MICROSCOPIC SIMULATION AND CALIBRATION OF AN INTEGRATED FREEWAY AND TOLL PLAZA MODEL

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ABSTRACT

In this paper, the development of a microscopic simulation model of the New Jersey Turnpike (NJTPK) using Paramics microscopic simulation software is presented. The model is validated/calibrated using the detailed vehicle-by-vehicle toll data at each toll plaza in the NJTPK. The dataset includes the entry toll plaza, exit toll plaza, entry and exit times, entry and exit lanes, etc. for each vehicle. This dataset is used to extract the origin-destination demand matrices and individual vehicle travel times between each interchange. Toll plazas are the most important components of the NJTPK. However, the default toll plaza model in Paramics cannot fully model the complex lane changing and lane choice behavior at toll plazas. It is shown that the Application Programming Interface (API) of Paramics is required for this purpose. The detailed data are also used to validate the developed toll plaza model.
INTRODUCTION AND OBJECTIVES
It is often very difficult to accurately estimate the impacts and benefits of operational strategies in complex transportation networks. Most of the macroscopic models are too aggregate to capture time-dependent changes in traffic patterns due to these operational strategies. Microscopic traffic simulation has thus been gaining popularity due to the ever-increasing computational power of modern workstations, and its ability to capture the time-dependent dynamics of traffic flow and demand.

Paramics is a widely used microscopic traffic simulation tool. It has a large set of functionalities that can be used to simulate and evaluate various policies and control strategies and their effects on the transportation system, such as vehicle delays and emissions. The most important feature of Paramics is the ability of overriding or extending the default models such as car following, lane changing, route choice, etc. using its Application Programming Interface (API). This feature helps the modelers to incorporate customized functionalities and test their own models.

The goal of this paper is to describe the development and validation/calibration efforts of an integrated freeway and toll plaza model of the New Jersey Turnpike (NJTPK). The developed model is an invaluable tool for conducting many analyses such as evaluation of traveler information systems, incident management strategies, the effect of changes to the infrastructure, and the impact of congestion pricing. However, due to the major role of the toll plazas in the operations of the overall system, a reliable model of the toll plaza operations is essential for building a valid network model of this facility. It is shown in this study that with the application of simple decision-making rules using the Paramics API, a more realistic toll plaza operation can be achieved.

First the methodology followed in the generation of the complete NJTPK network is explained. A description of the toll plaza and network modeling effort is presented next. The detailed description of the input data and the validation/calibration procedure are then presented. Finally, the validation and calibration results and the conclusions are presented.

NETWORK CREATION
The first step in the process of microscopic modeling of any transportation system is the preparation of a detailed geometry of the road network. However, obtaining and incorporating the correct geometric characteristics and the correct scale of a network is a demanding task. The level of difficulty of this task increases as the network size increases.

The geometric details of NJTPK were obtained from TransCAD® built-in data files. TransCAD networks can be exported in the format of ArcView® shape files. “Shape to Paramics” (S2P), a software developed by Vehicle Intelligence and Transportation Analysis Laboratory at University of California, Santa Barbara, converts the ArcView shape files to Paramics network files (1, 2). In this study, S2P was used to create the basic network. Finally, additional corrections had to be made to ensure the accuracy of the network characteristics.

The NJTPK network developed in Paramics consists of 4244 nodes, 8800 links, and 26 zones. The network includes 26 interchanges (entries and exits), each zone acting as an origin and a destination for each interchange.
TOLL PLAZA AND NETWORK MODEL

Toll plazas on the NJTPK areas are not barrier toll plazas located en route, but they are located at separate areas where users enter or exit the freeway. This kind of toll plaza configuration does not impede the traffic flow on the freeway. However, they are important features of the network because they affect the travel times between origin and destination (OD) pairs. Therefore, it is essential to develop an accurate model of the toll plaza operations to obtain a realistic simulation model of the network.

