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ALLOCATION OF ELECTRONIC TOLL COLLECTION LANES AT TOLL PLAZAS CONSIDERING SOCIAL OPTIMIZATION OF SERVICE TIMES AND DELAY

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Abstract: Electronic Toll Collection systems are expected to greatly reduce service times at toll plaza by reducing transaction times compared to manual toll collection. On one hand, the level that tollway users have equipped their vehicles with the necessary devices for ETC is changing. Marketing efforts are being directed at increasing usage of the E-PASS (ETC ID device for the South Luzon Expressway) to raise usage from the current 24% of traffic volume. Using queuing analysis, this study shows that service type allocations do affect the level of delay in toll plazas. This study demonstrated that it is possible to choose a service type allocation regime that will respond best to a given demand scenario (volume and percentage of E-PASS usage). By choosing the appropriate allocation of service types (manual or E-PASS) among available lanes for a toll plaza, the plaza service capacity can be maximized and delays minimized.

Key Words: ETC, service type allocation regime, delay minimization, queuing theory

1. INTRODUCTION

Electronic Toll Collection (ETC) systems are expected to benefit users of toll ways by increasing toll lane capacity, by reducing services times, resulting in reduced delays providing convenience to tollway users, and reducing fuel usage (by reducing waiting and idle times). However, not all tollway users are equipped with the necessary on-board devices to enable the electronic toll collection. And unless 100 percent take up of ETC by the motoring public is achieved, manual collection will always be required for those tollway users who do not have the on-board equipment.

Depending on the actual percentage of users who are equipped for ETC, and the corresponding level of ETC service provision (as influenced by the number of lanes that may be provided with ETC facility) only partial realization of potential user benefits. This is partly because of the segregation of users of the ETC method from the non-users through dedicated lane allocations. The main argument in favor of service type segregation is that by homogenizing the user type per lane, variability of service times can be kept to a minimum and as a result queues may be kept to a minimum (Van Dijk et al, 1999). However, depending on the actual proportion of users who are equipped or are unequipped, and due to the fact that users are discrete entities using a discrete and limited number of service lanes, this segregation of lanes may result in longer service times for unequipped users, compared to the time before the segregation by dedicated lanes was implemented. This leads to the question of whether or not partial ETC (partial in the sense that not all tollway users are equipped for ETC and not all toll booths are dedicated to ETC) implementation may results in a detriment to welfare of users, in a social sense. In other words, while a portion of the users will be benefited, another portion will be suffering negative effects such as delays or service times greater than before segregation was done due to the increase in the proportion of the service load for non-ETC lanes. For example, if there are only two lanes provided at the toll exit and one is given to ETC payments and the other one is for manual payments, this immediately results in an increase in the service load for the manual payments lane. Assuming that less than 50% of users are equipped, for the two lane scenarios this may result in an improvement in service times for ETC users while those who must pay using the manual method may suffer disproportionate increases in the service time.

Thus, there is an indication that if a tally of the individual benefits versus individual negative effects were made, it is possible that the net total effect may be negative. Therefore, it is necessary to examine the possible “social”[1] effect of partial implementation of ETC. At present, several countries are still in the process of implementing their ETC systems, and none expect 100 percent of tollway users to acquire the on-board equipment for using the ETC system. Also, based on the experiences of other countries, the share of ETC users has been increasing gradually, but this means that during the interim between zero usage of ETC up to possibly 100 percent usage by tollway customers, the way that service types are allocation among the lanes at toll plazas needs to be examined so that such allocation can be done rationally with the benefit of users in mind. As delay is considered as the main indicator of the level of service at toll plazas (Klodzinski and Haitham, 2002), this study will focus on estimating delay for users of ETC and non-users of ETC.

[1] “Society” in this case would refer to the total set of users comprised of ETC-enabled and ETC-unable motorists

2. PURPOSE OF THIS PAPER

This paper examines the effect of different toll lane allocation regimes on the delay of motorists being served by these toll facilities, in the context of various vehicle volume intensities and percentage of ETC users. Using queuing theory and based on service time commitments and observations from other studies that focused on the South Luzon Expressway (SLEX) toll plazas, the average delay of users is calculated. Through these analyses this paper hopes to:

- Describe the extent to which service type allocation regimes affect delay, toll plaza capacity
- Estimate the optimal percentages of E-Pass user uptake given a particular service type allocation regime
- Provide recommendations on selecting the best service type allocation regime for a given number of available lanes.

3. ELECTRONIC TOLL COLLECTION IN METRO MANILA

3.1 Tollways Connecting to Metro Manila

The South Luzon Expressway (SLEX) and the North Luzon Expressway (NLEX) are both Tollways that connection Metro Manila towards the south and north, respectively. The SLEX has been using a form of ETC since August 2000, while the NLEX is just recently introducing another version of the ETC system. The ETC system being used along the SLEX is referred to as the E-PASS.

Figure 1. Typical Toll Plaza Arrangement (C-5 Exit)

Figure 1 shows an exit toll plaza of the SLEX with a typical arrangement consisting of E-PASS only on the far left with a segregation from the mixed arrangements and the manual collection lanes. In addition, on the far right, all trucks and buses are segregated from the other vehicle types.

