Capacity and Level-of-Service of Expressway Toll Plazas in Bangkok

Kazunori HOKAO[1] and Somasundaraswaran. K[2]

1. Introduction

The capacity and level of service (LOS) for toll plaza facilities should be qualified for the several reasons such as, qualification of these parameters would enable designers to evaluate design alternatives using accepted standards, these would provide a scientifically sound basis for comparing traffic operations of various facilities, these would furnish a means to evaluate before and after conditions and thus determine the effective of any improvement, it would give the general public and legislative representatives a readily understandable and yet scientifically established measure of overall performance. Woo(1991) have conducted a study to establish LOS(s) based on aggregated measures of traffic density and volume-to-capacity (v/C) ratio. Further in 1993, Lin and Su forecasted a methodology to identified LOS(s) by examining operational characteristics of toll plazas through computer simulation using field parameters.

In this study, a methodology was carried out in micro view to find the relationship between total delay and vehicle in the queue by considering the mix of vehicle in the queue, in order to forecast a suitable methodology for the Level-of-Services(LOS) at Toll Plaza operation in Bangkok. It is true that a motorized on freeways are less tolerant to delay than whose at signalized intersections[1]. Therefore, for the evaluation purpose, comparing the delay values suggested for the LOS at a signalized intersection is may lead the results defer widely for the toll-plaza operation. The service rate has influence in the queue length and delay at the gate. Therefore, a methodology may be forecasted from micro view by considering service headway, delay, queue length. Further, service time for a truck or larger size vehicles are much higher than those for a passenger car due to variation of stopping time for ticketing and time consumed for clearing the rear potion of the vehicle from the service gate. The size of the vehicle has very strong influence in the LOS analysis. Therefore, various size of the vehicle should be converted to passenger car unit (pcu) in this proposed methodology, by considering service headway of each departing vehicles.

The main concern of this paper is to accomplish four objectives relevant to traffic characteristics at expressway toll plaza areas in Bangkok, such as

(a) to obtain the capacity of toll plaza in Bangkok.
(b) to identify the significant different on location of the toll plazas from the service headway results.
(c) to develop a methodology to establish a relationship between service headway, delay and queue length with different mix of vehicle for different locations.
(d) to develop a methodology to establish Level-of-Services criteria for toll plaza operation in Bangkok

2. Model

(1) Services Headway and Capacity

Actual service time at toll plaza booth has influence on the capacity, queue length and the delay in queue per a vehicle. According to Woo(1991), the service time is the time for a vehicle to stop, pay a toll and clear the area so that the next vehicle in the queue can be positioned to pay the toll. On the other hand it can be identified by time different between two toll collection for the subsequent vehicles during a congested period. More practically, it may be identified as the service headway which is very useful in measuring actual capacity of a toll booth. This service headway may become service time for the first vehicle during congested time. In order to avoid the two major factors that affect the service headway such as vehicle length and the drivers ability to accelerate the stopped vehicle, the reference line is located very near to the service booth. During the congested time,

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1. Reqular Member, DEng, AIT, Bangkok 1050
Tel : 524 5510, Fax : 524 5509
2. Student Member, MEng, AIT, Bangkok 10501. Tel : 524 5504, Fax : 524 5509

the service headway of a vehicle is the time duration between it's front vehicle rear end passing a reference line and this particular vehicle's rear end passing the same reference line.

The service headway for a longer vehicle in the system can be transferred by service headway for the passenger car. Further service headway can be determined for various toll collection types and geometric conditions. Assume that S_{ij} represents the service headway in seconds for vehicle type i and toll collection type j. By assuming that S_{cj} represents the service headway in seconds for passenger car, service headway for different toll collection types and different type of vehicle can be converted to a common scale as follows,

$$S_{ij} = \beta_{ij} S_{cj} \qquad (1)$$

Where

S_{ij} - represents the service headway in seconds for vehicle type i using type j toll collection booth

