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Optimization of Vehicular Traffic Congestion at Signalized Intersection

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Abstract: Traffic congestion has been a major challenge all over the world. In a bid to avoid losing revenue and man-hours on roads, traffic management and congestion control are to be given top priority. Traffic congestion will occur almost on any road system whenever instantaneous demand exceeds the capacity to provide a service. In this study, we modelled the traffic flows at signalized intersections during the peak periods by using M/M/1 model. Models from queuing theory are widely used in understanding and controlling congestion in computing, vehicular traffic flow, production and manufacturing systems. Based on the collected data from traffic counts and oral interviews, this work contributes to the prediction of road traffic intensity at Sango, Oyo State, Nigeria. The computed results showed that traffic intensity, $\rho < 1$ for all sessions and that queueing based method are competitive and promising when subjected to comparison with other approaches based on selected study areas. The model can also be applied in studies of other types of congestion in data telecommunication, healthcare delivery and access, etc. Finally, suggestions for better transport planning policies for the state government are proffered which include promotion of internet services, establishment of specialized traffic radio for accurate and real-time updates and the use of mobile phone services.
Keyword — Queuing theory, Signalized intersection, Traffic intensity, Traffic congestion, Waiting time.

1. 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 area. The causes of the congestion include lack of internal route expansion, bad roads and many vehicles in transit, poor parking by commercial vehicles, road side hawkers and the like, Ekeocha and Ihebom (2018). With traffic congestion worsening in urban areas, a growing number of signalized intersections are being operated at oversaturated conditions, and queue lengths on some roads are leading to spillovers,Ma, Wang, Sun, and Jin (2012). As the influence of traffic congestion and spillovers in city streets networks become significant, monitoring of traffic state of the roads (Ma et al., 2012) and evaluation of the performance of an existing transport system are important. This study aims to evaluate the existing traffic flow system at signalized intersection in busy routes in Sango (Ibadan North Local Government (INLG) Area of Oyo State, Nigeria). Also to do a comparative study during peak hours as well as with related past studies.
The traffic congestion in INLG of which Sango is one of the major and busiest roads has attracted a lot of attention but less research has been conducted to evaluate the performance of the existing traffic flow system. This we hope to achieve using M/M/1 queue model. The remainder of this paper is organized as follows. Research backgrounds are detailed in Section 2. Model formulations, basic queueing analysis, and methods of data acquisition using traffic counts and observations are discussed in Section 3. Discussion of data calculations, implementations and results are presented in Section 4. Finally, Section 5 closes the paper with a conclusion.

2. LITERATURE REVIEW

Mobility is crucial to functionality of cities as it affects their socio-economic activities Olagunju (2015). According to Olagunju (2015), an obvious hindrance to effective mobility is road traffic congestion, which the World bank (1999) stated that it constitutes about 54.5% of all noticeable externalities. The effects of this global phenomenon is enormous as it results in huge economic costs (productivity loss, reduction in sales, fuel wastage, etc), massive environmental

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hazards (e.g. degradation of the road infrastructures, global warming, noise, air pollution and traffic crashes), high social disconnects (e.g. reduction in quality of life, disruption of social relationship, etc) and undue health implications as a result of stress, frustration, tiredness and headache, Agyapong and Ojo (2018), Olagunju (2015), Ackaah (2019). As worrisome as the phenomenon is it cannot be totally eradicated, but can be reduced by either reducing traffic flow or increase road capacity, Muhammed and Faraj (2014).

