channels in Victoria Island, Lagos

LOCATION OR CHANNEL	SESSION	ARRIVAL RATE	SERVICE RATE	TRAFFIC INTENSITY	MEAN NO. OF VEHICLES WAITING IN THE SYSTEM	MEAN NO. OF VEHICLES WAITING IN THE QUEUE	MEAN TIME SPENT IN THE SYSTEM	MEAN TIME SPENT IN THE QUEUE
		λ	μ	ρ	L_s	L_q	W_s	W_q
Ahmadu Bello way-Victoria Island	Morning	21	32	0.6563	2	2	0.1	0.0687
	Afternoon	9	17	0.5294	1	1	0.125	0.0661
	Evening	26	28	0.9285	13	12	0.5	0.4642
Awolowo Rd - Victoria Island	Morning	12	13	0.923	12	11	1	0.923
	Afternoon	16	23	0.6956	2	2	0.1428	0.0993
	Evening	19	25	0.76	3	2	0.1667	0.1267
Akin Adesola Rd - Victoria Island	Morning	10	16	0.625	1	1	0.1667	0.1041
	Afternoon	18	27	0.5925	2	1	0.1111	0.074
	Evening	7	31	0.2258	0	0	0.0417	0.0094
1st/ 2nd gate - Victoria Island	Morning	21	33	0.6363	2	1	0.0833	0.053
	Afternoon	13	42	0.3095	0	0	0.0344	0.0106
	Evening	12	27	0.4444	1	0	0.0667	0.0296

Traffic situation in Victoria Island is observed at four intersections during the peak hours of morning (7-10am), afternoon (12-3pm) and evening (5-8pm) sessions. The routes/channels include Ahmadu Bello way, Awolowo road and Akin Adesola road as well as 1st /2nd gate intersections. Table 1 shows the number of arrivals (queue), time spent in minutes, number served (system) and time spent in minutes by vehicles. The arrival and service rates are derived from these quantities. Traffic intensity is derived from the arrival and service rates.

Table 2 shows the values of mean number of vehicles in the system (Ls), mean number of vehicles in the queue (Lq), mean time spent in the system (Ws) and mean time spent in the queue (Wq). The values are derived by the application of the respective formula above.
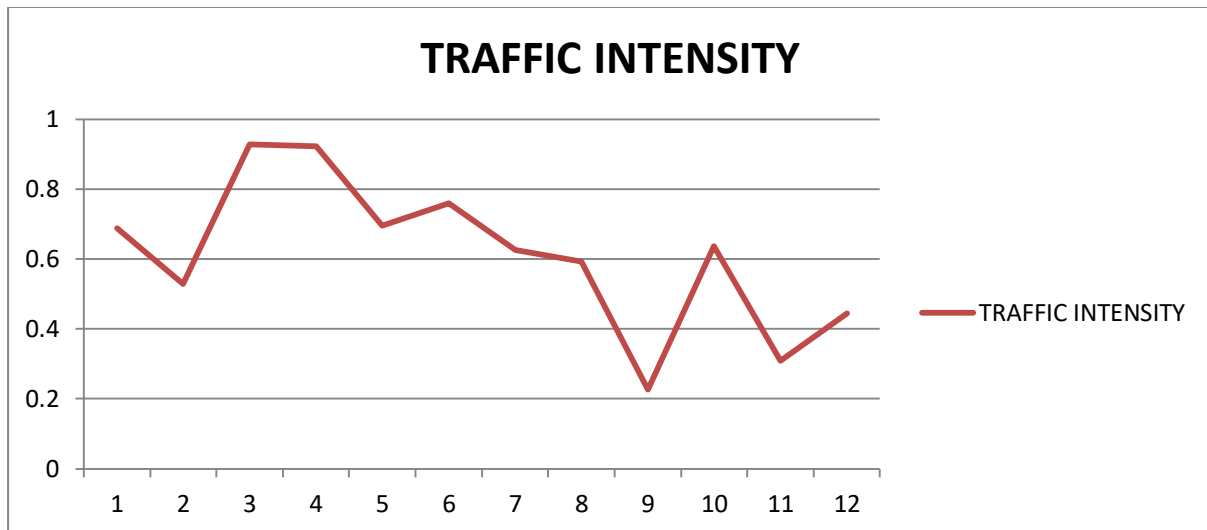

