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Performance Evaluation Of Two Toll Plazas On The Accra – Tema Motorway

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Abstract: The question of the number of toll lanes to open on the Accra – Tema motorway and indeed on various tolling facilities in Ghana to effectively handle arriving traffic and the long queues they generate has been of interest for a while now. Until now this question has, at best been addressed only on ad-hoc basis without any prior scientific analysis. Model prediction of the behaviour of toll lanes under traffic loading is only possible if the performance characteristics of the lane types are known. Traffic flow through the toll lane types of both plazas on the Accra –Tema motorway in Ghana was videotaped at peak hours and analyzed to ascertain their performance characteristics. The manual lanes performed with a capacity of 5.9 veh/min while the E – zone lane's capacity was established as 8.6 veh/min. The mean inter-vehicle time per vehicle for the manual lanes was 10 seconds when considering peak 15 min capacity periods with a mean service time and headway of 5 seconds per vehicle respectively, standard deviation of service times within the peak 15 min capacity periods was 3 seconds. The 85th percentile delay of vehicles in the manual lanes at the Accra toll plaza consistently gave a level of service of F while that at the Tema plaza was found to be at best D. Level of service of the E-zone lanes at both plazas was A due to low patronage. Proportion of toll lane type usage on the motorway was ascertained as 97% manual lane and 3 % E – zone lane. The findings of this research allows for the application of queuing models in decision making in respect of the number of manual and E – zone lanes to open.

Key words: Performance Characteristics, Toll Lanes, Manual lane, E – zone Lane, Accra – Tema motorway, Accra toll plaza, Tema toll plaza, Ghana.

I. INTRODUCTION

Funding for roads traditionally comes from government, but there is a growing trend to seek other sources of finance for building and maintaining networks. Many governments are seeking improved instruments for funding roads (Robinsons, 2008). One such instrument is Tolling which introduces a fiscal charge for road use. The collection of revenue from road users has two main aims according to Newbery et al. (1988); to charge road users for the cost they impose both on the administration and on other road users in terms of congestion, and to raise revenue for government.

The Ghana Road Fund (GRF) has a policy to toll most newly reconstructed roads in Ghana. The toll plazas on the Accra - Tema motorway are the oldest in Ghana. The Motorway is a 19km, four lane divided highway linking Accra the capital of Ghana to Tema the industrial city in the Greater Accra Region. The road has two toll plazas: one for the Tema bound and the other for the Accra bound traffic lanes.

The toll lanes in the plazas consisted of two manual lanes in either direction placed at a distance of 1km from adjacent intersections. Recently the toll plazas were relocated to about 2km from the adjacent intersections due to excessive queuing during peak demand which blocks these intersections. The number of toll lanes was also increased to five, comprising four manual and one dedicated electronic toll collection lane (E – zone lane). Following these interventions, however, very long queues are still frequently observed during peak periods and road users have been complaining about high and excessive delay.

The question of how many toll collection points to open for any demand to minimize delays has been the subject of media debate in Ghana for some time now. Until now, any increase in number of gates or toll collection points is done on ad hoc basis. The question of what combination of electronic and manual gates to operate for optimal flow and minimal delay has eluded the road authorities to date.

Mathematical modelling and analysis can facilitate the estimation of delay and optimum combination of electronic and manual systems. The objective of this research was to evaluate the performance of both the manual and the E - zone lanes using key performance indicators, such as service times, service rates, headway and inter-vehicle times. Information on these key indicators will provide the opportunity to apply models for prediction of the system performance under different scenarios of traffic intensity.

II. LITERATURE REVIEW

2.1 Performance indicators of a toll plaza

According to Padayhag and Sigua (2003), the key indicators of performance of a toll plaza include the service times of the different modes of payment, the toll-lane capacities and the motorist's waiting times or queue delays. This view is supported by Klodzinski and Al- Deek (2003), who also lists throughput, queue length, inter-vehicular time and speed of the toll lanes as other important toll-lane performance indicators. A description of these indicators and how they are measured is presented below.

