**Final Report**

# SIMULATION AND EVALUATION OF THE ORLANDO-ORANGE COUNTY EXPRESSWAY AUTHORITY (OOCEA) ELECTRONIC TOLL COLLECTION PLAZAS USING TPSIM©, PHASE II

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16. Abstract

A discrete-event stochastic microscopic simulation model developed by the Transportation Systems Institute (TSI) at the University of Central Florida known as TPSIM© was tested for transferability to other toll plazas. Real-life data was collected at the Orlando-Orange County Expressway Authority (OOCEA) system's Dean Toll Plaza. This data was used to calibrate and test the accuracy of the results from TPSIM©. Statistical tests indicated that there is no significant difference at the 95% confidence level between Measures of Effectiveness obtained from the model and those collected in the real world.

Animation capabilities were developed for TPSIM© as well. This feature enables the user to visually display the operating conditions at the toll plaza using the simulation data. Identifiable characteristics of the animation are the ability to decipher the difference between vehicles by payment type and vehicle classification. The model realistically depicts traffic operations such as queuing conditions and approaching congestion.

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The opinions, findings and conclusions in this publication are those of the authors and not necessarily those of the Florida Department of Transportation or the US Department of Transportation. This report does not constitute a standard specification, or regulation. This report is prepared in cooperation with the State of Florida Department of Transportation.

# EXECUTIVE SUMMARY

Traffic simulation models are used to enhance planning, design, operation, and management of transportation facilities. The UCF-TSI has developed a stochastic microscopic simulation model called "TPSIM©". TPSIM© was coded using Visual Basic 6.0 to provide a user-friendly interface under a Windows environment on a PC. TPSIM© describes traffic operations at toll plazas with up to 5 approach lanes and up to 10 toll lanes per peak direction. TPSIM© includes the ability to simulate toll plazas with Electronic Toll Collection (ETC). It has the capability of simulating 5 different lane types (Manual, Automatic, dedicated ETC, Manual/ETC, and Automatic/ETC). Within TPSIM©, traffic behavior and vehicle processes are represented by a set of mathematical and logic algorithms. These algorithms assign vehicle characteristics and control the interactions among vehicles. Car following, lane changing, and toll lane selection are the fundamental elements in TPSIM©. TPSIM© produces detailed measures of effectiveness for each toll lane and the whole plaza that can be used to evaluate the toll plaza system performance.

The intention of this project is to evaluate current and future traffic conditions at a toll plaza with different configurations and traffic characteristics in order to recommend the most appropriate plaza configuration. In Phase I, using data collected at the Holland East Plaza, the reliability of the TPSIM© model in predicting toll plaza performance was positively confirmed. In Phase II, the transferability of TPSIM© to another toll plaza is demonstrated by selecting the Dean Toll Plaza for evaluation. The main objectives of this project are to evaluate the transferability of the model by conducting a sensitivity analysis of a second OOCEA plaza and to compare the results of the second plaza to the results from the Holland East Plaza. Also in Phase II, animation capabilities are developed to visualize traffic behavior at toll plazas.

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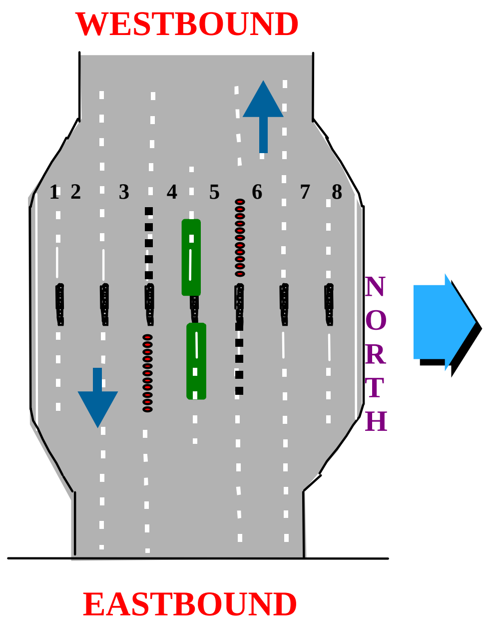
# CHAPTER 1

