(RESEARCH ARTICLE)

Analysis of traffic congestion at Jattu Junction (Auchi) with queuing theory using TORA and SIDRA softwares

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Abstract

Traffic congestion is a major problem in developing country like Nigeria. Traffic congestion at intersection is on the increase in Auchi metropolis as the numbers of vehicles increases there, which eventually lead to traffic delay and traffic crash casualties. For this research, an Markovian/Markovian/1 (M/M/1) queuing model was used to analyse the queuing characteristic of the intersection to determine the arrival rate and service rate of the vehicles. An operation research software known as Temporary-Ordered Routing Algorithm (TORA) version 2.5 was used to analyze the arrival and service time data obtained to determine the operating characteristics of the M/M/s model for each of the intersection. The result showed that the average traffic intensity of the intersections was more than the optimal traffic intensity of 0.5 indicating the intersections were congested. Signalised & unsignalised Intersection Design and Research Aid (SIDRA) software was further used to analyse the intersection to access the performance measure of the intersection. The result from the SIDRA software also confirmed that the intersection was congested. It was recommended that the capacity of the intersection should be increased; government should construct traffic signals and enforce law to sanction motorists that inappropriately park along the road sides close to intersection; appropriate government agency should carry out more public enlightenment on the use of traffic signal and other roads signs; and alternative roads should be constructed to mitigate the congestion at intersections.

Keywords: Intersection; Queuing model; Traffic Congestion; Traffic intensity; SIDRA software

1. Introduction

Nigeria's road infrastructure and development has lagged behind, prominently in most part of the country and most noticeable in rural areas. The main problems that exist along the road networks are the chaotic traffic intersections, road occupancy, low road capacity, backward transport facilities and mixed traffic interference. As the road intersections serve as the throat for the urban/rural traffic, their capacity is much lower than the total sum capacity of all road sections entrance for the intersection. The main reason for traffic congestion and bottleneck is shortage in intersection's capacity, rather than the road capacity.

An intersection is an at-grade junction where two or more roads meet or cross. Intersections may be classified by number of road segments and traffic control. According to [1], intersections are classified according to the number of road segments (arms) involved as three-way, T-junction, Y-junction, four-way, five-way and six-way intersections. Three-way intersection is a junction between three road segments (arms), T-junction and Y-junction occur when two arms form one road, four-way intersection usually involves a crossing over of two streets or roads, five-way intersection exits especially in urban areas with non-rectangular blocks and six-way intersection usually involves a crossing of three streets at one junction. For a signalized intersection to be successful, intersections have to be designed in form of islands

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with conformity with traffic flows, phase signals have to be set up and true cycle times to be calculated with respect to flow volumes [2].

According to [3, 4], level of service (LOS) qualitatively measures both the operating conditions within a traffic system and how these conditions are perceived by drivers and passengers. It is used to analyse intersections by categorizing traffic flow (q) and assigning traffic quality levels based on parameters like vehicle speed, density and congestion. Speed-flow-density relationships are the main determinant of LOS of a highway segment under ideal conditions. It is qualitative measure of the effect of speed and travel time, traffic interruptions, freedom to manoeuvre, safety, operating cost and driving comfort and convenience. LOS is of six types namely A, B, C, D, E and F, its operating condition diminishes from A to F. The minimum LOS per leg for arterial roads and sub-arterial Main Street are C and D respectively.

Queuing theory is a major applied mathematics topic that deals with phenomenon of waiting and arises from the use of powerful mathematical analysis to describe production processes. It is the branch of operational research that explores the relationship between the demand on a service system and the delays suffered by the users of that system [5, 6]. Queuing models are used to represent the various types of queuing systems that arise in practice, the models enable in finding an appropriate balance between the cost of service and the amount of waiting. They provide the analyst with a powerful tool for designing and evaluating the performance of queuing systems and there are five different types namely M/M/1, M/G/1, M/M/c, M/G/ ∞ and G/G/1 [7, 8, 9] where M and G are Markov and General respectively but only M/M/1 was used in this research.

