

OPERATIONAL PLANNING FOR ELECTRONIC TOLL COLLECTION: A UNIQUE APPROACH TO COMPUTER MODELING/ANALYSIS

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ABSTRACT

For many years the operations of toll plazas have been studied to determine the optimal number of booths needed to provide service during specific times of the day. With the advent of Electronic Toll Collection (ETC) technology or Automatic Vehicle Identification (AVI) as it is also known, a new opportunity exists to increase the toll processing capabilities at plazas whose size (number of toll booths) are usually constrained by economics and geography. The cost of the ETC equipment and its operational impact on plaza throughput, make the task of fully evaluating the technology (prior to its implementation) a critical one.

This paper will present a new approach to modeling a toll plaza and evaluating a number of possible scenarios for an ETC equipped toll plaza. Utilizing a spreadsheet based "Demand/Capacity" model, (which was validated and created in a relatively short time frame) rather than using the traditional complex simulation language, the effectiveness of ETC technology was evaluated. The result was the development of a unique and successful approach to evaluating toll plaza queuing dynamics which many modelers have faced, but few have conquered.

1 PROJECT BACKGROUND

The Port Authority of New York and New Jersey (PA) is a public agency responsible for promoting and facilitating trade, commerce and transportation in the New York-New Jersey region. It is a self-supporting bi-state agency which provides, operates and maintains numerous transportation facilities in and around the New York city metropolitan area. The current demands for these facilities are especially severe on

the six tunnel and bridge crossings which link New York and New Jersey at key locations within the metropolitan region. The crossings include the George Washington Bridge in the northern portion of New York City, the Lincoln and Holland Tunnels which link New Jersey and the Manhattan Central Business District and the Outerbridge, Goethals and Bayonne Bridges which connect Staten Island and New Jersey. Travelling to New York at each of these crossings, patrons are required to stop and pay a toll. By its nature, toll collection with the required stopping of vehicles and the time needed to transact the payment between driver and toll collector, creates congestion in the form of vehicle queues. Long queues are more evident during the morning and evening peak travel periods, when the number of vehicles needed to be processed sometimes greatly exceeds the tolls processing capacity at a given crossing.

Principally for this reason, we have recently intensified the examination of Electronic Toll Collection (ETC) technology for possible implementation at our tunnel and bridge crossings. ETC technology involves the use of small electronic "tags" that are mounted in each patron's vehicle which broadcasts a unique signal that is interpreted by equipment placed in a specially equipped toll lane. The in-lane equipment relays information from the tag to a computer system which then automatically debits the toll payment from the customer's prepaid account (or credit card). Of the six bridge and tunnel crossings the PA operates, the Goethals Bridge toll plaza was initially selected for an evaluation of the ETC technology and possible operational impacts, because of its proximity to the Verrazano Narrows Bridge, where this technology was also being planned for testing by the Triborough Bridge and Tunnel

Authority (the agency which operates intra New York City toll bridges and tunnels).

During the past twenty years, the Management Engineering and Analysis group of the PA has periodically performed operational evaluations of new technology being considered for our facilities by employing the use of computer simulation models. Discussions between our staff and those PA staff involved with the examination of ETC technology made it evident that the use of computer based modeling techniques would greatly aid in assessing the potential operational impacts of ETC equipment. The key questions on the planners minds for different operating scenario's (e.g., dual-use vs. dedicated lanes) were; (1.) what would be the impact on queuing and other level of service measures given uncertain levels of patron utilization? and (2.) how much equipment should be installed and where? Consequently, we agreed to develop, validate and apply a Personal Computer (PC) based "Demand/Capacity" model to evaluate the potential operational impacts of ETC technology at the Goethals Bridge toll plaza.

Our intent was to develop a model which could easily be adapted and applied to evaluate ETC technology for other PA bridge and tunnel toll facilities with minimal modification to the model structure and internal workings. The focus of this paper is to describe our efforts concerning the development and validation of the model. To authenticate our work and for the benefit of the reader, we have also included a brief discussion of the results of applying the model for examining the impact of ETC technology at the Goethals Bridge toll plaza.

2 DATA COLLECTION PROGRAM

Our initial task under this program, involved a number of observations made during the AM/PM peak travel periods, which were then used to establish the initial structure/logic, assumptions, inputs and data which were needed for the development, validation and the use of the demand/capacity model.

Our data collection program was comprised of a number of elements for which information was collected empirically and used for model validation and/or runs, as shown in Table 1.

For data that was collected empirically at the Goethals Bridge toll plaza, it was necessary to select a base data day on which to obtain the required information. We decided that the base data day should be the 85th percentile demand day for a representative time period. Our review of daily volumes during 1990, resulted in the identification of

an 85th percentile daily demand volume of 35,800 vehicles, which occurred on a Friday. Our analysis also revealed that the highest traffic volumes consistently occurred on a Friday. Hence, Friday, April 6th, 1990 was selected as the base data day.

