



Transitioning Barrier Toll Collection Systems to Open Road Tolling: Flow and Management Issues

Jonathan Peters, Ph.D.

The University Transportation Research Center – Region II

Jonathan K. Kramer, Ph.D.

Kutztown University

Michael E. Kress, Ph.D.

The College of Staten Island

Toll Roads

- Tolls are some of the oldest forms of taxes.
- They were popular prior to 1900 and were one of the major sources of funds used to construct and maintain roads.
- After 1910, fuel taxes replaced tolls as the major source of funding for roads in the United States.
- We have seen a renewed interest in tolls in the last 10-15 years due to a desire to avoid raising taxes and to use “user fees” to pay for government services.
- There are even movements to privatize roads – such as the Chicago Skyway & The Indiana Turnpike

Road User Charges

Forkenbrock in his recent paper in the Transportation Research Record No. 1864 outlined the 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.”

Toll Road Performance

- As we move forward with toll road systems – a number of questions should be answered in detail:
- How efficient are toll roads in raising road funding revenue? Peters & Kramer (2003)
- What is the environmental impacts of toll collection? (Peters & Kramer (2005))
- When is it appropriate to utilize a toll system?
- How do we evaluate the performance of a toll collecting system?
- How does a toll system impact society? Is it a just and fair as a means of raising transportation revenue?
- What are the benchmarks in terms of performance that we should expect from a toll system?

Toll Systems

In this paper we would like to develop some of the flow performance metrics that should be appropriate to evaluating a toll collection system and we would also like to explore what systematic difficulties exist in operating a toll collection system and their possible solutions.

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Transitioning Systems

We will 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.

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 lower speed, full service, or slow speed ETC tolling and another portion devoted to high speed ETC.

Types of Toll Collection Systems

- Human Toll Taker
- Mechanical Coin/Token Machines
- Slow Speed Electronic Tolling-RFD
- High Speed Electronic Tolling-RFD
- License Plate Recognition
- GPS Tracking

Manual Tolls

Many toll roads continue to collect tolls in a manual method either by cash transactions or automated mechanical coin processing machines.

This method of collection requires a full stop for the vehicle and the slowest processing speed per transaction.

This method remains popular on many toll facilities.

Barrier Type System



Pointer 40°36'07.62" N 74°03'41.13" W

Streaming 100%

Eye alt 1694 ft

New Hampshire Turnpike – July 2005



Hybrid Barrier Systems

Migrating to a hybrid system that allows both Electronic Toll Collection as well as manual cash transactions has occurred on most traditional toll roads.

Here, the authority continues to allow manual transactions but may also offer automated coin collection as well as Low Speed Electronic Toll Collection (any speed less than normal road speed) and High Speed Electronic Toll Collection (road speed collection)

The development of hybrid facilities may require significant capital outlays and roadway reconfiguration.

Hybrid Plaza



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Pointer 25°46'56.39" N 80°13'41.99" W

Streaming ||||| 100%

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Open Road Tolling

In many new toll facilities, no provision is made for manual toll collection and electronic tolls are collected at road speed only.

While this offers significant operation advantages, it relies on the vehicles being equipped with the correct ETC technology for a given road. In areas with significant holiday travel or vacation activity, this requirement may significantly reduce road performance as well as increase violation rates.

Case Study:

The Garden State Parkway

- New Jersey's Garden State Parkway (GSP) is 173 miles long
- It has 11 major toll barriers and 20 ramp toll plazas.
- Collects \$207,740,845 from 610,453,084 vehicles.
- Average distance per ride is 15 miles.
- Serves an urban core in the north and suburban and recreational communities in Central New Jersey and South Jersey.
- Heavy summer traffic to shore beach communities
- Region is non-compliant with the Clean Air Act.



