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Research Article

MANAGING TRAFFIC INTENSITY WITH QUEUING THEORY

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Abstract

The objective of road transport policies is multifaceted, encompassing the mitigation of traffic congestion and the reduction of road accidents, particularly in urban areas. These policies also emphasize sustainable development through efficient resource utilization and the promotion of alternative transportation modes.By integrating these goals, road transport policies seek to foster a balanced and resilient transportation system that addresses societal needs while promoting environmental sustainability and equitable mobility.This paper seeks to predict road traffic intensity in various locations within Lagos State, Nigeria, using queuing theory as its analytical tool.

Keywords: *Queuing Process, Traffic Intensity, Traffic Management.*

Introduction

Addressing traffic congestion necessitates a multifaceted approach that encompasses both infrastructure improvements and technological innovations. Enhancing public transportation options through investments in efficient bus and rail networks encourages a shift away from individual vehicle use. Concurrently, the development of pedestrian walkways and cycling lanes promotes sustainable modes of travel. Implementing smart traffic management systems, such as adaptive signal controls and real-time traffic monitoring, optimizes traffic flow and reduces bottlenecks in congested areas. By utilizing queuing theory to forecast traffic buildup at intersections, this study aims to enhance traffic management strategies in Lagos State, Nigeria. These predictive insights are crucial for ensuring smoother and more efficient mobility across the urban landscape, ultimately benefiting both commuters and the environment.

Arrival Rate Λ

This is the average number of customers arriving per unit time.

Service Rate μ

This gives the average number of customers served per unit of time.

Traffic Intensity ρ

The average number of customers served is the arrival and service rate ratio.

$$\rho = \frac{\lambda}{\mu}$$

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 the utilization factor of the server.

Average Number of Customers in The System

The average number of customers in the system is equal to the average number of customers waiting in the queue.

$$L_S = \frac{\lambda}{\mu - \lambda}$$

Average Number of Customers in Queue

It can be viewed as the average queue length that is, the average number of customers who are waiting in the queue. It is defined as

$$L_q = \frac{\rho^2}{(1-\rho)}$$

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

$$W_S = \frac{1}{(\mu - \lambda)}$$

Average Waiting Time in Queue

The average waiting time in a queue is the average time a customer waits in the queue to get service. It is expressed as

$$\mathbf{W_q = W_S - \frac{1}{\mu}}$$

Calculations

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

Location /Channel	Session	Arrival		Service	Arrival		Service	Traffic
		Veh.	Time	Veh.	Time	Rate	Rate	Intensity
Ahmadu-Bello way-Victoria Island	Morning	25	1.20	34	1.04	21	32	0.6563
	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
	Morning	26	1.23	35	1.03	21	33	0.6363
1st/2nd gate-Victoria Island	Afternoon	30	2.32	50	1.20	13	42	0.3095
	Evening	56	4.6	60	2.19	12	27	0.4444

Traffic situation in Victoria Island is observed at four intersections during the peak hours of morning (7-10 am), afternoon (12-3 pm), and evening (5-8 pm) sessions. The routes/channels include Ahmadu Bello Way, Awolowo Road, and Akin Adesola Road as well as a 1st / 2nd gate intersection.

The Values Are Derived By the Application Of The Respective Formulas Given Below

Ahmadu Bello Way Victoria Island

Mean No. of Vehicles Waiting in the System: $\mathbf{L_S = \frac{\lambda}{\mu - \lambda}}$

Morning → λ = 21, μ = 32

$\mathbf{L_S} = \frac{\lambda}{\mu-\lambda} = \frac{21}{32-21} = 1.9090 = \mathbf{2}$

Afternoon → λ = 9, μ = 17

$\mathbf{L_S} = \frac{\lambda}{\mu-\lambda} = \frac{9}{17-9} = 1.125 = \mathbf{1}$

Evening → λ = 26, μ = 28

$\mathbf{L_S} = \frac{\lambda}{\mu-\lambda} = \frac{26}{28-26} = \mathbf{13}$

Mean No. of Vehicles Waiting in the Queue: $\mathbf{L_q = \frac{\rho^2}{(1-\rho)}}$