TABLE 1

PROGRAM DATA ASSUMPTIONS & ELEMENTS

| <u>ELEMENT</u> | <u>SOURCE</u> | <u>PURPOSE</u> |
|------------------|-----------------|-------------------|
| ETC Market Share | Assumption | Model Runs |
| ETC Scenarios | Assumption | Model Runs |
| Vehicle Arrivals | Empirical Model | Validation & Runs |
| Processing Times | Empirical Model | Validation & Runs |
| Vehicle Queue | Empirical Model | Validation |
| Vehicle Thruput | Empirical Model | Validation |

On this day, information was collected empirically for the applicable data elements (see table above) for the a.m. and p.m. peak periods defined as occurring from 6-10 a.m. and 4-7 p.m., respectively. For each of the elements, data was collected and recorded at two minute intervals, to provide the level of detail necessary for validating and executing the model.

2.1 Vehicle Arrivals - Number and Mix

Vehicle arrivals specific to each class [automobile, light truck (two axles), heavy truck (three or more axles) and bus] were recorded at two minute intervals for the duration of the a.m. and p.m. peak periods. By recording arrivals by each class of vehicle, we were able to determine the percentage of each vehicle type in the traffic stream. The data was a key input to validate existing traffic conditions and execute the model for different ETC scenarios.

2.2 Vehicle Processing and Transaction Times

Processing time is defined as the amount of time that a vehicle occupies a toll lane and includes the time required to decelerate and accelerate to and from the lane, respectively. Transaction time relates to the duration of the interaction for payment (by cash or pass) between the toll collector and the vehicle operator. Our data collectors acquired processing and transaction times by moving periodically to different lanes to ensure that the data base exhibited a sampling of different toll collectors.

Actual vehicle processing and transaction times for patrons using cash or pass, provided us with base

information for developing similar times for ETC technology. When running the model for ETC scenarios, an ETC vehicle transaction time of 0.1 seconds (the time the ETC reader needs to read the vehicle's transponder) would be substituted for the transaction times recorded by the Study Team. The difference would be quantifiable as the transactional time savings ETC technology offers, as a component of the overall measured vehicle processing time. Over three days during a.m. and p.m. peak periods, we recorded approximately 5,700 vehicle processing and transaction times for the four different classes of vehicles (automobiles, light truck, heavy truck, bus). The resulting average transaction and processing times by specific vehicle class and method of payment were used to develop our processing/transaction rate formula.

2.3 Total Vehicle Queue

On occasions when vehicle arrivals increase and exceed the maximum rate at which they can be processed by the toll plaza, vehicle queues form. The extent of these queues usually varies over time. The data was useful as a measure of base day service level for comparative purposes to similar queue levels produced as an output for our ETC model runs. Additionally, the aggregate base day queue levels (collected empirically) were used for model validation purposes. Total queue in the plaza was counted and recorded at two minute intervals during the base data day a.m. and p.m. peak periods.

2.4 Total Vehicle Throughput/Lanes Open

An index which is used to measure level of service is toll plaza throughput, which is the number of vehicles that the toll plaza can process in a given amount of time with a specified number of toll lanes open. The rate of throughput is a function of vehicle arrival rate and toll plaza processing capability (toll collector/ETC processing speed and number of toll lanes open). The data was used to validate the model's output for the base day run, and also as a measure of base day service level. Service level comparisons between the base day (traditional) toll plaza operation and the various ETC scenarios/cases run were possible given this information.

2.5 Data Collection For Model Validation

The aforementioned data elements were collected on our April 6, 1990 base data day. This information provided the input and the basis for

developing the processing rate formula for running the ETC model. However, in order to validate the model, a different day's data was also required which was not used for development of the processing rate formula. We selected Friday, June 15, 1990 to collect data for our model validation task. To be consistent with the base day data collection, we recorded at two-minute time intervals similar data elements for an a.m. and p.m. peak period. In addition to our April 6th data, the data was used to run the model and the output compared to the empirical data.

During the June 15th data collection we also recorded utilization levels for each toll lane which represented the time that vehicles were actually present in the toll lane. As a result of our model development efforts using the April 6th data, it became evident to the Study Team that simply using the number of "lanes open" in our vehicle processing formula was not sufficient enough to provide an acceptable level of precision for estimating throughput and queue. Significant errors were found between the initial model output and the data empirically collected for the base day. Hence, lane utilization rates were developed for the time period that each lane was actually open for processing (excluding closures for occurrences such as breaks and delays). This approach resulted in an acceptable level of validation.

3 MODEL STRUCTURE

Our goal in this study was to design a mathematical Personal Computer based model that would replicate the processing of vehicles through a toll plaza. In order to accomplish this, a number of variables (e.g., type and frequency of vehicles arriving, number of lanes in operation, type of toll payment of each vehicle) must be taken into account. Our model must utilize the variables to estimate the number of vehicles that these toll plaza will process through in a given time period, and complete this process accurately under a wide variety of conditions.