Connecticut

New Jersey

Maryland

Delaware Image © 2006 MDA EarthSat

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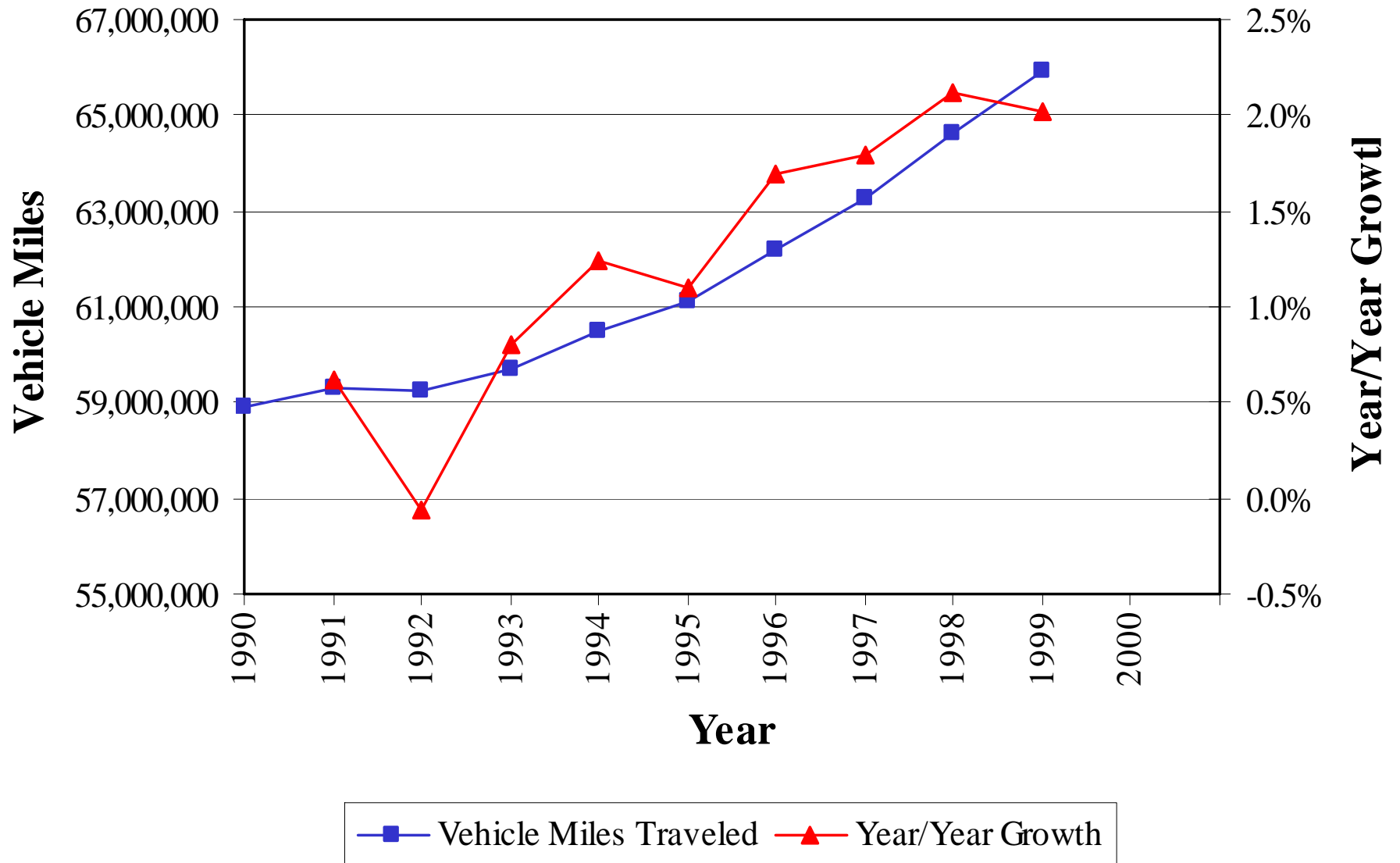
Pointer 40°10'48.65" N 74°27'52.20" W

Streaming ||||| 100%

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New Jersey Vehicle Miles Traveled