Literature Review of Toll Plaza Simulation Models

Most of the microscopic simulation software packages including Paramics do not have a built-in toll plaza model. Some researchers have taken up the task of developing customized toll plaza simulation models. Al-Deek and Mohamed (3), Al-Deek et al (4), (5) developed a toll plaza simulation model for the Holland East toll plaza in Orange County, Florida for different lane configurations and vehicle characteristics. The model has various input variables such as approach speed, acceleration, deceleration, etc. and it generates various output variables such as throughput and delays. Chien et al. (6) investigated the effect of various lane configurations and the removal of toll plazas on the Garden State Parkway, New Jersey. For five toll plazas the optimal lane configuration was determined using a Paramics simulation model. The authors used the lane changing behavior that was provided by the default Paramics simulation package. Moreover, the toll plazas on the Garden State Parkway are barrier tollbooths (located on the freeway) and the complexity of lane changing is much less as compared to the toll plazas located on the NJTPK, where the toll plazas are not on the freeway. In other words, since most of the vehicles follow the same path after crossing the toll plaza, the lane changing behavior at the barrier toll plazas is not as complicated. (The effect of different paths on the lane changing behavior is explained in the Modeling Procedure section). Correa et al (7) implemented an object-oriented simulation model (TOLLSIM) of a toll plaza in MODSIM III simulation software. The lane choice is based on shortest queue at the toll booth lanes. Danko and Gulewicz (8) used a spreadsheet to model the toll plaza and calculate the throughput and queue length at the toll plaza. Burris and Hildebrand (9) created a discrete-event microscopic simulation model of a toll plaza to study the toll plaza at A. Murray MacKay Bridge at Halifax, Canada. The lane selection by a vehicle is based on a logistical routine, which is based on queue length, traffic volume, and proximity of the preferred payment-type lane. Ceballos and Curtis (10) used VISSIM simulation software to model the toll plazas and parking toll plazas and compared their results to multi-server queuing analysis. Astarita et al. (11) developed a microscopic simulation model of a toll plaza with a lane changing, car-following and a utility-based lane selection model.

Although Paramics has some of the basic features that can be used to build a toll plaza model, additional work using the API had to be performed to represent toll plaza operations accurately. The novelty of this study can be summarized as follows:

- Unlike other models presented in (3) and (7), the toll plaza model presented in this study is fully integrated with the freeway model.
- It is not a set of barrier tollbooths but it is a stand-alone configuration at the exit or entry points. This type of configuration requires improved lane changing and merging logic.

Toll Plaza Model Inputs

In order to model the toll plaza in Paramics the necessary inputs are:
- Toll plaza geometry: Satellite pictures available on the Internet were used as overlays to procure the information about the number of lanes in the toll plazas and the geometry of each toll plaza area.
- Toll plaza configuration: There are only two user and lane types at the NJTPK namely, the electronic toll collection (ETC), called E-ZPass and manual toll payment. The number of lanes dedicated for each payment type was obtained from the New Jersey Turnpike Authority (NJTA) staff.
- Service time distribution at the toll plaza for each vehicle type: In the literature, there is very limited amount of information that distinguishes the entry and exit service times for toll plazas similar to NJTPK. Wilbur Smith Associates’ study on the benefits of E-ZPass on the NJTPK prepared for the NJTA used different entry and exit service time. An entry service time for the cash users of around 4.0 seconds and exit service time of around 7.5 seconds were used as the mean service time, adapted from the study by Wilbur Smith Associates. The service time for each individual vehicle was randomly generated from a normal distribution with this mean service time. Most of the available studies in the literature specify only the mean of the service time. Because the variance of service time is not available, a variance of 1.0 second was chosen arbitrarily in this study. Also, choosing a higher service time variance resulted in unrealistic (negative) service times.