3.2 E-PASS System

The E-PASS system uses Transcore technology which employs an electronic transponder that is placed in front of the rearview mirror. When the vehicle enters a toll booth allocated to E-PASS users, the tag is read, automatically identifying the account, and debiting the toll fee amount from the corresponding account. The tag is simply an identification card and all information regarding the user account is stored separately by the tollway operations company. After the amount has been debited, the control gate will lift and the vehicle will be allowed to depart. This is supposed to happen within 4 to 7 seconds, which is the service commitment of the operator. Toll fees collected under the E-PASS system are identical to those under the manual collection system. At present, the tollway operators do not provide any incentives for taking up of the E-PASS (such as reduced fares), nor do they charge anything in excess of the device cost for time savings (surcharge on time saved).

Initially, the cost to users for the acquisition of the tag is 2,700 Pesos (approximately 50 US$). This includes a 400 Peso load and a 1-year service warranty. The tag is also transferable between up to three (3) vehicles, with an added 300 Pesos for each additional vehicle, 150 Pesos for the registration and 150 Pesos for the tag clip. Replenishment can be accomplished at selected gasoline stations and authorized sales offices. However, although more than 80,000 tags have been issued, only around 33,000 are actively being used. This has been attributed by the SLEX operator to be due to poorly designed initial marketing efforts. Because of the limited amount of space for expansion at the existing toll plazas, the operator considers it a necessity to shift to the E-PASS which is a service type with much greater capacity that would require lesser space for queued vehicles waiting for their tolls to be collected. In addition, the operator plans to reduce the number of personnel on its workforce and thus reduce the cost of salaries correspondingly.

Table 1. SLEX Daily Average Traffic Summary for October 1- 31, 2004 .

TOLL PLAZA	NO. OF LANES		TOTAL		
	NB	SB	Total Toll Plaza Volume	ETC	% ETC
Skyway Toll Plaza Barrier	2	4	23,634.48	10,915.58	46.18%
Doña Soledad N/S Entry/X		2	2,273.35	971.97	42.75%
Merville		2	2,551.84	412.55	16.17%
Nichols (A) North Exit	10		30,837.19	5,016.48	16.27%
Nichols (B) North Exit	7		15,640.13	4,571.00	29.23%
C5 North Exit	5		17,958.71	4,284.97	23.86%
Bicutan N/S Exit	3	5	21,418.03	4,464.58	20.84%
Sucat N/S Exit	2	4	23,813.97	6,347.26	26.65%
Alabang N/S Exit	3	4	16,212.90	2,532.84	15.62%
Filinvest N/S E/X	2	3	22,170.90	9,769.65	44.07%
Susana Heights N/S E/X	1	3	10,874.26	1,794.48	16.50%
Southwoods North E/X	2	3	14,436.26	3,429.61	23.76%
Carmona N/S E/X	2	3	15,065.42	2,022.81	13.43%
Mamplasan N/S E/X	1	1	5,466.90	1,344.35	24.59%
Sta. Rosa N/S E/X	2	4	18,966.29	3,397.00	17.91%
Cabuyao North E/X	1	2	8,163.42	1,623.03	19.88%
Silangan South Exit		3	4,867.61	937.77	19.27%
Calamba South Exit		8	27,125.74	4,550.61	16.78%
TOTAL	**41**	**35**	**281,477.42**	**68,386.55**	**24.30%**

At present, it is estimated that 24% of the vehicle volumes exiting the SLEX are E-PASS users. As Table 1 shows, the percentage of E-PASS usage varies among the different toll plazas along the SLEX.

Current operational targets of the tollway operator entail the provision of at least one (1) E-PASS lane at each exit toll plaza. Gradually, the SLEX operator plans to reduce the number of Manual toll collection booths to one (1) lane only, and convert the rest to E-Pass collection. This range of provision is used later in the analysis. In between the present condition and the planned future, guidance on the most appropriate regime is necessary since the actual performance is dependent on the level of E-Pass take up by tollway users.

4. FRAMEWORK FOR DECIDING ON THE MOST APPROPRIATE SERVICE TYPE ALLOCATION REGIME

Deciding on the best way to allocate E-PASS and Manual collection service types among available toll plaza lanes requires an appropriate framework. Using a cost-benefit analysis approach, the main basis for selecting the service type allocation regime would be the one that which minimizes the cost to operator or users separately or that which minimizes the combined costs to the operator and the users (which could be treated as "social" combination). The framework that is described here is limited only to the costs that are described in the following sections.

4.1 Costs Related to the Toll Plaza Operations

The total cost of toll collection facility operations includes initial expenditures to establish the structures and support facilities, hire and train personnel, among others. Naturally, the amounts required of these are a function of the service requirements. However, if we consider the aggregate of the cost for these to be essentially identical between service type shifts (i.e. from Manual to E-PASS) then the main concern will be with respect to the particular costs related the Manual collection and E-PASS facilities as:

- Manual Collection Facilities – Facilities needed to allow manual toll collection, such as air-conditioned booth for tellers. Also included under this are the teller salaries, inclusive of employee benefits provided by the toll plaza operator.

- E-PASS Collection Facilities – This includes the devices for E-PASS tag detection, user identification, and account debit actions.

4.2 User Cost Considerations

User costs could be treated as the monetization of the time that they are delayed at the toll plaza (time of delay multiplied by a value-of-time parameter) plus the additional costs to utilize the E-PASS system. This includes cost for the use of the E-PASS tag only and does not include the fares that are paid since, as mentioned earlier, toll fees collected under the E-PASS system are identical to those under the manual collection system.