# MODEL APPLICATION TO A SECOND OOCEA PLAZA

## 1.1 STUDY SITE DESCRIPTION

The Dean Toll Plaza is one of the eleven Orlando-Orange County Expressway Authority (OOCEA) mainline toll plazas. This plaza was selected because of the availability of data from 1994 and the changes that have occurred during the six-year span from 1994 to 2000. It has a total of eight lanes. Each direction has four stationary lanes though at the time of data collection in August and September of 1994, only three lanes were open. In 1994, the Dean plaza area consisted of 2 approach lanes that eventually branched out into four individual toll lanes, as shown in Figure 1.01. By the year 2000, a third approach lane beginning downstream of the Rouse Road on-ramp was added to accommodate the rising traffic volumes. Before installing Electronic Toll Collection (ETC) technology, there were three manual lanes and one automatic coin lane in each direction. The automatic coin lane was second from the right in both directions.

After installing the ETC technology known as E-PASS toward the end of September 1994, the fourth lane from the right in each direction was converted from a manual lane to a dedicated E-PASS lane. All other lanes became mixed ETC lanes to accept E-PASS customers. At the end of August 1995, eleven months after the implementation of E-PASS, the percentage of E-PASS customers at the plaza averaged about 30%. Presently, the Dean mainline toll plaza is still operating with four lanes in each direction with one dedicated E-PASS lane but the traffic volume since 1995 has increased by over 88%, *OOCEA, 2000.*




| Lane | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Year 1994 | M/T | ACM | M | CLOSED | CLOSED | M | ACM | M/T |
| Year 2000 | MIXED | MIXED | MIXED | E-PASS | E-PASS | MIXED | MIXED | MIXED |

**Figure 1.01: Dean Plaza Layout**

Some historical traffic volume data was obtained from OOCEA as background information about Dean Plaza, *OOCEA, 2000.* The reported Annual Average Weekday Traffic volume for Dean Plaza was 14,700 vehicles per day (vpd) in 1993, and increased to 16,300 vpd in 1994. In 1995, the plaza processed an average of 20,400 vpd with 30% E-PASS usage. This was approximately 3% higher than the E-PASS usage at the Holland East Plaza. In 1999, Dean Plaza processed an average of 38,500 vpd and 53% of these vehicles were E-PASS users. This daily traffic volume is expected to jump to 56,300 by the year 2015. Analysis of the historical traffic volumes at Dean Plaza indicates that the plaza has had an average annual demand growth of approximately 16% from 1992 to 1999.

## 1.2 DATA COLLECTION

Generally, field data collection and analysis of toll plaza performance is an expensive, time consuming, and tedious process. It is, however, an unavoidable task for the purpose of calibrating and testing the transferability of the developed model. Many different parameters are required as inputs for the model. Two synchronized video camcorders were used to record traffic behavior at the Dean toll plaza. One of the camcorders was placed on top of the toll plaza canopy to capture vehicle arrivals and queue length. The other camcorder was placed at a vantage point on the roadside downstream of the plaza facing the tollbooths to capture the departure time and service time for each vehicle. For the purpose of the TPSIM© calibration process and transferability testing, data collection was conducted during the morning peak hour (7:00-8:00 AM) on weekdays. Three days were selected for analysis. Wednesday, August 17, 1994, Wednesday, September 14, 1994 and June 6, 2000. The two days from 1994 represent the toll plaza before ETC payment was accepted and the year 2000 day represents the toll plaza with ETC payment capabilities (ETC on all lanes and a dedicated ETC lane). These days were used as part of the TPSIM© calibration process and transferability testing.

The videotapes were viewed for the upstream traffic to extract arrival time of each individual vehicle and for the downstream traffic to determine the departure time of each vehicle. These two data groups were matched up to calculate the waiting delay for each individual vehicle. Service time for these vehicles was obtained using the downstream camera. Vehicles that depart the toll plaza every minute were also counted (lane throughput). These data groups were collected for each individual lane, stored in a database format, analyzed and used in the simulation process. Some of these data groups were inputs for the TPSIM© model (e.g. service time and arrival rate) and the others were used as real-life performance measures (e.g. vehicle delay and lane throughput) to be compared with the TPSIM© model outputs.

