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Estimation of traffic Delay Using Queuing model

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Abstract

The introduction of tricycles and the removal of power bikes in many cities of Nigeria have made the transport system more complex and increasingly congested. Traffic delay due to incidents is estimated using a deterministic queuing model that assumes that traffic arrival rate, capacity reduction and incident duration can be identified exactly. Major road junctions and link roads in the city of Warri and environs experience traffic jam or road block daily. This work determines maximum delay time on a link road to a major road junction. A queuing model of the traffic situation has been formulated and illustrated numerically.

Keywords: Traffic congestion, incident duration, queuing model, dissipation rate, flow rate.

1.0 Introduction

Traffic congestion causes delay of vehicular movement and negative environmental effects arising from higher fuel consumption and combustion. Traffic flow is a stream of vehicles (particles) subjected to the law of fluid dynamics. Traffic congestion may be as a result of incidents on the highway. Incidents such as broken down vehicle along the road, pot holes (bad spots), wood or trees falling across the road, wrong parking or vehicular accidents. According to Skabardonis et al. [1], incident is any occurrence that affects capacity of the roadway. Traffic congestion leads to decreasing flow rate. In this work, we present a queuing based approach for estimating delays caused by traffic incidents. We are worried about the traffic situation at PTI road and the entire road junctions in Warri city. The blockage of the Eku axis of the PTI junction was as a result of the beautification project of the Government of Delta state. What originally took about 2 or 3 minutes depending on the density of the traffic, now takes about 15minutes to 1hour . Hence, it is the aim of this paper to present a model for estimating traffic delay. For performance evaluation of freeways under incident conditions, it is important to estimate average delays due to incidents. This is possible in situations where there are intelligent transport system (ITS). Applications such as route guidance system (RGS) and freeway traffic management system (FTMS) are good examples of ITS. These applications provide information that help individual drivers identify optimal routes based on current traffic conditions. But these systems also have their short coming in the sense that they only provide information like when the incident occurred or detected and current status of the incident (removed or not). However, the link demand volume is not stated. In real time situations, the incident duration is unknown.

Fu and Rilett [2] were of the view that incident delay is best modeled by a random variable that represents the stochastic characteristics associated with the incident rather than using a deterministic value. They noted that the variance of incident delay is ignored when using a deterministic model of incident duration in real- time situations. Baykal-Gursoy et al.[3] presented a comparative approach of delay estimation for traffic flow interrupted by incidents using simulation models and queuing models. Previous delay estimation studies under incidents usually employed either queuing models or various traffic simulation models consistent with shockwave theory proposed by Lighthill and Whitam[4]. Morales [5] used deterministic queuing models as an analytic procedure for estimating delay under a specific incident scenario. Chow [6] and Wirasinghe [7] used shock-wave theory in estimating delays and showed that total delay estimated using shock wave analysis technique is identical to that obtained using deterministic queuing models. Rakha and Zhang [8] demonstrated the consistency in delay estimates derived from queuing theory and shock-wave analysis and highlighted the common errors that are made with regard to shock-wave analysis delay estimation. Notable also is the contribution of Melout et al. [9] which developed a robust decision support tool based on simulation optimization for mitigating traffic congestion. Al- Deek et al [10] used shock-wave theory to develop a method to estimate incident delays for cases both with single and multiple incidents. Several

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models focus on individual vehicles and their driving behaviours. Some with exact optimization approaches such as the cutting plane algorithms (Pesenti et al. [11]), joint optimization problem following Wardrops principles (Chiou [12]) and using different types of modeling programmes (Maze and Kamayab[13]; Ukkusuri and Waller[14). While others with heuristic approaches include, an ant-colony based metaheuristic (Poorzahedy and Abulghasemi, [15]), particle swarm optimization (zhang and Gao [16]). However, in this work, we are interested in the causes of traffic delays in the city of Warri and environs and the maximum delay time for a small incident at a major road junction. We will also make suggestions on how delays could be reduced or eliminated to give way to free flow of traffic, especially at road junctions. In section 2, we present the assumptions of queuing model as it affects traffic flow. In Section 3, we will introduce the method utilized to evaluate the traffic delay while a numerical illustration is given in section 4.