4.3 Choosing Service Type Allocation Regime

There are several viewpoints that the service type allocation regime may be chosen. From a managerial viewpoint (the toll way operator), this would be to choose the layout that minimizes the total cost. From a user viewpoint, this would be to choose the layout that minimizes the total user delay. A social viewpoint, would combine the two preceding viewpoints and takes the layout that minimizes their combined cost. Since the calculations described in the preceding sections focus only on the vehicle delay, this paper is thus limited to the second viewpoint. Within the second viewpoint, there is also the distinction between E-Pass user and non-users. Definitely, each E-Pass user will always have faster service and shorter delay than the non-user. However, since these types of users will be segregated to the appropriate service lane, the percentage of E-Pass users is an indication of the volume that is concentrated in each lane for a given allocation regime. Thus, the regime that would be chosen is the one that minimizes total user delay at a given level of E-Pass user take up.

5. ANALYSIS

5.1 Application of Queuing Theory

The toll plaza problem involves multiple user types and multiple server types. The service rate depends on combination of server type and user type. For example, due to the different driver heights for cars and trucks, the service time can be longer for the more inaccessible one. However, for the purposes of this paper, it was deemed sufficient to treat each of the lane-booths as M/M/1 servers[2] with corresponding average service rates for the E-PASS lane and the Manual collection lanes, the two basic types that were assumed for this study based on the service commitments of the toll plaza operator. Although at present there are several other service types for tollbooths, such as the Mixed E-PASS/Manual, based on our interviews with toll way operation officials, the lane allocations will be simplified and a combination service of E-PASS and Manual will no longer be made available. This corresponds to findings that the best service is provided when greater homogeneity of users (and therefore less variance in service times) is maintained (Van Dijk, et al. 1999). Since the percentage share of E-PASS users from the total users was identified as an evaluation parameter for this study, the number of E-PASS users was treated as the share of E-PASS users multiplied by the total toll plaza vehicle volumes. Then the total Manual lane users is just the Total minus that of the E-PASS lanes, and then total Manual users were equally distributed among the Manual lanes. Furthermore, the total number of E-PASS using vehicles was allocated equally among the E-PASS lanes, and the total number of vehicles using Manual collection lanes divided equally among Manual collection booths. In actuality, the distribution of vehicles among the available toll lanes may be more complicated than uniform distribution, due to factors such as layout, distance of target lanes from the oncoming vehicles, visibility, driver preparedness, length of queues and other factor. The researchers considered this simplified lane use allocation sufficient for this study.

Using the volumes allocated to each service type, the total time spent in the system (which includes time in queue plus time being served) using the following equation:

$$E(v) = \frac{\rho}{1-\rho} \cdot \frac{1}{\lambda} \qquad \text{(Eqn. 1)}$$

Where E(v) = average time spent in the system (toll plaza)

[2] The essentials of queuing theory are not discussed in this paper. However readers are referred to an excellent description of basic methods by Gerlough and Huber, 1975.

$$\rho = \frac{\lambda}{\mu} \qquad \text{(Eqn.2)}$$

Where ρ = utilization factor
λ = average arrival rate (vehicles / hour)
μ = average service rate (vehicles / hour)

On the other hand,

$$E(s) = \frac{1}{\mu} \qquad \text{(Eqn. 3)}$$

Where E(s) = the service time (hours/vehicle)

Thus waiting time E(w), is just:

$$E(w) = E(v) - E(s) \qquad \text{(Eqn. 4)}$$

These are then calculated for each lane type using the allocated volumes under the various analytical scenarios.

5.2 Analytical Scenarios

The main parameters for differentiating the analytical scenarios are in terms of (1) the total number of booths in a plaza, (2) the manner allocation of the different service types among the booths, (3) the percentage of E-PASS enabled users, and (4) total vehicle volumes at the toll plaza. The values used for these parameters are as follows:

(1) The total number of lanes provided considered cases of 3 up to 10 booths
(2) E-PASS and Manual service types only, ranging from a regime with only one E-Pass lane and the rest of the lanes are for Manual collection, up to the regime with only one Manual lane and the rest set up for E-Pass operation; since lanes are discrete, therefore the exact number of regimes depends on the total number of lanes being considered.
(3) The percentages of E-pass users out of the total plaza users that were tested for were: 10, 25, 50, 75, 90
(4) Toll plaza vehicles volumes ranging from 100 up to 3000 vehicles per hour were considered; this was based on the available information on traffic volumes recorded for various toll plazas of the SLEX
(5) E-PASS lane service time of 4 seconds per vehicle, based on the service commitments of the SLEX operator
(6) Manual lane service time of 20 seconds per vehicle; based on observed service conditions and the service commitments of the SLEX operator

Using these assumed parameters, the following were calculated:

- average delay per lane
- total average delay (average delay weighted by the volumes allocated to each lane with corresponding service type)

- at specific volume and service type allocation regimes, the total plaza volume at which at least one lane type will be saturated and thus be unable to serve with the volume within the hour. This is used as an indicator of the regime capacity.