**Modeling Procedure**
The toll plaza simulation model involves the following processes:

*Updating the Queue Lengths*
The queue length is updated at every time step for each lane in the toll plaza. In the case of cash users, the lane change decision depends to a large extent on the queue length. This assumption leads to the concept of perceived queue length when lane choice decisions are made.

*Lane Choice Decision of Vehicles*
The lane changing behavior at a toll plaza is complicated to simulate, more so if the number of service lanes is high and the lane configuration at the toll plaza does not clearly isolate the E-ZPass and the cash lanes. Also, the traffic flow at the toll plaza also influences the lane choice decisions.

**Lane Choice – Driver Behavior Mechanism:** When the toll plazas are external to the freeway, the vehicles must be allowed to enter and exit the freeway in their intended direction of travel (northbound or southbound in the case of NJTPK). This requires a system of ramps at each toll plaza that should allow for movement in various directions, as shown in FIGURE 1.

As a result of this configuration, the northbound or southbound users tend to choose the lanes closer to the median and eastbound users tend to choose lanes closer to the curb (See FIGURE 1). Paramics by default does not support this type of lane choice behavior, since it does not have a path-based route choice model. Instead, it uses a route choice model that is link-based. It uses a lookup table that stores the cost involved in traversing each link. Vehicle routes are built up of the links based on this lookup table. Whereas, in reality drivers have an abstract idea of the route as a path connected by points, where a decision of which path to choose next is made (e.g., an intersection or a split). This behavior is illustrated in Oh et al. (14), Jayakrishnan et al. (15) in detail. Although, there is no specific reference to the lane choice at toll plazas in
current literature, the lane choice made by a driver, in general, is path-based. Hence, a path-based route choice model, which is similar to the process explained above, is more realistic and was employed in the model.

The routing decision in Paramics is made two links ahead of the current link for each vehicle (14), (15). So, in the case where the network has short links (such as toll plaza links) the vehicles are not able to make realistic routing decisions. As a result, the appropriate lane decisions cannot be made at the intended point in time and space, which causes unrealistic delays.

An extended lane choice model at the toll plaza has to be incorporated using an API developed in the Paramics.

**Path-based Lane choice model:** The need for a “path-based” approach in Paramics is mentioned in (14), (15). There is a way to circumvent the problem of memory and computational burden for the present case when using path-based approach. For the network under study, there is only one possible path between each OD pair (though there are few toll plazas where the passenger car users have the option of using either of the dual-dual roadway, this choice is not made immediately after the toll plaza and hence does not affect the lane choice at the toll plaza). Therefore, the paths for all OD pairs are fixed and need not be dynamically updated. In other words, there is only one location where the vehicles have to make lane choice based on their path. In this regard, a path matrix, which stores the information about the entry ramp that the user should take to reach his/her destination, is created. This concept is similar to the path dynamics approach used in several other studies (14), (15).

The Path Matrix is an n x n matrix, where n is the number of zones, since the decision is made only at one location i.e. at the entry Toll Plaza. A value of 1 implies that the user has to be in a lane range closer to the median, –1 indicates that the user has to be closer to the curb, and a value of 0 indicates the user can choose any lane range. The lane choice models are implemented using Paramics API (16).
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FIGURE 1 Path-based Lane Choice at the Toll Plaza and Links at the Toll Plaza.

The assumptions of the model described below are similar to the ones used in (3), (4), (5), (8):

- The primary assumption is that vehicles start making decisions about their path-based lane choices two links before the toll plaza link (see FIGURE 1).
- For E-ZPass vehicles, if the difference in queue length between the “target” lane and the current lane is two vehicles or less, the user does not make a lane change to the target lane. Two vehicles can be called as the perceived queue for the driver, based on which lane changes and choices are made.
- Also, it is assumed that E-ZPass users do not make lane changes that are more than 4 lanes away from the current lane, since the processing of queues in E-ZPass lanes is relatively fast.
- In the case of the “path-based” model, in addition to the above assumptions, another assumption is that the user decides the lane range (based on the Path Matrix) in the first decision
link, and then decides which particular queue or lane to join in the second decision link. The flow chart of this decision process is shown in FIGURE 2. Danko and Gulewicz (8) used the General Purpose Simulation System to evaluate the optimal staffing requirements at a toll plaza. This study suggested that most drivers exit the plaza from the same side as they have entered. This indirectly substantiates the path-based lane choice at a toll plaza.