Prior to establishing criteria for evaluation, we establish some definition of key variables as follows:

Throughput;

The throughput is the volume of traffic per unit time departing from the toll plaza for each lane for the direction analyzed

Inter - Vehicle time;

The inter-vehicle time is the difference between two consecutive vehicular departure times at the toll plaza for each lane. The departure time is recorded immediately after the vehicle is serviced and begins moving (accelerating) away from the plaza. The individual recorded times for each lane is averaged to obtain an overall inter-vehicle lane average

Headway;

The headway is the time it takes for a vehicle to pull up for service at a toll booth when the lead vehicle departs

Service time;

Service time is the length of time in seconds that a vehicle spends paying a toll at a toll booth. It is estimated as the difference between the inter-vehicular time and the headway of a vehicle

Capacity;

Capacity of toll lanes can be either measured or calculated, the measured capacity is computed from the highest consecutive throughput (departures) of a selected time interval during the entire peak hour. The calculated capacity is computed using the average inter-vehicular time during the peak selected time interval of the hour

Queue length;

Queue length is the number of vehicles in queue calculated at one minute intervals for the entire 60 minutes of each peak hour. It is the difference between the volume of traffic departing from the toll booth for each minute and the volume of traffic arriving to the toll lane for the same minute, plus any remaining vehicles from the previous minute interval

Waiting time or delays;

Waiting time or delay is the difference between a specific vehicle's arrival and departure time. A vehicular arrival is recorded as the time the vehicle was filmed in queue, the departure time is recorded immediately after the vehicle is serviced and begins moving (accelerating) away from the plaza. The average delay for each payment lane is the average of the individual vehicular delays for each lane of each peak hour. Total lane delay is the summation of all the individual vehicular delays for one lane during one peak hour for one direction. Waiting time includes any queuing delay, the vehicle service time and headway.

The average and total delay provide some useful information about the performance of a toll plaza, however the 85th percentile of individual vehicular delay is a more representative measure. This measure considers the majority of vehicles delayed without the significant influence of possible outliers. Table 1 gives the hierarchy developed by Klodzinski and Al – Deek (2002) to identify the level of service of a lane or an entire plaza based on the 85th percentile of the individual vehicular delays.

Table 1 Toll plaza level of service criteria, (Klodzinski and Al – Deek, 2002)

Level of service	85th percentile delay (seconds/vehicle)
A	≤ 14
B	> 14 – 28
C	> 28 – 49
D	> 49 – 77
E	> 77 – 112
F	> 112

III. METHODOLOGY

3.1 Site Description

The schematic diagram of the Tema bound and Accra bound lanes and Toll plazas are presented in figure 1 and 2. There are two carriageway lanes for each direction of travel and five (5) payment lanes at each toll plazas.