Morning → λ = 21, μ = 32, ρ = 0.6563

$\mathbf{L_q} = \frac{\rho^2}{(1-\rho)} = \frac{(0.6563)^2}{(1-0.6563)} = 1.2532 = \mathbf{1.25}$

Afternoon → λ = 9, μ = 17, ρ = 0.5294

$\mathbf{L_q} = \frac{\rho^2}{(1-\rho)} = \frac{(0.5294)^2}{(1-0.5294)} = 0.59 = \mathbf{1}$

Evening → λ = 26, μ = 28, ρ = 0.9285

$\mathbf{L_q} = \frac{\rho^2}{(1-\rho)} = \frac{(0.9285)^2}{(1-0.9285)} = \mathbf{12}$

Mean Time Spent in thesystem: $\mathbf{W_S = \frac{1}{(\mu-\lambda)}}$

Morning → λ = 21, μ = 32

$\mathbf{W_S} = \frac{1}{(\mu-\lambda)} = \frac{1}{(32-21)} = 0.0909 = \mathbf{0.1}$

Afternoon → λ = 9, μ = 17

$\mathbf{W_S} = \frac{1}{(\mu-\lambda)} = \frac{1}{(17-9)} = \mathbf{0.125}$

Evening → λ = 26, μ = 28

$\mathbf{W_S} = \frac{1}{(\mu-\lambda)} = \frac{1}{(28-26)} = \mathbf{0.5}$

Mean Time Spent in the Queue: $\mathbf{W_q = W_S - \frac{1}{\mu}}$

Morning → λ = 21, μ = 32

$\mathbf{W_q} = W_S - \frac{1}{\mu} = 0.1 - \frac{1}{32} = \mathbf{0.0687}$

Afternoon → λ = 9, μ = 17

$\mathbf{W_q} = W_S - \frac{1}{\mu} = 0.125 - \frac{1}{17} = \mathbf{0.0661}$

Evening → λ = 26, μ = 28

$\mathbf{W_q} = W_S - \frac{1}{\mu} = 0.5 - \frac{1}{28} = \mathbf{0.4642}$

Awolowo Rd- Victoria Island

Mean No. of Vehicles Waiting in the System: $\mathbf{L_S = \frac{\lambda}{\mu-\lambda}}$

Morning → λ = 12, μ = 13

$\mathbf{L_S} = \frac{\lambda}{\mu-\lambda} = \frac{12}{13-12} = \mathbf{1}$

Afternoon → λ = 16, μ = 23

$\mathbf{L_S} = \frac{\lambda}{\mu-\lambda} = \frac{16}{23-16} = 2.2857 = \mathbf{2}$

Evening → λ = 19, μ = 25

$\mathbf{L_S} = \frac{\lambda}{\mu-\lambda} = \frac{19}{25-19} = 3.1666 = \mathbf{3}$

Mean No. of Vehicles Waiting in the Queue: $\mathbf{L_q = \frac{\rho^2}{(1-\rho)}}$

Morning → λ = 12, μ = 13, ρ = 0.923

$\mathbf{L_q} = \frac{\rho^2}{(1-\rho)} = \frac{(0.923)^2}{(1-0.923)} = 11.064 = \mathbf{11}$

Afternoon → λ = 16, μ = 123, ρ = 0.6956

$\mathbf{L_q} = \frac{\rho^2}{(1-\rho)} = \frac{(0.6956)^2}{(1-0.6956)} = 1.589 = \mathbf{2}$

Evening → λ = 19, μ = 25, ρ = 0.76

$\mathbf{L_q} = \frac{\rho^2}{(1-\rho)} = \frac{(0.76)^2}{(1-0.76)} = \mathbf{2}$