![Flow Chart of the Lane Changing Behavior.](image)

**FIGURE 2 Flow Chart of the Lane Changing Behavior.**

*Processing of Vehicles*

The processing of vehicles in the toll plaza model is based on the service time, which is expressed as stop-time at the end of the toll plaza link (see FIGURE 1) for manual toll payment...
vehicles at the location of the tollbooth. The E-ZPass vehicles would just pass through the tollbooth (at the end of the Toll Link) at a specified speed limit namely, 5 mph.

Apart from the manual (cash) and electronic (E-ZPass) payment lanes, there are some mixed payment lanes at the NJTPK toll plazas. *Paramics* does not have the capability to model mixed-transaction type lanes. An API for the toll plaza model was coded to incorporate the mixed payment lanes. Also, *Paramics Modeller* has the capability for modeling only the uniformly distributed service times at the toll plaza (17). However, usually the service time distribution at the booths handled by human operators is a normal distribution (Al Deek and Mohamed (3) use an empirical distribution of observed service times at toll plazas in Florida, which is close to normal distribution). This API also incorporates the use of a normal distribution for the service times at toll plazas.

It should be noted that in this particular effort of microscopic simulation, the aim was to model the vehicular traffic on the entire network of NJTPK (which, as stated above, is 150 miles long and consists of 52 toll plazas). Hence, not only the computational time for the simulation, but also the calibration involves high amount of time and effort. Also, the toll plazas constitute a small part of the simulation model of the network. The simulation of each of the 52 toll plazas to a very high degree of accuracy necessitates large amount resources for the purpose of field data collection, processing of the data and incorporating the resulting observations in the model. The refinement of the simulation model is an on-going process and will be performed for the future studies.

**Other Network Features**

*Inclusion of “Cars Only” lanes*
From Interchange 8A to Interchange 14 the NJTPK is a dual-dual roadway. Namely, there are both inner (cars only) and outer (car, truck and bus) travel lanes in both the northbound and southbound directions. So, to model the “Cars Only” lanes, the truck route was changed to the alternate roadway when they are present on the “decision making” links.

**DESCRIPTION OF THE INPUT DATA AND CALIBRATION OF THE NETWORK MODEL**

**Input Data**

*O-D Demand Data and Percentage of Vehicle Types*
For this study, the raw data, consisting of the individual vehicle-by-vehicle entry and exit time data, were provided by the NJTA. It also consists of the information regarding the lane through which each vehicle is processed for all the vehicles (both E-ZPass and Cash users). From this data the number of E-ZPass and Cash users was directly available for the months of January through May for the year 2005 for seven days in a week and for the entire day. From this raw data, available for the year 2005, the O-D demand in terms of number of E-ZPass and Cash users was extracted for the AM and PM peak and peak shoulder periods for a typical weekday.

*Average Daily Traffic*
Average daily traffic (ADT) data of the NJTPK were obtained from the NJTA for each direction for the months, January through May, in the year 2005. This dataset consists of the daily volume between each interchange pair based on the vehicle type. The total average daily traffic volume
on the mainline between each interchange was generated from this dataset. This value was used to calculate the average peak hour flow, assuming peak hour factor as 0.07.

\[
\text{Peak hour flow} = \text{ADT} \times K \times D
\]

Where,
- \(\text{ADT}\) = Average Daily Traffic
- \(K\) = Peak Hour Factor
- \(D\) = Directional Flow Factor

Since, in the data provided, the \(\text{ADT}\) for each section was available for each direction, a directional flow factor was not required. \(D = 1.0, K = 0.07\) was assumed, since the exact values were available. Detector station volumes were available for only four of the mainline sections. They were used to validate the volumes generated from the peak hour factor analysis.

