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Analysis of Queue at a Nigerian Toll Plaza

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ABSTRACT [ENGLISH/ANGLAIS]

The toll plaza on the Kaduna – Zaria highway has been modeled as a queue system by adapting the Makino model. Data collected on several days at the site was used to calibrate the model. Field conditions wherein a police check – point is encountered just before the toll plaza justified the idealization of the system as a two – stage queue. Allowance for U – turning in – between the police check - point and the toll plaza was made by incorporating a fixed probability, devised from field observations into the model. A wide range of vehicle arrival rates was simulated for each of the vehicle categories served. Results from the simulation correlated highly with actual observed simulations and the trends obtained conform with theoretical value. The result show that blocking in the system become pronounced at a certain critical value of the utilization factors used in the study which is equal to 0.0411 for cars, 0.0191 for Buses and 0.0005 for Truck. The information derived from the queue data and their distributions are useful in predicting arrival rates of vehicle at a point, and testing the randomness of traffic flow.

Keywords: Toll plaza, queue, arrival rate, utilization factors, model calibration

RÉSUMÉ [FRANÇAIS/FRENCH]

Le péage sur la Kaduna - Zaria autoroute a été modélisé comme un système de file d'attente en adaptant le modèle de Makino. Les données recueillies sur plusieurs jours sur le site a été utilisé pour calibrer le modèle. Conditions sur le terrain où un contrôle de police - point est rencontrée juste avant le péage a justifié l'idéalisation du système en tant que deux - la file d'attente scène. Provision pour U - tournant dans - entre le contrôle de police - et le point de péage a été fait en intégrant une probabilité fixe, conçu à partir d'observations de terrain dans le modèle. Une large gamme de taux d'arrivée des véhicules a été simulée pour chacune des catégories de véhicules servi. Les résultats de la simulation une forte corrélation avec les simulations réelles observées et les tendances obtenues sont conformes avec la valeur théorique. Les résultats montrent que le blocage dans le système deviennent prononcés à une certaine valeur critique de l'utilisation des facteurs utilisés dans l'étude qui est égal à 0,0411 pour les voitures, 0,0191 et 0,0005 pour les autobus pour les camions. L'information provenant des données de file d'attente et leurs distributions sont utiles pour prédire les taux d'arrivée des véhicules à un point, et de tester le caractère aléatoire de la circulation.

Mots-clés: Péage, la file d'attente, le taux d'arrivée, des facteurs d'utilisation, l'étalonnage de modèle

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INTRODUCTION

This study is concerned with the analysis of queuing process with random clearing of the queues. It aimed at identifying some of the factors which can lengthen or reduce waiting times in the toll plaza. The development of mathematical models for replicating inter – arrival (or arrival rate) and service time (or mean service rate) and their distribution in the traffic stream is one of the primary tasks undertaken in this study.