2.0 Assumptions of the Model

Since this model is deterministic, the probability distributions are not required to describe the arrival and the service patterns. Here, the arrival rate is random and constant and the service times are also constant except interrupted by incident. The service pattern is in the order of first come, first serve basis. As such, if the arrival rate is $\frac{1}{a}$, then the inter arrival time will be **a** . similarly, if the service rate is $1/_b$, then the inter-service time will be b. Thus,

i) When b<a, the service time is less than the inter-arrival time. This implies that no car will have to wait and the queue will go on diminishing.

ii) When b=a, the queue length will remain constant. Also , no car will have to wait.

iii) When b>a, the number of cars on the link road increases indefinitely. Thus, oncoming vehicle will have to slow down and possibly wait for some time before crossing the road junction.

3.0 Queuing Model

Using the Kendall's notation (A|B|C) for queuing models where A represents the arrival process, B representing the service process and C denoting the number of servers or the capacity of the queuing. The arrival process and the service time are independent of each other. The arrival rate depends on the number of vehicle already on the road. The model is assumed to have a Poisson arrival while the service times is assumed to adopt exponential process. In analyzing vehicular traffic flows, the service rate (vehicular travelling speed) is assumed to be a decreasing function of the number of vehicle on the link road that represent the congestion caused by traffic volume. In this model, vehicles are considered travelling on a road link which is subject to traffic incidents. The space occupied by each vehicle on the road segment is considered as one 'server' which starts service as soon as a vehicle joins the link and carries the 'service' (the act of travelling) until the end of the link is reached. When a traffic incident happens, either all links leading to the road junction or part of a lane is closed to traffic. As a result, all vehicles coming from either direction towards the incident slows down even if all the lanes are not closed. We model these interruptions as a partial failure where servers work at a reduced service rate. The service rate of all servers are restored to their normal level once the incident is cleared.

Let λ denote the arrival rate and μ denote the service rate(departure rate). If there are no incident or service interruption, then the average travel time is an A|B|∞ queuing system experiencing service interruptions, the expected number of vehicles on the link can be represented as;

$$E(No.of\ \ vehicles\ \ on\ the\ link) = \left(\frac{\lambda^2}{\mu(\mu-\lambda)} + \mu\right) e^{\frac{\lambda}{\mu}l} \qquad (1)$$

That is, the number of cars present on the queue plus the number of new arrivals and the ones crossing the road junction. l is the length of the link road in question. The average travel time on the link is the expected number of vehicles on the link given the arrival rate; that is

$$T = \frac{E(No.of\ vehicle\ on\ the\ link)}{\lambda} \qquad (2)$$

The average number of vehicles on the link (k) implies that the link cannot take more than N number of vehicles

$$k = \left(\frac{\lambda}{\mu}\right)^N \left[\frac{1-\lambda/\mu}{1-\left(\lambda/\mu\right)^{N+1}}\right] \qquad (3)$$

The arrival rate is random and constant such that without any incident occurring, traffic flow is infinite. However, if an incident occurs along the stretch of road (road link), all the vehicles plying that link road will be forced to slow down or stop before the incident spot. During this period, the queue grows and the link road can only accommodate N number of cars. Vehicular movement is virtually at a halt and the delay time becomes higher. Thus, the vehicle reaching there, after the incident, experiences maximum delay. Vehicle arriving the spot after the incident has been cleared and the queue dissipated, experience no delay. The maximum time of the incident is

$$T_1 = T^* + \left(\frac{\mu - \mu^*}{\mu - \lambda}\right)k \qquad (4)$$

If the vehicles arriving at the incident spot start forming queue and the queue will not be dissipated until after the vehicles traverse the link then the time the incident is cleared is a function of the reduced capacity, arrival rate and incident duration . Therefore, time taken is

$$T_1 = T^* + (k)\frac{\lambda^*}{\mu} \qquad (5)$$

The incident duration such that arrival time of the individual vehicle coincides with the time the incident is cleared can be derived from equation (4)

$$D = \frac{\mu - \lambda}{\mu - \mu^*}\left(T^* - N\right) \qquad (6)$$

But if the incident duration is such that the arrival time of an individual vehicle coincides with the time when the maximum delay occurs, then T_1 will be greater than N and the vehicles will experience maximum delay. Thus,

$$D = \frac{\lambda}{\mu^*}\left(T^* - N\right) \qquad (7)$$

Therefore, the delay is a function of the incident duration D, the arrival rate and the capacity of the link road. The maximum delay time, T* on the link is the time lag between when the incident occurred and vehicles begin to form queues to the time when the incident is cleared and the vehicles on queue dissipates.