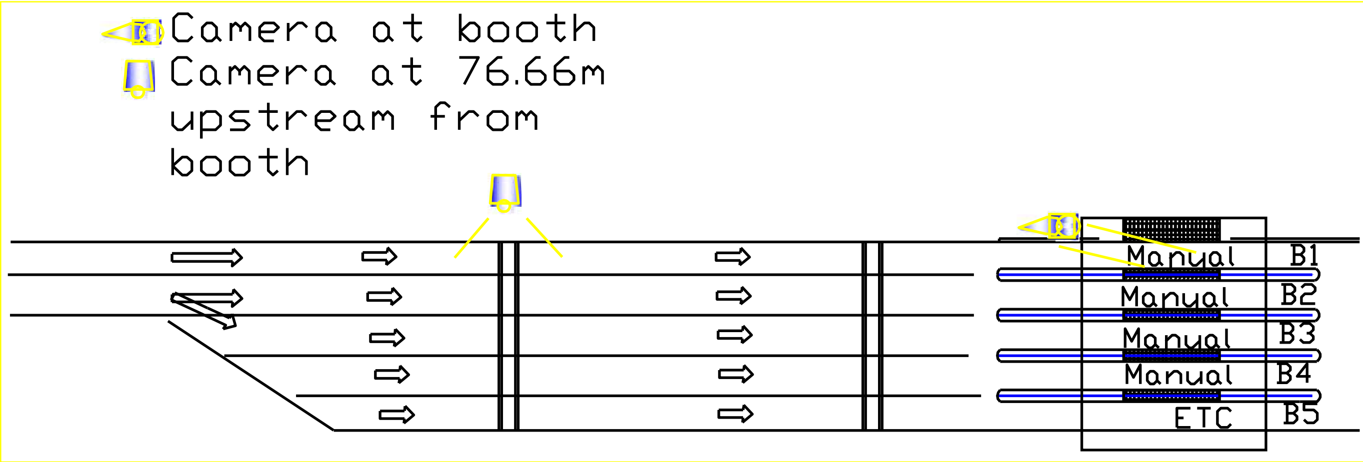

Figure 1 Motorway toll plaza layout at Accra end

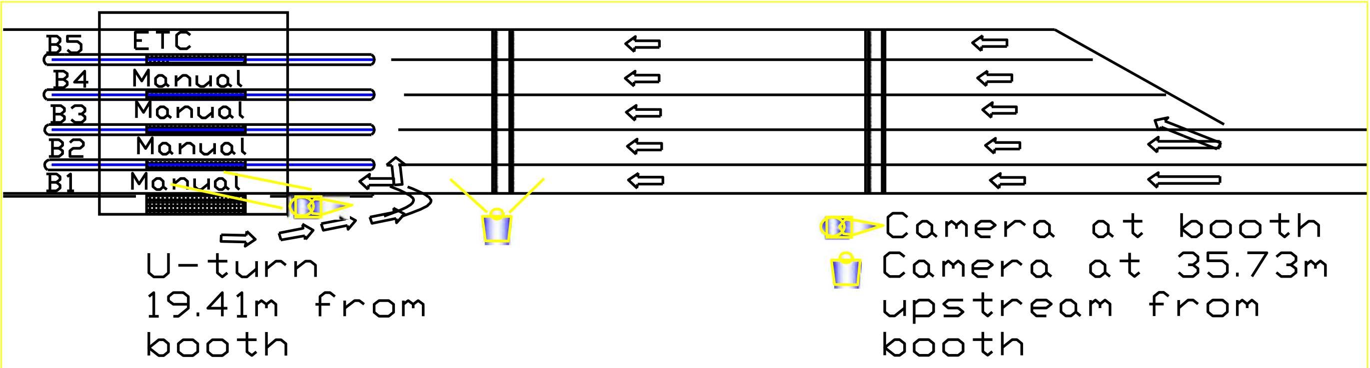

Figure 2 Motorway toll plaza layout at Tema end

3.2 Data Collection

Upstream and downstream traffic flow through the B1 cash lane (see Figure 1) at both the Accra and Tema plazas were videotaped for the morning and evening peak hours. Data collection was done from 30th August to 2nd September 2010 at the Accra end during the periods 09:30 – 10:30 and 17:00 – 18:00 hrs and from 6th to 9th September at the Tema end during the period 07:30 – 08:30 and 14:30 – 15:30 hrs. Figure 1 and 2 shows the camera positions during the study.

Traffic was recorded from the shoulder of the tollgates in order to capture individual vehicular service times (actual arrival and departure at the toll booth) in seconds. A benchmark or reference point was set at 76.66m upstream at the Accra end and 35.73m upstream at the Tema end, respectively, to make sure that as a vehicle in queue reached these reference points it was recorded to capture queuing delay. These reference points were set because aerial cameras were not available for an aerial survey of the queuing delay and the points were already existing identifiable points in the approach lanes to the toll booths. A total of eleven individual peak hours were recorded on the motorway: seven at the Accra plaza and four at the Tema plaza respectively. Traffic flow throw the E – zone lanes was also recorded for each peak hour.

3.2.1 Limitations to the data collection task

- Frequent break down of the ticketing system meant that data for some hours were not continuous for a complete hour and thus could not be used for analysis.
- The majority of motorist wanting to use the plaza at the Tema end during peak hours were doing an unauthorized u - turn into the toll lanes 19.41m from the booths, rendering delay measurement upstream difficult.

3.3 Data abstraction and analysis

Video data abstraction and analysis were completed by manually viewing both the upstream and downstream video recordings on a desktop computer with 22" screen and tracing each recorded vehicle through the toll booths. A total of 3642 vehicles were individually traced through the toll plazas. A vehicle was deemed to have arrived at the toll plaza/lane when it was passed a marked point filmed on the upstream benchmark in queue. A vehicle was deemed to have started paying its toll as soon as the driver of that vehicle stopped in front of the toll booth to pay or attempted giving his/her money to the toll collector, whichever one came first. The time each vehicle finished paying its toll and immediately begun moving (accelerating) away from the plaza was noted and recorded as the departure time for that vehicle. The data was reduced into MS Excel workbooks and analyzed to determine the service time and waiting time for each vehicle. The capacity (maximum service rate) in a 15 min period for each hour was also measured. The difference between every two consecutive vehicle departure times was recorded as inter - vehicle time, whiles the difference between the departure time for a leading vehicle and the start of service for the next vehicle directly following it was recorded as time headway.