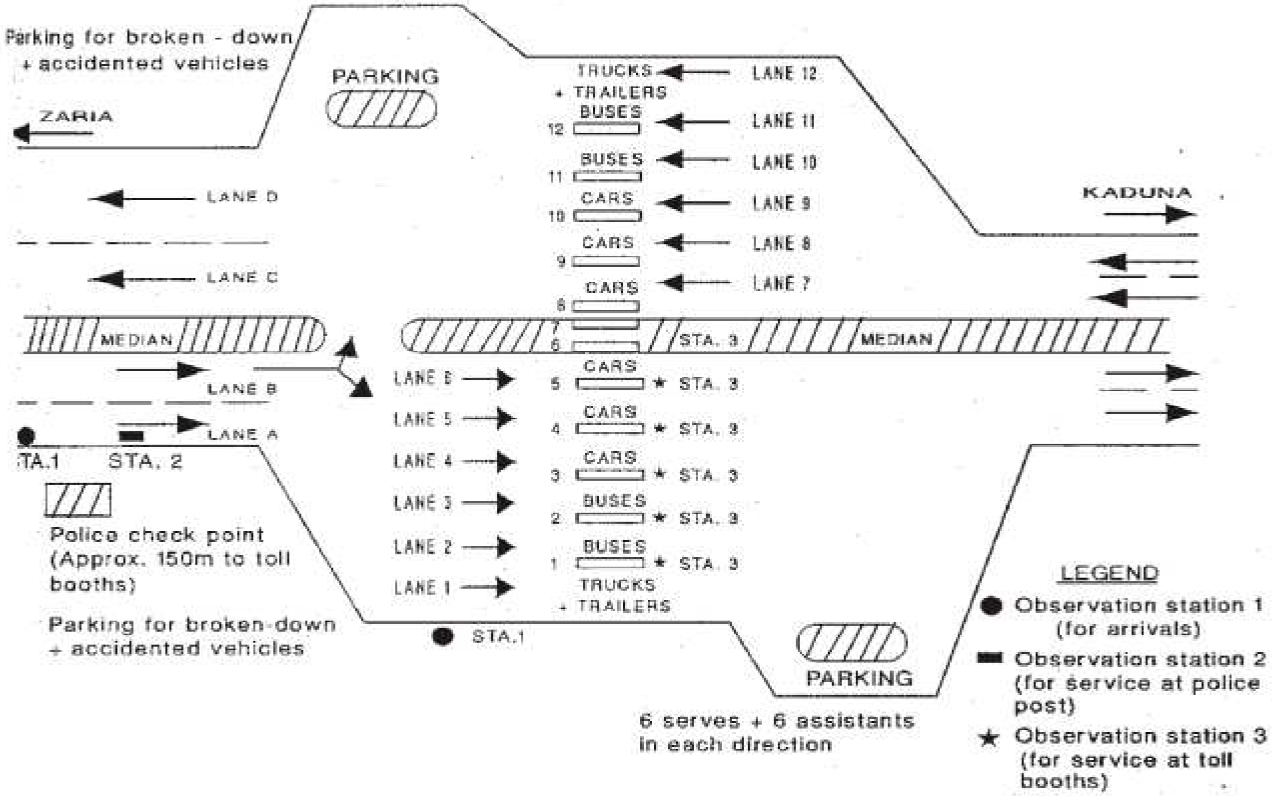
The work analyzed the queuing system and determined some system effectiveness measures which provide indices to a better understanding of the factors contributing to unsatisfactory toll booth service at the Kaduna – Zaria Road in Nigeria.

However, most common queuing situations are not single queues, and are soon modified to the two-channel system when patronage level appreciates. Many authors [1, 2, 3, 4, 5, 6, 7, 8, 9] present excellent approaches for the formulation and solution of this type of queuing problems.

STUDY AREA

The study site is located in the outskirt of Kaduna. It is about 12 kilometers away from Kaduna Metropolis, and two kilometers away from Maraba town. It lies in the Kaduna – Zaria express way and houses twelve toll collection booths. The express way is a dual carriage way with two lanes in each direction. The two lanes in each direction empty into six booth stations (via six traffic lanes) where motorists have to pay tolls. Just before entering the service lanes, motorists are forced to go through police checks. Thus, a queue builds up even before the toll gate is reached. The general disposition and layout is shown in figure 1 [7].

Figure 1: This figure shows diagrammatic sketch of the Zaria – Kaduna Expressway Toll Booth Station



Sources: [7]

MATERIALS AND METHODS

For the purpose of data collection, the study site was divided into four zones namely – (a) area before the police checking area; (b) police checking area; (c) waiting area, where vehicles queue just before the toll plaza (i.e. covering the toll booth lanes); and (d) Toll booths.

Data collection from each zone was designed to capture queue characteristics and other activities taking place at the particular zone. In order to obtain the needed parameters, the following activities were undertaking at each zone:

i. Collection of data on the volume of traffic on hourly basis, spanning 7 a.m. to 7 p.m. on carefully selected days (peak days of the week when passengers travel for weekends ie Friday, Saturday and Sunday). The duration of observation agrees with the recommendation by Pignataro [10].
ii. Collections of data on inter – arrival and service time distributions within the same period in each zone.
iii. Collection of data relating to number of vehicles making u – turn.
iv. Collection of data on the different vehicle types so as to determine the proportion (s) of vehicle types (e.g. cars, buses and trucks) in the traffic stream.

The data collectors were positioned so as not to interrupt the normal traffic flows in any way.