**Quality of Data**
The data for the O-D demand for the NJTPK was available through the entry and exit data at the toll plaza, where the vehicles enter the system. Since, this data are collected electronically for each vehicle that enters and exit the system, there are no “ghost” vehicles. The travel time data are collected through the time stamps that the vehicles create electronically when they enter and exit the system. The accuracy of the travel time information is thus ideal.

**Model Calibration**
Calibration is a crucial but a time-consuming step of the microscopic traffic model building process. There are various default model parameters, and these have to be adjusted to produce a realistic representation of the study network. There are several approaches that use a systematic methodology for calibration (18), (19), (20). Ma and Abdhu (20) used the genetic algorithm to calibrate a part of the Toronto downtown network. The authors minimized the difference between the observed and simulated flows (objective function) by varying various parameters using the genetic algorithm. Construction of such objective functions and determination of the optimum values, although very attractive, is a very time-consuming task for complex and very large networks such as the NJTPK network that consist of more than 8800 links. Also this process based on the use of the simulation as the objective function does not have a closed form solution, and it can be infeasible given the numerous and highly randomized parameters that Paramics uses. In this study, a trial-and-error approach that attempts to modify various important input variables to achieve an acceptable level of accuracy was adopted.

The number of trips produced and the travel times for the portion of the E-ZPass vehicles for 8 hours on a typical weekday were used to validate/calibrate the network.

**Calibration Procedure**
The basic steps of calibration involve: Calibration of driver behavior, calibration of route choice decisions, adjustment of the OD matrix, and fine-tuning (18).

*Calibration of Driver Behavior*
In Paramics, there are many parameters based on which the driver behavior can be calibrated. These are mean reaction time, mean target headway, speed memory, minimum queue gap, etc. (17). These parameters are explained briefly below.
- Mean Reaction Time: This is a global network-wide parameter that is used to set the average reaction time of drivers.
Mean Target Headway: Another global parameter, which is used to set the average headway that vehicles, aim to maintain during the simulation. The simulation is very sensitive to both mean reaction time and mean target headway, because these parameters control the car following, gap-acceptance and lane-changing behavior of the vehicles during the simulation. These are the two basic parameters that analysts use to calibrate the simulation models in Paramics.

Speed Memory: It is the number of time steps that each vehicle “remembers” its current speed. It must be increased or decreased in conjunction with the number of time steps of the simulation and the mean reaction time, so that higher or lower reaction times can be modeled accurately for the same number of time steps per second.

Minimum queue gap: This parameter is used to set the minimum gap between the vehicles when they are in a queue. Minimum gap can be useful when simulating queues at the intersections and the toll plazas (17).

Calibration of Route Choice Decisions
It should be noted that there is only a single route between most of the O-D pairs of the NJTPK network. The users entering using or bound to the interchanges, 8A, 9, 10, 11, 12, 13, 13A and 14 have the option of using either of the roadways among the dual roadway sections, namely, the “Cars Only” and the general sections. Only for these users, the route choice (as to which section the user might use) had to be calibrated.

Using the ADT data of the NJTPK, the total number of each vehicle type, between each interchange, was generated. But in the case of the above stated interchanges, the volume on each section in the dual-roadway is required. For obtaining these volumes a methodology similar to that stated in (21) was used. As explained in the “Inclusion of Cars Only Lanes” section the inner roadway can only be used by passenger cars, whereas the outer section can be used by trucks, buses and cars. In order to obtain the users on each roadway, the number of passenger car equivalents (PCE) was balanced on either of the roadways. A PCE of 1.5 was assumed for the truck and bus.