The ETC Demand/Capacity model was created utilizing the electronic spreadsheet software package Lotus 123®. The ETC model consists of 17,500 cells within the spreadsheet, in which approximately 6,000 simultaneous calculations are made. The calculations were structured to closely replicate actual toll plaza operations. Although initially structured for the Goethals Bridge, the model's logic and internal workings were designed for application at other toll plazas (with different configurations and operations) with minimal enhancements required. The structure can be found in Figure 1.

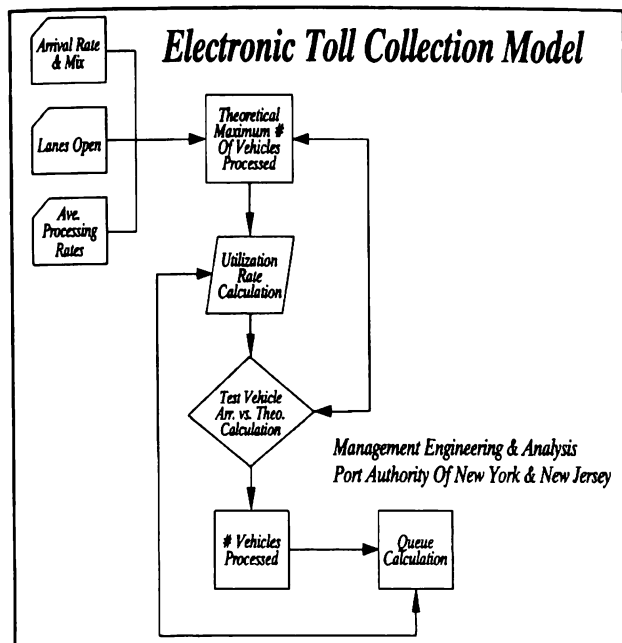


Figure 1 - Conceptual ETC Model Flow Diagram

The model's structure closely matches the process that a vehicle must encounter in order to proceed through the plaza. The vehicles are generated in the input parameters section (the section of the model which contains input information and parameters such as the vehicle arrival rate and processing times) and from there are entered into the plaza queue. The model's input parameters section is where information which characterizes the toll plaza (i.e., the variables noted above) for different operating scenarios is set. This section allows the user of the model to customize it to a specific condition or scenario. Here the volume of arriving traffic, processing rates, and arrival mix, can be set. Two types of ETC toll plaza operations were used in the model. First was the dedicated lane scenario, which allowed only ETC vehicles to be processed in specified ETC lanes. Second was the dual-use which allowed both ETC and Non-ETC vehicles to be processed in the same lane. The Non-ETC dedicated lane and dual-use lane processing rates used in each model were averaged by class from the field collected data. At the time the data collection was conducted, no ETC lanes existed to be measured; hence, the ETC processing rates for the dedicated lane scenarios are represented by the following equation:

$$\text{ETC Dedicated Lane Processing Time} = \frac{\text{Non-ETC (Processing Time)} - (\text{Transaction Time}) + 0.1 \text{ Seconds}}{\dots}$$

Thus, the ETC processing time is computed using non-ETC processing times, substituting the ETC transaction time. The processing times include the deceleration time of a vehicle into the toll lane, plus the time the ETC reader needs to read the transponder (0.1 seconds), plus the acceleration time for a vehicle out of the lane. The ETC model is capable of calculating an ETC processing time for each class if needed. However, in all the cases analyzed for this study, only the car ETC processing rates were calculated and used in the throughput estimation. This was done based on an assumption for this study that only the car market would utilize the ETC technology. Autos were the only market used because they make up 90% of the arrivals at the Goethals Bridge. The corresponding low percentage of remaining classes would not have an impact on the model results and therefore, were not used. For the dual-use lane scenarios, the above dedicated lane rates were averaged with the non-ETC processing rates to form the overall dual-use rates. This average is weighted based on the number of ETC and non-ETC vehicles arriving in each two-minute interval.

In addition to the basic inputs to the model, it is also important to identify what market share will be utilized for a particular scenario. The Market Share distribution is set in this section by the user who enters what percentage of arriving vehicles (see section on data collection program) will be utilizing the ETC toll lanes.

The model also contains a Throughput & Queue section which calculates the number of vehicles processed and queued in the toll plaza. In this section, the processing information from the input section (processing times for each type of vehicle, number of ETC & Non-ETC lanes in operation, vehicle mix, etc.) are combined into the Throughput calculation which processes only a specific number of vehicles. The remaining vehicles (if any) comprise the queue for that time interval and are added into the number of vehicles arriving in the next time interval. As all of these calculations are taking place, the model tabulates statistics on such variables as total vehicles queued, average single lane queue, vehicle throughput, and the distance the queue will reach from the toll plaza.