$$T^* = T + \frac{\lambda}{k} \qquad (8)$$

4.0 Numerical Illustration

A Philanthropic group is interested in knowing the maximum delay experience experienced during an incident at major road junctions in Warri metropolis. They are also interested in proffering solutions to alleviate the stress encountered by road users. On a particular day, a petrol tanker broke down right at the middle of the express way by a road junction. Coincidentally, an on coming big lorry over loaded with garri and plantain ran into the parked petrol tanker, somersaulted, dislodging its content on the tarred road causing a serious road block. If the distance from the road junction to the link road 'round about' is 2.5km and the distance between the junction and adjacent link road is about 2km , calculate the delay time on the link roads. Also, if the arrival rate of vehicles at the road junction is 1 car in every 5 seconds and the time it takes to cross the road junction is 3 cars on the average per 10 seconds per 200M stretch of the road.

Solution

If one car on the average arrives in every 5 seconds , then 12 cars on the average will arrive in every 1minute and 720 cars in 1hour on the average. Thus,

λ = 12 vehicles per minute

μ = 18 vehicles per minutes without any incident.

Probability that a vehicle will have to wait at the roads junction is $\lambda/\mu = 2/3$

that is, the traffic intensity is 0.667. The expected number of vehicles on the link from (1) is given by

$$E(x) = \left(\frac{\lambda^2}{\mu(\mu-\lambda)} + \mu\right)e^{\frac{\lambda}{\mu}l} = \left(\frac{144}{18(6)} + 18\right)e^{\frac{\lambda}{\mu}l}$$

$$= (19.33)5.078 = 98.16$$

From the lengths of the 2 link roads *l* to the junction is 2.5km and 2km respectively. From the 2.5km , we have E(x) = 98 vehicles on the average.

From (2), the average travel time is

$$T = \frac{E(x)}{\lambda} = \frac{98.16}{12} = 8.18 \text{ mins}$$

$$K = \left(\frac{\lambda}{\mu}\right)^N \left[\frac{1-\frac{\lambda}{\mu}}{1-\left(\frac{\lambda}{\mu}\right)^{N+1}}\right]$$

$$= \left(\frac{2}{3}\right)^5 \left[\frac{1-\frac{2}{3}}{1-\left(\frac{2}{3}\right)^6}\right] = 0.132(0.365) = 0.048$$

$$T^* = T + \frac{\lambda}{k} = 258.18 = 4\text{hr } 18\text{mins } 11 \text{ seconds.}$$

This result shows that if there is an incident at this particular road junction, chances are that the vehicle will have to wait for at least four hours eighteen minutes instead of about six minutes. If the incident is such that a vehicle experienced maximum delay, then the time it takes for the incident to be cleared is obviously greater than N

Conclusion

This work demonstrates that queuing theory provides a simple and accurate technique for estimating delays at road junctions and busy highways. Incident delay traditionally is estimated by using a deterministic model that assumes that duration and capacity reduction are known or can be estimated exactly. As a result of the nature of our roads especially the road junctions, vehicles usually experience delay. This situation is worst when there is an incident along the road. We have successfully used a numerical illustration to show that vehicles experience delay. Traffic delay and congestion due to incident on the road way has many detrimental effects which include loss of time, higher fuel consumption, vehicle emission and accident prone and greater transportation cost. Under certain circumstances, the incident delay has been shown to have a high variance even when the expected delay is low. The maximum delay occurs when the vehicle arrives at the incident location or the road junction first. It is our view that the state government through the beautification project should create a round about at the PTI – Eku road junction. This will reduce the length of time spent driving through Effurun –Sapele round about and Effurun –DSC round about. There should be a standby road maintenance agency from the arm of the government that handles minor repairs of bad portion of the road way and the filling of potholes within the state immediately detected rather than wait for the situation to degenerate. The maintenance agency should be assisted by the road safety officers and traffic wardens.

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