Approach speeds, deceleration to the plaza and acceleration from the plaza are also necessary data. This data was captured using a Distance Measuring Instrument (DMI). A DMI is a portable device that has the capability of determining the instantaneous time, distance, and speed of the vehicle for which the DMI is connected to. A previous study of this type was completed using DMIs, *Al-Deek et al, 1997*. A group of five teams collected this data for each lane type (manual/truck, ACM, dedicated ETC, manual) at the Holland East Plaza. Each team consisted of a driver and a DMI operator. The starting and ending locations of the data collection section were carefully chosen to allow enough time for the drivers to reach an acceptable cruise speed in the flow of traffic before approaching the plaza and after departing from the plaza. This allowed for the capture of the platoon speed profile through the toll plaza area. Figure 1.02 illustrates a sample of speed profile for three different lane types. A total of five runs for each of the five lanes included in the study were completed during the morning peak hour for seven days, resulting in a total of 35 runs. This data was used to determine the approaching speed, deceleration rate, and acceleration rate.

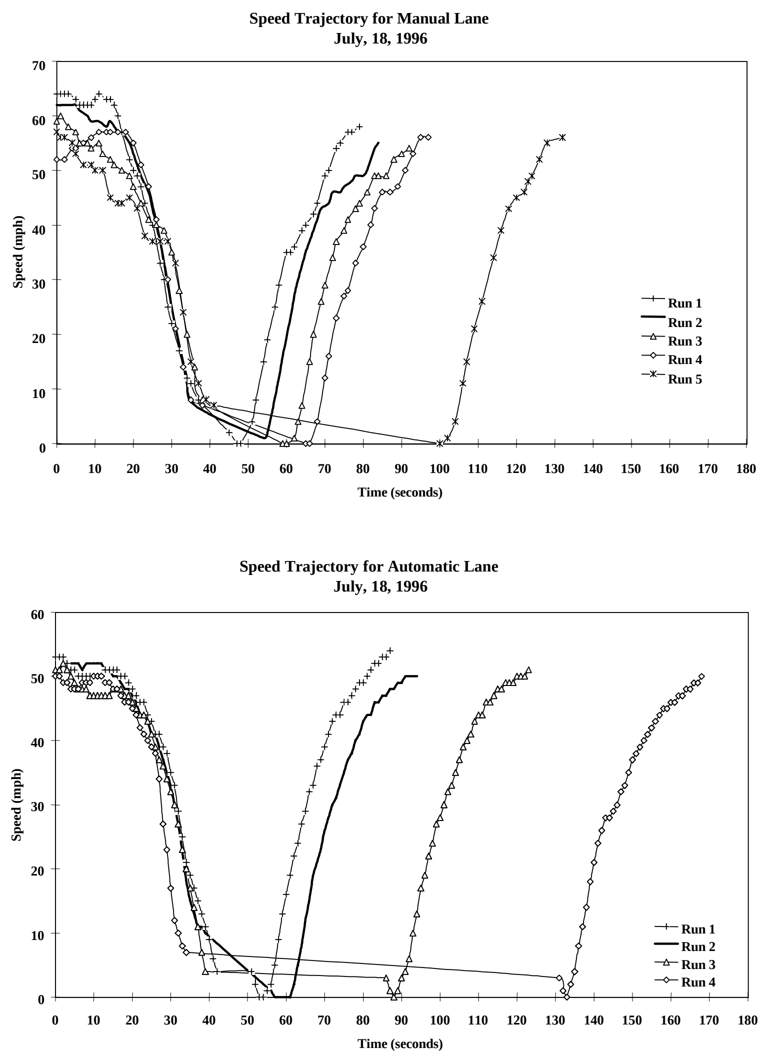



**Figure 1.02: Speed Profiles for Holland East Plaza's Manual and Automatic Lanes**

## 1.3 MODEL INPUT

### *1.3.1 RUN SPECIFICATION*

The beginning time of simulation was set to be the starting time of the morning peak at 7:00 AM and the ending time was set to 8:00AM. The Random Offset Number (RON) was changed for each run of each day for each simulation group (consisting of 10 runs). The RON is a "number seed" necessary to ensure each run is unique for a specific set of input variables by introducing internal traffic variations based on the specified number. The default RON is "5". Figure 1.03 displays the run specification parameters window. This is the first window for initializing a TPSIM© simulation run. The date defaults to the date set on the computer the program is loaded on, and the beginning and ending time default to "7:00:00" and "8:00:00".