3.1 ETC & Non-ETC Throughput Calculation

The heart of a toll plaza model is the Throughput calculation. This calculation uses as variables the vehicular arrival rate, processing rates, and the number of lanes that are open for each two minute interval. A throughput calculation is made in each two minute interval for each individual class of vehicle. These class calculations are summed as a theoretical maximum throughput value and then multiplied by a utilization factor which is discussed below.

During the data collection phase of the study, it was observed that a direct relationship existed between the total vehicle queue and the rate at which vehicles were processed. The analysis of the data from April 6, and June 15, 1990, revealed that if the total queue exceeded 65 vehicles in the plaza mouth (about 8 per lane), the toll collectors would process more vehicles per two minute interval. This was observed to be consistent through both days of data collection.

To utilize the relationship of vehicles processed to queue length, the percent of time in which the observed queue exceeded 65 was calculated. This created a two step utilization rate with the "shift" to the higher rate occurring at the point where the queue was equal to or greater than 65 vehicles. This variability in the utilization rate "tailored" the throughput to better reflect the "real-world" toll plaza vehicle processing rates.

In addition to the queue relationship, the initial Theoretical Throughput formula had to be modified because its results were found to overestimate the number of vehicles that would be processed every two minutes. The overestimation stemmed from the fact that the throughput calculation is based on the number of lanes open. However, a lane that is open may not be occupied. Therefore, the model was calculating the throughput as if all lanes were both open and fully occupied in each two minute interval. In reality, this is not the case. As was observed in our data collections, there is a percentage of the total time a lane is open in which it is actually occupied. Because of this, the time that the lane was NOT occupied was not being taken into account by the existing throughput calculation in the model. Based on the June 15 data collection, it was determined that the average occupied rate (percent of time that a vehicle occupies an open lane) for a toll lane at the Goethals was 88.5% during the p.m. peak period (4:00 to 7:00 p.m.).

The data from the queue driven utilization rate was consolidated with the average occupied rate to

form the overall utilization rate formula for the model. This resulting formula is based on the average of 88.5%, with an upper limit of 93% and a lower limit of 83.5%. The final calculation (which we termed the Utilization Rate Deterministic Formula) used for calculating theoretical throughput is:

$$\text{Total Toll Plaza Throughput} = (\sum(\text{Individual Class Calculations})) \times (\text{Utilization Rate})$$

$$\text{Utilization Rate} = \begin{cases} \text{If Queue} \geq 65, \text{ Rate} = 0.93, \\ \text{If Queue} < 65, \text{ Rate} = 0.835 \end{cases}$$

The choice of utilization rate is determined by the total queue from the previous two minute interval. The final product from each of the ETC & Non-ETC theoretical throughput calculations is the total theoretical number of vehicles that can be processed through the toll plaza in a two-minute interval.

For the dedicated lane scenarios of the model, two separate throughput calculations were made. The model would distinguish vehicles arriving for ETC or Non-ETC processing and assign them to the appropriate lanes. In the dual use scenario, ETC and Non-ETC vehicles were not segregated but were processed in any available lane. In order to make this throughput calculation, a weighted average processing rate was determined utilizing the ETC and Non-ETC processing rates and the number of each type vehicles arriving each two minutes. The result is an overall average combined (ETC and Non-ETC) processing rate by class that varies in every two minute interval based on the mix of vehicles arriving.

3.2 ETC & Non-ETC Queue Calculation

Since in the dedicated lane scenario, only ETC vehicles can be processed in an ETC lane, the calculation for ETC processed vehicles are made separately from the Non-ETC processed vehicles. The calculations for the throughput and resulting queue are made in two independent section of the model called the "ETC Queue" and "Non-ETC Queue" sections. In these sections, the plaza's total queue is first calculated based on the throughput calculation and the vehicular arrival information. The model also makes an estimate of the average single lane queue by dividing the current total queue by the number of lanes open in that two minute interval and plots the average single lane queue over time for the simulated period. An example of the average single lane queue graph can be found in Figure 2. The graph represents the 15% auto ETC user market share scenario which

are processed in 1 dedicated lane of the 8 available.

Since in the dual use lane scenario model both ETC and Non-ETC vehicles can be processed at each lane, one queue calculation is made based on the dual use weighted average processing rates as described earlier. The total queue is distributed uniformly across the entire toll plaza rather than separating the queue as in the dedicated lane scenarios.