IV. RESULTS AND DISCUSSION

4.1 Headway, Service time and Inter -vehicle time

Table 2 present the headway, service times and inter-vehicle times of the B1 cash lane for each peak hour recording at the Accra (Tema bound) and Tema (Accra bound) toll plazas respectively.

Table 2 Headway, Service and Inter-vehicle times of the B1 cash lanes on the motorway

Date/Plaza	**Hourly measures**			**Peak 15 min capacity**			
ACCRA	Avg. Inter Vehicle time (sec)	Avg. Head-way (sec)	Avg. Service time (sec)	Avg. Inter Vehicle time (sec)	Avg. Head - way (sec)	Avg. Service Time (sec)	Std Dev of Service time (sec)
30/08/10 am	12	6	5	10	5	5	3
30/08/10 pm	11	5	6	10	5	6	2
31/08/10 am	11	5	6	11	6	5	3
31/08/10 pm	11	5	6	10	5	5	4
01/09/10 am	11	5	6	10	5	5	3
01/09/10 pm	11	6	5	10	6	5	4
02/09/10 pm	10	6	5	10	6	5	3
Mean values	11	6	6	10	5	5	3
TEMA							
7/9/2010 am	10	6	5	10	6	5	4
8/9/2010 pm	13	6	6	11	5	6	3
9/9/2010 am	11	5	6	10	5	5	4
Mean values	11	6	6	10	5	5	4
9/9/2010.pm	16	7	9	13	7	7	4

Though these measures were obtained from the B1 cash lane in each direction, they reflect conditions in all the manual lanes for each plaza because vehicles arriving at a toll plaza and intending to use a particular toll payment type lane, would normally join the shortest queue available and thus arrival percentage per lane for any toll collection is uniformly distributed across each lane of the payment type with negligible differences (Boronico and Siegel, 1998).

4.1.1 Headway

The headway is the time it takes for a vehicle to pull up for service at a toll booth when the lead vehicle departs. The mean headway for the manual lane was 6 seconds when data was aggregated for an hour. However, the headway was 5 seconds when considering peak 15 min periods. A paired t – test at the 95% confidence level between the mean headway for each hour and the mean for the peak 15 min in each hour was not significant for either plazas with two tailed P-values of 0.12 and 0.29 for the Accra and Tema plazas respectively. This means that the time it took a vehicle to pull up to the booths for service when a leading vehicle departed did not vary significantly within each hour.

4.1.2 Service time

The manual lane performed with a mean service time of 6 seconds per vehicle when the service time for all vehicles in each hour was averaged, this reduced to 5 seconds per vehicle when considering the peak 15 min capacity in each hour with Standard deviations of 3 seconds at the Accra toll plaza and 4 seconds at the Tema plaza. The standard deviations give the dispersion of the individual service times from the average.

The mean service time for the entire hour at the Accra plaza was found to be significantly higher than the mean within the peak 15 min at the 95% confidence level with a one tailed t- test P - value of 0.0002. This was not unexpected since the peak 15 min capacity is the period with the highest number of departures and hence should have the comparatively lesser service time of the two if a significant difference existed. Service time is dependent on the behavior of motorists after stopping in front of the booth, the currency denomination offered to the server and the ability of the server, a change in any of these factors could affect the service time. The individual impact of these factors could be explored in further research. It is expected however that within the peak 15 min capacity period the server is working to his maximum. At the Tema plaza on the other hand, a paired t - test at the 95% confidence level showed no significant difference between the mean service times within the peak 15 min capacity periods and that for the entire hour with a two tailed P-value of 0.21, meaning that the servers were able to maintain the same service times throughout the hour.

ETC lanes theoretically do not have a service time. The E- zone lanes however use a barrier or gate for enforcement, which means that if a user arrives at the E – zone lane directly following a leading vehicle, the user would have to stop for the leading vehicle to clear the barrier before being given the right of way. It takes 2 seconds for the barrier to fall and rise again and to give the right of way to the next user. This indicates a fixed delay in the system of 2 seconds.

