TRANSITIONING BARRIER TOLL COLLECTION SYSTEMS TO OPEN ROAD TOLLING: FLOW AND MANAGEMENT ISSUES

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ABSTRACT

Converting traditional barrier-type toll facilities to open road tolling has the potential to dramatically increase the flow rate of a given road. However, the process of transforming a barrier-type system into a free flow toll road presents a number of operational challenges for decision makers. In this paper, we use a simulation model of toll plaza flow to measure the impact of such a conversion on capacity and queuing. We find that the process of conversion is complex and has the potential to undermine many of the flow improvements that are inherent in electronic toll collection.

INTRODUCTION

Tolls are one of the oldest forms of taxation. They became popular prior to 1900 and were one of the major sources of revenue used to construct and maintain roads. After 1910, fuel taxes replaced tolls as the major source of funding for roads in the United States. However, there is a renewed interest in tolls in the last 10-15 years because of a desire on the part of politicians to avoid raising taxes, and instead, substitute “user fees” to pay for government services and infrastructure.

Tolls are also at the forefront of the road privatization debate. For example, the Chicago Skyway has been privatized, and other major roads such as the New Jersey Turnpike & Garden State Parkway are currently being discussed as potential privatization candidates. Proponents of toll collection as a means of financing transportation infrastructure need to be concerned about the efficiency of the toll collection process. Forkenbrock (2004) outlines standards for the design of road user charges:

> …(a) is capable of ensuring a stable stream of revenue to provide adequate funding for the U.S. road and highway system and (b) has a series of other desirable qualities. These other qualities include a low evasion rate, efficiency in relation to the cost of collection for the agency and the user, convenience and ease of use, and, above all assurance that the privacy of road users will be protected.

Some of these issues have already been addressed. For example, Peters and Kramer (2003) have shown that toll collection is inefficient in comparison to other means of financing such as income and fuel taxes. Sisson (1995) examined the impact of electronic toll collection (ETC) on air pollution and Friedman and Waldfogel (1995) focused their work on the cost of collection – in particular, the administrative and consumer compliance costs of toll collection.

Convenience and ease of use is an important area of study. We will define ease of use as a system that has no significant impact on traffic flow and also no significant additional costs to the road user. ETC has been hailed as the tool that potentially can solve all of the issues related to traffic flow for toll collection systems, and a considerable literature has developed in analyzing the performance of ETC systems around the nation and the world.

A number of studies have attempted to identify the impacts of ETC on road performance. Wilbur Smith Associates (2001) working for the New Jersey Turnpike Authority analyzed the impact of the installation of the ETC on the New Jersey Turnpike in 2000. Saka, Agboh, Ndiritu and Glassco (2000) examined the performance of the new ETC system that was installed on the Fort McHenry Tunnel in Baltimore. Spasovic, Juckes, Opie and Hausman (2003) studied the potential traffic flow impact during peak periods of removing toll barriers from the Garden State Parkway. In most cases, the primary focus of these studies was on the morning and evening rush hours on weekdays. While it is important to examine flow during the regular work week, this also happens to typically be the period with the highest percentage of ETC users – and this improves the performance of an ETC system.

Others have studied the impact of toll collection on road user travel time choices. Muriello and Jinji (2004) is a good example of this literature where they examine the impact of a time of day pricing system on traffic flow by period. Brownstone and Small examine the use of a variable-priced toll road in California and the willingness of road users to pay a toll to decrease their travel time.

The Federal Highway Administration is currently encouraging the use of toll collection systems to provide the financing for additional road capacity as well as to relieve the Federal Highway Trust Fund of the ongoing maintenance and capital costs for particular road facilities. Buckeye and Munnich (2004) outline some of the significant political hurdles that the development of a new toll facility can face prior to implementation. To reduce the resistance to road pricing, we must develop analytical tools as well as operational policies that will make toll roads efficient and reduce public resistance to future toll projects.

In this paper, we focus on Forkenbrock's concern with convenience and ease of use. In particular, capacity and queuing issues related to the switch from barrier-type collection systems to open road tolling.