This study has connection with three streams of literature. First, it is closely connected to those papers which study the queueing system to estimate the queue length, waiting time and environmental impact of road traffic. Vandaele, Woensel, and Verbruggen (2000), based on queueing theory analytically constructed the well-known speed flow-density diagram. With the aid of several queueing models, speed is determined, based on different arrival and service processes. The model is reported to be effective in assessing the environmental impact of road traffic. Ekeocha and Ihebom (2018) derived the arrival and service rates to estimate road traffic intensity on some areas in Lagos state, Nigeria. In the same vein, Odhiambo et al. (2017) performed queueing analysis with M/M/1 model for the management and control of vehicular traffic on Nakuru total road stretch in Kenya. Chavoushi (2010) analyzed an M/M/1 queue with customer interjection. Two parameters are introduced to describe the interjection behavior: the percentage of customers interjecting and the tolerance and the tolerance level of interjection by individual customers who are already waiting in the queue. The work of Anokye, Abdul-Aziz, Annin, and Oduro (2013), adopted queuing theory to vehicular traffic flow and recommended full involvement of public transport system for mobility in Ghana. However, our paper studies a queueing system to predict traffic intensity in Sango, Ibadan North Local Government (INLG) Area of Oyo State. On the other hand, a geospatial approach is employed by authors Adewuyi, Ajani, and Oyekunle (2019) to examine and assess traffic congestion on major roads in INLG area. Koko, Burodo, and Suleiman (2018) considered queueing approach on bus services using single and multiple servers whereas Prasad and Usha (2015) compared M/M/1 and M/D/1 models by the determination of common performance measures. The proposed M/M/1 model based on traffic intensity is adopted in this study because it is an easy-to -understand and easy-to-use approach at the same time it satisfies objectives of the study. In addition, achievements of closely related past studies by authors (Anokye et al., 2013; Ekeocha & Ihebom, 2018; Odhiambo, Orwa, & Odhiambo, 2017) motivated the study. Other approaches proposed in literature for the derivation of the common characteristics of interest for queueing analysis are simulation and use of software (Ali, Resaglna, & Tosan, 2018; Chew, 2019; Ma et al., 2012), transient performance analysis of the model (Kumar & Sharma, 2018), matrix analytic method and stochastic comparison methods (Chavoushi, 2010), etc.

Secondly, the work is connected with several papers that study traffic congestion at signalized intersections. According to Haight (1959) and Darroch (1964) as reported in Tanackov et al. (2019), applying queueing theory in solutions for signalized intersection has a classic theme status and tradition longer than 60 years, with developed analytic models and approaches. Vehicular traffic researches have been reported to be dominant on signalized intersections Tanackov et al. (2019). Many researchers and scientists had contributed immensely to the development of queueing model of traffic flow at intersections (both signalized and unsignalized). Ali et al. (2018) studied the assessment and comparison of performance of traffic flow at four signalized intersections and two roundabouts using SIDRA 5 software. Adewuyi et al. (2019) study how to analyze and assess traffic congestion on major roads and its intersections (signalized and unsignalized) in INLG Area of Oyo State, Nigeria. Likewise at unsignalized intersections, Tanackov et al. (2019) derived the probability of the state of a queueing system with a short lane on a finite capacity for taking a left turn and shared lane of infinite capacity. The authors also affirmed that significance of signalized intersections has proven to be more important than unsignalized intersections as it services a higher part of the traffic flow. Hence, the study focuses on analysis of traffic flow at signalized intersections.

The third streams of literature are those studies on causes and effects of traffic congestion. There is a very rich literature on causes and effects of this global problem. To mention a few, Adewuyi et al. (2019)Achyuta and Bansal (2016); Ackaah (2019); Agyapong and Ojo (2018); Muhammed and Faraj (2014); Olagunju (2015) and references therein addressed the causes and effects of the mobility problem in different countries and proffered mitigation strategies suitable for their study areas. The studies above on analyzed traffic information and assessment motivated the study as well.

3. RESEARCH METHODOLOGY

This section introduces model formulations, basic queueing analysis and methods of data acquisition using traffic counts, observations and oral interviews. All these are considered for the purposes of presentation to minimize vehicular traffic congestion in order to avoid road accidents, delay in meeting up appointments and loss of revenue. The figures below shows Ibadan city and Sango (study area).