4.1.3 Inter - vehicle time

The inter-vehicle time is useful for estimating a toll lane's capacity and performance in processing vehicles. The inter – vehicular time for the manual lane was found to average 11 seconds per vehicle in an hour, however in terms of a 15 min capacity the inter – vehicular time was found to be 10 seconds per vehicle. A paired t – test at the 95% confidence level between the mean inter – vehicle time for the hour and that for the 15 min capacity periods gave a one tailed P – value of 0.00022 at the Accra plaza which was significant, while the Tema plaza had a two tailed P - value of 0.25 and was not significant.

The significant difference observed at the Accra plaza is due to the fact that inter- vehicle time is equal to the sum of the headway and service time for each vehicle, the mean service time within the peak 15 min capacity periods was significantly lower than that for the hour at the Accra plaza, this significantly lower service time in the peak 15 min periods yielded a significantly lower inter - vehicle time. Thus the time between vehicle departures from the B1 manual lane was lower within the peak 15 min periods compared to the whole hour at the Accra plaza. The Tema plaza on the other hand showed no difference between the mean peak 15 min inter – vehicle time and that for the hour meaning that the time between vehicle departures remained constant throughout the hour.

4.2 Capacity and Throughput

Table 3 present the capacity and throughput of the B1 cash lanes for each peak hour recording at the Accra (Tema bound) and Tema (Accra bound) toll plazas respectively.

Table 3 Capacity and Throughput of the B1 cash lanes on the motorway

ACCRA TOLL PLAZA				TEMA TOLL PLAZA			
Date	Thru put (veh/ hr)	Capa-city (veh/ 15 min)	Svc rate (veh/ min)	Date	Thru put (veh/ hr)	Capa-city (veh/ 15 min)	Svc rate (veh/ min)
30/08/10 am	311	88	5.9	7/9/2010 am	332	88	5.9
30/08/10 pm	328	89	5.9	8/9/2010 pm	284	82	5.5
31/08/10 am	314	85	5.7	9/9/2010 am	341	92	6.1
31/08/10 pm	312	87	5.8	Mean values	319	87	5.8
01/09/10 am	324	89	5.9	9/9/2010.pm	228	67	4.5
01/09/10 pm	323	88	5.9				
02/09/10 pm	346	89	5.9				
Mean values	323	88	5.9				

Capacity of toll lanes can either be measured or calculated. The measured capacity is the highest consecutive throughput (departures) of a selected time interval during the entire peak hour. A time interval of 15 min was used in this study (HCM, 2000). The mean of the highest consecutive throughputs within a 15 min period was 5.9 veh/min at the Accra plaza and 5.8 veh/min at the Tema plaza. An unequal variance t - test for the difference between the means was not significant at the 95 % confidence level with a two tailed P – value of 0.88, thus there is not enough evidence to suggest a difference between the two mean capacities obtained.

The calculated capacity is computed using the average inter-vehicular time during the peak selected time interval of the hour, the hour in seconds (3600 sec) is divided by the average inter - vehicular time. The average inter – vehicular time for the peak 15 min period for the manual lane was 10 seconds and thus the calculated capacity for the manual lane would be 360 veh/hr (6 veh/min). The calculated capacity however gives conservative values and is only used when the measured capacity could not be computed due to lack of continuous queuing and at least fairly constant arrivals are obtained.

The mean hourly throughput observed for the B1 manual lane was 323 veh/hr at the Accra plaza, and 319 veh/hr at the Tema end. This works to 5.4 veh/min and 5.3 veh/min respectively. A paired t - test at the 95% confidence level between these mean throughput values in minutes and their respective capacity values gave a one tailed P - value of 0.0001 at the Accra plaza which was significant and a two tailed P – value of 0.05 at the Tema plaza and was not significant. This means that at the Tema plaza service rates in the B1 manual lane did not vary between the peak 15 min capacity periods and the rest of the hour unlike the Accra plaza which saw higher service rates in the peak 15 min. It is worth remembering that in the case of the Tema plaza, some drivers were doing an unauthorized U – turn into the toll lanes 19.41m from the booths (see Fig 2), this meant that gaps in the traffic stream approaching the booths were being competed for, this could account for why the headway, service time, inter-vehicle time and service rates did not vary significantly within the hour.