ANALYSIS

Typical hourly volume distribution patterns are shown in figures 2a and 3b which show periods of high traffic intensity and thus indicate the peak period(s). Interestingly, the weekend data gave the peak volume. Also sets of representatives (figures 2a, 2b, and 2c) on inter – arrival times for both police and tool booth queues in the manner discussed earlier, are presented.

Goodness of Fit Tests

The Kolmogorov – Smirnov test was used in evaluating the goodness of fit of the negative exponential model. The Observed data were analyzed to obtain the values of the negative exponential cumulative distribution function F (X) and compared with the value of observed relative cumulative frequency S_n (X). The maximum absolute deviations between F (X) and S_n (X), Dn were obtained and compared with the standard published values that corresponded to 0.05 level of significance, D_n (0.05). When D_n was greater than D_n (0.05), the null hypothesis, Ho, that the distribution function of the observed random variable is negative exponential was rejected but otherwise accepted (figures 3a, 3b, and 3c).

Figure 2a: This figure shows hourly traffic volume pattern at the police checkpoint on Friday (both lanes combined)

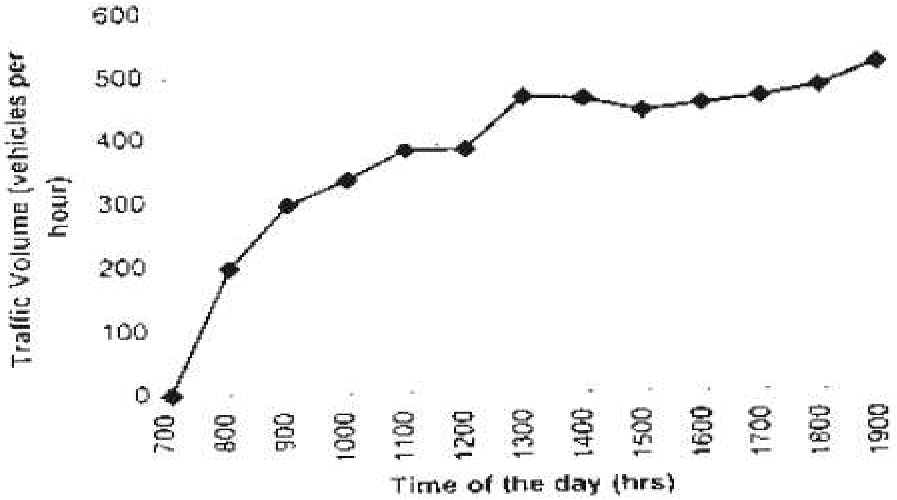


Figure 2b: This figure shows hourly traffic volume pattern at the police checkpoint on Saturday (both lanes combined)

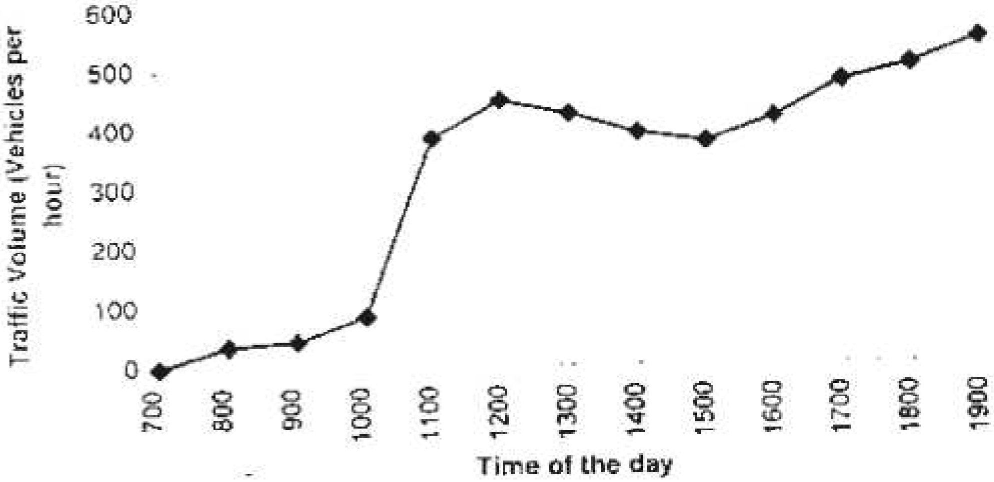


Figure 2c: This figure shows hourly traffic volume pattern at the police checkpoint on Sunday (both lanes combined)