TOLL COLLECTION METHODS

Barrier-type toll collection systems rely on a number of collection technologies to process the vehicles that arrive at their tollbooths. The most basic form of toll collection is the manual human transaction where a person is present in the tollbooth to take cash payment of tolls and make change as needed. Some very significant transportation facilities operate today with only manual forms of toll collection (e.g. the Chesapeake Bay Bridge-Tunnel). The disadvantages of this type of system include: the cost of monitoring cash transactions for theft; the generally slow speed, and thus high compliance cost, of such a system; high labor costs; and the pollution generation from deceleration and reacceleration. Based on currently reported practices (URS Greiner Woodward Clyde Consultants, Inc. (2002)) manual toll takers are able to collect between 350 and 400 tolls per hour. The best-case scenario for manual toll collection is 500 transactions per hour (New Jersey Highway Authority (2001)).

The automated token or exact change processing machine was a significant improvement in toll collection technology. Many of these machines have been in place for over 40 years. They replace a human toll collector with an automated counting machine that accepts highway authority-specific tokens or exact change coin transactions. The automated token machine offers the ability to process tolls at a significantly higher rate than manual toll collection. The methodology still requires the automobile to fully decelerate and the driver to deposit the coins or tokens in the basket prior to proceeding (not withstanding the tradition that the authors have observed of rolling through a toll plaza at a decreased speed and throwing change at the bucket while avoiding a full stop).

Toll authorities report a significant improvement in efficiency in the hourly processing rate via automated token machines. For example, The Garden State Parkway Authority reports a range of 750 to 800 transactions per hour for exact change machines. The best-case scenario for exact change machines is 900 transactions per hour (direct communication with the authors by the New Jersey Highway Authority in 2002).

Electronic toll collection (ETC) is now being widely deployed both in the United States as well as in Europe and Asia. These systems rely on a number of methods to identify a particular vehicle as it passes a toll collection point and charge the account of the driver the correct toll. This form of toll collection has three main variants. First there is the traditional barrier system with an electronically operated lift gate that only releases after the user's account has been charged. This kind of system is currently deployed by a number of toll collection agencies in the United States (e.g. The Metropolitan Transportation Authority Bridges and Tunnels in New York City, and the Delaware River Port Authority in Philadelphia). This form of ETC is desirable from the toll collection agency's perspective in that violations and misreads can be minimized. However, from a compliance perspective, the cost is still high because the driver has to come to a complete stop.

The second variation is the slow speed ETC system. With this system, the ETC reader is mounted in a traditional tollbooth. In some cases, this booth is solely dedicated to ETC transactions. In some cases, the tollbooth processes both manual toll collections as well as ETC transactions. In both cases, drivers are typically required to slow down to some posted speed (typically 5 to 15 miles per hour) and then proceed through the toll facility. These booths have a processing speed that is higher than the barrier systems and with each booth able to process approximately 1200 vehicles per hour.

Table 1: Summary of System Processing Rates

Hourly Processing Rates **By Collection Method**		
	Average	**Maximum**
Full Service	350-400	500
Exact Change	750-800	900
Slow Speed ETC	1,200	1,400

The third variation of ETC is the full highway speed ETC system. In this case, the toll booths are removed and a fixed gantry is erected over the traffic lanes. The ETC toll collection readers are mounted on these gantries and processing can occur at full highway speeds.[1] Because of their ability to collect tolls at the full highway speed, these systems can typically process at the rate of flow for a highway lane – 2200 vehicles per hour.

[1] It is interesting to note that the most common ETC system in the United States (The EZ-Pass System) is capable of processing transactions at up to 125 miles per hour.

Many existing toll systems are migrating, or considering migrating, from a barrier-type low speed system to a mixed system with a portion of the facility dedicated to low speed collection methods (e.g. full service, exact change, or slow speed ETC) and another portion devoted to high speed ETC.

Photograph 1: Satellite photo of the Southbound Raritan Toll Plaza, pre-high speed ETC

For example, the Southbound Raritan Toll Plaza on the Garden State Expressway in Jew Jersey (Photograph 1), as it was configured from 1999 to 2004, represents a traditional mix of full service, exact change, and slow speed ETC. The main plaza containing the 17 main line lanes is shown on the left with the two eastern slip lanes at top right and the four western slip lanes at bottom right.