Source - NJ Department of Transportation

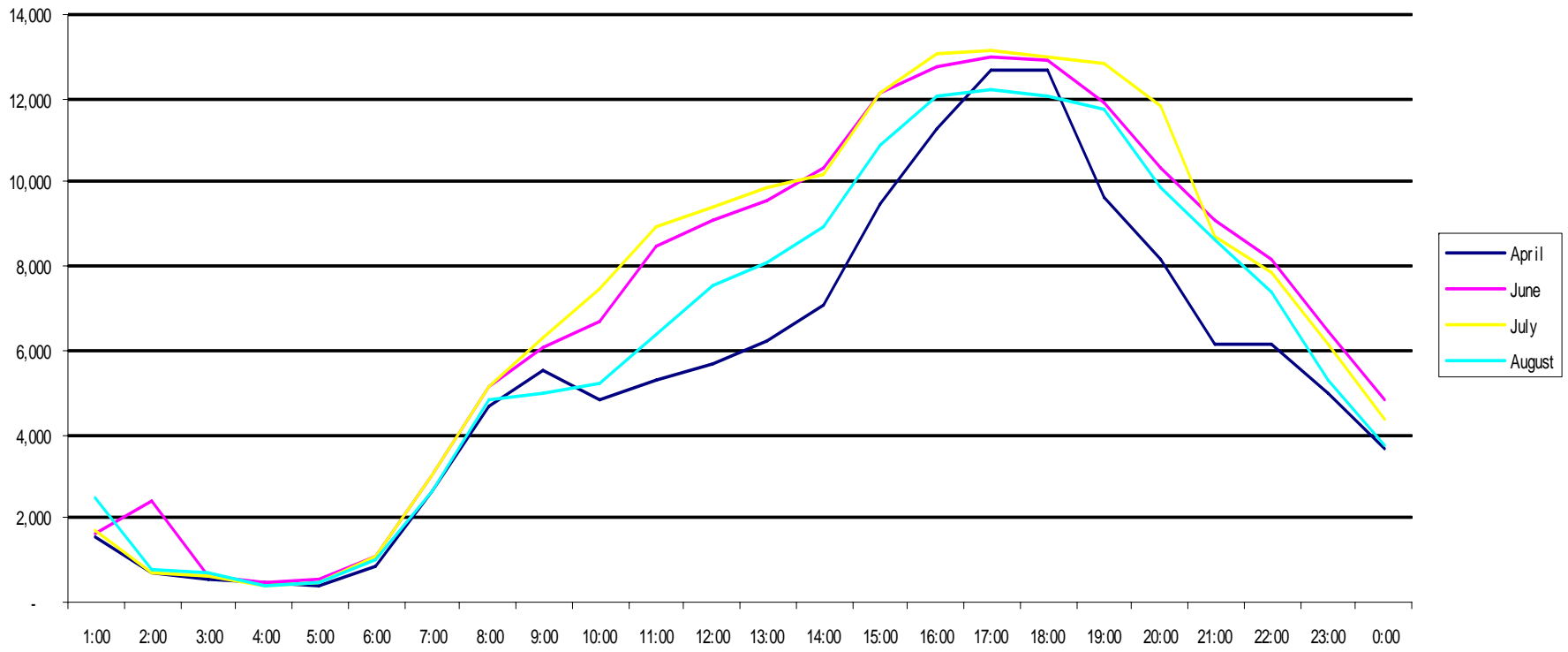




Raritan Toll Plaza

- Configuration prior to current modifications.
- 20 lanes
- Mix of cash, exact change and low speed electronic tolls

GARDEN STATE PARKWAY
Raritan South Friday
April 2002, June 2002, July 2002, August 2001



System Processing Rates

Garden State Parkway Hourly Processing Rates		
By Collection Method		
	Average	Maximum
Full Service	350-400	500
Exact Change	750-800	900
Slow Speed ETC (15 MPH)	1,200	1,400
High Speed ETC (55 MPH)	2,200	2,200

System Performance

Orlando-Orange Co. Expressway Hourly Processing Rates		
By Collection Method		
	Average	Var.
Full Service	498	+/-48
Exact Change	618	+/- 30
Slow Speed ETC (35MPH)	1,560	+/- 120

Changes to Raritan Plaza



Theoretical Processing Rates

	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			19,600

Vehicle and Road Characteristics

- 6 Lane Bridge feeds Plaza – flows 13,200 vehicles per hour maximum.
- 7 Lane Road after plaza – so no constraint on outflow of vehicles.
- Car only facility – no trucks.
- Vehicle Mix is fixed at 10% Cash Vehicles, 40% Exact Change and 50% EZ-Pass.
- 3 EZ-Pass Lanes must be maintained in the toll barrier for traffic safety purposes.