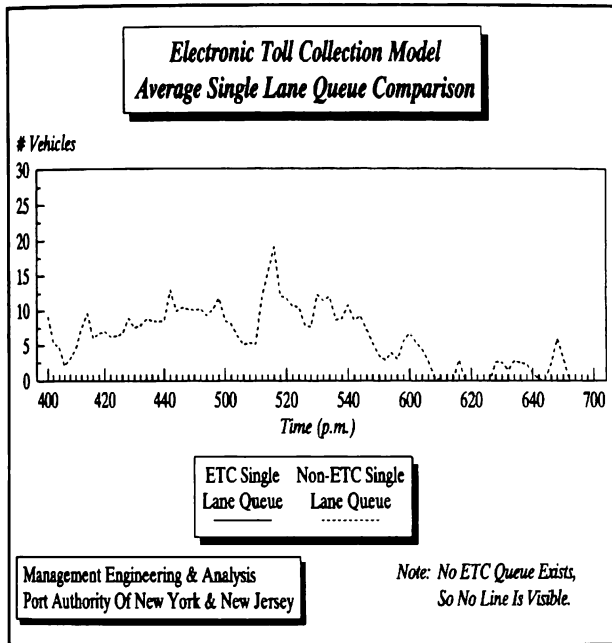


Figure 2 - Average Single Lane Queue Graph

With the total vehicles queued now calculated, the model can estimate the distance from the toll plaza that the queue will extend in each two minute interval. This distance is the linear measurement of an average single lane queue [separate for ETC & Non-ETC queues under the dedicated lane scenario] from the toll booths. At this point, the distance is calculated by multiplying the total queue value by the Weighted Average Vehicular Length that is calculated in the Input section. This average length is based on the 95 percentile standard vehicle lengths for the four classes used in the model. These standards were taken from the American Association of State Highway And Transportation Officials' "Geometric Design of Highways and Streets." Since the average lengths are weighted (based on the percent of vehicles utilizing ETC technology) two independent calculations for ETC and Non-ETC queues are made. In the dual use scenarios, the queues are distributed uniformly across all lanes, so the queue distance is calculated based on this uniform queue distribution.

The queue distance formula also adjusts the linear measurement of the queue to take into account that at a specific distance from the Goethals Bridge toll plaza (456 ft.), the number of queuing lanes available decrease from eight to four. The result of reducing the available lanes for queuing by half will double the rate at which vehicles will queue beyond the 456 ft. mark in the plaza mouth.

There are several distance markers within the mouth area of the plaza at the Goethals Bridge. In the Input section, these physical distances are set for the Distance To The Midpoint of Toll Plaza Mouth (228 ft.), Distance To The End Of The Toll Plaza Mouth (456 ft.), and Distance To The Mouth Approach (516 ft.). The model checks at each interval to see where the queue distance is in relation to these three markers. The markers are used in the graphical output of the model to show a visual reference to the marker points. Figure 3 shows an example of the vehicle distance queue graph, for a 15% ETC market share with 1 dedicated ETC lane.

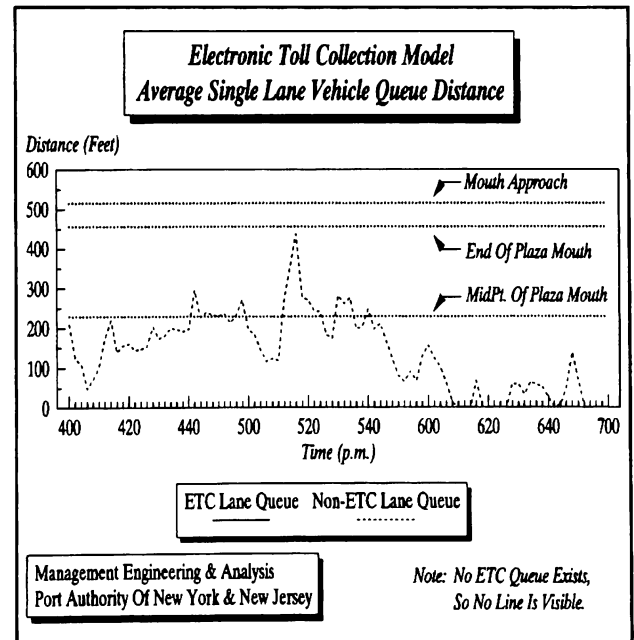


Figure 3 - Average Single Lane Queue Distance Graph

Lastly, it is not only important to know how far back the queue is in relation to the designated distance markers, but also to know the amount of time an arriving vehicle will spend in the queue. The model continuously monitors the queue length and tabulates, at two minute intervals, an average of the amount of time a vehicle will spend in the queue.

3.3 Statistical Output

The section in the model which tabulates the results of the model run, such as queue and throughput data, is the Output Results section. This section calculates a variety of output variables which are tabulated for the ETC & Non-ETC lanes. The average/maximum values for the "Total" and "Single Lane Queue" are calculated along with the amount of time in queue for each. These average/maximum wait time values (which are expressed in minutes) are calculated by multiplying the average/maximum "Single Lane Queue" values by the weighted average processing rate (which is expressed as seconds/vehicle) in the Processing Times portion of the Input section. Additionally, the model tabulates the "Average ETC/Non-ETC Lanes In Operation." Lastly, the "Total Time Queued Beyond The Plaza Mouth" and "Total Time Queued Beyond The Plaza Mouth Approach" is produced by a summation of the number of minutes exceeding each respective marker.