3.1 Study area

In the city of Ibadan, as population is increasing with the volume of the vehicles, the traffic congestion has as well increased. It therefore necessary to minimize the waiting time in queuing system as experienced in traffic congestion. The information received at the Oyo State Licensing office and Town Planning Department of Ibadan North Local

Figure 1: Map of Ibadan and road networks   Source: Google Map

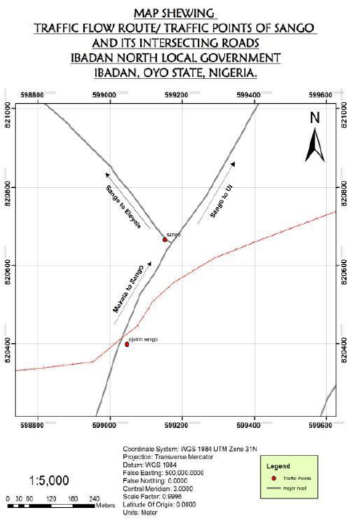

Figure 2: Map of Sango area and its intersecting roads   Source: Adewuyi et al. (2019)

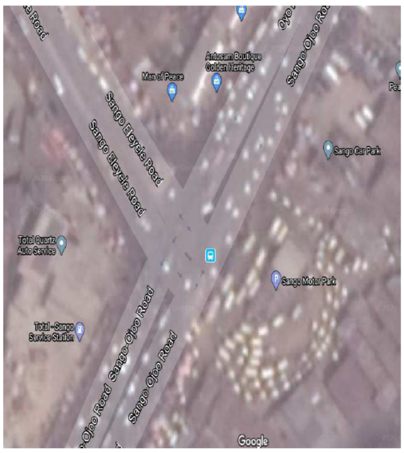

Figure 3: Satellite Image of Sango Road Junction   Source: Google Map

Government revealed that the routes that linked to Sango intersection were dualized in 2006, which is about fourteen years ago. However, the traffic congestion that necessitated the dualization has gradually returned doubly in size due to increase in demand for private transportation as well as the strategic location of Sango. In addition, Sango intersection provide link to some public and private institutions like University of Ibadan, The Polytechnics, Ibadan, the Nigeria

Institute of Social and Economic Research (NISER), Bodija International market, Ventura club house, inter-city parks and some religious worship centers. The government of Oyo State is making frantic effort at traffic management and congestion control through Oyo State Road Transport Management Agency (OYRTMA). However, Sango area still constitutes one of the major roads of the Ibadan North Local Government area that is worth investigation for improved traffic. Additional statistics of the study area can be found in Adewuyi et al. (2019).

3.2 M/M/1 model and basic analysis

Generally, a queue is formed when either units requiring service, referred to as customers, wait for service or the service facilities, stand idle and wait for customers (Sharma, 2014). The theory of queues involves the mathematical study of these waiting lines and explains various characteristics of the waiting line, such as waiting time or length of queue (Vandaele et al., 2000). Kendall-Lee notation is the most widely used classification scheme of different models in queueing theory and is of the form $\{(a/b/c) : (d/e)\}$, where the symbols a, b, c, d and e respectively indicate the arrivals distribution, service time distribution, number of service channels (servers), the system capacity and the queue discipline. The next Table 1 gives the overview of parameters used for vehicular traffic flow in this paper: The queueing

Table 1: Nomenclature

λ	Mean customer arrival rate
μ	Mean service rate
ρ	Traffic intensity
L	Mean number of customers in the system (L_s) or queue (L_q)
W	Time in the system (W_s) or queue (W_q)

model adopted for the work is M/M/1 refers to negative exponential arrivals and service times with a single server. It assumes a Poisson arrival process and some other assumptions which include infinite population size of customers, first come first serve queue discipline, independent customers, etc., can be found in Prasad and Usha (2015). Based on the parameters above, the relationship among performance measures true for all queuing models follows:

$$\text{(i)}\ L_s = \frac{\lambda}{\mu-\lambda} \quad \text{(ii)}\ L_q = \frac{\lambda^2}{\mu(\mu-\lambda)} \quad \text{(iii)}\ W_s = \frac{\lambda}{\mu(\mu-\lambda)} \quad \text{(iv)}\ W_q = \frac{1}{\mu-\lambda} \quad \text{(v)}\ \rho = \frac{\lambda}{\mu}$$

For a stable system, the traffic intensity ρ (or utilization factor of the server) should always be less than 1.

3.3 Data sources

This paper uses the primary source of data recorded within the working period of morning, afternoon and evening sessions in Sango along three routes (A (Mokola to Sango), B (Ojoo to Sango) and C (Polytechnic to Sango)) as indicated by the arrows in Figure 3 below. The traffic counts using manual counting by direct observations were conducted for 2 weeks between hours of 7:00 am to 10:00am, 2:00pm to 4:00pm and 4:00pm to 7:00pm. Late night hours were neglected because the traffic flow is drastically reduced. The data obtained are summarized in Table 2.