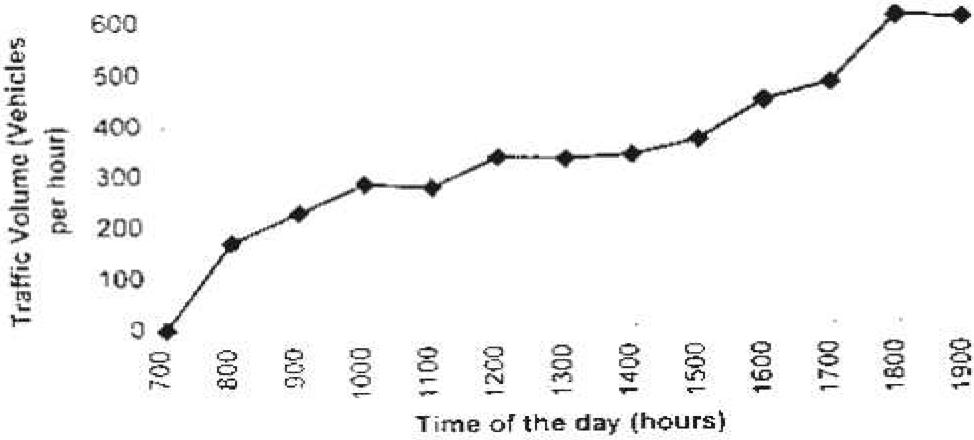


Figure 3a: This figure shows observed cumulative frequency versus expected distribution function for car lanes at 5% level of significance

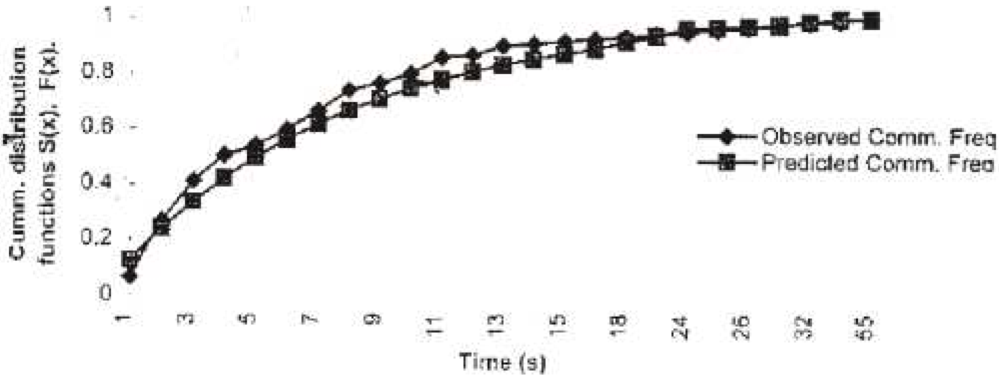


Figure 3b: This figure shows observed cumulative frequency versus expected distribution function for bus lanes at 5% level of significance