4 MODEL VALIDATION

The process of validation is the conclusive way of verifying a model's accuracy by comparing its output against some "real world" measured data. In the ETC model, the two critical model outputs are the toll plaza's throughput and queue. The plaza queue is a function of its throughput, therefore, any change in the throughput characteristics will result in a direct change in the queue. It was decided by the Study Team to validate the model's accuracy on the toll plaza's throughput and queue because of the sensitivity of these variables and their importance in making the kinds of decisions for which the model would be useful. It was also decided that since the ETC technology is not in operation at the Goethals Bridge, the validation of the model would be based on the current Non-ETC processing of vehicles.

During the data collection on April 6 and June 15, 1990, the vehicle throughput count and the total plaza queue were measured at two minute intervals. With four rush periods of data collected, four versions of the model were created. Each model contained a specific day and rush period's data. Both the actual throughput and queue values for each of the four time periods were compared at two minute intervals to the projected throughput and queue values calculated by the model. The percent variation for the throughput and queue were also calculated at each time interval. The "Average Deviation - Queue And Throughput" values for each model are averages of all the two minute model results for each period. These values

are used to validate the model's performance. The results of the four validation models are documented in the Table 2.

The validation values show a marked difference in accuracy in calculations for the a.m. and p.m. rush periods. There were distinctly different arrival demand levels for the a.m. and p.m. periods in the data we collected.

TABLE 2

Average % Deviation Thruput & Queue

| | <u>Thruput</u> | <u>Queue</u> |
|-------------------|----------------|--------------|
| 4/6/90 P.M. Rush | 1.7% | 6.4% |
| 4/6/90 A.M. | 52.1% | 40.4% |
| 6/15/90 P.M. Rush | 7.6% | 18.3% |
| 6/15/90 A.M. | 76.5% | 33.4% |

The validation graphs for the p.m. period models are presented in Figures 4, 5, 6 & 7.

The p.m. rush period arrivals were fairly constant, with infrequent breaks in the arrival pattern. This relatively constant arrival pattern resulted in a measured toll lane unoccupied rate averaging 11.5% for all booths open during the p.m. period of the data collection. The a.m. arrivals arrived in a "non-continuous" flow pattern (intermittent arrivals) into the toll plaza resulting in a unoccupied rate of 81.7% for all lanes. The large gaps between arrivals in the a.m. had a significant impact on the throughput calculation accuracy of the model. In addition to inconsistent vehicular flow pattern in the a.m., these gaps may occur because of the higher percentage of truck traffic. Because of the slower movements of the trucks, the other vehicles on the span must maneuver around the trucks which are impeding their flow. This impedance of the flow is partly the cause of the gaps in the arrivals. The number of vehicles arriving in each class is one of the variables in the model's throughput calculation. The study team's belief is that as more gaps occur in the arrival stream (as did in the a.m. periods), the model's ability to correctly calculate the throughput will decrease. This would account for the fact that the deviation percentages listed above are lower in the p.m. than in the a.m. Based on these results, the Study Team decided that the model was valid for the p.m. rush period only. However, this was satisfactory for the ETC Project Team since the p.m. period actually represented the