Photograph 2: A Hybrid Plaza on the Florida Turnpike

On the other hand, the Florida Turnpike (Photograph 2) operates a hybrid plaza with both high speed ETC (top) and manual and slow speed ETC collection (bottom) segments.

As toll authorities move forward with high speed ETC, they need to examine the impact of hybrid toll plazas on compliance and administrative costs. In particular, the balance of tollbooth types is critical as is motivating drivers to migrate towards ETC methods. The mix of booths must be matched and managed in relation to the arrival rates and types of vehicles that need to be processed by the toll plaza. Additional ETC booths will do little to alleviate traffic queues if the drivers that are arriving at the plaza are using the full service lanes.

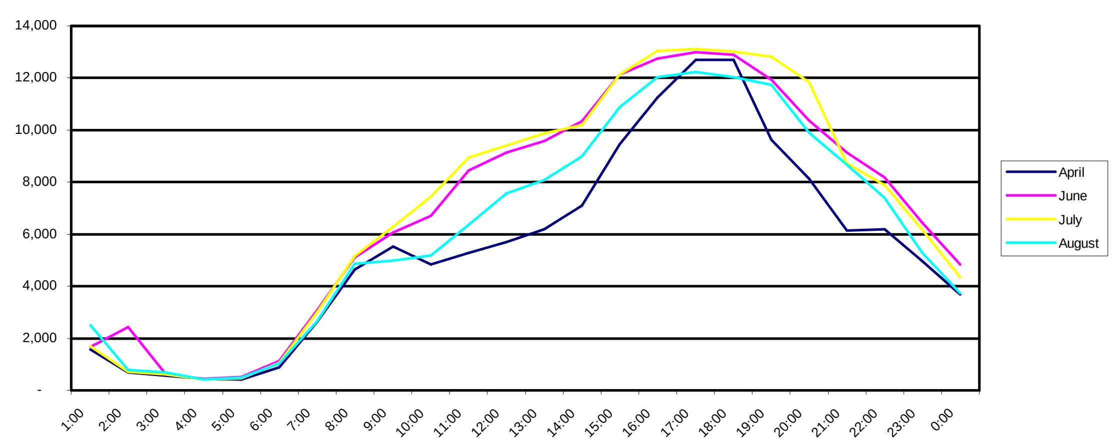
Case Study: The Garden State Parkway

New Jersey's Garden State Parkway (GSP) is 173 miles long and has 11 major toll barriers, and 20 ramp toll plazas. The GSP serves the eastern shore of New Jersey and is the sole North-South highway on the New Jersey coast. The GSP is subject to significant summer traffic loads caused by recreational travel to coastal areas. It is also a major commuter route into the New York Metropolitan region.   In this paper, we use data from the New Jersey Highway Authority (and other sources as noted), and Monte Carlo simulation to analyze the performance characteristics of the Southbound Raritan Toll Plaza both before and after its conversion to a hybrid plaza.

The Raritan Toll Plaza (RTP) serves a high-volume section of the GSP and is fed by a six-lane bridge. Construction is currently underway on an additional bridge that will increase the flow to this plaza in the near future. Thus, issues such as capacity and queuing are especially important in this case.

The RTP typically handles 18% of the major toll barrier transactions on the GSP. In 2000, the plaza handled 81.9 million transactions. The Southbound plaza alone handled 40.6 million transactions in 2000. The traffic flow at this plaza is subject to considerable day of the week and seasonal variation. In the summer months, the RTP is subjected to strong peak period demand with Friday nights being particularly problematic (see Figure 1). On a typical summer Friday, the RTP is subject to over six hours of flow in excess of 11,000 vehicles per hour. The southbound rush begins at approximately 2:00 PM on summer Fridays and does not end until after 8:00 PM. Figure 1 illustrates the typical traffic flow pattern for sample Fridays in August 2001 and April, June and July 2002.