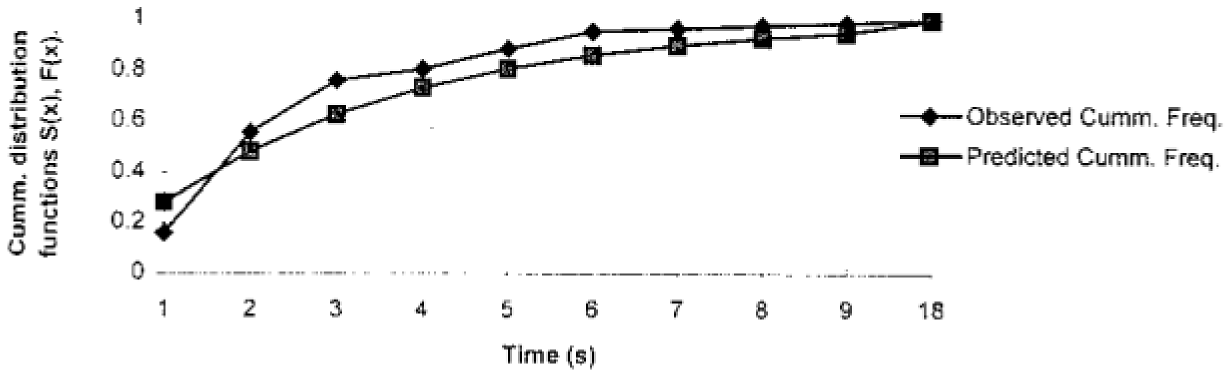
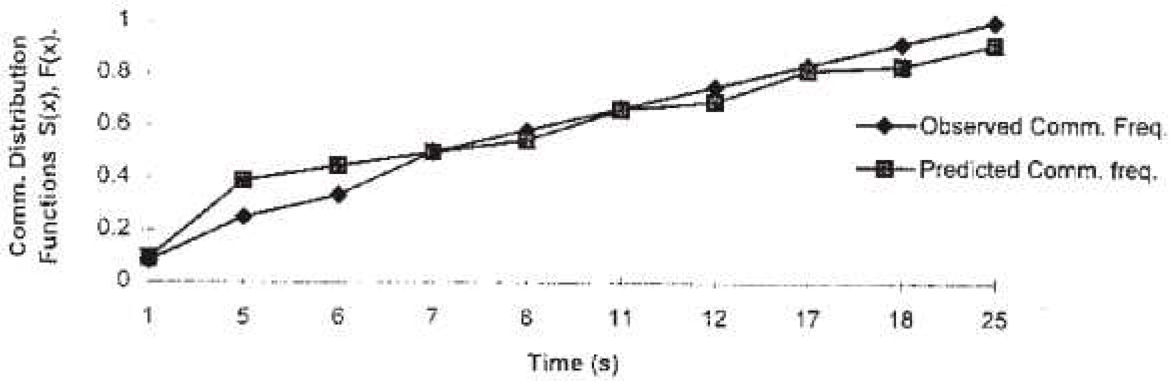


Figure 3c: This figure shows observed cumulative frequency versus expected distribution function for truck lanes at 5% level of significance



RESULTS

Model Solution

The primary objective of model solution is to enable us compare the observed with the theoretical queue distributions. This is done by fitting in the mathematical distribution to measured (or observed) queue distributions. Figure 4 shows the flow chart of model calibration.

The following sets of data were generated for each vehicle type in this study:

a. *Model Validation:* Validation is an essential part of model building and application of existing models to real life problems. Briefly, the process sought to justify the model with regards to its prediction of the system behavior. Table 1 shows a direct comparison of some measures of effectiveness predicted by the model and those actually observed. Table 1 observed and predicted measures of effectiveness

b. *Working Curves Data:* The data here are so selected that some of the predicted system measures can be linked to others either through graphs or table. By so doing, data which could serve as a working tool are prepared in the form of table and graphs or table. By so doing, data which could serve as a working tool are prepared in the form of tables and graphs as a practical guide in the study of the system. For this work utilization factor results were selected as the independent variable and its relationship with some other measures like the mean waiting time in queue, customer loss ratio, and the mean queue length is plotted in graphs of figures 5a, 5b, 6a, 6b and 7.