Paramics allows the analyst to perform a simple all-or-nothing traffic assignment, stochastic traffic assignment, or dynamic feedback-based traffic assignment. In order to modify the traffic assignment procedure the following set of parameters are provided (17):

- Perturbation: It is used to model the level of stochasticity in the user route choice – for stochastic traffic assignment
- Feedback Period duration: The periodic duration for which the costs on all the links are calculated
- Feedback Smoothing Factor and Feedback Decay Factor: The extent to which the costs from the previous feedback periods be used to calculate the current cost of the links and assign traffic using dynamic traffic assignment
- Cost Coefficients and Cost Factors: These are used to specify and quantify the parameters based on which the cost function for a particular route can be calculated.

In order to calibrate the route choice in the network model, the two roadway sections were classified under a different category. A cost factor was appropriately assigned to the each category to reach the balance explained above. Once the user chooses a particular roadway, he/she cannot change to a different roadway due to the network configuration of this facility. In order that the costs are calculated based on the latest congestion pattern, a very low value for the Feedback Smoothing (0.1) and Feedback Decay (0.1) factor were used.
Validation of the section volumes
The ADT data was used to generate the peak hour volume on the mainline between each interchange (as specified in the Input Data description). These average peak hour volumes were used to cross-validate the volumes from the simulation at sections of the mainline of the NJTPK between each interchange. The comparison of volumes and the results of the calibration are discussed in the Results of the Calibration Procedure section.

Fine-Tuning
Fine-tuning of the model is performed to reduce the difference between the observed and simulated travel times of OD pairs. In addition to the global driver behavior parameters, link-specific parameters such as sign posting distance, sign range and link cost factors were used in this process. Sign posting is the location at which the drivers become aware of the impending hazards such as change in the road geometry, presence of exits on a freeway, etc. Sign range is the distance over which the driver makes the appropriate change in their speed or lane responding to the hazard. Link cost factors are used to assign cost factors to specific link in order to change the route choice.

Results of the Calibration Procedure
The comparison of mainline volumes estimated from the available 2005 ADT data was made with simulated volumes and the absolute relative error. The peak hour factor was assumed to be the same for all the interchanges as 0.07 for the peak direction and 0.04 for the off-peak direction. But the daily variation of traffic volume is not the same at all the interchanges of the NJTPK, which is 148 miles long. For some of the sections, the peak hour factors had to be modified in order to get closer matches with the observed volumes. The reason for this adjustment is that the peak traffic volumes are not similar at all the sections.

The absolute average relative errors for the peak directions for AM and PM peaks were 8.9% and 9.1% respectively. For the off-peak direction the absolute average errors were 11.1% and 10.6% for the AM and PM peak periods. The maximum absolute average error was 22.2% and the minimum was 0.2%.

The OD travel times were compared with the travel times of the trips from each entry point to all other exit points. The difference between the observed and the simulated vehicle travel times was used to compare the results of various simulation runs with different mean target headway and mean reaction time.

The trip lengths on the NJTPK network vary from 0.4 miles to 140 miles. As a result, higher percentages of travel time errors occur for the trips that have smaller trip length. In other words, for short trips even small errors in travel times were reflected as large percentage errors. The trip delay for the short trips may be under-estimated or over-estimated as a result. Therefore, the percentage errors were scaled for all trips based on trip distance. The scaled percentage error and the percentage of trips in each category of error are shown in TABLE 1.
TABLE 1 Distribution of Percentage Deviation in Travel Times

<table>
<thead>
<tr>
<th>Range of Percentage Deviation</th>
<th>Percentage of O-D trips</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5%</td>
<td>93.24</td>
</tr>
<tr>
<td>5-10%</td>
<td>3.15</td>
</tr>
<tr>
<td>10-15%</td>
<td>2.03</td>
</tr>
<tr>
<td>15-20%</td>
<td>0.0</td>
</tr>
<tr>
<td>20-25%</td>
<td>0.225</td>
</tr>
<tr>
<td>25% - more</td>
<td>1.35</td>
</tr>
</tbody>
</table>