Fig 1: Graphical presentation of the Traffic Intensity of channels in Victoria Island Lagos
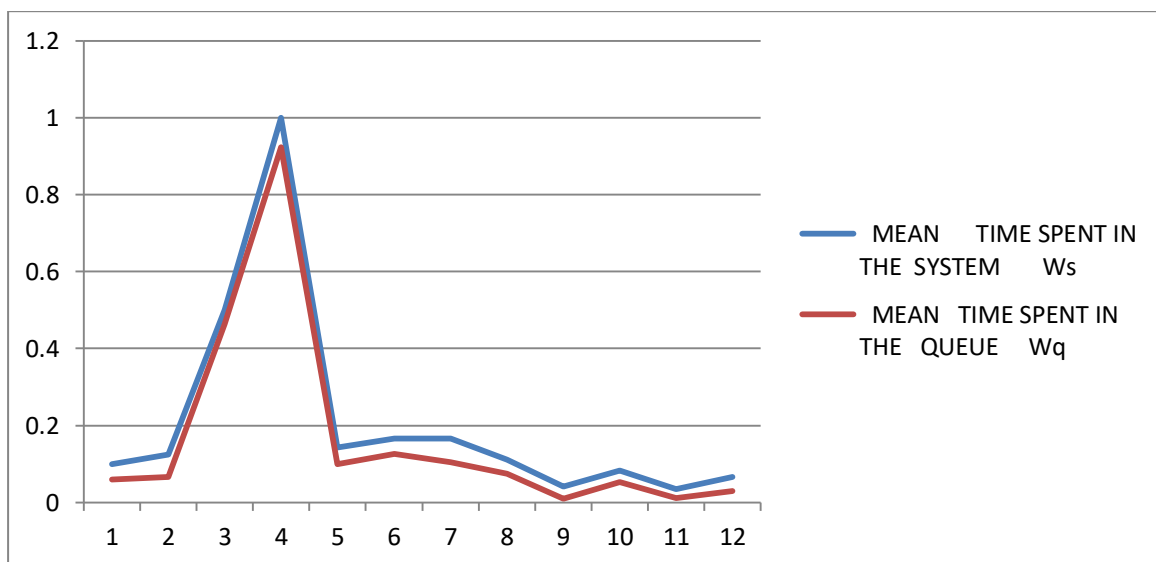

Fig 2: Graphical presentation of the mean time spent in the queue (Wq) and the mean time spent in the system (Ws) of some channels in Victoria Island, Lagos.
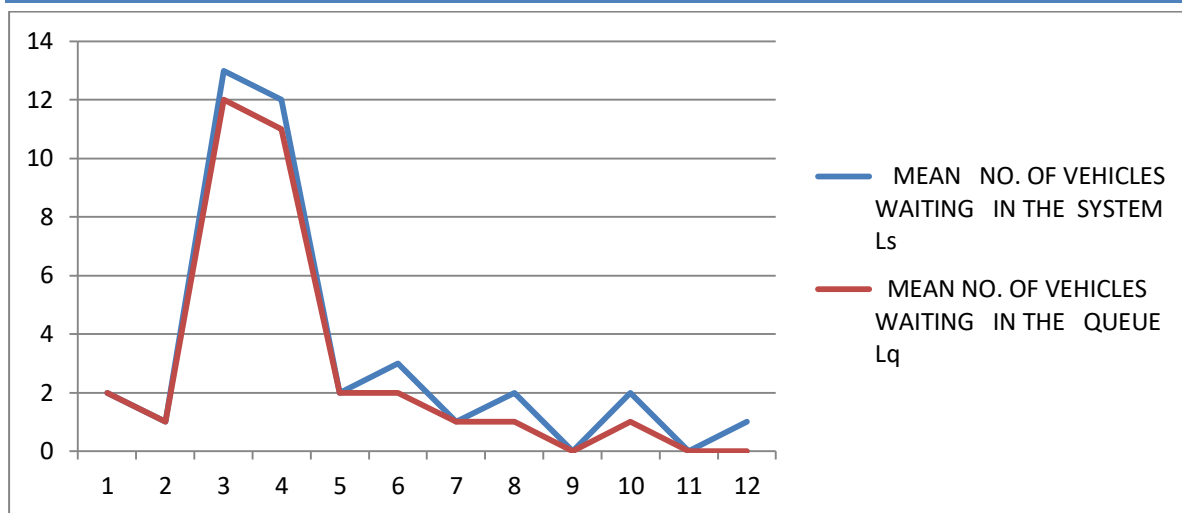
Fig 3: Graphical presentation of the mean number of vehicles waiting in queue (Lq) and mean number of vehicles waiting in system (Ls) of some channels in Victoria Island, Lagos.

RESULT/ANALYSIS
Comments on the sessions for routes/channels
Morning session
Ahmadu Bello way- Victoria Island
The arrival and service rates are 21 and 32 respectively and hence the traffic intensity is 0.6563. This is an indication of a stable traffic situation but not a very smooth flow of traffic. The mean number of vehicles in the system (L_s) and queue (L_q) as well as the mean waiting time in the system (W_s) and queue (W_q) tend to confirm the traffic situation.

Awolowo road– Victoria Island
The arrival and service rates are 12 and 13 respectively and hence the traffic intensity is 0.9230 which is almost unity. This is an indication of an unstable and critical traffic flow. The derived values of L_s, L_q, W_s and W_q support the traffic situation.

Akin Adesola road–Victoria Island
The arrival and service rates are 10 and 16 respectively. The traffic intensity is 0.6250 which is an indication of a fairly stable traffic flow. The derived parameters are agreement with the traffic situation.

1st and 2nd gate –Victoria Island
The arrival and service rates are 21 and 33 respectively and hence the traffic intensity is 0.6363. This is an indication of a stable traffic situation but not a very smooth traffic flow. The derived values give credence to the reported traffic situation.