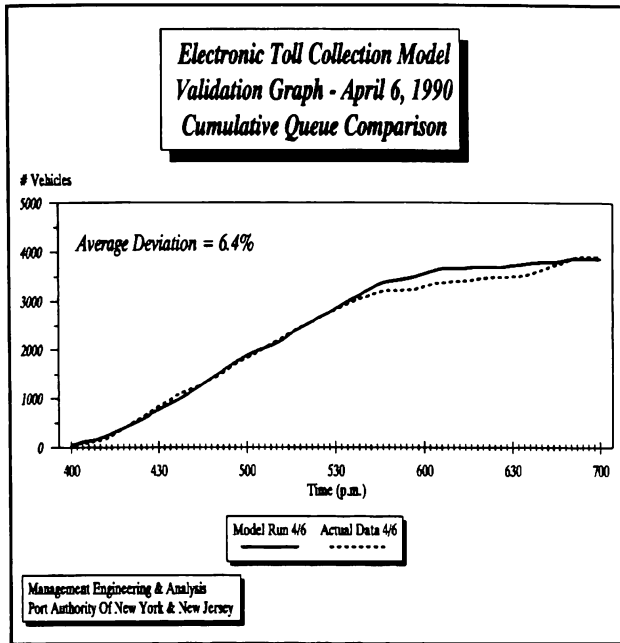


Figure 4 - Queue Validation Graph, April 6, 1990

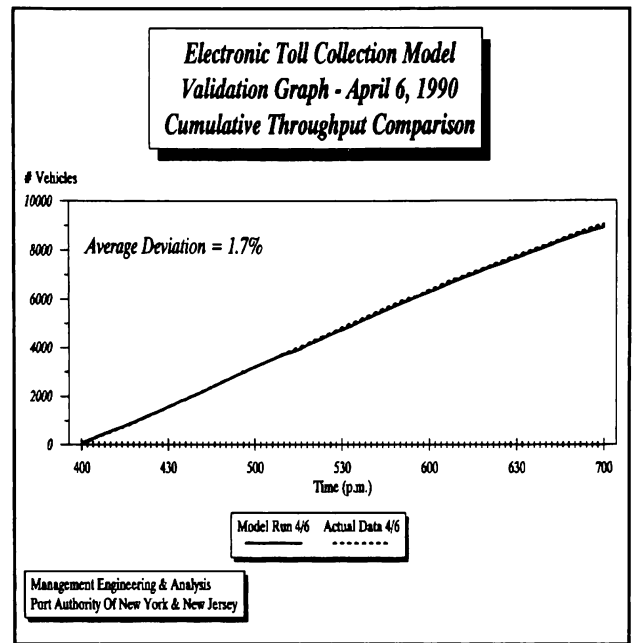


Figure 6 - Throughput Validation Graph, April 6, 1990

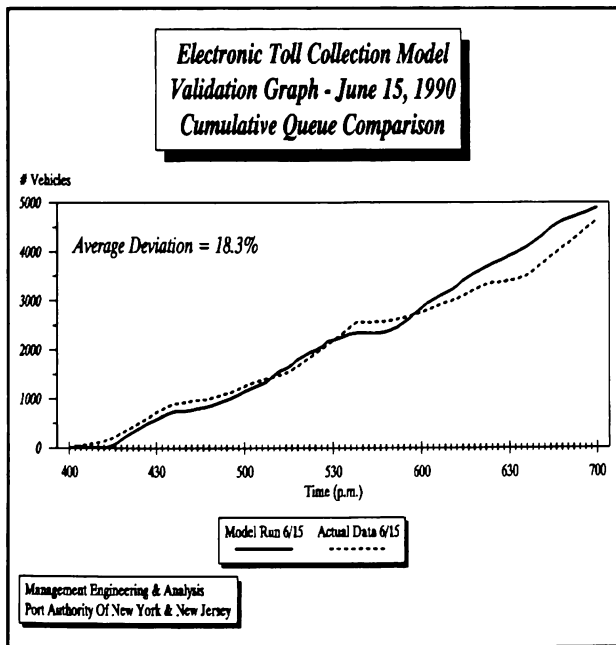


Figure 5 - Queue Validation Graph, June 15, 1990

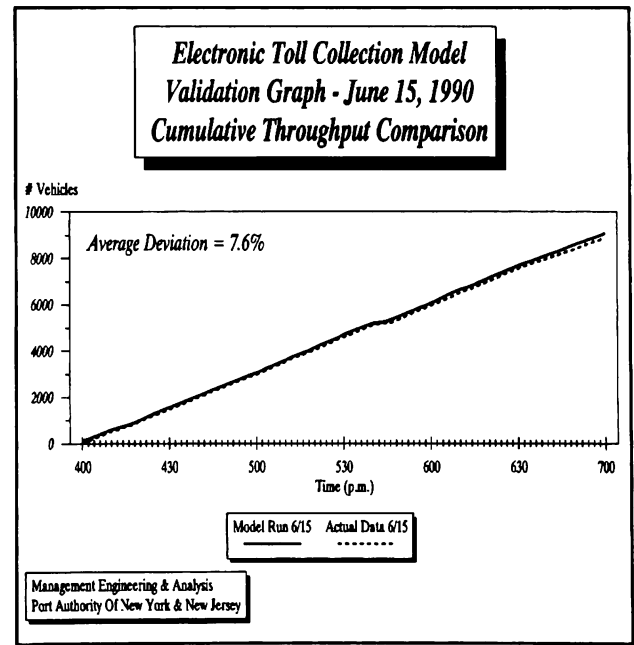


Figure 7 - Throughput Validation Graph, June 15, 1990

maximum flow volume for the day.

Additionally, the deviation results calculated for June 15 were higher than those calculated for April 6. The Study Team believes the higher deviation was caused by an accident which occurred at 5:36 p.m. on June 15. The accident on the span completely stopped the flow of traffic to the toll plaza for a few minutes. This temporary break in the flow created a

pattern of arrival similar to the a.m. period for those few minutes. This caused the model's calculations to skew significantly, resulting in the higher deviation percents.