The Calibration Efforts of the Previous Studies

Chu et al (18) used deviation between the observed and simulated volume and travel time to calibrate the microscopic traffic simulation model of a highly congested network in the city of Irvine, California. The network consists of a 6-mile section of I-405, 3-mile section of I-5, 3-mile section of SR-133 and adjacent surface streets. The average travel time error was found to be 3.1%. Hourdakis et al. (19) suggested a root mean squared error of around 15% to be satisfactory in the volume-based calibration step where a close match of volumes in the simulation model and real-time at the loop detector stations was performed. The network in this study consisted of a 12-mile circumferential freeway TH-169 and adjoining surface streets, located in the state of Minnesota, United States. Lee et al. (23) obtained an average relative error of around 15% in volume in the calibration of the traffic simulation model of a five-mile section of I-5 interstate freeway in California using Genetic Algorithm. Zhang and Owen (24) validated the multi-regime simulation (MRS) for an advanced microscopic traffic simulation model, by using various microscopic and macroscopic parameters. As a part of this study the authors compared the simulated and observed travel times in a weaving section of Baltimore-Washington Parkway located in Prince George’s County, Maryland. They obtained a travel time of 21.72 s in the simulation model as compared to an observed travel time of 21.8 s – a percentage error of 0.3%. Jha et al. (25) developed a microscopic traffic simulation model for the Des Moines area located in Iowa, United States. In a comparison of travel times for four corridors that is presented, an error of 4% was obtained for a freeway (I-235).

The average error obtained in the current study was about 5.5% in terms of travel time and this is on par with other studies. Also, given the size of the network (NJTPK), the accuracy of the predictions of the calibrated network is promising.

LANE USAGE AT THE TOLL PLAZA – VALIDATION AND DISCUSSION

The lane change behavior at the toll plaza, more specifically those present on the NJTPK, is very complex. Since, the default Paramics toll plaza model was not able to simulate the lane changing behavior reasonably, the Paramics API was used to modify the lane change behavior. The path that the user is going to follow after crossing the toll plaza (the path plan factor), as explained earlier, has a major impact on the lane choice.

The lane usage and lane selection criteria resulting from the use of API were validated using the detailed vehicle-by-vehicle data provided by NJTA. The observed and the simulated (with and without API) lane usage percentages for the entry toll plazas at the interchanges 11 (FIGURE 3) and 14 (FIGURE 4) are compared. Also, the percentage of “violators” of the path-based lane choice logic is also compared for all three cases. Since the middle lanes can be used by any of the users, the violations are not counted for those lanes.
It can be seen that there are a few violations of the path-based lane choice assumption in the observed data. Since, the API is based on a complete adherence of the path-based lane choice, there are no violators in the simulation with the API. Also, since the lane choice in the default *Paramics* routine is only path-based for two links, there is a high percentage of violation. The violation of the path-based lane choice could be attributed to the fact that some drivers might choose a lane farther from the ramp that they might take, because the closer lanes could be congested. The reason could also be the level of awareness of the ramp structure the users might face. Quantifying these factors and improving the model would be a part of the future work.

![Lane Usage Percentage and Percentage Violations of Path-based Lane Choice Behavior at Entry Toll Plaza](image)

**FIGURE 3** Lane Usage Percentage and Percentage Violations of Path-based Lane Choice Behavior at Entry Toll Plaza 11.
CASE STUDY: IMPACT OF ELECTRONIC TOLL COLLECTION (E-ZPASS)

The impact of the introduction of E-ZPass on the traffic delays was performed using the integrated Paramics freeway and toll plaza model.