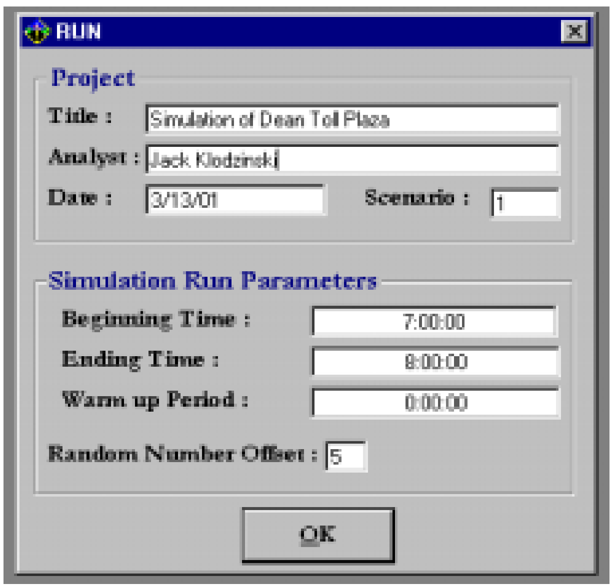



**Figure 1.03: Run Specification Window**

### *1.3.2 PLAZA GEOMETRIC*

As mentioned before, the Dean Plaza consisted of 2 approach lanes and 3 toll lanes in 1994 and 3 approach lanes with 4 toll lanes in 2000. The default length for the approach lanes was set at 3000 ft. This value was suggested in order to capture any extended queue that may spill back from the toll lanes and reach the approach lanes.

Lengths of the toll lanes and the transition zone at the Dean Plaza were 600 ft and 200 ft, respectively. A 12-foot width was used because the only difference is the manual/truck lane that has a mountable curb in the event of requiring accommodation for an extra wide vehicle. Figure 1.04 illustrates an example of the Plaza Geometric Window.


**Figure 1.04: Plaza Geometric Window**

Figures 1.5 and 1.6 illustrate the Toll Lane Type and Schedule Window. In 1994, no ETC service was available. In 2000 except for lane 4, the toll lane types accepted the ETC payment option as well. Lane 4 had become a dedicated ETC lane. During the data collection period for the available days, all toll lanes were open during the morning peak hour. Therefore no data was entered for the closing time in the lane schedule table, see Figures 1.05 and 1.06.

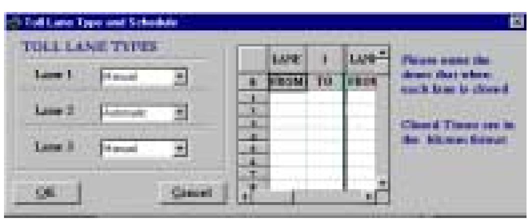


**Figure 1.05: Toll Lane Type and Schedule Window for 1994 Data**

**Figure 1.06: Toll Lane Type and Schedule Window for 2000 Data**

### *1.3.3 GLOBAL PARAMETERS*

Inter-arrival time distribution (time between the arrivals of two consecutive vehicles) is an important input for TPSIM©. Using the arrival time for each vehicle obtained from the Dean Plaza videotapes, the inter-arrival times were calculated and fitted for each approaching toll lane to identify which distribution is truly representative of the inter-arrival time distribution. Figures 1.07, 1.08 and 1.09 show the observed inter-arrival time distributions for the three days from Dean Plaza. The inter-arrival time distributions follow a negative *exponential* distribution.