Figure 1
GARDEN STATE PARKWAY
Raritan Southbound trafic
Fridays in April 2002, June 2002, July 2002, August 2001



The Raritan Toll Plaza was originally a two directional plaza that served both north and southbound traffic on the Garden State Parkway. It was reconfigured in 2004 into a one-way facility (southbound) and the toll charged was doubled to 70 cents for a private automobile. The southbound plaza historically operated with 17 mainline tollbooths with two slip lanes on the eastern side of the road (fed by 1 main line toll booth) and four slip lanes on the western side of the plaza (fed by 2 main line toll booths). The net number of tollbooths was 20 (17 mainline + 6 slip lanes – 3 feeder lanes). These tollbooths had historically been a mix of full service and exact change/token lanes.

In 2001, the GSP installed the EZ-Pass ETC system at the Raritan Toll Plaza and added slow speed ETC to the mix of 20 tollbooths. In 2004, five high speed EZ-Pass lanes were opened. The eastern slip lanes, as well as 8 main line tollbooths, were removed to accommodate these five high speed ETC lanes. In addition to the five high speed ETC lanes, the reconfigured RTC includes 11 low speed options (9 mainline lanes plus 4 slip lanes minus 2 feeder lanes). The post-2004 configuration has a higher theoretical maximum hourly throughput (see Table 2).

Table 2: Capacity of the Raritan Toll Plaza

Throughput and Booth Utilization Rates—2002 Raritan Toll Plaza (from Peters & Kramer 2005)			
	Throughput Rate Per Hour (average)	Toll Booths Utilized	Maximum Vehicles Processed Per Hour
2002 Mix:			
Cash	375	3	1,125
Exact Change/token	775	6	4,650
Low Speed EZ- pass	1,200	11	13,200
Total		**20**	
Total Hourly Throughput			***18,975***
High Speed ETC Mix:			
Cash	375	3	1,125
Exact Change/token	775	5	3,875
Low Speed EZ-Pass	1,200	3	3,600
High Speed EZ-Pass	2,200	5	11,000
Total Hourly Throughput		**16**	***19,600***

The addition of high speed EZ-Pass increases the plaza's capacity by 3.2% or 625 vehicles per hour. The modest size of the increase is due largely to the generally good functionality of low speed EZ-Pass and the reduction in the number of total lanes (20 to 16) necessitated by the safety requirements of high speed toll collection.

Seasonality and System Performance

Peters & Kramer (2005) outline some of the significant challenges that the GSP faces in terms of seasonal performance. They show that the share of tolls paid via ETC declines significantly in the summer months. This impacts the performance of the toll plaza and increases the processing time of the average transaction.

The seasonal patterns in ETC usage can have a significant impact on the performance of the toll facility. The most troubling problem is queue blocking. Queuing occurs when the number of vehicles ready to pay via a particular collection method exceeds the method's processing rate and vehicles begin to queue. Queue blocking occurs when the line of vehicles reaches a point where it blocks access to other methods that do not have a queue. Unfortunately, this phenomenon is quite prevalent and has been observed at many toll facilities around the world (Şahin and Akyıldız 2005).

The pre-2004 configuration of the RTP allows 15,700 lane feet of capacity[2] to contain the vehicles queuing at the plaza. Based on the engineering standard of 19 feet per vehicle and 50% density, under the pre-2004 configuration, the RTP could have contained 413 vehicles without queue blocking the low speed EZ-Pass lanes. In contrast, the addition of high speed ETC in 2004 reduced the queuing capacity of the toll plaza to onliy 265 vehicles – a 35.8% reduction in queuing capacity.

To measure the impact of the reconfiguration on queuing, we use a simulation model based on the General Purpose Simulation System (GPSS). Simulation analysis allows us to observe the performance of the plaza under various loading and processing conditions. First we simulate a peak period load by "loading" the pre-2004 configured RTP (3 full service, 6 exact change/token and 11 Low Speed EZ-Pass lanes) at a rate of 13,200 vehicles per hour for five hours (see Figure 1). The simulator generates statisics for the following performance parameters of the toll plaza (see Table 3):

1) Vehicles processed by each lane in the plaza with loading always being placed at the lowest number plaza if it is availiable
2) Utilization Rate – a measure of the percent of time that the toll lane is utilized during the simulation with 1.00 representing full utilization and 0.00 representing an unused facility.
3) Average collection time – a measure that shows the processing speed of a particular method of collection.

