Estimating the Air Quality Impacts of Hybrid Toll Plaza Operations Using Monte Carlo Simulation

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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 computer simulation model of toll plaza flow to measure the impact of such a conversion on capacity, queuing and pollution output. By altering the mix of vehicle payment types and toll plaza operational configuration, we can examine the potential traffic flow conditions and payment lane utilization. We then can estimate the pollution output that will occur given a particular set of traffic conditions and plaza configuration. Using actual data from existing hybrid plazas, this model will provide us with an estimate of the air quality impacts of a number of toll facilities in the North Eastern United States.

PERFORMANCE ISSUES

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."

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.

Some of these issues have already been addressed. For example, Peters and Kramer (2003) show that toll collection is inefficient in comparison to other means of financing such as income and fuel taxes. Sisson (1995) examines the impact of electronic toll collection (ETC) on air pollution and Friedman and Waldfogel (1995) focus 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 that analyzes 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, analyze the impact of the installation of the ETC on the New Jersey Turnpike in 2000. Saka, Agboh, Ndiritu and Glassco (2000) examine the performance of the new ETC system that was installed on the Fort McHenry Tunnel in Baltimore. Spasovic, Juckes, Opie and Hausman (2003) study 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 is on weekday morning and evening rush hour traffic. While it is important to examine flow during the regular work week, this is also typically the period with the highest percentage of ETC users – and this improves the performance of an ETC system.

In this paper, we focus on Forkenbrock's concern with convenience and ease of use. In particular, capacity and queuing issues related to the management of a hybrid toll plaza and its impacts on air quality

COLLECTION SYSTEMS

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.

Hybrid Barrier System

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.

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.

COMPARATIVE COLLECTION METRICS

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. Alternatives including automated token or exact change processing machines, low speed electronic tolling and high speed electronic tolling are currently utilized by many authorities. The technical performance of these systems appears similar across systems as is illustrated in Table 1. The technical processing rates for roads in both New Jersey and Florida are generally the same.

Table 1 – 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

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

Utilizing these known average processing rates, we can calculate the theoretical maximum hourly capacity of a given plaza configuration. This maximum flow rate is useful as a basic benchmark of system performance and reflects the best possible performance of the plaza if the vehicles arriving at the plaza are utilizing the optimal mix of payment methods. Performance of the plaza facing a sub-optimal mix of payment choices by users is explored using Monte Carlo Simulation.

Table 2: Example - Capacity of the Outerbridge Crossing Plaza (OBXP) – New York and New Jersey

Throughput and Booth Utilization Rates - 2005

Pre ETC Plaza Configuration	Booths	Per Lane Hourly Throughput	Total Throughput
High Speed ETC	0	2200	0
Low Speed ETC	0	800	0
Cash Transactions	8	375	3000
Total	8		3000

Low Speed ETC Plaza	Booths	Per Lane Hourly Throughput	Total Throughput
High Speed ETC	0	2200	0
Low Speed ETC	3	800	2400
Cash Transactions	5	375	1875
Total	8		4275

Current Hybrid Toll Plaza Configuration	Booths	Hourly Throughput	Total Throughput
High Speed ETC	2	2200	4400
Low Speed ETC	2	800	1600
Cash Transactions	3	375	1125
Total	7		7125