5.3 Analysis of Results

The first result of the application of queuing theory to estimating average delay under various toll plaza traffic volume, percentage of E-Pass users at the toll plaza, and lane allocation regimes is presented using the cases of three lanes, six lanes and ten lanes in order to give an indication of the way that average delay per vehicle varies from case to case. Due to limitations in the available space to present the other cases, the reader may interpolate the conditions for cases not discussed here (such as with 4, 5, 7, 8 and 9 lanes).

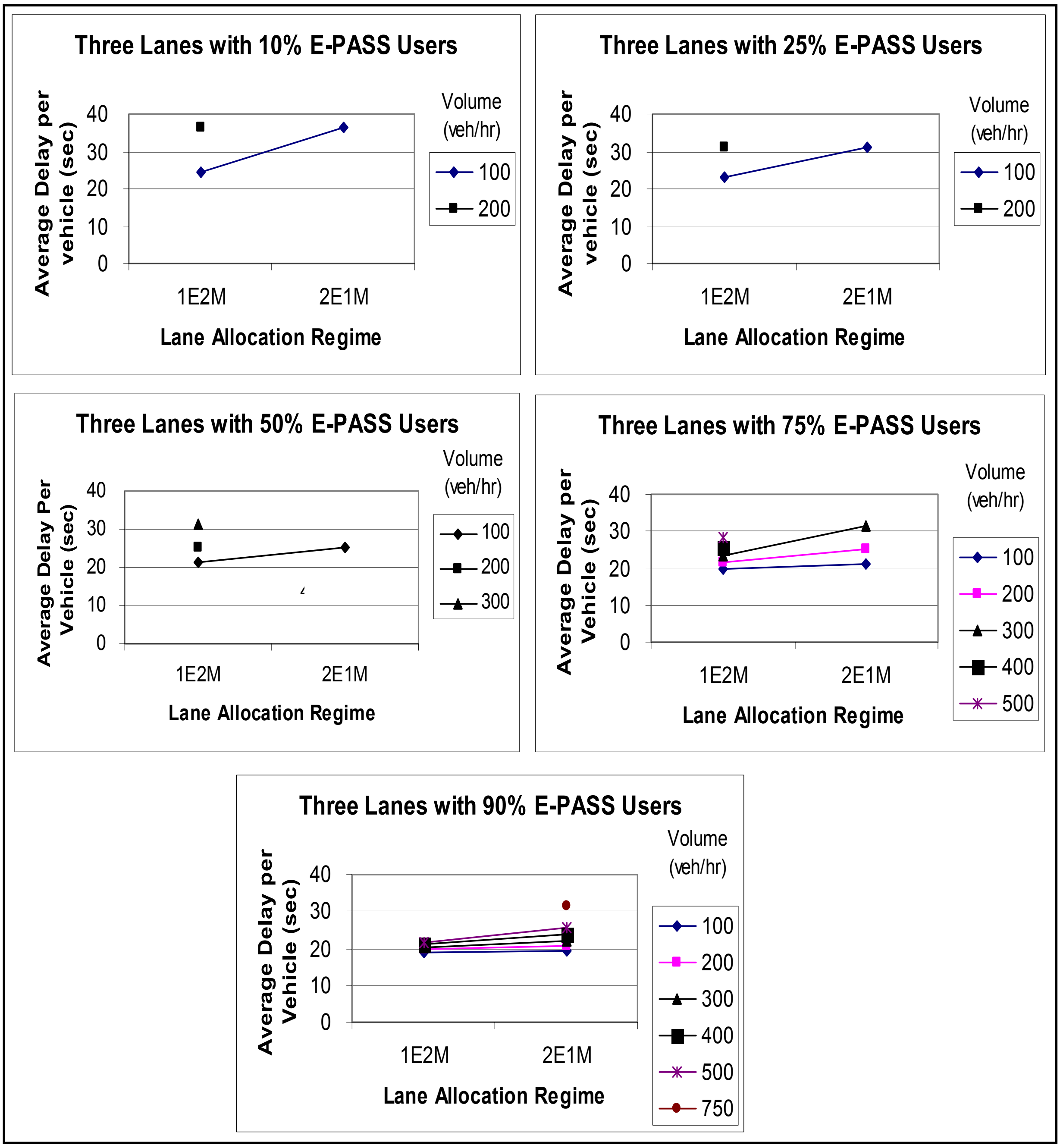

Figure 2. Average Delay per Vehicle for a Three-Lane Toll Plaza.

The two-lane case is not discussed since based on the rule mentioned in the last paragraph of section 3.2, there would be no alternative allocation regime, and only one regime would be possible. In the toll plaza with three lanes, in all combinations (where 1E2M refers to 1 E-PASS lane and 2 Manual lanes; 2E1M refers to 2 E-PASS lanes and 1 Manual lane), it is apparent that at all levels of E-PASS usage, for almost any given volume, the 1E2M regime shows lower average delays. Also, as expected average delays increase, toll plaza volumes increase.