M/M/1 queuing model is a queue system whose model follows Poisson arrivals, exponential service and single-channel service or server. The assumptions associated with this type of queuing model are arrivals at server on a first in and first out (FIFO) basis, no balking, no reneging but are random; arrivals are independent of each other; arrivals follow Poisson distribution; service times follow negative exponential distribution; service times are variable, independent but the average is known; average service rate (μ) is greater than average arrival rate (λ); and arrival rate and service rate must be for the same time period. Balking occurs when someone leaves the queue when the line is too long while reneging occurs when someone leaves when the queue is moving too slowly.

[10] described queue discipline as the order in which customers in a queue are served. The queuing disciplines are first in first out (FIFO) when customers are served in order of arrival, last in first out (LIFO) when the last customer to arrive is served first, service in random order (SIRO) when customers are served at random, processor sharing (PS) when customers are served at the same time and priority ordering (PRI) when customers with the highest priority are served first.

TORA is an operation research software. It is an algorithm, a mathematical set of programs, for routing data across wireless mesh networks. It was developed by Vincent Park & Scott Corson at the University of Maryland and the Naval Research Laboratory. Operation research is a qualitative approach that solves problems, using a number of mathematical techniques. It is the scientific study of operations for the purpose of making better decisions. SIDRA software package is used to check the performance measure of the intersection. It is used for intersection (junction) and network capacity, level of service and performance analysis, signalised and unsignalised intersection, network timing calculations by traffic design, operations and planning professionals. Standard performance measures such as delay, queue length and number of stops as well as measures to help with environmental impacts and economic analysis are provided. SIDRA offers a variety of output features that can help in the analysis and reporting of model performance. The core performance elements that should be assessed for any intersection modelling using SIDRA are degree of saturation (DOS), 95th percentile queue distance, LOS, vehicle delays and number of vehicle stops.

2. Material and methods

2.1. Brief description of the study area

Jattu is a town in Edo state, Nigeria. It is the headquarters of Uzairue Clan in Etsako West council of Edo state. It is located within latitude 7°05'N and longitude 6°17'E and bounded by Auchu (the second largest city in Edo State), Afashio, Elele/Iviamho, Ayua and South Ibie. It has a population of 27,876 which make it the largest in Uzairue Clan [11]. Notable locations in Jattu include the Palace of the Ogieneni of Uzairue, Jattu New Market, St. Philips Catholic Church, Central Mosque, Notre Dame Catholic hospital, NTA Uzairue, Jattu Grammar School, General Post Office and Divisional Police station.

Jattu intersection is a four-way intersection since the express road from Abuja and Benin meets here. It is created on the highway by four (4) collectors namely Okella, Jattu, Secretariat and Aviele roads as shown in Figure 1. The design vehicle on this intersection is motor cycle in the sense it has the highest traffic composition (54.3%) when compared to the other vehicle types plying the intersection [12].

Figure 1: Jattu intersection showing the road channels

2.2. Material

The materials used for this research were video cameras, audio recording devices, twenty-four (24) persons recording traffic parameters, coding sheets, TORA and SIDRA softwares.

2.3. Methods

In this research, the pattern of arrival follows Poisson distribution and service time follows exponential distribution and the server is more than one. The M/M/s queuing model was adopted based on the queuing characteristics of the intersections.

2.4. Data collection

The data were collected at Jattu intersection. The system comprises of multiple servers. The arrival pattern and service rates follow Markovian distribution with multiple servers in an infinite manner. The data were generated by manual means using audio recording devices and video cameras by three sets of different team of 8-persons stationed at the stop line of every junction with two persons at each of the four approaches/channel to the intersection monitoring the number of cars arriving on queue and number of cars leaving the queue from 7:00am to 7:30pm. The peak hours was further classified into morning (7:01-11:20am), afternoon (12:01-4:00pm) and evening (4:01-7:30pm) for each of the channel of the intersections. A total of twenty-four (24) persons participated in the data collection and recording of the arrival and service time for five (5) working days. The arrival time and service time were gotten from the camera and the audio recording devices. The data were recorded on coding sheet designed by the researcher.