Mean Time Spent in the system: $\mathbf{W_S = \frac{1}{(\mu-\lambda)}}$

Morning → λ = 12, μ = 13

$\mathbf{W_S} = \frac{1}{(\mu-\lambda)} = \frac{1}{(13-12)} = \mathbf{1}$

Afternoon → λ = 16, μ = 23

$\mathbf{W_S} = \frac{1}{(\mu-\lambda)} = \frac{1}{(23-16)} = \mathbf{0.1428}$

Evening → λ = 19, μ = 25

$\mathbf{W_S} = \frac{1}{(\mu-\lambda)} = \frac{1}{(25-19)} = \mathbf{0.1667}$

Mean Time Spent in the Queue: $\mathbf{W_q = W_S - \frac{1}{\mu}}$

Morning → λ = 12, μ = 13

$\mathbf{W_q} = W_S - \frac{1}{\mu} = 1 - \frac{1}{13} = \mathbf{0.923}$

Afternoon → λ = 16, μ = 23

$\mathbf{W_q} = W_S - \frac{1}{\mu} = 0.1428 - \frac{1}{23} = \mathbf{0.0993}$

Evening → λ = 19, μ = 25

$\mathbf{W_q} = W_S - \frac{1}{\mu} = 0.1667 - \frac{1}{25} = \mathbf{0.1267}$

Akin Adesola Rd-Victoria Island

Mean No. of Vehicles Waiting in the System: $\mathbf{L_S = \frac{\lambda}{\mu-\lambda}}$

Morning → λ = 10, μ = 16

$\mathbf{L_S} = \frac{\lambda}{\mu-\lambda} = \frac{10}{16-10} = \mathbf{1}$

Afternoon → λ = 18, μ = 27

$\mathbf{L_S} = \frac{\lambda}{\mu-\lambda} = \frac{18}{27-18} = \mathbf{2}$

Evening → λ = 7, μ = 31

$\mathbf{L_S} = \frac{\lambda}{\mu-\lambda} = \frac{7}{31-7} = 0.2916 = \mathbf{0}$

Mean No. of Vehicles Waiting in the Queue: $\mathbf{L_q = \frac{\rho^2}{(1-\rho)}}$

Morning → λ = 10, μ = 16, ρ = 0.625

$\mathbf{L_q} = \frac{\rho^2}{(1-\rho)} = \frac{(0.625)^2}{(1-0.625)} = 1.04166 = \mathbf{1}$

Afternoon → λ = 18, μ = 27, ρ = 0.5925

$\mathbf{L_q}=\frac{\rho^2}{(1-\rho)}$ = $\frac{(0.5925)^2}{(1-0.5925)}$= 0.8614 = **1**

Evening → λ = 7, μ = 31, ρ = 0.2258

$\mathbf{L_q}=\frac{\rho^2}{(1-\rho)}$ =$\frac{(0.2258)^2}{(1-0.2258)}$= 0.06585 =**0**

Mean Time Spent in the system: $\mathbf{W_S} = \frac{\mathbf{1}}{(\mu-\boldsymbol{\lambda})}$

Morning → λ = 10, μ = 16

$\mathbf{W_S} = \frac{1}{(\mu-\lambda)} = \frac{1}{(16-10)}$ = **0.1667**

Afternoon → λ = 18, μ = 27

$\mathbf{W_S} = \frac{1}{(\mu-\lambda)} = \frac{1}{(27-18)}$ = **0.1111**

Evening → λ = 7, μ = 31

$\mathbf{W_S} = \frac{1}{(\mu-\lambda)} = \frac{1}{(31-7)}$ = **0.0417**

Mean Time Spent in the Queue: $\mathbf{W_q} = \mathbf{W_S} - \frac{\mathbf{1}}{\mu}$

Morning → λ = 10, μ = 16

$\mathbf{W_q}$= $W_S - \frac{1}{\mu}$ =0.1667 $-\frac{1}{16}$ =**0.1042**

Afternoon → λ = 18, μ = 27

$\mathbf{W_q}$= $W_S - \frac{1}{\mu}$ = 0.1111 $-\frac{1}{27}$ =**0.074**

Evening → λ = 7, μ = 31

$\mathbf{W_q}$= $W_S - \frac{1}{\mu}$ = 0.0417 $-\frac{1}{31}$ =**0.0094**

3.1.4 1st/2nd Gate-Victoria Island:

Mean No. of Vehicles Waiting in the System: $\mathbf{L_S} = \frac{\boldsymbol{\lambda}}{\mu-\boldsymbol{\lambda}}$