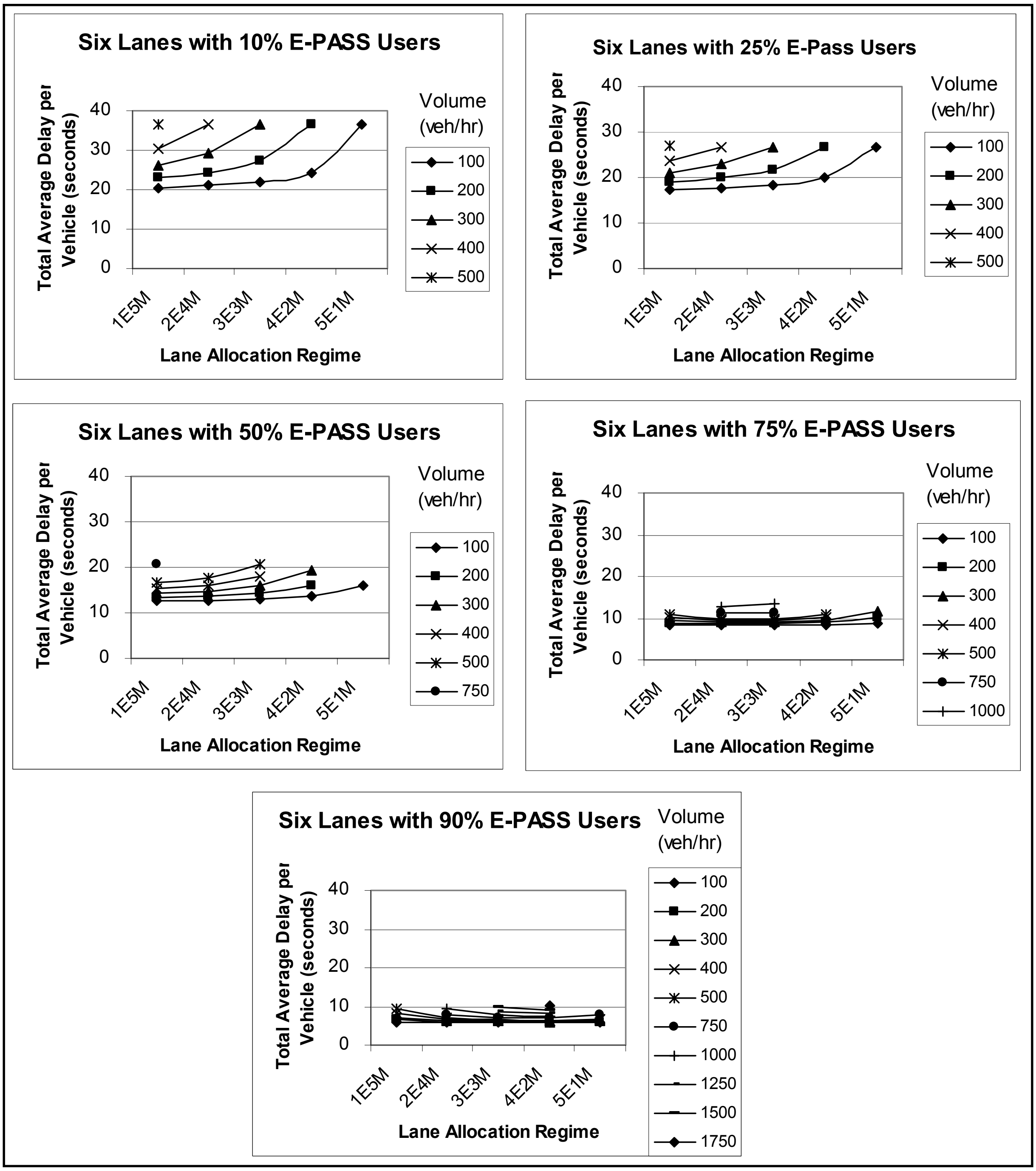

Figure 3. Average Delay per Vehicle for a Six-Lane Toll Plaza.

For the toll plaza with 6 available lanes (as shown in Figure 3), for lower level of E-PASS usage, the lowest average delays gravitate to the regimes with fewer lanes allocated to E-PASS. As the percentage of E-PASS users increases, more E-PASS lanes are required. The reported delays are roughly the same as the reported delays for the 3-lane toll plaza at E-PASS usage below 50%. But as this percentage goes above 50% and approaches 90%, the average delays fall to around half of delays for the 3-lane plaza. Since the graphs are in the same scale, it is easy to see that under different combinations of traffic volumes there is a lane allocation regime that can be expected to provide optimal service given the amount of traffic that must be served.