Queue Blocking - I

A significant performance limitation of the new configuration is the reduction in plaza capacity caused by the introduction of high speed tolling.

This reduced holding capacity of the plaza exposes the road to the potential for faster queue blocking.

Queue blocking occurs when a toll plaza has filled to capacity due to insufficient processing speed and the queue overflows the plaza and disrupts the flow of other vehicles attempting to reach the high speed ETC lanes.



Pointer 40°29'10.70" N 74°18'10.99" W

Image © 2005 State of New Jersey

Streaming ||||| 100%

Eye alt 1661 ft

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Queue Blocking II

Pre-2004, the configuration of the RTP had 15,700 lane feet of capacity^[1] to contain the vehicles that were 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 only 265 vehicles – a 35.8% reduction in queuing capacity.

^[1] We estimate the capacity from aerial photographs and Geographic Information Systems mapping software.

GPSS Simulation

To measure the impact of the reconfiguration on queuing, we use a simulation model based on the General Purpose Simulation System (GPSS). This Monte Carlo microscopic simulator 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 representing an average Friday Night in Summer (see Figure 1).

Simulation Results

The simulator generates statistics for the following performance parameters of the toll plaza:

- 1) Vehicles processed by each lane in the plaza with loading always being placed at the lowest number plaza if it is available
- 2) Utilization Rate – a measure of the percent of time that the toll lane is utilized during the simulation with 100% representing full utilization and 0% representing an unused facility.
- 3) Average collection time – a measure that shows the processing speed of a particular method of collection.

Scenario I

Facility	# Vehicles Processed	Utilization Rate	Avg. Collection Time
Full Service 1	1922	100.0%	9.519
Full Service 2	1903	99.9%	9.610
Full Service 3	1907	99.9%	9.587
Exact Change 1	3977	99.7%	4.588
Exact Change 2	3940	98.9%	4.594
Exact Change 3	3819	95.6%	4.582
Exact Change 4	3479	87.0%	4.576
Exact Change 5	2843	71.6%	4.606
Exact Change 6	2004	50.2%	4.582
Low Speed EZ-Pass 1	6108	100.0%	2.995
Low Speed EZ-Pass 2	6078	99.6%	3.000
Low Speed EZ-Pass 3	6043	98.6%	2.985
Low Speed EZ-Pass 4	5805	95.1%	2.999
Low Speed EZ-Pass 5	5312	87.2%	3.004
Low Speed EZ-Pass 6	4451	72.7%	2.990
Low Speed EZ-Pass 7	3163	51.4%	2.972
Low Speed EZ-Pass 8	1908	31.4%	3.007
Low Speed EZ-Pass 9	909	14.9%	3.005
Low Speed EZ-Pass 10	347	5.8%	3.068
Low Speed EZ-Pass 11	97	1.6%	3.016

Results of Scenario I

Old Low Speed Toll Plaza Configuration

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

Scenario II

Facility	# Vehicles Processed	Utilization Rate	Avg. Collection Time
Full Service 1	2122	100.0%	9.635
Full Service 2	2146	100.0%	9.526
Full Service 3	2144	100.0%	9.533
Exact Change 1	4447	100.0%	4.598
Exact Change 2	4420	100.0%	4.625
Exact Change 3	4432	100.0%	4.613
Exact Change 4	4442	100.0%	4.602
Exact Change 5	4439	100.0%	4.604
Low Speed EZ-Pass 1	5248	77.0%	3.000
Low Speed EZ-Pass 2	1992	29.1%	2.986
Low Speed EZ-Pass 3	320	4.7%	3.024
High Speed EZ-Pass 1	11932	94.7%	1.624
High Speed EZ-Pass 2	9704	77.2%	1.627
High Speed EZ-Pass 3	5625	44.9%	1.631
High Speed EZ-Pass 4	2112	16.8%	1.622
High Speed EZ-Pass 5	489	4.0%	1.653