The utilization of the cash and exact change lanes is extensive (99%+ for the cash lanes and 83.8% for the exact change lanes). The EZ-Pass lanes are significantly underutilized (40% of the capacity is unused). After a run of 66,000 vehicles over a period of 5 hours and 5 minutes, the total queue builds to 1,116 vehicles. Queue blocking occurs after 102 minutes and 22,000 vehicles.

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[2] We estimate the capacity from aerial photographs and Geographic Information Systems mapping software.

Table 3: Simulation Results for the Raritan Toll Plaza Configuration as of 2002: 3 Full Service Lanes, 6 Exact Change Lanes and 11 Low-Speed EZ-Pass Lanes.

Payment assumptions: **10% full service, 40% exact change/token, and 50% slow speed EZ-Pass.**[3]			
Facility	# Vehicles Processed	Utiliztion Rate	Avg. Collection Time
Full Service 1	1922	1.000	9.519
Full Service 2	1903	0.999	9.610
Full Service 3	1907	0.999	9.587
Exact Change 1	3977	0.997	4.588
Exact Change 2	3940	0.989	4.594
Exact Change 3	3819	0.956	4.582
Exact Change 4	3479	0.870	4.576
Exact Change 5	2843	0.716	4.606
Exact Change 6	2004	0.502	4.582
Low Speed EZ-Pass 1	6108	1.000	2.995
Low Speed EZ-Pass 2	6078	0.996	3.000
Low Speed EZ-Pass 3	6043	0.986	2.985
Low Speed EZ-Pass 4	5805	0.951	2.999
Low Speed EZ-Pass 5	5312	0.872	3.004
Low Speed EZ-Pass 6	4451	0.727	2.990
Low Speed EZ-Pass 7	3163	0.514	2.972
Low Speed EZ-Pass 8	1908	0.314	3.007
Low Speed EZ-Pass 9	909	0.149	3.005
Low Speed EZ-Pass 10	347	0.058	3.068
Low Speed EZ-Pass 11	97	0.016	3.016

Next, we simulate the same peak period load moving through the reconfigured RTP (3 full service, 5 exact change/token, 3 low speed EZ-Pass, and 5 high speed EZ-Pass lanes). The results are contained in Table 4. After a run of 66,000 vehicles, the toll queue builds to 1,030 for the cash lanes and 7,622 for the exact change lanes for a total queue of 8,663. The entire run takes 5 hours and 41 minutes. The plaza loads to full capacity, and queue blocking occurs after only 1,800 vehicles and 9 minutes and 22 seconds. Obviously, this should be of particular concern since queue blocking in such a short period of time presents serious challenges to the system during peak periods.

The flow problems that occur in this scenario result from the demand for cash and exact change lanes exceeding the supply. One solution may be for the toll authority to reallocate some of the existing lanes to the exact change customers. However, that is very difficult since, under the current configuration, theoretically the authority has the ability to alter the mix of only 11 lanes (cash, exact change and low-speed EZ-Pass). Practically, they can only alter 9 lanes since at least 2 lanes (one in the main plaza, and one in the western slip lane) must remain in place for EZ-Pass users that wind up in the toll plaza.

[3] Our assumptions on the share of EZ-Pass, Exact Change and Cash shares are drawn from the NJIT (2001) report on the plan to remove toll plazas from the Garden State Parkway.

Table 4: Simulation Results for the Reconfigured Raritan Southbound Plaza with 3 Cash Lanes, 5 Exact Change Lanes, 3 Low Speed EZ-Pass Lanes and 5 High Speed EZ-Pass Lanes.