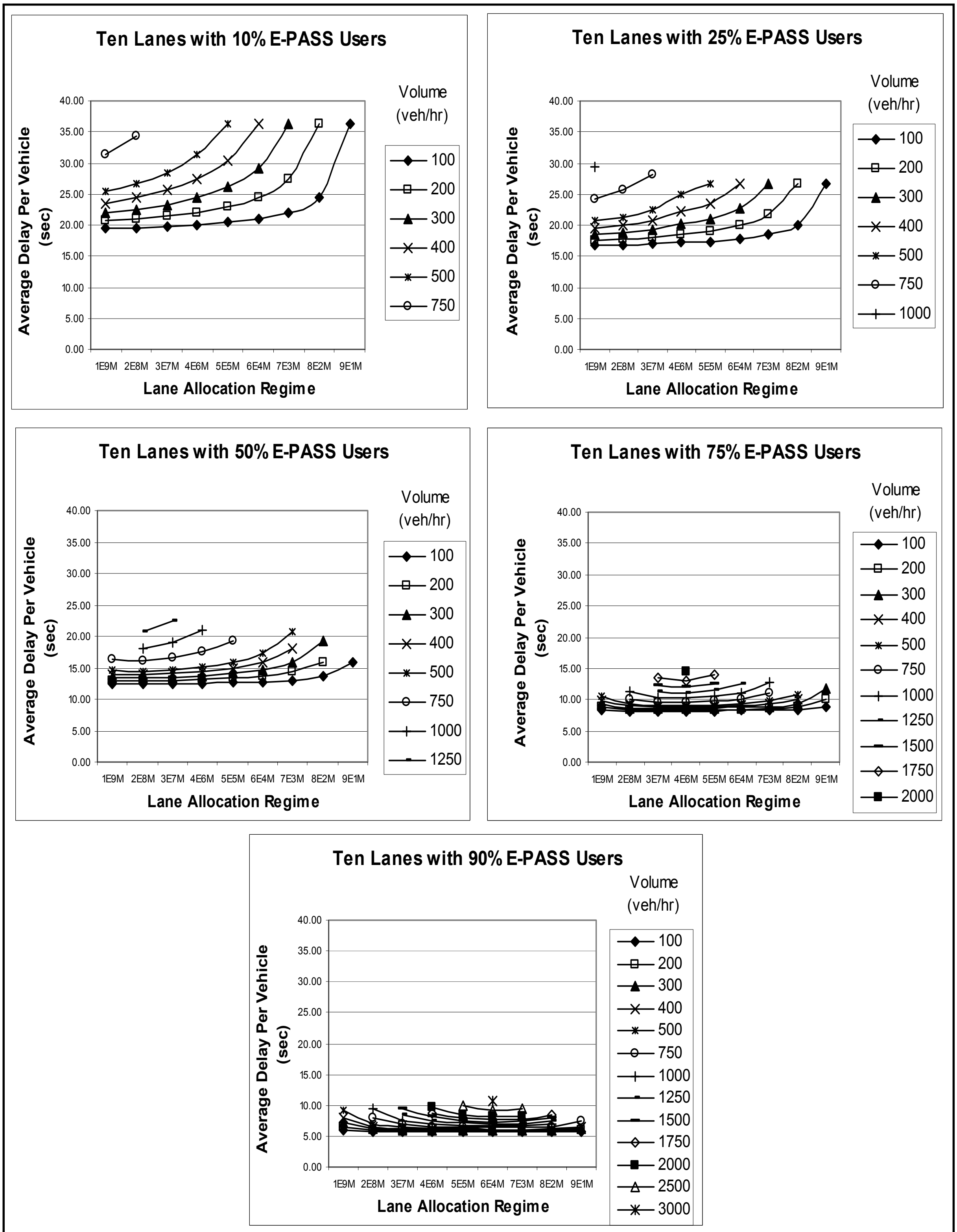

Figure 4. Average Delay per Vehicle for a Ten-Lane Toll Plaza

Comparing the 10-lane plaza (shown in Figure 4) with the 3 and 6-lane ones, we can clearly observe that there is a socially (among toll plaza users) optimal allocation of service types among available lanes. Therefore, we can say that the toll plaza operator may minimize the delay by selecting the most appropriate regime for a given percentage of E-PASS usage and traffic volume at the toll plaza.

Taking the converse point of view, it was also found that, for a given lane allocation regime, there is an optimal percentage of E-PASS usage that is the same for all levels of traffic volume up to the capacity of the toll plaza under a given regime (see Table 2). If either the set of E-PASS lanes or the set of Manual lanes reaches saturation level, then this is interpreted as the capacity of the toll plaza.

Table 2. Average Delay Per Vehicle (sec) at Optimum Percentage of E-PASS Users.