Results of Scenario II

Results of Scenario 2: Table 4

New High Speed Toll Plaza Configuration

- 1) After a run of 66,000 vehicles, the toll queue had built to 1,030 for the cash lanes and 7,622 for the exact change lanes for a total queue of 8,663.
- 2) The entire run took 5 hours and 41 minutes.
- 3) The plaza loads to full capacity and queue blocking occurs after only 1,800 vehicles and 9 minutes and 22 seconds.
- 4) This fast queue blocking is caused by two issues – a sub-optimal share of ETC and a reduction in plaza holding capacity.

System Limitations

- Given the current plaza configuration and the vehicle payment choices, it is difficult to optimize the plaza.
- As a possible solution, we introduce the concept of a mixed payment plaza, where all barrier toll booths accept ETC payments as well as cash or exact change transactions.
- This allows us to eliminate the three ETC exclusive booths from the plaza and add them to the cash or exact change booths.

Scenario III

Facility	# Vehicles Processed	Utilization Rate	Avg. Collection Time
Full Serv/Low Spd EZ 1	2597	99.0%	7.514
Full Serv/Low Spd EZ 2	2497	95.6%	7.551
Full Serv/Low Spd EZ 3	2263	87.1%	7.587
Full Serv/Low Spd EZ 4	1801	68.8%	7.531
Full Serv/Low Spd EZ 5	1230	47.3%	7.591
Exact Change/LS EZ 1	4452	100.0%	4.430
Exact Change/LS EZ 2	4442	100.0%	4.439
Exact Change/LS EZ 3	4424	100.0%	4.457
Exact Change/LS EZ 4	4417	100.0%	4.464
Exact Change/LS EZ 5	4446	100.0%	4.435
Exact Change/LS EZ 6	4442	99.9%	4.437
High Speed EZ-Pass 1	11482	95.0%	1.633
High Speed EZ-Pass 2	9372	77.9%	1.639
High Speed EZ-Pass 3	5561	46.1%	1.636
High Speed EZ-Pass 4	2106	17.6%	1.644
High Speed EZ-Pass 5	482	3.9%	1.584

Results of Scenario III

One 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.

- 1) 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.
- 2) The run took of 5 hours and 29 minutes.
- 3) The plaza loads to full capacity after 3500 vehicles in 17 minutes and 31 seconds.
- 4) Again, this results in queue blocking that impedes the performance of the ETC and Exact Change lanes.
- 5) This change in booth configuration improves the low speed lanes overall utilization rate to 90.7% from 82.8%

Scenario IV

Further adjustment of dual processing lanes allows us to optimize the toll plaza given the existing vehicle mix.

- 1) After a run of 66,000 vehicles, the toll queue builds to 115 for the cash lanes, 1848 for the exact change lanes, and a total queue of 1888
- 2) The run took 5 hours and 9 minutes.
- 3) The plaza loads to full capacity after 13800 vehicles in 64 minutes and 43 seconds.
- 4) This again results in queue blocking.
- 5) We have optimized the toll plaza performance given the current mix of users.
- 6) Low speed lane utilization is improved to 99.0%
- 7) Further performance improvements require higher ETC share.