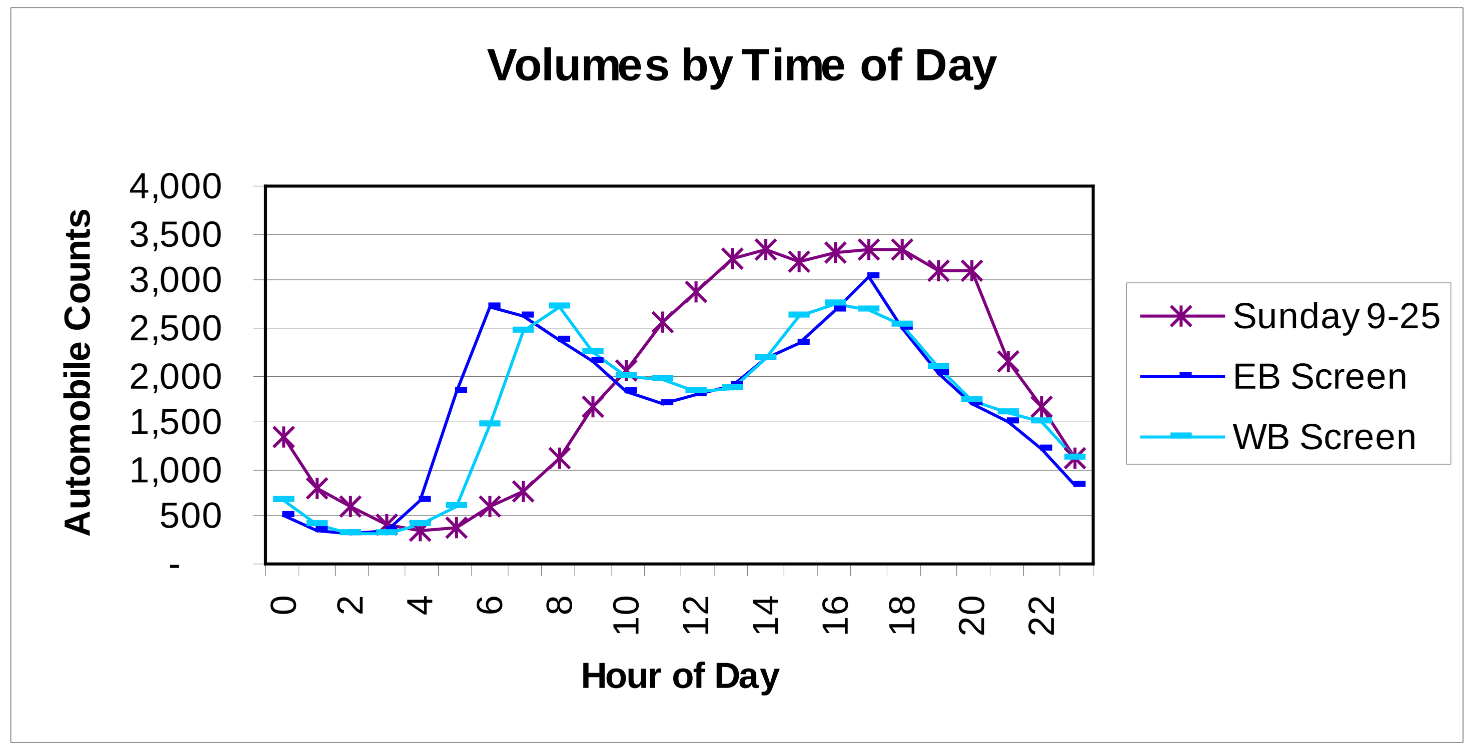
The addition of High Speed ETC increased the OBXP's maximum theoretical capacity by 137.5% or 4125 vehicles per hour. The large magnitude of the increase was due to broad expansion of ETC capacity. As such, to utilize this capacity, users must be equipped with the appropriate ETC transponders. Based on the existing volumes on the Outerbridge Crossing (OBX) provided by the Port Authority of NY and NJ we analyzed in Table 3, the High Speed ETC and the Low Speed ETC lanes are significantly underutilized at the OBXP, given the current lane allocations.

Table 3: Current Hourly Utilization Rates

Outerbridge Crossing Volumes - September 1, 2005 to November 30, 2005				
Metric	**Cash**	**Low Speed ETC**	**High Speed ETC**	**Total**
Mean	374	188	1,202	1,763
Maximum	863	948	2,575	3,499
Minimum	8	1	2	4
90th Percentile	626	331	2,046	2,915
95th Percentile	685	353	2,149	3,109
99th Percentile	754	398	2,262	3,282
Observations	2182	2184	2183	2183

TIME OF DAY VARIATION

Figure 1 – Outerbridge Crossing - Volumes by Time of Day



In 2005, the OBX plaza handled 15.6 million transactions. The traffic flow at this plaza is subject to considerable day of the week and seasonal variation. On a typical Sunday, the OBXP is subject to over eight hours of flow in excess of 3,000 vehicles per hour. The eastbound rush begins at approximately 12 Noon on Sundays and does not end until after 8:00 PM. Figure 1 illustrates the typical traffic flow pattern for a sample Sunday in September 2005. This peak period loading must be processed quickly to avoid excess delay for motorists as well as extra pollution. This peak period is more extensive than the average daily flow that has both a morning and evening peak period as illustrated above in both directions. In addition, as illustrated in Table 4, the OBX has considerable variation in payment methods over the 91 days that we studied.

Table 4: Variation In Payment Methods and Volumes by Day

Port Authority Outerbridge Crossing Volumes 91 Days from September 1, 2005 to November 30, 2005	High Speed		Low Speed			Payment Method		
	High ETC	**Total High**	**Cash**	**Low ETC**	**Total Low**	**Total Cash**	**Total ETC**	**Total**
Mean	28,825	28,825	8,958	4,515	13,473	8,958	33,340	42,299
Maximum	32,487	32,487	12,330	5,863	16,789	12,330	37,230	48,500
Minimum	22,939	22,939	6,195	3,442	9,789	6,195	26,533	32,728
Total Transactions	2,623,034	2,623,034	815,140	410,879	1,226,019	815,140	3,033,913	3,849,178

HYBRID BARRIER PLAZAS

As toll authorities move forward with high speed ETC, they need to examine the impact of hybrid toll plazas on compliance and flow performance. 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.

Photograph 1: Typical Barrier Toll Plaza

Photograph 2: Typical Hybrid Plaza

For example, the Verrazano Narrows Bridge Toll Plaza of the Metropolitan Transportation Authority in New York City (Photograph 1), as it is currently configured, represents a traditional mix of full service and slow speed ETC (zero MPH with gate arm). The main plaza (westbound) contains 21 main line lanes is shown on the top of the photograph with the eastbound bypass lanes (no toll collected) in the bottom of the photograph.

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