Figure 4: This figure shows program flowchart of model calibration

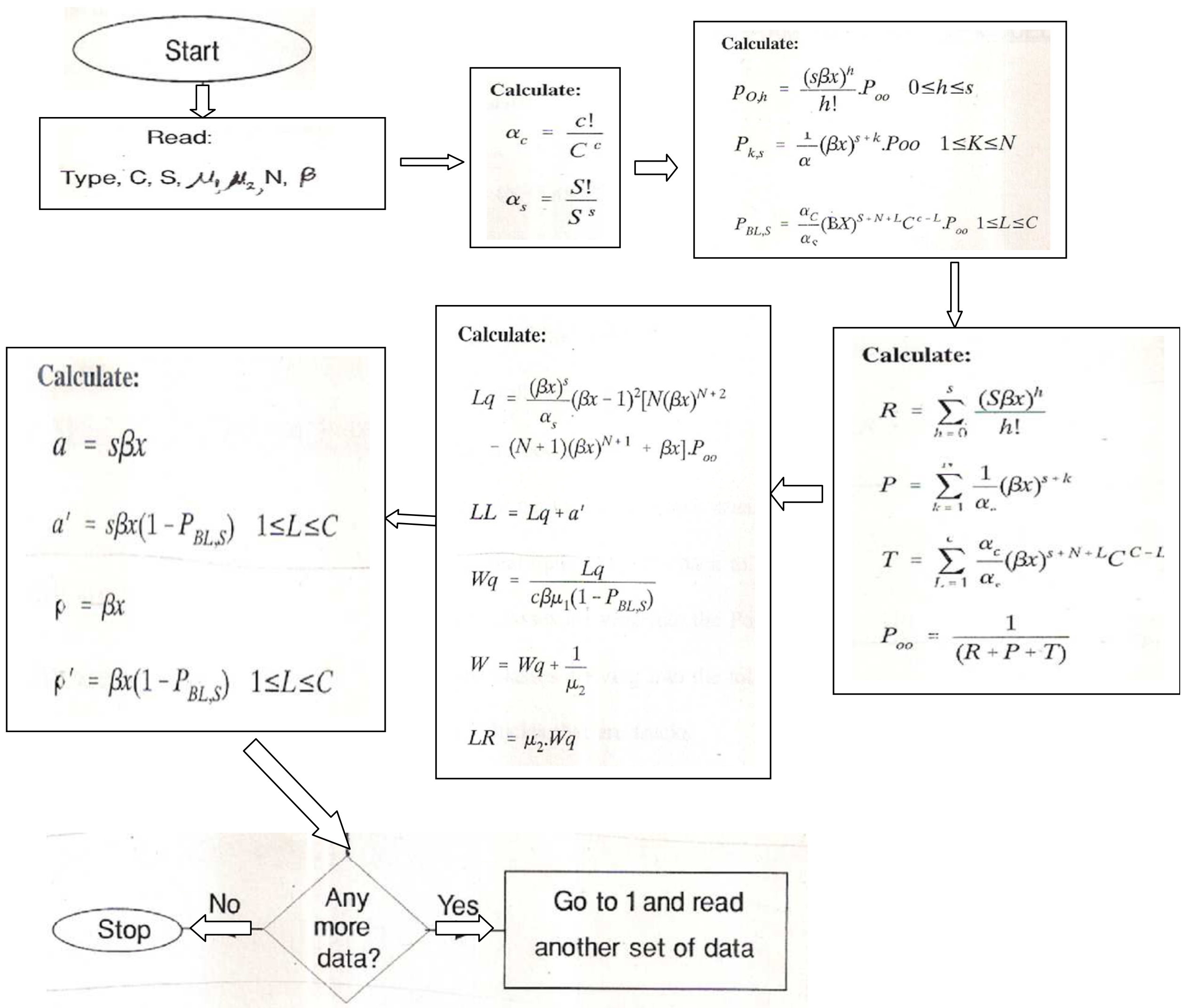


Table 1 Observed and Predicted Measures of Effectiveness

Type of Vehicle	Observed Utilization ρobs	Predicted Utilization Spread ρpred	Observed Waiting Time in Queue WQ	Predicted Waiting Time in Queue WQ pred.	Observed Customer Loss LRobs. (SEC)	Predicted Customer Loss Ratio LRpred (sec)
Cars	0.9880	0.9541	19.50	18.72	10.1000	9.3899
Buses	0.7800	0.8444	8.00	9.00	3.5000	3.9339
Trucks	0.3500	0.5017	0.5017	3.60	0.8500	0.9887

Figure 5a: This figure shows system effectiveness measures versus utilization for cars in terms of customer loss ratio, and mean number in queue

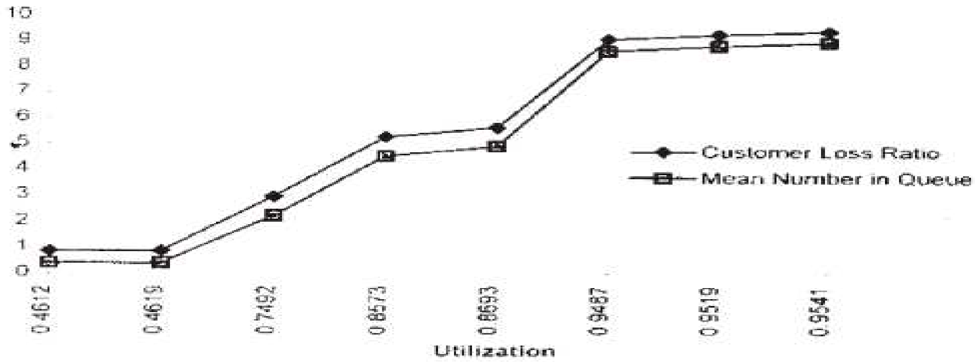


Figure 5b: This figure shows system effectiveness measures versus utilization for cars in terms of mean time in queue