Afternoon session
Ahmadu Bello way – Victoria Island
The arrival and service rates are 9 and 17 respectively and hence the traffic intensity is 0.5294. This is an indication of a stable and smooth flow of traffic. The derived values are in line with the reported traffic situation.

Awolowo road– Victoria Island
The arrival and service rates are 16 and 23 respectively and hence the traffic intensity is 0.6956.

This is an indication of a relatively unstable and unsmooth traffic flow. The derived values corroborate the reported traffic situation.

Akin Adesola road–Victoria Island
The arrival and service rates are 18 and 27 respectively and hence the traffic intensity is 0.5925. This is an indication of a stable and smooth flow of traffic. The derived parameters justify the reported traffic flow.

1st and 2nd gate –Victoria Island
The arrival and service rates are 13 and 42 respectively and hence the traffic intensity is 0.3095 which is an indication of a fantastic traffic flow. This is the best traffic situation when compared to the other channels for the afternoon session. The derived values validate the reported flow of traffic.

Evening Session
Ahmadu Bello way–Victoria Island
The arrival and service rates are 26 and 28 respectively hence the traffic intensity is 0.9285 which is close to unity. This is an indication of an unstable and chaotic traffic flow. It is also the worst condition of traffic when compared to other channels for all sessions. The traffic situation is buttressed by the derived parameters.

Awolowo road– Victoria Island
The arrival and service rates are 19and 25 respectively and hence the traffic intensity is 0.7600. This is an indication of a relatively stable but unsmooth traffic flow. The reported traffic situation is validated by the derived values.

Akin Adesola road– Victoria Island
The arrival and service rates are 7 and 31 respectively and the traffic intensity is 0.2258. This is an indication of a very stable and smooth traffic flow. It is also the best traffic condition in comparison to the other channels for all sessions. This situation is devoid of delay after service. The reported traffic situation is validated by the derived parameters.

1st gate and 2nd gate –Victoria Island
The arrival and service rates are 12 and 27 respectively. The traffic intensity is 0.4444 which is an indication of a very stable and smooth traffic flow. This is another free flowing and fantastic traffic situation. The derived values are in line with the reported traffic situation

DISCUSSION

This study is focussed on the management of vehicular traffic based on queuing theory. It is assumed that the time interval between successive arrival and service times is independent and normally distributed. The system is also assumed to reach a stable state with constant arrival and service rates. The study also adopts the FCFS (first come first serve) approach where the vehicles are made to line-up or queue according to their time of arrival as customers waiting to be served by a signal of functioning traffic light in a given channel or location to minimize traffic congestion.

The number of vehicles in each service station for every channel is counted and the time in minutes noted when waiting to be served and after being served. These values are used to derive the arrival and service rates of the vehicles. This situation was observed for 5 days in peak hours of morning, afternoon and evening (7-10am, 12-3pm and 5-8pm respectively).

The intersections in Victoria Island of interest involve the following routes/channels; Ahmadu Bello way, Awolowo road, Akin Adesola road and 1st and 2nd gates. The traffic intersection is currently operating with one service channel from the various routes to Victoria Island.

Traffic flow is unstable and critical on Awolowo road in the morning session but fairly stable on the other routes. Traffic flow is stable and smooth on all the routes in the afternoon session with the best traffic situation occurring on 1st/2nd gate route. In the evening session, traffic flow is critical/chaotic on Ahmadu Bello way, relatively stable on Awolowo road, stable/smooth on Akin Adesola road and very smooth and devoid of delays on 1st/2nd gates route. Generally, traffic intensity is below unity for all routes/channels in all sessions ($\rho < 1$).

From the foregoing the application of first come first serve (FCFS) technique of queuing theory in the management of traffic flow is justified. Its application cuts across a range of traffic congestion situations. Other likely areas of application of the FCFS technique include the ATM machine, commercial bus queue, thanksgiving procession in church, gas station, toll gates, security check points and the like.

CONCLUSION

The objective of the study is to apply the queuing theory in minimizing vehicular traffic congestion using four routes/channels in Victoria Island as case study. This study reveals that traffic intensity is highest in the morning session when commuters are reporting for work/business and in the evening session at the close of work/business especially on Awolowo road and Ahmadu Bello way respectively. It is therefore necessary to allot more time at intersections for traffic into such routes in the morning and evening sessions. The increase of traffic light time will reduce traffic intensity which in turn minimizes delays on such routes/channels at peak periods of morning and evening sessions.

In the design and implementation of road network, designers and planners should take into consideration some factors that may engender free flow of traffic. The consideration should include but not limited to the following factors:

- Construction of separate lanes for commercial vehicles with increased road capacity.
- Construction of flyovers for areas prone to traffic congestion.
- Construction of service lanes and bye pass to areas with high traffic intensity.
- Installation of parking restriction signs at strategic points along routes that are prone to traffic congestion. Enforcement of the parking restriction is necessary to ensure compliance by private and commercial vehicles.

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