Scenario IV

Facility	# Vehicles Processed	Utilization Rate	Avg. Collection Time
Full Serv/Low Spd EZ 1	2359	99.8%	7.830
Full Serv/Low Spd EZ 2	2360	99.1%	7.770
Full Serv/Low Spd EZ 3	2204	97.0%	7.794
Full Serv/Low Spd EZ 4	2236	93.8%	7.766
Exact Change/LS EZ 1	4173	100.0%	4.435
Exact Change/LS EZ 2	4206	100.0%	4.400
Exact Change/LS EZ 3	4186	100.0%	4.421
Exact Change/LS EZ 4	4185	100.0%	4.421
Exact Change/LS EZ 5	4475	100.0%	4.432
Exact Change/LS EZ 6	4196	99.9%	4.406
Exact Change/LS EZ 7	4194	99.8%	4.405
High Speed EZ-Pass 1	10802	95.5%	1.637
High Speed EZ-Pass 2	8854	78.3%	1.637
High Speed EZ-Pass 3	5250	46.1%	1.624
High Speed EZ-Pass 4	2025	17.8%	1.624
High Speed EZ-Pass 5	508	4.4%	1.618

Plaza Flexibility

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. In a case such as the one we examine here, reconfiguration needs to be accompanied by a systematic program to migrate drivers to the new technology.

ETC AND PLAZA PERFORMANCE

Once you make the the decision to modify the plaza for high speed ETC you have reduced the flexibility of the plaza and now you are reliant on the utilization of ETC. In that case, we need to develop performance metrics for ETC utilization as well as system of incentives to stimulate ETC participation.

To some degree the usage of ETC becomes a quasi-public good, where the ubiquitous availability of ETC causes significant positive social impacts, so the individual user at the margin may need to be subsidized to promote the common good. The historical analogy is the universal service provision of early telephone regulation. In that case, all users paid into a universal service fund that subsidized low volume and remote users to provide greater connectivity.

We may want to consider the spillover effect of ETC and perhaps the cost of ETC should be borne by all users.

Capacity and Queuing

Unless toll plaza area is unrestricted, the modification of the toll plaza to include High Speed ETC may result in a reduction in the theoretical capacity of the plaza.

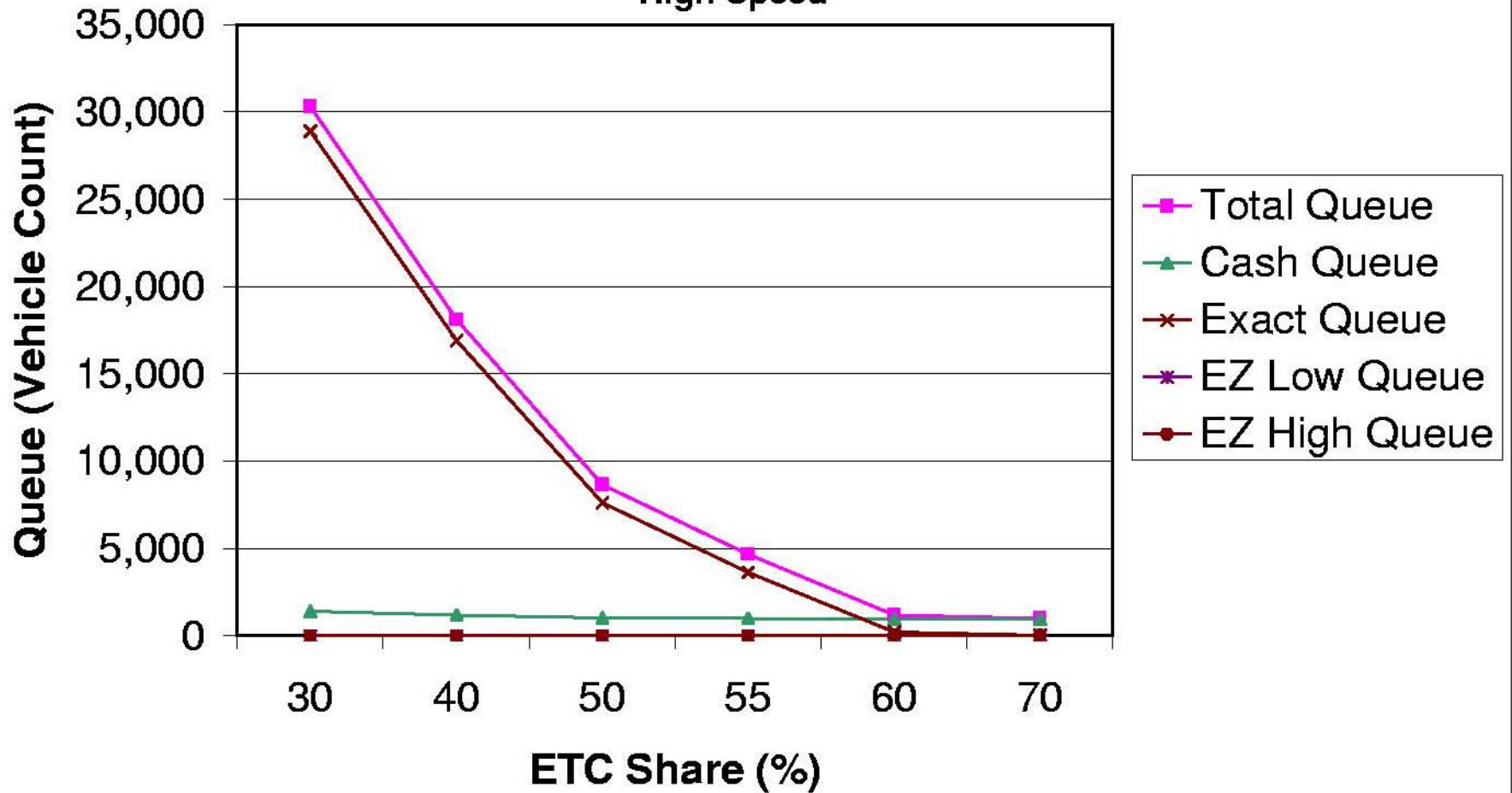
The reduction in the physical size of the toll plaza significantly reduced its vehicle holding capacity. The original plaza had a capacity of 413 vehicles before queue blocking occurred. The reconfigured plaza has a maximum capacity of only 265 vehicles – a reduction of 35.8%