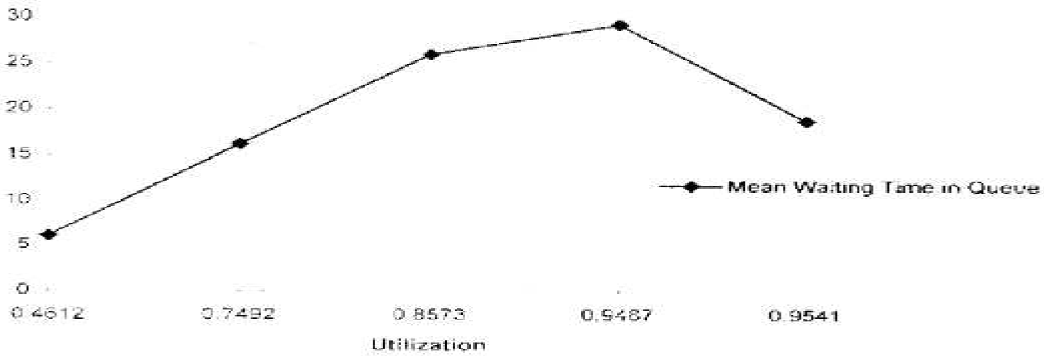


Figure 6a: This figure shows system effectiveness measures versus utilization for cars in terms of customer loss ratio, and mean number in queue

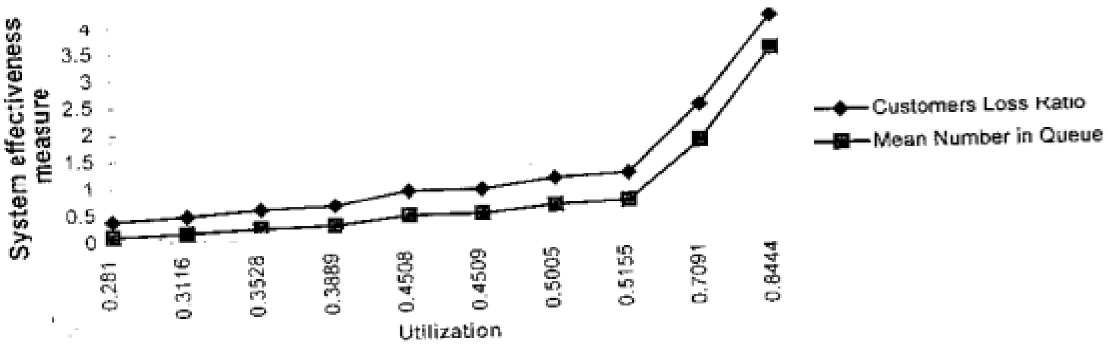


Figure 6b: This figure shows system effectiveness measures versus utilization for buses in terms of mean time in queue