Payment assumptions: **10% full service, 40% exact change 10% Slow Speed EZ-Pass and 40% High Speed EZ-Pass**			
Facility	# Vehicles Processed	Utiliztion Rate	Avg. Collection Time
Full Service 1	2122	1.000	9.635
Full Service 2	2146	1.000	9.526
Full Service 3	2144	1.000	9.533
Exact Change 1	4447	1.000	4.598
Exact Change 2	4420	1.000	4.625
Exact Change 3	4432	1.000	4.613
Exact Change 4	4442	1.000	4.602
Exact Change 5	4439	1.000	4.604
Low Speed EZ-Pass 1	5248	0.770	3.000
Low Speed EZ-Pass 2	1992	0.291	2.986
Low Speed EZ-Pass 3	320	0.047	3.024
High Speed EZ-Pass 1	11932	0.947	1.624
High Speed EZ-Pass 2	9704	0.772	1.627
High Speed EZ-Pass 3	5625	0.449	1.631
High Speed EZ-Pass 4	2112	0.168	1.622
High Speed EZ-Pass 5	489	0.040	1.653

Another option is to modify the existing cash and exact change lanes to allow dual processing of cash and EZ-Pass transactions, or exact change and EZ-Pass transactions. This would allow the authority to allocate all 11 low speed lanes as needed and produce better outcomes. In Table 5, we report the results of one such reconfiguration (Mix 1): 5 full service/low speed EZ-Pass, 6 exact change/low speed EZ-Pass, and 5 high speed EZ-Pass lanes. The results are based on the same market share by mode of payment as illustrated above. Now, however we allow mixed cash/low speed EZ Pass and mixed exact change/low speed EZ Pass. After a run of 66,000 vehicles, the toll queue builds to 26 for the cash lanes, 5,870 for the exact change lanes, and a total queue of 5,885 after the run of 5 hours and 29 minutes. The plaza loads to full capacity after 3500 vehicles in 17 minutes and 31 seconds. Again, this results in queue blocking that impedes the performance of the ETC and Exact Change lanes.

Table 5: Simulation Results for the Raritan Southbound Plaza with 5 full service/low speed EZ-Pass, 6 exact change/low speed EZ-Pass, and 5 high speed EZ-Pass lanes (Mix 1).

Payment assumptions: **10% full svc., 40% exact change 10% Slow Speed EZ-Pass and 40% High Speed EZ-Pass**			
Facility	# Vehicles Processed	Utiliztion Rate	Avg. Collection Time
Full Serv/Low Spd EZ 1	2597	0.990	7.514
Full Serv/Low Spd EZ 2	2497	0.956	7.551
Full Serv/Low Spd EZ 3	2263	0.871	7.587
Full Serv/Low Spd EZ 4	1801	0.688	7.531
Full Serv/Low Spd EZ 5	1230	0.473	7.591
Exact Change/LS EZ 1	4452	1.000	4.430
Exact Change/LS EZ 2	4442	1.000	4.439
Exact Change/LS EZ 3	4424	1.000	4.457
Exact Change/LS EZ 4	4417	1.000	4.464
Exact Change/LS EZ 5	4446	1.000	4.435
Exact Change/LS EZ 6	4442	0.999	4.437
High Speed EZ-Pass 1	11482	0.950	1.633
High Speed EZ-Pass 2	9372	0.779	1.639
High Speed EZ-Pass 3	5561	0.461	1.636
High Speed EZ-Pass 4	2106	0.176	1.644
High Speed EZ-Pass 5	482	0.039	1.584

Based on a review of the performance of scenario Mixed 1, we change the improved mix of lanes to (Mix 2): 4 full service/low speed EZ-Pass, 7 exact change/low speed EZ-Pass, and 5 high speed EZ-Pass Lanes. Once again, we allow the plaza to use mixed-lane processing with the cash and exact change lanes also processing the 10% slow speed EZ-Pass.

The results of the fourth run of the GPSS simulator (Table 6) are based on the same market share by mode of payment as illustrated above. After a run of 66,000 vehicles, the toll queue builds to 115 for the cash lanes, 1,848 for the exact change lanes, and a total queue of 1,888 and a run time of 5 hours and 9 minutes. The plaza loads to full capacity after 13,800 vehicles in 1 hour, 4 minutes and 43 seconds.

The results of Mix 2 represent a significant improvement over the prior runs. Total processing time is reduced by 32 minutes and the time to queue blocking time increases by 55 minutes. We have optimized the toll plaza performance given the current mix of users – 10% cash, 40% exact change, 10% Low Speed EZ-Pass and 40% High Speed EZ-Pass. This represents the best possible mix of lanes given the existing user choice of payment method and the 5 High Speed ETC lanes that cannot be modified to any other payment method.