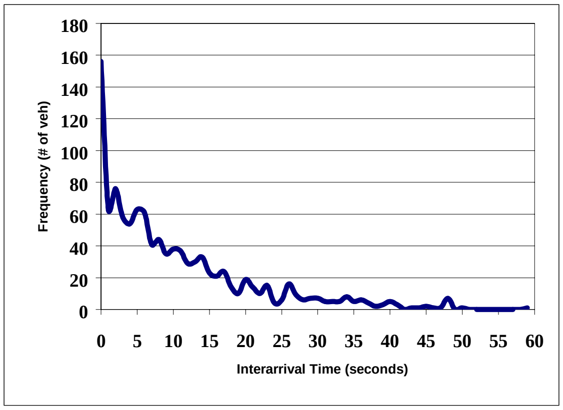



**Figure 1.07: Inter-arrival Distribution for August 17, 1994**

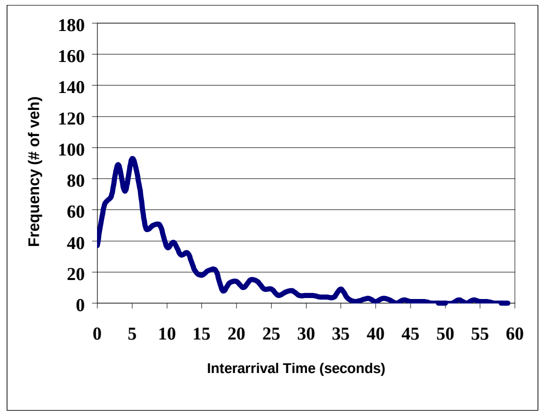



**Figure 1.08: Inter-arrival Distribution for September 14, 1994**

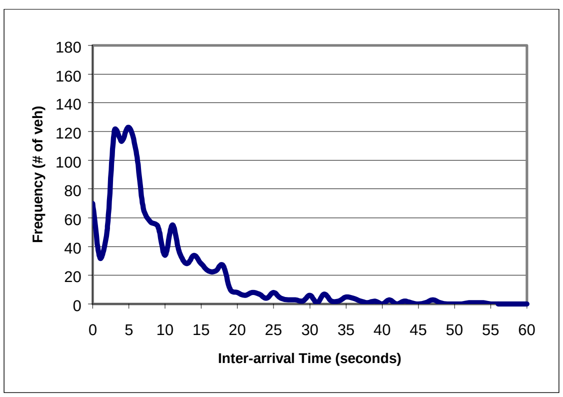



**Figure 1.09: Inter-arrival Distribution for June 6, 2000**

Percentage of lane changing was assumed to be 100%. In other words, any vehicle that is being affected by a slower leader will attempt to change lanes to avoid the slower leader. It was assumed that reaction time among vehicles follows a *uniform* distribution with a minimum of 0.4 second and a maximum of 1 second. These are also the default values for the model.

Approaching speed data was obtained from the sample data collected by the DMIs. This sample data consisted of approach speeds derived from the observation points collected with the DMI before the vehicle was influenced by the toll plaza (decelerating to stop or to join the queue). By fitting the approaching speed observations, it was found that speeds for vehicles approaching the toll plaza follow a *normal* distribution. The average approach speed of a vehicle at the Holland East and Dean Plazas are 60 mph (95 km/hr) with a standard deviation of 5 mph (8 km/hr).

Deceleration rate and acceleration rate distributions were also derived from the sample data collected by the DMIs. Deceleration and acceleration rates were obtained by using the observations collected by the DMI when the vehicle was being influenced by the toll plaza queues. It was found that vehicle deceleration rates follow a *normal* distribution with an average of 3 $ft/s^2$ (0.9 $m/s^2$) and a standard deviation of 0.5 $ft/s^2$ (0.20 $m/ s^2$). Also, acceleration rates of vehicles approaching the toll plaza follow a *normal* distribution with an average of 5.5 $ft/s^2$ (1.7 $m/s^2$) and a standard deviation of 0.5 $ft/s^2$ (0.20 $m/ s^2$).

Clearance distribution is assumed to be a *uniform* distribution with the default values in the model set at a minimum of 20 ft and a maximum of 40 ft (one to two car lengths). These values can be changed by the user. Figure 1.10 illustrates the window for the global parameters.