2.5. Data processing

Appropriate statistical techniques such as mean for grouped data was used to compute the average arrival time and service time for each of the intersection. TORA version 2.5 was used to analyse the arrival and service times data obtained to determine the operating characteristics of M/M/s model for each of the intersections. The average arrival

time and average service time gotten from the video camera and audio recording devices were inputted into the software which gives the arrival rate, service rate and the utilization factor value. SIDRA software was then used to assess the performance level of the intersections by using output from the TORA software as input. The resulting core performance elements got were degree of saturation, 95% back of queue, level of service, vehicle delays and number of vehicle stops were used to assess the intersection modelling.

3. Results and discussion

The J1 through J4 are the channels leading to the intersection. Table 1 shows the average arrival rate is more than the average service rate during the morning, afternoon and evening sessions. The average daily traffic intensity is 0.663 which is higher than the 0.5 optimal traffic intensity value confirming that the intersection is congested.

Table 1: Jattu Junction Traffic Data

JD	Morning session			Afternoon session			Evening session		
	AR (veh/hr)	SR	TI	AR (veh/hr)	SR	TI	AR (veh/hr)	SR	TI
J1	9.06	7.75	0.689	8.91	7.97	0.482	9.06	7.75	0.701
J2	7.79	7.75	0.647	8.90	7.95	0.680	9.06	7.75	0.647
J3	9.06	7.95	0.868	7.91	5.82	0.745	9.06	7.74	0.676
J4	7.75	7.60	0.641	7.60	7.87	0.639	7.60	7.80	0.535
Average	8.42	7.76	0.711	8.33	7.40	0.637	8.69	7.76	0.640

N.B.: JD, AR, SR and TI means junction description, arrival rate, service rate and traffic intensity respectively.

Table 2 shows the result gotten from SIDRA software. The degree of saturation of the intersections is 3.136 which are higher than the 0.85 maximum practical degree of saturation for roundabouts and sign-controlled in intersections implying the intersection is congested. The level of service gotten for the intersection is Level of Service F (LOS F) which is lower than the allowable minimum LOS C on road, which shows that the operating conditions are highly unstable with constant queuing. The total control delay as well as the total demand flow is high in Jattu junction as the junction is linked to an express road. The effective intersection capacity is 1722veh/h which is less than the total demand flow of vehicles (5403veh/h) through the intersections resulting to traffic congestion at the intersections.

Table 2: Performance level of the intersections using SIDRA software- Hourly values

Junctions	DOS	LOS	TCD (veh-h/h)	TES (veh/h)	TDF (veh/h)	PSC	EIC (veh/h)	EBOQ (veh)	PQ
Jattu	3.136	F	633.77	31181	5403	-72.9%	1722	256	1.00

N.B.: DOS, LOS, TCD, TES, TDF, PSC, EIC, EBOQ, PQ means degree of saturation, level of service, total control delay, total effective stops, total demand flow, practical spare capacity, effective intersection capacity, 85th back of queue and proportion queued respectively.

The minimum allowable Back of queue is 95%, which is higher than the Back of Queue of 85 % which means that the queue length has 15 percent probability of being exceeded during the analysis time period which is above the maximum 5-percent probability to be exceeded, and this resulted to a long queue length at the intersections. The proportion queued represents vehicles which have to wait behind other vehicles on the subject approach before arriving at the stop line or the probability of finding a vehicle waiting on the approach, which can be anything between 0 and 1. The proportion of vehicles queued at the intersection is 1.00, which implies that the intersection is congested.

4. Conclusion

The congestion of the intersection is mainly at the peak hours of the day (morning and evening). The SIDRA software analysis report shows that the flow of vehicles through the intersections is more than the capacity of the intersections. The degree of saturation of the intersections from the SIDRA software analysis is more than the 0.85 maximum practical degree of saturation for round-about. The Level of Service (LOS F) of the intersections is below the allowable minimum level of service (LOS C) for each leg/lane.

Compliance with ethical standards

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Disclosure of conflict of interest

All authors declare that there is no conflict of interest.

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