Morning → λ = 21, μ = 33

$\mathbf{L_S} = \frac{\lambda}{\mu-\lambda} = \frac{21}{33-21}$ = 1.75 =**2**

Afternoon → λ = 13, μ = 42

$\mathbf{L_S} = \frac{\lambda}{\mu-\lambda} = \frac{13}{42-13}$= 0.448 =**0**

Evening → λ = 12, μ = 27

$\mathbf{L_S} = \frac{\lambda}{\mu-\lambda} = \frac{12}{27-12}$ =0.8 =**1**

Mean No. of Vehicles Waiting in the Queue: $\mathbf{L_q}=\frac{\boldsymbol{\rho^2}}{(\mathbf{1}-\boldsymbol{\rho})}$

Morning → λ = 21, μ = 33, ρ = 0.6363

$\mathbf{L_q}=\frac{\rho^2}{(1-\rho)} = \frac{(0.6363)^2}{(1-0.6363)}$ = 1.11 = **1**

Afternoon → λ = 13, μ = 42, ρ = 0.3095

$\mathbf{L_q}=\frac{\rho^2}{(1-\rho)}$ = $\frac{(0.3095)^2}{(1-0.3095)}$= 0.1387 = **0**

Evening → λ = 12, μ = 27, ρ = 0.4444

$\mathbf{L_q}=\frac{\rho^2}{(1-\rho)}$ =$\frac{(0.4444)^2}{(1-0.4444)}$= 0.3554=**0**

Mean Time Spent in the system: $\mathbf{W_S} = \frac{\mathbf{1}}{(\mu-\boldsymbol{\lambda})}$

Morning → λ = 21, μ = 33

$\mathbf{W_S} = \frac{1}{(\mu-\lambda)} = \frac{1}{(33-21)}$ = **0.0833**

Afternoon → λ = 13, μ = 42

$\mathbf{W_S} = \frac{1}{(\mu-\lambda)} = \frac{1}{(42-18)}$ = **0.0344**

Evening → λ = 12, μ = 27

$\mathbf{W_S} = \frac{1}{(\mu-\lambda)} = \frac{1}{(27-12)}$ = **0.0667**

Mean Time Spent in the Queue: $\mathbf{W_q} = \mathbf{W_S} - \frac{\mathbf{1}}{\mu}$

Morning → λ = 21, μ = 33

$\mathbf{W_q}$= $W_S - \frac{1}{\mu}$ = 0.0833 $-\frac{1}{33}$ = 0.05299 =**0.053**

Afternoon → λ = 13, μ = 42

$\mathbf{W_q}$= W_S – $\frac{1}{\mu}$ = 0.0344 $-\frac{1}{42}$ = 0.01059 =**0.0106**