The Study Team set a +/-10% error in queue calculation and +/-15% error in throughput as acceptable values for validation of the model. The

results of both the throughput and queue variations for the two p.m. models were in or close to these values. Based on these results, the Study Team concluded that the model satisfactorily replicated the actual field p.m. rush condition for our validation day.

Since the plaza throughput is the most critical processing section in the model, its validation also confirmed the ability to use the model to project the Goethals Bridge toll plaza's performance during the p.m. rush with the introduction of ETC lanes at the plaza.

5 MODELING APPLICATION

For each ETC operating scenario and possible market share, the output from our model runs was used for a series of graphical and statistical presentations of the operational impacts of ETC technology at the Goethals Bridge. For the dedicated lane scenarios, impacts were reported for both ETC and Non-ETC vehicles.

5.1 Base Day

For the base data day we empirically measured queue levels at two minute intervals throughout the p.m. three hour peak period. For the peak analysis period, a maximum queue of twelve vehicles was recorded. We obtained from our data collection average single lane queues of six vehicles. For almost all of the peak period, the maximum average single lane queue value did not exceed ten vehicles in any two minute interval of time. Hence, for most of the period, queues did not extend past the mid-point of the plaza mouth. From the information presented, we concluded that fair to good service levels prevailed during the peak period, in which regular toll collection methods were employed.

5.2 Dedicated Lane Scenarios

The goal of the study was to evaluate the ETC technology under varying conditions. These conditions took the form of the number of ETC lanes in operation and the assumed market share of arriving vehicles which would require ETC processing. In addition, two toll plaza scenarios were evaluated. The first involved ETC lanes which were dedicated to ETC ONLY vehicle processing. In order to evaluate one scenario against another, the Average Single Lane Queue calculation (and the resulting Average Time In Queue) were used. The output for the dedicated scenarios follows:

Base Day Condition

Average Single Lane Queue = 6 vehicles
Average Time In Queue = 46 seconds

Case One - One Dedicated ETC Lane

Assumed ETC Market Share = 15 percent.
Average Single Lane ETC Queue = 0 vehicles
Average Time In ETC Queue = 0 seconds
Average Single Lane Non-ETC Queue = 6 vehicles
Average Time In Non-ETC Queue = 48 seconds

Case Two - Two Dedicated ETC Lanes

Assumed ETC Market Share = 35 percent.
Average Single Lane ETC Queue = 0 vehicles
Average Time In ETC Queue = 0 seconds
Average Single Lane Non-ETC Queue = 1 vehicle
Average Time In Non-ETC Queue = 11 seconds

Case Three - Three Dedicated ETC Lanes

Assumed ETC Market Share = 50 percent
Average Single Lane ETC Queue = 0 vehicles
Average Time In ETC Queue = 0 seconds
Average Single Lane Non-ETC Queue = 1 vehicle
Average Time In Non-ETC Queue = 9 seconds

5.3 Dual Use Lane Scenarios

The second toll plaza scenario was created by allowing ALL arriving vehicles (whether ETC processing or not) the ability to be processed at any toll booth. The output results of the Dual Use scenario's are as follows:

Case Four: 15 percent ETC market share

Average Vehicles In Queue = 6 vehicles
Average Time In Queue = 6 seconds

Case Five: 35 percent ETC market share

Average Vehicles In Queue = 0 vehicles
Average Time In Queue = 0 vehicles

Case Six: 50 percent ETC market share

Average Vehicles In Queue = 0 vehicles
Average Time In Queue = 0 seconds

6 CONCLUSIONS

For each scenario, dedicated and dual use and the associated cases run, our modeling effort showed that the implementation of ETC technology should result in an improved toll plaza operation.

Also, for the majority of our toll plaza users, the results from our modeling effort showed that by implementing ETC technology, service levels would

improve; and in most cases, significantly so. Although we examined two operating scenarios, and three levels of possible ETC market penetration for one class of vehicle, we recognize that additional work may be needed concerning other operating conditions, vehicle classes and possible ETC market levels at the Goethals Bridge as well as at other Port Authority tunnel and bridge facilities.

Based on the results of the study, the model was proven to successfully replicate the processing of vehicles through a toll plaza. It provided the necessary structure with which to evaluate the operational impacts of implementing ETC technology at a toll plaza.

The model's structure and output results were accepted by Port Authority management, and the results have been extremely useful in developing a Port Authority wide implementation plan for the use of ETC technology. Illustrative of the flexibility built into the model structure and logic, it has been applied recently at the Outerbridge Crossing toll plaza to assess the operational impacts of introducing exact toll lanes. This analysis resulted in an estimation of impact on vehicle queue and throughput that the introduction of exact toll lanes (exact payment by cash or pass, no change given) may have during peak summer weekend travel. Results were presented and accepted by management for exact and non-exact users, assuming different market scenarios. Lastly, expectations are that the model will be used to evaluate the results of ETC technology at other Port Authority bridge and tunnel toll plazas.

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