		Optimum Percentage of E-Pass Users	Toll Plaza Volume (veh/hr)													
			100	200	300	400	500	750	1000	1250	1500	1750	2000	2500	3000	3500
2 Lanes	1 E 1 M	83.33	7.3	8.2	9.2	10.6	12.4									
3 Lanes	1 E 2 M	71.43	9.3	10.2	11.2	12.6	14.2									
	2 E 1 M	90.91	5.7	6.1	6.4	6.8	7.3	8.8								
4 Lanes	1 E 3 M	62.50	10.7	11.6	12.6	13.8	15.3									
	2 E 2 M	83.33	7.0	7.3	7.7	8.2	8.7	10.2	12.4							
	3 E 1 M	93.75	5.2	5.4	5.6	5.8	6.1	6.8	7.7	8.8						
5 Lanes	1 E 4 M	55.56	11.8	12.7	13.6	14.8	16.1	20.7								
	2 E 3 M	76.92	8.0	8.4	8.8	9.3	9.8	11.3	13.4							
	3 E 2 M	88.24	6.1	6.3	6.5	6.8	7.0	7.8	8.7	9.9	11.5					
	4 E 1 M	95.24	4.9	5.0	5.2	5.3	5.5	5.9	6.5	7.1	7.9	8.9				
6 Lanes	1 E 5 M	50.00	12.7	13.5	14.4	15.4	16.6	20.6								
	2 E 4 M	71.43	8.9	9.3	9.7	10.2	10.7	12.2	14.2	17.0	21.2					
	3 E 3 M	83.33	6.9	7.1	7.3	7.6	7.9	8.7	9.6	10.9	12.4					
	4 E 2 M	90.91	5.6	5.7	5.9	6.1	6.2	6.7	7.3	8.0	8.8	9.8				
	5 E 1 M	96.15	4.7	4.8	4.9	5.0	5.2	5.5	5.9	6.3	6.8	7.4	8.1			
7 Lanes	1 E 6 M	45.45	11.5	12.1	12.9	13.7	14.6	17.6								
	2 E 5 M	66.67	8.3	8.6	9.0	9.4	9.8	11.1	12.7	14.9						
	3 E 4 M	78.95	6.5	6.7	6.9	7.2	7.4	8.1	8.9	10.0	11.3					
	4 E 3 M	86.96	5.3	5.5	5.6	5.8	5.9	6.4	6.9	7.5	8.2	9.0	10.1			
	5 E 2 M	92.59	4.5	4.6	4.7	4.8	5.0	5.3	4.5	8.9	6.4	6.9	7.6			
	6 E 1 M	96.77	3.9	4.0	4.1	4.2	4.3	4.5	4.7	5.0	5.3	5.6	6.0	7.0		
8 Lanes	1 E 7 M	41.67	10.5	11.0	11.6	12.3	13.0	15.3	18.6							
	2 E 6 M	62.50	7.8	8.1	8.4	8.7	9.1	10.1	11.5	13.3						
	3 E 5 M	75.00	6.2	6.4	6.5	6.8	7.0	7.6	8.3	9.2	10.3	11.7				
	4 E 4 M	83.33	5.1	5.2	5.4	5.5	5.7	6.1	6.5	7.0	7.7	8.4	9.3			
	5 E 3 M	89.29	4.4	4.5	4.6	4.7	4.8	5.0	5.3	5.7	6.1	6.6	7.1	8.5		
	6 E 2 M	93.75	3.8	3.9	4.0	4.0	4.1	4.3	4.5	4.8	5.1	5.4	5.7	6.6		
	7 E 1 M	97.22	3.4	3.4	3.5	3.6	3.6	3.8	3.9	4.1	4.3	4.6	4.8	5.4	6.2	
9 Lanes	1 E 8 M	38.46	9.6	10.1	10.6	11.1	11.7	13.6	16.1							
	2 E 7 M	58.82	7.3	7.6	7.8	8.1	8.4	9.4	10.5	11.9	13.8					
	3 E 6 M	71.43	5.9	6.0	6.2	6.4	6.6	7.1	7.8	8.5	9.5	10.6				
	4 E 5 M	80.00	4.9	5.0	5.1	5.3	5.4	5.8	6.2	6.6	7.2	7.9	8.6			
	5 E 4 M	86.21	4.2	4.3	4.4	4.5	4.6	4.8	5.1	5.4	5.8	6.2	6.7	7.9		
	6 E 3 M	90.91	3.7	3.8	3.8	3.9	4.0	4.2	4.4	4.6	4.9	5.2	5.5	6.3		
	7 E 2 M	94.59	3.3	3.3	3.4	3.5	3.5	3.7	3.8	4.0	4.2	4.4	4.6	5.2	5.9	
	8 E 1 M	97.60	3.0	3.0	3.1	3.1	3.1	3.3	3.4	3.5	3.7	3.8	4.0	4.4	4.9	5.6
10 Lanes	1 E 9 M	35.71	8.9	9.3	9.7	10.2	10.7	12.2	14.2	17.0						
	2 E 8 M	55.56	6.9	7.1	7.3	7.6	7.9	8.7	9.6	10.9	12.4					
	3 E 7 M	68.18	5.6	5.7	5.9	6.1	6.2	6.7	7.3	8.0	8.8	9.8				
	4 E 6 M	76.92	4.7	4.8	4.9	5.0	5.2	5.5	5.9	6.3	6.8	7.4	8.1			
	5 E 5 M	83.33	4.1	4.2	4.2	4.3	4.4	4.6	4.9	5.2	5.5	5.9	6.4	7.4		
	6 E 4 M	88.24	3.6	3.6	3.7	3.8	3.8	4.0	4.2	4.4	4.7	4.9	5.2	6.0	6.9	
	7 E 3 M	92.11	3.2	3.3	3.3	3.4	3.4	3.5	3.7	3.9	4.0	4.2	4.5	5.0	5.6	
	8 E 2 M	95.24	2.9	2.9	3.0	3.0	3.1	3.2	3.3	3.4	3.6	3.7	3.9	4.3	4.7	5.3
	9 E 1 M	97.83	2.6	2.7	2.7	2.7	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.7	4.1	4.5

Table 2 presents the average delays of various sizes of the toll plazas under various regimes, considering the optimum percentage of E-PASS users and various toll plaza volumes. The blanks indicate that the toll plaza has already exceeded its capacity at that volume. In addition, the calculations indicated that optimal percentage of E-PASS users is the percentage at which volumes are allocated in such a way that no slack is left to any lane, meaning all available capacities of the lanes is utilized. Table 2 also shows, as logically expected, that the optimal percentages of E-PASS usage increase as the number of E-PASS lanes is increased. These results indicate that at various stages of the development of the market for E-PASS usage, there is a level of usage that should be targeted by the toll plaza operators or management group in order to minimize delay at different stages of marketing towards increased E-PASS usage.