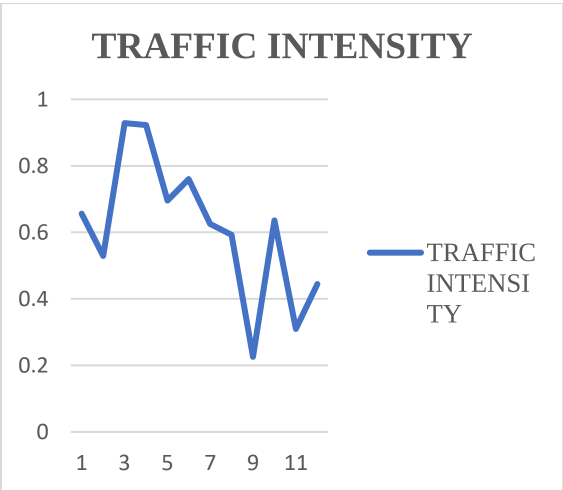
Evening → λ = 12, μ = 27

$\mathbf{W_q}$= $W_S - \frac{1}{\mu}$ = 0.0667 $-\frac{1}{27}$ = **0**

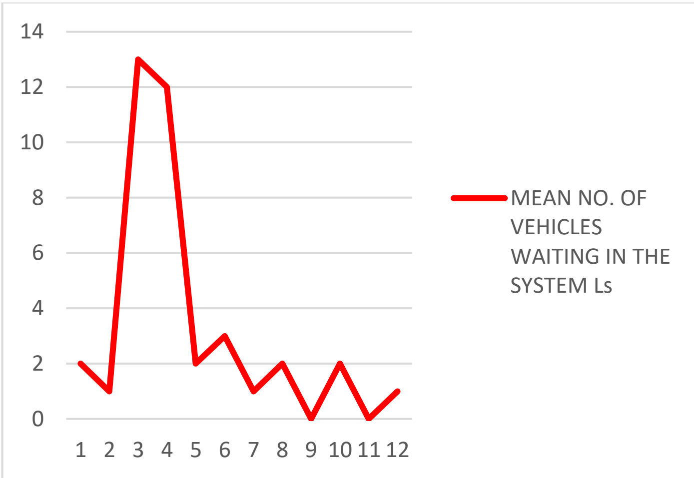
TABLE 2: Tabular presentation indicating mean system waiting for L_s queue waiting L_q, system time W_s, and, queue time W_q of some channels in Victoria Island, Lagos.

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	1.25	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	0.9230
	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	0.1042
	Afternoon	18	27	0.5925	2	1	0.1111	0.0740
	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	0.0530
	Afternoon	13	42	0.3095	0	0	0.0344	0.0106
	Evening	12	27	0.4444	1	0	0.0667	0.0296

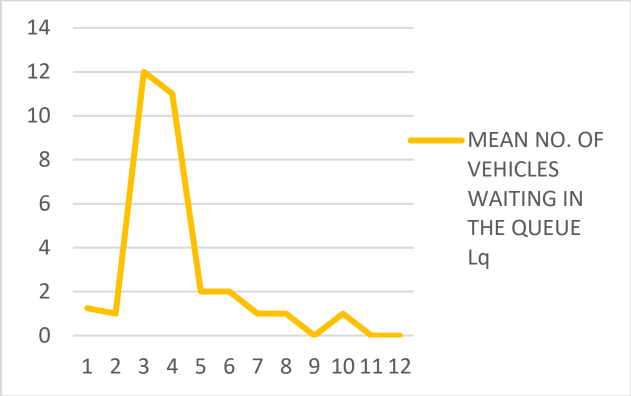
The Values In Table 2 Are Given In Graphical Representation As Follows



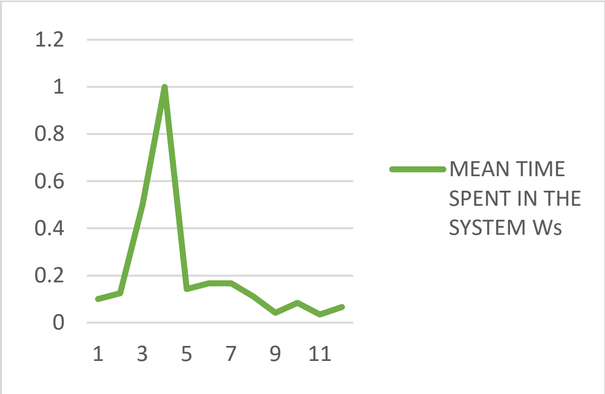
Graphical presentation of the Traffic Intensity of channels in Victoria Island Logas.



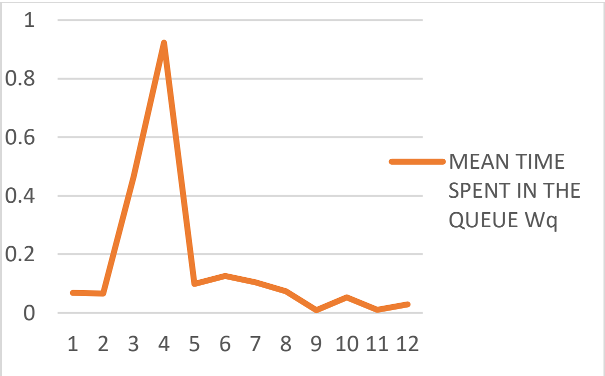
Graphical presentation of the mean number of vehicles waiting in the system (L_s) of some channels in Victoria Island, Logas.



Graphical presentation of the mean number of vehicles waiting in queue (L_q) of some channels in Victoria Island, Logas



Graphical presentation of the mean time spent in the system (W_s) of some channels in Victoria Island, Logas.



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 a 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.

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 passes to areas with high traffic intensity.

Increasing road capacity can reduce traffic congestion.

Construction of separate lanes for two-wheelers and four-wheelers.

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