There were two scenarios that were considered for the analysis: year 2005 (with the current E-ZPass usage percentage) and year 2005 without E-ZPass. The analysis periods were 7
A.M. to 8 A.M. (AM Peak 1), 8 A.M. to 9 A.M. (AM Peak 2), and 4:30 P.M. to 5:30 P.M. (PM Peak 1), 5:30 P.M. to 6:30 P.M. (PM Peak 2) for a typical weekday. Average toll plaza delay was considered for the analysis. TABLE 2 shows the delays for the scenarios stated above. It shows that there is a significant reduction in the delay at the toll plaza due to introduction of E-ZPass. For the AM Peak periods the reduction was 86.8% and for the PM peaks the reduction was 92.04%.

### TABLE 2 Average Toll Plaza Delay

<table>
<thead>
<tr>
<th>Period of Analysis</th>
<th>Average Toll Plaza Delay (s) 2005</th>
<th>Average Toll Plaza Delay (s) 2005 - No E-ZPass</th>
</tr>
</thead>
<tbody>
<tr>
<td>AM Peak 1</td>
<td>12.7</td>
<td>138.4</td>
</tr>
<tr>
<td>AM Peak 2</td>
<td>15.7</td>
<td>92.0</td>
</tr>
<tr>
<td>PM Peak 1</td>
<td>7.3</td>
<td>147.8</td>
</tr>
<tr>
<td>PM Peak 2</td>
<td>11.6</td>
<td>105.3</td>
</tr>
</tbody>
</table>

**SUMMARY AND CONCLUSIONS**

In this paper, the efforts involved in developing and calibrating an integrated freeway and toll plaza model of the NJTPK are described. The toll plaza operations affect to a great extent the performance of the facility. Thus, the simulation model had to be integrated with an accurate toll plaza model. *Paramics* microscopic simulation software was used for this purpose, since it allows modelers to modify the default simulation routine for their specific purposes using API capabilities. The simulation model as a whole and the lane usage at the toll plaza is validated using the detailed vehicle-by-vehicle data provided by the NJTA.

A comparison of the observed lane usage, the simulated lane usage (with and without API) is shown in FIGURE 3 and FIGURE 4. The developed simulation model was used to evaluate the impact of electronic toll collection technology, E-ZPass. The introduction of E-ZPass had significant effect on delays. The analyses of the simulation output (shown in TABLE 2) shows that although the average trip delay remained more or less the same, the time savings at the toll plaza can be as much as 89% by the introduction of E-ZPass for a typical weekday peak period for the year 2005.

As a part of the refinement of the simulation model, which is an on-going process, more field observations and subsequent refinements would be made for the future work. The following factors should be considered to improve the model:

- The distribution of signposting distance that the drivers follow at the toll plazas to make their decisions regarding lane choice.
- The dependence of lane choice on various factors such as distance of the vehicle from the toll plazas, the acceptable gap, distance of the ramp that the driver is expected to use after the toll plaza, etc.
- Dependence of all the above factors on the familiarity of the driver with the network. In the current study, a familiarity of 100% was assumed, since almost all of the trips were work trips.
- The limiting value of queue length for the driver to make a shift from path-based lane choice to minimum queue-based lane choice.
- Non-parametric calibration can be performed where instead of the mean travel time the distribution of travel time can be used to validate the travel time between the ODs.
The developed simulation model can be used as a test bed for several evaluation studies such as operational changes at the toll plazas, evaluation of the impact of various incident management strategies, traveler information systems and other toll collection technologies such as high speed E-ZPass.

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REFERENCES
1. Chruch, L.R. and Noronha, V. Translating GIS street network files for use with Paramics – final report. Vehicle Intelligence and Transportation Analysis Laboratory, National Center for Geographic Information and Analysis, University of California, Santa Barbara, 2003
3. Al-Deek, H. and, Mohammed, A. Simulation and Evaluation of the Orlando-Orange County Expressway Authority (OOCEA) Electronic Toll Collection Plazas using TPSIM, BC096-11, Final Report for Florida Dept. of Transportation Research Center, April 2000.