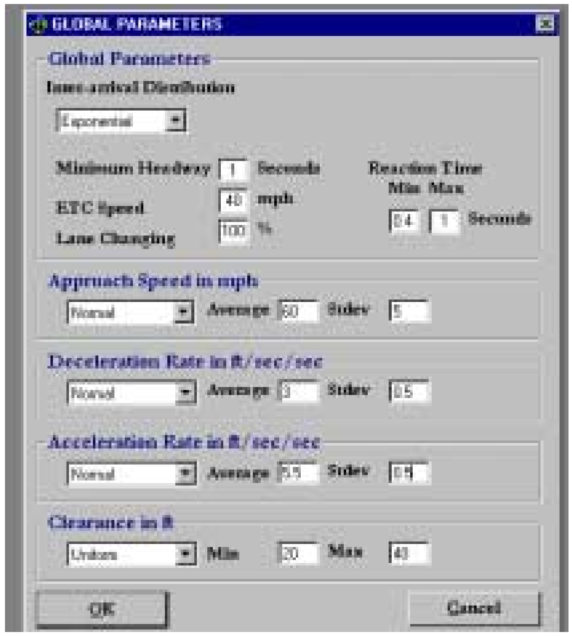



**Figure 1.10: Global Parameters Window**

### *1.3.4 TRAFFIC CHARACTERISTICS*

Selections of the time interval(s) were the same as what was entered in the Run Specification Window. If the interval covered more than one hour, multiple selections were done. For the purpose of the runs for this project, only a peak one-hour interval was selected from 7:00 - 8:00. Figure 1.11 displays the Traffic Data Window used for the time interval selection(s).

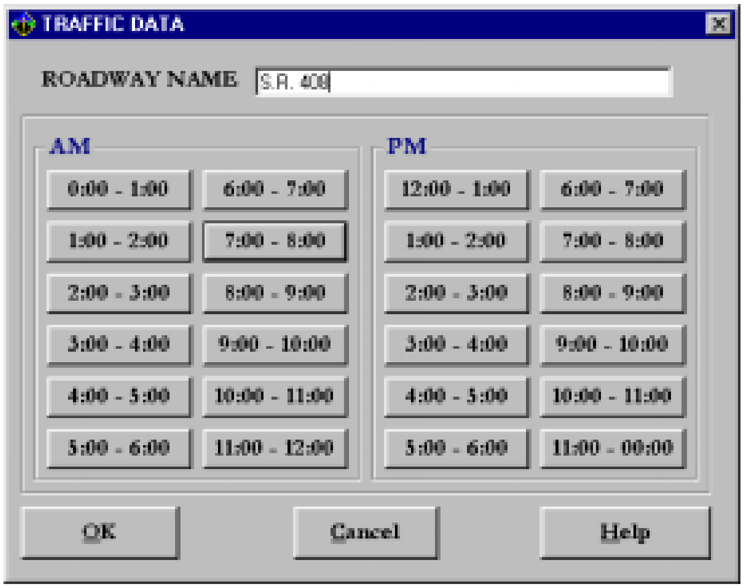



**Figure 1.11: Traffic Data Window**

The Traffic Volume Window, Figure 1.12, is where the volume interval was selected and the volumes for the simulation entered. The individual lane volumes are summed together to represent the traffic for the entire plaza. The arrival time of each vehicle, extracted from the videotapes, was summed for each 5-minute interval for all lanes. This was completed for all three days. Table A2 in Appendix A displays the total plaza volumes for each of the three days.

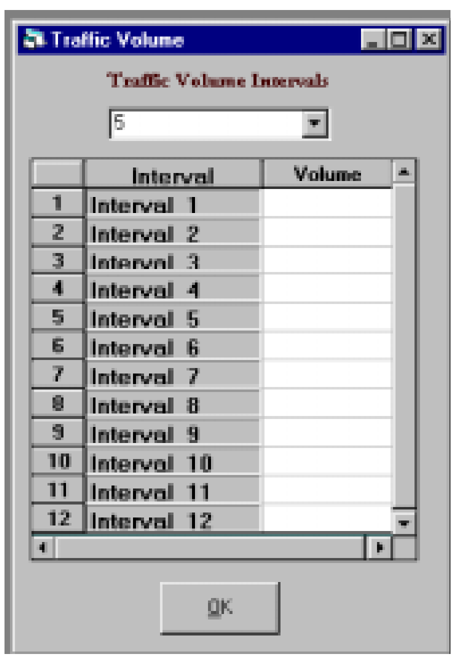



**Figure 1.12: Traffic Volume Window**

The Traffic Condition Window, Figure 1.13, allows the user to input the characteristics of the vehicle fleet. For simulations where a toll plaza may be near a heavy truck generator, this would be of great importance. Also, determining the sensitivity of the toll plaza operations on a significant change in the type of toll transactions on a current plaza configuration is another useful application. This type of sensitivity analysis was conducted successfully in Phase I of this project.