Table 2: Traffic Data at Sango Intersection, Ibadan, Nigeria.

LOCATION	SESSION	ARRIVAL	TIME	SERVICES	TIME
		Average No car	Min	Average No cars	Min
Route A	Morning	11	0.43	15	0.40
Route B	Morning	12	0.52	17	0.43
Route C	Morning	06	0.80	08	0.35
Route A	Afternoon	16	0.48	17	0.43
Route B	Afternoon	17	0.68	19	0.58
Route C	Afternoon	14	1.07	16	0.65
Route A	Evening	17	0.53	21	0.48
Route B	Evening	19	0.75	22	0.53
Route C	Evening	10	0.47	15	0.37

4. DATA CALCULATIONS, ANALYSIS AND RESULTS

This section discusses computation of performance measurement parameters to determine the behavior of a queueing system. This was followed by the discussion of results.

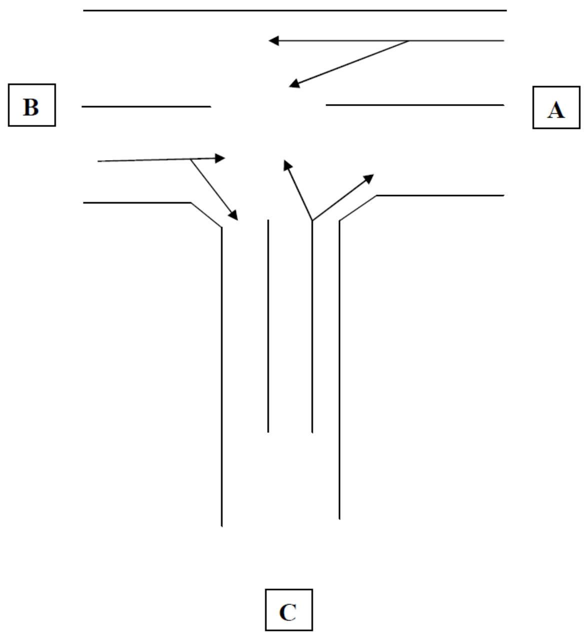

Figure 4: Schematic illustration of Sango intersection

4.1 Computation of queueing parameters

The data from Table 2 were used to obtain the mean performance parameters of the M/M/1 queue model based on formulae (3.2 (i) - (v)). Details of calculation can be found in Anokye et al. (2013) and Odhiambo et al. (2017).

Table 3: Traffic Data at Sango Intersection, Ibadan, Nigeria.

LOCATION	SESSION	λ	μ	ρ	L_s	L_q	W_s	W_q
Route A	Morning	26	38	0.6842	2	1	0.0833	0.0570
Route B	Morning	23	40	0.5750	1	1	0.0588	0.0338
Route C	Morning	8	23	0.3478	1	0	0.0667	0.0231
Route A	Afternoon	33	39	**0.8462**	6	5	0.1667	0.1410
Route B	Afternoon	25	33	**0.7577**	5	2	0.1250	0.0947
Route C	Afternoon	13	25	0.5200	1	1	0.0833	0.5185
Route A	Evening	32	44	**0.7273**	3	2	0.8330	0.0606
Route B	Evening	25	42	**0.5952**	1	1	0.0588	0.0350
Route C	Evening	21	41	0.5122	1	1	0.0500	0.0256

4.2 Discussion of Results

We begin with the analysis of the results and follow with general discussion of the system. According to the Table 3, we discuss the traffic flow situations based on routes for all sessions in the first instance unlike the studies of authors Odhiambo et al. (2017), Ekeocha and Ihebom (2018) and Anokye et al. (2013) that was based on sessions. This manner of discussion affords the opportunity to compare our results with two of our routes considered in Adewuyi et al. (2019).

Route A: The results on Table 3 showed the busy nature of this route for all sessions. Presence of public utililies is one of the causes of traffic congestion on this route. The traffic intensities are: 0.6842, 0.8462 and 0.7273 for morning, afternoon and evening sessions respectively. According to the stability condition ($\rho < 1$) , traffic situations are interpreted as stable but not very smooth traffic, unstable but critical traffic flow and relatively stable but unsmooth traffic flow respectively.