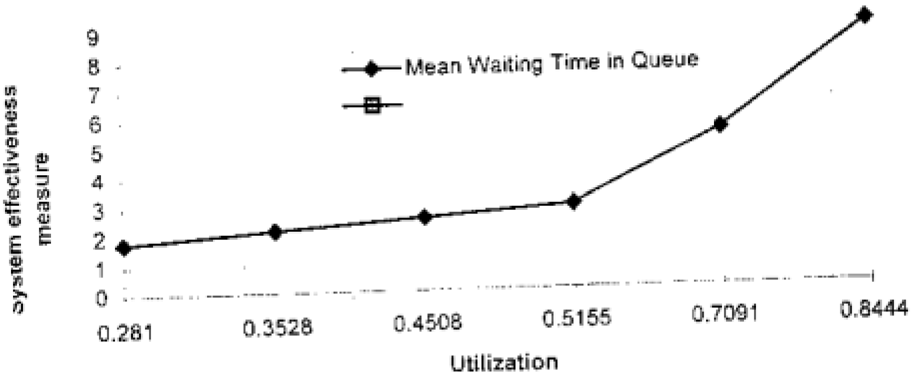
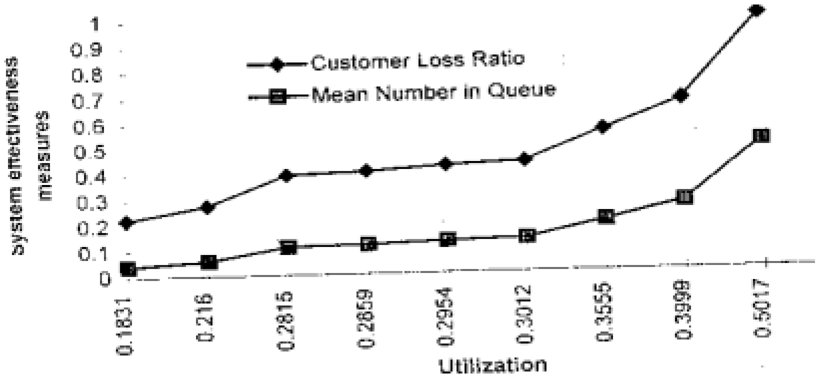


Figure 7: This figure shows system effectiveness measures versus utilization for cars in terms of customer loss ratio, and mean number in queue



These methods could be used to produce extensive practical results such that once a value of system measure is known through field measurement, other system measures such as waiting time in queue, customer loss ratio and mean queue length can then be determined.

DISCUSSION

Looking at the traffic flow patterns of figures 2a, 2b and 2c, it is clearly discernible that the number of vehicles arriving at both stages of the queue does not remains constant throughout the observation period. The peak periods are 1300 to 1800 hours for Fridays, 1100 to 1400 hours and 1600 to 1900 hours for Saturdays and 1200 to 1800 hours for Sundays. On the average the peak volumes are not substantially too different for the three days of the weekends.

From the coefficient of variation and K – S statistical tests, it is evident that the negative exponential distribution is quite appropriate to describe the arrival and service times characteristics in the system. The results in figures 3a, 3b, and 3c for the K – S tests show these clearly as a good number of the data sets are accepted at 5% level of significance that is the model output compares favorably with the actual observation.

An inspection of table 1 shows that the utilization factors portray the car lanes to be the most utilized followed by the bus lane and then the truck lane. Blocking is therefore less kely to occur in truck lane compared to the other lanes. The vehicular lanes are detailed as follows:

a. Car Lane: The probability of being in an empty state (i.e. idle server) is 0.0459 which is at acceptable level, but the queue length of 9 cars, waiting time (18.72 seconds) and loss ratio (about 9.4) are high enough to warrant concern for a patron requiring only a small service time. The toll collectors are operating at 95% utilization. The blocking probability is not negligible for a simple analytical approach.
b. Bus Lane: The probability of being in an empty state is 0.01556. The mean queue length is 3, resulting in a wait of 9.00 seconds. The customer loss ratio of 3.9 is unacceptable for motorist requiring small service time. The toll collectors are operating at 84% utilization. The blocking is not negligible for a simpler analytical approach.
c. Truck Lane: The probability being in the empty state (i.e. Idle server) 0.2105 is high enough to warrant concern since this is also an unhealthy queuing situation where a server is idle for most of the time. This may be considered advantageous by the customer since the queue length and waiting time are very low. The toll collectors are operating at 50% utilization while the loss ratio of 0.9887 is acceptable. The blocking probability is in this case negligible for practical purposes.

CONCLUSION

The toll plaza on the Kaduna – Zaria, Nigerian highway has been analyzed and modeled as a queue system by adapting the Makino model [11]. The negative exponential is apparently a sound model for describing the queue. Likewise the Makino model is justified for practical applications.

The results show that the blocking in the system becomes pronounced at a certain critical value of the utilization factors used in the study, is equal to 0.0411 for cars, 0.0191 for buses and 0.0005 for trucks. For a wide range of values of the maximum waiting room, it could be seen that while the effective measures appear to increase with increasing size of waiting room, the blocking probability decreases rather gradually with increasing waiting room.

The information derived from the queue data and their distributions are useful in:

- Predicting arrival rates of vehicles at a point;
- Testing the randomness of traffic flow.

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CONFLICT OF INTEREST

Nil