β_{ij} - conversion factor for type i vehicle using type j toll booth collection

For the simplicity, vehicles were divided into four categories such as passenger car, small truck type, truck and buses, and tailer trucks referred as type 1, type 2, type 3 and type 4 respectively. At present, the toll booth at Bangkok expressway are manually controlled. There are three types of tool booths are available at main line toll plaza in Bangkok. Those are; exact change users and change users and for the users who really need ticket for their own needs. Normally, in a small toll plaza located in ramp areas, the change toll booth is used not only by passenger car but also by other heavy and longer vehicles. For the simplicity, toll collection booth were divided into two categories, such as booth with exact change and change as type 1 and type 2, respectively. By considering the conversion factor, the effect of longer vehicles also converted for passenger car units to find the actual capacity of the toll booth. The capacity of the toll booth with collection type j is

$$c_j = 3600/s_{cj} \qquad (2)$$

Generally, if there are n_j booths with collection type j, similar to Woo the capacity of a toll plaza would be

$$C = \Sigma n_j c_j \qquad (3)$$

By considering the toll-plaza as a service station, when arrival rate exceeding the toll plaza capacity then queue started to be formed. Hence, the queue length, delay for the motorized become measures for the congestion evaluation, which results could be converted to LOS by considering those amount. These measures can be analyzed in two way, macro or micro. Most of the simulation models in a service station like toll plaza operations are mainly in macro analysis. In this study, a micro analysis also was carried out to find the actual relationship between representatives measures for the LOS. A special attention was given by considering the mix of vehicle categories.

Suppose, one vehicle is joining in a queue as n th vehicle in the system and let d_{nij} represents the delay in the system.

$$d_{nij} = \alpha \; s_{1ij} + s_{2ij} + s_{3ij} + \dots\dots\dots + s_{nij} \qquad (4)$$

Where α is a factor value ($0 \le \alpha \le 1$) depending of the condition that 0 for the first vehicle at the booth is about to leave the defined area and 1 for the vehicle just stop at toll booth for it's pay. Therefore by assuming that i th type of vehicle in the system is p_i percentage, then the n th vehicle's delay can be calculated.

(2) LOS

There are no existing criteria to define the LOS for toll plaza operations. Similar to the signalized intersections, the LOS have been defined to represent reasonable ranges by two critical variables such as average delay and queue length. Based on the type of the booth, maximum expected delay for a vehicle in the system may be for the poor operational booth and minimum expected delay in the system may be for the efficiently operating booth. On the other hand, for a particular type of booth, based on the mix of vehicle, maximum delay for the n th vehicle may be expected, when the front vehicles are having more percentage of trailers and vise versa. It has been suggested like Lin[1] that the following average queue lengths be used to define LOS; up to on vehicle for LOS-A, then greater then one vehicle but less than two for LOS-B, and greater then two vehicle but less than three for LOS-C, then greater then three vehicles but less than six for LOS-D, and greater then six vehicles but less than ten for LOS-E and more than ten vehicle for LOS-F. However, the corresponding delay values have to be obtained based on the mix of vehicle and location of the toll plaza

3. Data Collection

There are 29 toll plazas in the Bangkok expressway. Among these 29 toll plazas 16 are located in the first stage expressway and rest of 13 toll plazas were located in the second stage expressway. The traffic volumes and mix of vehicle are widely varying. In this proposed study, in order to identify the bias two toll plazas were selected. The data were collected by synchronized video cameras. Cameras are positioned to identify the service headway queuing behavior. Field study was carried out at Toll Plaza at Port on August 10 from 9:00 to 11:00 AM and at Din Daeng on August 11, 1994, from 9:00 to 11:00 AM.

4. Evaluation

(1) Service Headway

After the video tapes were rerecorded with time, they were replayed and service headway for difference type of vehicle in different type of toll-booths was observed as shown in Table 1. At the Din Daeng toll plaza, the service headway for exact change toll booth (Type 1) for passenger cars ranged from 6.00 sec to 7.31 sec with the mean of 7.24 sec, while for change toll booths (Type 2) these values from 7.51 sec to 9.94 sec with the mean of 7.77. Conversion factor for type 2 toll booth when comparing with the type 1 toll booth is about 0.93. For the case of toll plaza at Port all toll booths are change and the service headway for automobiles ranged from 7.82 sec to 9.35 sec with the mean of 8.29. Conversion factor for type 2 toll booth when comparing with the type 1 toll booth is about 0.83. Further, among these two selected sites, the type 2, 3 and 4 categories vehicle have been converted as give by equation 1, and the results shown in Table 1. Further, in change toll gate type, the passenger car equivalent (β_{ij}) for small trucks (β_{2l}) ranged from 1.05 to 1.43 with mean of 1.24 buses and trucks (β_{3l}) ranged from 1.18 to 1.64 with mean of 1.37 and longer tailers (β_{4l}) ranged from 1.40 to 1.98 with mean of 1.47. A significant test was carried out for these all type of vehicle service headway at exact change and change booths for both study site. The results indicate that, at a five percent significant difference in service headway between all type of vehicles with in a site. But significant test fails between locations. The reason was identified as the effect of mix of flow and different geometric conditions.