Route B: The traffic is relatively congested here for all sessions. Presence of public utilities such as the University of Ibadan, Shopping malls and parks are the causes of traffic congestion on this route. The traffic intensities are recorded as 0.5750, 0.7577 and 0.5952 respectively. The study revealed a stable and smooth, relatively stable but unsmooth and stable and smooth traffic respectively.

The two routes above are among major roads analyzed and assessed in (Adewuyi et al., 2019) and were reported to be congested for all sessions. The results of our queueing based analyses were in agreement with authors ' geospatial approach which confirms the effectiveness of our method.

Route C: The derived parameters are 0.3478, 0.5200 and 0.5122 for morning, afternoon and evening sessions respectively. The morning session revealed an indication of a very stable and smooth traffic which seems to be the best traffic condition in comparison with other sessions, while afternoon and evening indicated a stable and smooth flow of traffic.

Analysis of the data collected at Sango intersection revealed proximity to a under perfect system. This is so, since the server at each channel was not able to serve all the cars in waiting queue when the server resumes work especially on routes A and B because of the timing of the traffic light. This study reveals that traffic intensity is highest in the afternoon and in the evening session on routes A and B for the following reasons: the park for campus shuttle (Ibadan Polytechnic and University of Ibadan), a park for commercial motor bikes riders, inter-city park, a big market, a shopping complex and other road side hawkers are all in existence within this same environment. All these contribute to the traffic congestion at Sango intersection. The afternoon and evening session is the period for market women to open their shops and stalls and other commercial activities.
Consequently, route C is relatively stable and smooth which implies that a chaotic situations may arise early part of the night, say 7:00pm -10:00pm when majority of road users (from markets, parks, shopping complex, etc) are leaving for their respective homes. However, the study did not take care of this situation and left for further study.

Table 4: Traffic Data at Sango Intersection, Ibadan, Nigeria.

	Arrivals	Time(min)	λ	Service	Time(min)	μ	ρ
Average results	13.56	0.637	22.89	16.67	0.464	36.11	0.6184

5. CONCLUSION

In this work, we have measured the traffic flow at the study area for all sessions and examined features of queue built up with data and presented the M/M/1 model for traffic situations in Sango. It therefore gives insight into possible undesirable levels of vehicular traffic congestion. Results in Table 4 are generated from Tables 2 and 3 to draw interesting conclusions. From the table we can conclude that the rate at which vehicles arrive in the queueing system is approximately 22.89 vehicles per second and the service rate is approximately 36.11 vehicles per second. The traffic intensity index is at a maximum of 0.8462 and at a minimum of 0.3478 with a general mean of 0.6184. This traffic intensity is relatively high (an indication of stable but not a very smooth flow of traffic) and not sustainable despite the dual carriage of the routes. In order to improve the capacity and safety of road users, urgent consideration for roundabout construction at the intersection is recommended. The following mitigating strategies are further suggested to minimize waiting time in the study area:

- Installation of a digital traffic light at Sango intersection rather than analogue one that is there presently. This will enhance a smooth traffic flow system.
- The timing of the traffic light on routes A and B should be adjusted from what it is now (45 seconds) to 60 seconds, so that most of the cars in waiting queue could be served.
- More of public transport system should be introduced so that people do not travel with their personal cars to their places of work, thus reducing congestion on the road, which in turn boosts productivity.
- Consideration for a flyover should be given top priority at Sango intersection.
- Establishment of a specialized traffic radio.
- Continual research to investigate from time to time the traffic situation in the selected area.
- Promote the use of mobile phones and internet services.

Among other challenges, vital data that can adequately support this kind of research could not be secured. For instance, traffic information and human travel information for analysis are lacking. Likewise, statistics of vehicles registration to back up the claim of tremendous motorization among road users could not be obtained due to their classification as "sensitive". Despite the support of licensing and town planning offices, the study required much more in terms of up-to-date data and equipment. Traffic professionals working closely with traffic enforcement agencies can take the study up.

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