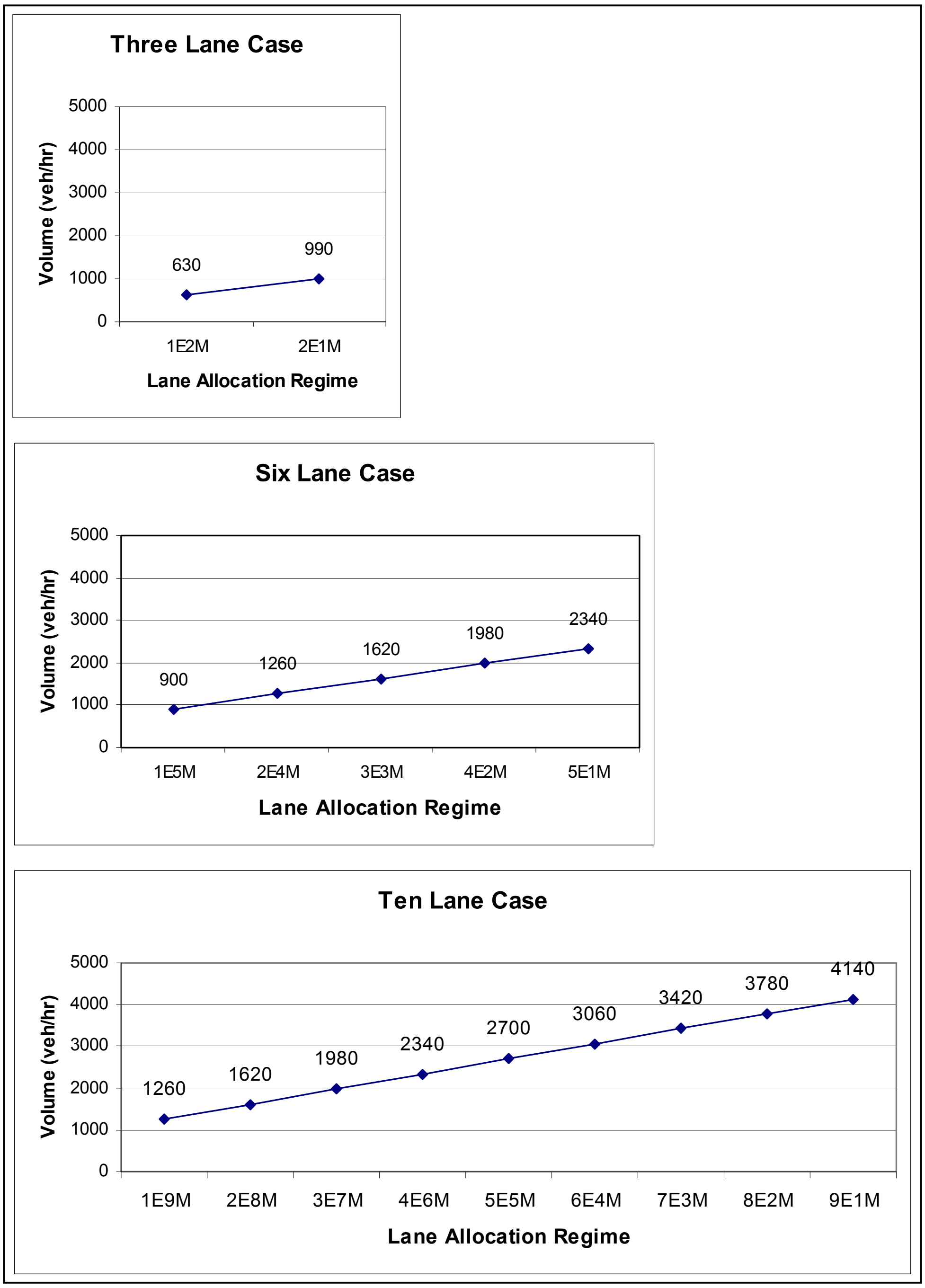

Figure 5. Toll Plaza Volume at which One Service Type Reaches its Capacity

The last part of this analysis is a discussion of the processing capacity of a toll plaza under the combination of a particular traffic volume and a particular regime. Figure 5 shows the corresponding capacities that were found under the assumption that traffic volumes are completely segregated according to the toll collection service type that they use, and under the assumption that its corresponding optimum percentages of E-PASS usage were achieved. Figure 5 also shows that as the number of E-PASS lanes is increased, the capacity of the toll plaza increases (but under the assumption that the level of E-PASS usage has kept pace accordingly).

6. CONCLUSIONS

The study was able to demonstrate that service type allocations do affect the level of delay in toll plazas. Furthermore, it was shown that it is possible to choose a service type allocation regime that will respond best to a given demand scenario (volume and percentage of E-PASS usage). This indicates that as marketing efforts of the tollway operator become more successful (increasing E-PASS usage), the tollway operator can adjust the mode of toll plaza operation to minimize total delay to users.

It should be noted that the results of the analysis change if different service rates are assumed. Service rates may change as further advances are made in the operating set-up. But this same analysis may be applied again using these adjusted service assumptions. It is expected that the particular percentages may change but general patterns will remain similar.

The study considered what is actually a partial social optimization, since the costs and benefits to the toll plaza operator, among others, were not considered. Future studies may try to extend this work by considering the cost of the technology and related facilities, as well as other aspects.

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