Table 6: Simulation Results for the Raritan Southbound Plaza with 4 full service/low speed EZ-Pass, 7 exact change/low speed EZ-Pass, and 5 high speed EZ-Pass lanes (Mix 2).

Payment assumptions: 10% full service, 40% exact change 10% Slow Speed EZ-Pass and 40% High Speed EZ-Pass			
Facility	# Vehicles Processed	Utiliztion Rate	Avg. Collection Time
Full Serv/Low Spd EZ 1	2359	0.998	7.830
Full Serv/Low Spd EZ 2	2360	0.991	7.770
Full Serv/Low Spd EZ 3	2204	0.970	7.794
Full Serv/Low Spd EZ 4	2236	0.938	7.766
Exact Change/LS EZ 1	4173	1.000	4.435
Exact Change/LS EZ 2	4206	1.000	4.400
Exact Change/LS EZ 3	4186	1.000	4.421
Exact Change/LS EZ 4	4185	1.000	4.421
Exact Change/LS EZ 5	4475	1.000	4.432
Exact Change/LS EZ 6	4196	0.999	4.406
Exact Change/LS EZ 7	4194	0.998	4.405
High Speed EZ-Pass 1	10802	0.955	1.637
High Speed EZ-Pass 2	8854	0.783	1.637
High Speed EZ-Pass 3	5250	0.461	1.624
High Speed EZ-Pass 4	2025	0.178	1.624
High Speed EZ-Pass 5	508	0.044	1.618

Any further improvements in system performance must come from increasing the level of participation in highway speed electronic toll collection. The results in Table 6 show that the High Speed EZ-Pass Lanes have a current average utilization rate of only 48.2% - leaving over 50% of their capacity unutilized. In all of our simulations at least 48% of the ETC capacity is unutilized. Therefore any improvement in flow will be dependent on improvements in ETC participation.

Conclusion

Toll authorities can significantly alter the performance of their toll plazas in terms of processing rates and consumer time costs by modifying the method of toll collection. We evaluate the reconfiguration of the Raritan Toll Plaza on the Garden State Parkway using the flow characteristics of the road and the participation in electronic toll collection as our management variables. We find that conversion to high-speed toll collection will not significantly impact the theoretical processing rate of a toll plaza. In this case, adding high speed EZ-Pass and reducing the number of lanes (from 20 to 16) had a minimal impact on the maximum theoretical capacity of the toll plaza. While the high speed toll lanes have a greater capacity than the lanes that are removed, the net effect is an increase in capacity of only 3.2%.

The reduction in the size of toll plaza significantly reduced its vehicle holding capacity. The original plaza had a capacity of 413 vehicles before queue blocking occurred. The reconfigured plaza has a maximum capacity of only 265 vehicles – a reduction of 35.8% This reduction in queue capacity makes the plaza less durable in terms of its ability to manage queuing. The processing of cash and exact change transactions becomes critical and the share of electronic toll collection must be maintained at a very high level to maintain the processing efficiency of the plaza.

Implementing High Speed Electronic tolling significantly reduces the flexibility of toll plaza operations. The RTP originally had 20 lanes that could be configured as needed with any toll collection method. After the implementation of highway speed toll collection, the number of lanes that can be reconfigured dropped to 9 – a 55% reduction.

Using the GPSS model we illustrate the difficulties that toll authorities face when a reconfiguration makes it more difficult to manage the mix of collection methods.
High speed ETC works very well during commuting times when the road is populated with sophisticated road users who have high ETC participation rates. During these times high speed ETC dramatically improves traffic flow, thus lowering the social costs (compliance time, pollution) of toll collection.

However, roads like the GSP are subject to strong seasonal demand. During peak travel seasons, the percentage of users without ETC capability increases dramatically, and ETC utilization rates drop. Therefore, based on our simulations, it is unlikely that high speed electronic toll collection will solve queuing problems during periods of peak seasonal demand. In order to improve efficiency at all times of the year, reconfiguration should be accompanied by a systematic program to encourage more drivers to adopt the new technology.

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