(2) Capacity

For the toll plaza at Din Daeng, the exact change toll booth (type 1) capacities ranged from 492 to 600 passenger cars per hour, and the change toll booth (type 2) ranged from 385 to 479 passenger cars per hour. Similarly for the case of toll plaza at Port the exact change capacity did not calculated due to mixed used by change uses as well. The change toll booth (type 2) capacities ranged from 385 to 460 passenger cars per hour.

(3) Relation between delay and queue length for LOS Criteria

The average traffic flow through the toll booths are categories into 4 types as stated. Through the toll plaza at Din Daeng about 79% are cars, 7% are small trucks, 9% are buses and truck, and about 5% are long tailers and the values for the toll plaza at Port are 74%, 2%, 8% and 16%, respectively. For the proposed LOS criteria this mix of flow in the traffic flow was taken in to consideration

It was identified from this study that fluctuation in the service headway to the longer vehicle is more. Hence, a relation between queue length and expected maximum and minimum delay were found for the mix of vehicle in the actual field traffic flow. Also, for the flow rate of 439 vph at Din Daeng, a result from macro model results also falling with in this range, which were calculated by the method based on Little's formula in widely used queuing theory. The results revealed minimum expected delay in the toll plaza at Port is higher than that for the toll plaza at Din Daeng. The reason for this phenomena was identified as mix of vehicles, which have influences on the delay per vehicle trough a significant amount.

5. Suggested Level of Service Model for Bangkok

The following general operating conditions are proposed for each of the level of services in Bangkok, as shown in Table 2. The LOS-A describes operations with low delay; less than 15 sec per vehicle. This occurs when most of the vehicle arrived, the service gate is ready to service them out. Vehicle just stop and pay the toll and go. Similar, LOS-B delay values ranged between 15 to 30 sec per vehicle. This generally occurs for the vehicle just joining as second vehicle in a queue, highly acceptable to motorized in many ways. Further, LOS-C delay values ranged between 30 to 45 sec per vehicle. In this stage number of vehicle stopping significantly, but queue length is less than 3 and acceptable for divers to wait. LOS-D delay values ranged between 45 to 65 sec per vehicle, and the influence of congestion become more. Further, the LOS-E delay values ranged between 65 to 105 sec per vehicle. This is an result of higher v/C ratio, but delay still little bit over the acceptable limit. Finally, the LOS-F delay value is more than 105 sec per vehicle. This is unacceptable to most of the motorized and v/C ratio become closer to one or even more. The criteria based on queue length and delay in the toll plaza system could be applied to define the LOS of the toll plaza in Bangkok.

6. Conclusion and Recommendation

The manually controlling toll plazas at Bangkok have very low capacity than those are in other developed countries. Also, the service headway of the toll plaza has significant different in location. Further, it was identified that the mix of vehicle in a queue is an important factor to be considered for capacity and LOS evaluations. Correlation between queue length and delay visualized that as queue length is becoming more than 3 vehicle then the expected delay per a vehicle in the queue become more. By considering all these into account a level-of-service criteria for manually controlling toll plaza at Bangkok was suggested. Further, it is recommended that it is very important to do more detail survey in many locations with different mix of traffic to find the actual result for LOS evaluation.

7. References

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Table 1. Coparison of service headway by vehicle and booth types

	Gate No	Type 1		Type 2		Type 3		Type 4	
		S_{cj} sec	Nos	β_{2j}	Nos	β_{3j}	Nos	β_{4j}	Nos
Din Daeng	4*	7.31	447						
	5*	7.21	499						
	6*	7.20	497						
	7	6.00	283	0.18	56	0.16	46	0.22	12
	8	7.51	181	0.00	97	0.00	120	0.00	23
	9	9.94	253	0.00	45	0.00	69	0.00	106
Port	2**	7.82	287						
	3	8.50	228			1.22	17		
	4	9.35	81	1.06	14	0.96	47	1.31	127

* gate for exact change only

** for exact users only but other also using

Nos - sample number

Table 2. Level-of -Service Criteria for Bangkok

LOS	Average Queue Length, L (veh)	Average Delay in System, d (sec)	LOS	Average Queue Length, L (veh)	Average Delay in System, d (sec)
A	L < 1	d < 15	D	3 < L < 6	45 < d < 65
B	1 < L < 2	15 < d < 30	E	6 < L < 10	65 < d < 105
C	2 < L < 3	30 < d < 45	F	10 < L	105 < d