Capacity measurements for dedicated ETC lanes are only accurate when there is a period of constant departures. The E – zone lanes at both plazas have low patronage, and constant departures could not be sustained long enough for a direct measurement of its capacity. A conservative estimate of the capacity of the E – zone lane was, therefore, calculated on the basis of the following considerations:

The E – zone lanes are a retrofit of a previously existing cash lane, and have the same geometric characteristics as the manual or cash lanes. In addition, they use a barrier or gate for enforcement and it takes 2 seconds for the barrier to fall and rise again and to give the right of way to the next user. The user would not be able to depart just after the 2 seconds because they would need to keep a separation distance from the leading vehicle. It is assumed that the spacing between vehicles (clearance) as well as driver behavior or influence due to lane constraints in the E – zone lane would be the same as observed in the manual lane because both lanes have the same geometric characteristics (HCM, 2000). This means that the average headway of 5 seconds observed in the manual lanes at capacity could be used for the E – zone lane. Thus inter – vehicular time for the E – zone lane is estimated as 7 seconds, giving rise to a conservative capacity of 514 veh/hr or 8.6 veh/min.

4.3 Waiting time or delay and Queue lengths

Table 4 gives the waiting time and queue lengths of the B1 cash lanes on the Accra – Tema motorway. Waiting time or delay is expressed in three forms, average delay, total delay and the 85th percentile delay. The average delay is the average of the individual vehicular delays in each peak hour. The highest average delay observed for the manual lane at the Accra end was 164 seconds. This was observed during the peak evening hour on the 1st of September, and this period also recorded the highest total delay in an hour of 50148 seconds.

Table 4 Waiting time and Queue lengths of the B1 cash lanes on the motorway

Date/Plaza	**Hourly measures**						**Peak 15 min**	
ACCRA	Avg queue (veh/ min)	Max queue (veh/ min)	Avg. delay (sec)	Total delay (sec)	85th % - tile delay (sec)	LOS	Avg. Delay (sec)	Total. Delay (sec)
30/08/10 am	10	13	106	31713	122	F	95	8295
30/08/10 pm	10	13	115	34931	137	F	106	8982
31/08/10 am	10	13	107	31732	125	F	101	8264
31/08/10 pm	13	19	119	33976	145	F	109	9358
01/09/10 am	10	15	102	30984	122	F	94	8403
01/09/10 pm	15	18	164	50148	188	F	159	13810
02/09/10 pm	10	12	103	34184	115	F	102	8190
Mean values	11	15	117	35381	136	F	109	9329
TEMA								
8/9/2010 pm	4	7	51	13034	65	D	52	4121

The total lane delay is the summation of all individual vehicular delays for one lane during one peak hour for one direction, it provides an overall measure of delay and useful for simulation model calibration and validation (Klodzinski and Al – Deek, 2003). The mean of the average delays per vehicle observed for the manual lane at the Accra end was 117 seconds, whilst the mean of the total vehicle delays per lane in an hour was 35381 seconds.

The 85^{th} percentile delays of the manual lane at the Accra end was found to average 136 seconds; which gives a LOS of F, in fact all the peak hour recordings of the manual lane at the Accra end gave a LOS of F. The LOS of D observed at the Tema end was due to the fact that a shorter reference point (35.73m upstream) was used in the analysis. This was because the majority of motorists wanting to use that plaza were doing an unauthorized u-turn into the toll lanes 19.41m from the booth, rendering delay measurement upstream virtually impossible. It is worth noting also that queuing delay outside the reference points was not used in the analysis and thus actual delays could be much worse than reported.

The number of vehicles in queue or queue length was calculated at one – minute intervals for the entire 60 minutes of each peak hour. Average queue lengths for the manual lane at the Accra end ranged between 10 and 15 veh/min, whilst the maximum queue lengths ranged between 12 and 19 veh/min. These lengths reflect the queuing within the benchmark point of videotaping of queuing delay and not necessarily the total for the whole plaza.

4.4 Proportion of toll lane type usage

The proportion of lane type usage of all arrivals per hour was about 3% E – zone and 97% manual lane as shown in Table 6. This was ascertained by comparing the traffic flow through the E - zone lane to the traffic flow recorded through the B1 manual lane for each peak hour in accordance with the principle that the arrival percentage per toll collection lane type is uniformly distributed across each lane of the payment type with negligible differences (Boronico and Siegel, 1998). Since there were four manual lanes at each plaza, the recorded throughput through the B1 manual lane plus any remaining vehicles in queue on the hour was multiplied by four to estimate the number of manual lane users for each peak hour recording.