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.

Garden State Parkway Raritan Toll Plaza South

Queue and ETC Share

Booths - 4 Cash, 4 Exact Change, 3 EZ-Pass Low Speed and 5 EZ-Pass High Speed



Queue Blocking Example – Port Authority of NY & NJ
Outerbridge Crossing – December 24, 2005 5:30 PM



4.5 Mile Backup
Caused by Queue
Blocking

About 1300 Vehicles
45 Minutes+



Pointer 40°30'58.03" N 74°16'17.98" W

Streaming ||||| 100%

Eye alt 19227 ft

Lane Configuration – 2 mixed payment (Cash & ETC)

2 ETC Low Speed

2 ETC High Speed



Conclusions - I

By modifying the method of toll collection a toll authority can significantly alter the performance of their toll plazas in terms of processing rates and consumer time costs.

We evaluate the Raritan Toll Plaza on the Garden State Parkway using the flow characteristics of the road and participation in electronic toll collection as our management variables.

We find that conversion to high-speed toll collection did 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) (20% reduction) 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%.

Conclusions - II

High Speed ETC works well during commuting times when the road is populated with sophisticated road users who have high ETC participation rates. During these times, it dramatically improves traffic flow and lowers the social costs (compliance time, pollution) of toll collection.

However, in the case of the RTP, it is likely that High Speed ETC will not solve queuing problems during peak seasonal travel times. The Garden State Parkway is subject to strong seasonal demand in the summer months when the number of casual users is high and ETC share drops.

Conclusions - III

ETC participation is a key component in reducing transaction time and improving plaza throughput.

Highway geometry may limit the performance of any queue management barriers.

Many toll agencies appear to have a mixed set of goals with regard to ETC participation: Some are applying monthly fees, others are removing discounts for ETC use, others are charging for replacement or new transponders. Others seek to promote usage. All of these charges and reductions in discounts will tend to limit the adoption rate of marginal users and will limit the performance of toll plazas with mixed payment methods.

Problems with inter-operability between different regions and authorities limits the value of ETC systems for interregional travelers. This reduces value of ETC in terms of traffic congestion impacts.



Image © 2005 Bluesky

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Pointer 40°31'31.46" N 74°14'02.61" W

Streaming [progress bar] 100%

Eye alt 514 ft