Table 6 Proportion of E – zone usage on the motorway

Date/Plaza	Time	Arrivals to Manual lane	Arrivals to E - zone lane	Total arrivals	Percentage Of E - zone users
Accra					
30/08/10	9:30 – 10:30 am	1288	41	1329	3.09
30/08/10	5:00 – 6:00 pm	1348	39	1387	2.81
31/08/10	9:30 – 10:30 am	1304	40	1344	2.98
31/08/10	5:30 – 6:30 pm	1296	38	1334	2.85
01/09/10	9:30 – 10:30 am	1344	42	1386	3.03
01/09/10	5:00 – 6:00 pm	1348	37	1385	2.67
02/09/10	5:00 – 6:00 pm	1428	45	1473	3.05
Mean					2.93
Tema					
7/9/2010	7:30 – 8:30 am	1328	40	1368	2.92
8/9/2010.	2:30 – 3:30 pm	1144	36	1180	3.05
9/9/2010.	7:30 – 8:30 am	1364	43	1407	3.06
9/9/2010.	2:30 – 3:30 pm	912	32	944	3.39
Mean					3.11

V. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Based on the results of this study the following conclusions may be drawn:

- The results show that the manual lanes at both the Accra and Tema toll plazas are operating at poor levels of service which is manifested in the long queues.
- Future decisions as to the number of manual lanes to open should incorporate the fact that it has a capacity of 5.9 veh/min with a service time standard deviation of 0.05 min (3 sec).

- Queuing rarely occurs in the E – zone lanes at both toll plazas due to low patronage of the lane.
- It must be a matter of concern to the toll facility operators that only some 3% of all plaza users actually use the E-zone lane.
- Future decisions as to the number of E - zone lanes to open should incorporate the fact that it has a capacity of 8.6 veh/min with a service time standard deviation of zero.

5.2 Recommendations

- Effort should be made to increase the proportion of E –zone lane usage through attractive packages such as discounts per a number of trips, while some days and hours with very low traffic volume could have no toll charges at all.
- If the proportion of manual lane usage is not reduced substantially in the short term then additional manual lanes would have to be provided to improve the level of service. These additional lanes could be retrofitted into E – zone lanes in the future.
- Though the E – zone lane is an improvement over the manual lanes, the fact that it uses a barrier for enforcement reduces its capacity, much higher capacities could be obtained if the barriers were removed and a system of cameras, backed by appropriate legal framework, were used for the enforcement.
- Electronic toll collection lanes whether dedicated or express are typically centered at mainline toll plazas. This is to ensure that users with transponders do not have to undergo any merging maneuver after the booths and to maintain relatively higher speeds. The E – zone lanes on the Accra - Tema motorway should thus be moved from the B5 lane to the B1 lane.
- The size of the toll lanes may have to be increased in the future from the current size of 3.65 m as there are instances of some load carrying articulated vehicles actually hitting the booths and scratching against the medians in an attempt to use the lanes with some eventually having to be asked to use the E - zone lane because it has a median on one side only.

References

[1] Boronico, J. S., and Siegel, P. H. (1998). Capacity planning for toll roadways incorporating consumer wait time costs. Transportation Research Part A, 32(4), 297- 310.

[2] Klodzinski, J., and Al- Deek, H. M. (2003). Evaluation of toll plaza performance from adding express toll lanes at a mainline toll plaza. Paper presented at the 83rd

[3] Annual meeting of the Transportation research board, Washington, D.C. Klodzinski, J., and Al- Deek, H. M. (2002). New methodology for defining the level of service for a toll plaza. ASCE Journal, 128(2), 1-9.

[4] O'Flaherty, C. A. (1986). Highways: Traffic planning and engineering (3rd ed.). Edward Arnold, London.

[5] Newbery DM et al (1988). Road Transport Taxation in Developing Countries. World Bank Discussion apersNo. 26 Washington DC.

[6] Padayhag, G. U., and Sigua, R. G. (2003). Evaluation of Metro Manila's electronic toll collection (ETC) system. Journal of the Eastern Asia Society for transportation Studies, 5, 1946-1961.

[7] Robinson, Richard (2008). Restructuring Road Institutions, Finance and Management. Volume 1: Concepts and Principles, Published by the University of Birmingham, United Kingdom.

[8] Robinson, R., Danielson, U., and Snaith, M. (1998). Road Maintenance management. Palgrave, Hampshire.

[9] Transportation Research Board. (2000). Highway capacity manual. Transportation Research Board special report 209, Washington, D.C.