The vehicle type refers to what percent of the vehicle fleet is using a specific payment method. This data was extracted from the videotapes of the downstream portion of the toll plaza and in year 2000, can be extracted from transaction data. Transaction data are detailed individual computer records of each payment conducted at each tollbooth, automatic coin machine or transponder reading in a dedicated ETC lane. The vehicle class is separated into two categories, passenger cars and trucks. Trucks are considered any vehicle large enough to impede the traffic operations in the toll plaza area. For this analysis, a truck was any heavy-duty vehicle with three or more axles (e.g. cement or refuse truck).


**Figure 1.13: Traffic Condition Window**

Service time is how long a vehicle spends at the booth to pay a toll. The actual service time may be influenced by a number of factors, such as the quantity of coins being processed, the experience of the toll collector, and the class of vehicle being serviced. Since the service time value can change for each customer, fitting a stochastic distribution for service time for each lane is the appropriate way to represent the fluctuation in service time. Service time distribution is a very important parameter in simulating toll plazas. Therefore, fitting the right distribution for each lane was critical. By extracting the service time for each vehicle in each lane from the videotapes, it has been found that the best fit for service time is a *discrete* distribution. The service times used for each of the three days are shown in Tables A5, A6, and A7. The service time is in seconds. The Service Time Window, Figure 1.14, displays one entry for each lane of the toll plaza being simulated. This was determined from the Plaza Geometric Window. The distribution was selected first and then the pertinent data for the distribution entered. This was the final input data before execution of the simulation run.

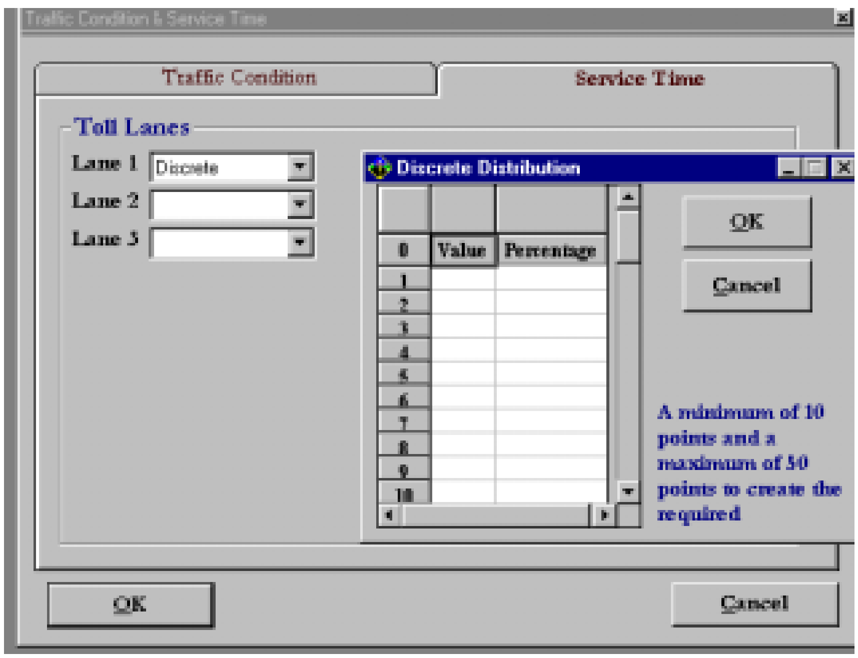



**Figure 1.14: Service Time Window**

## 1.4 MEASURES OF EFFECTIVENESS (MOEs)

To provide concluding results that TPSIM© is transferable to other plazas (Dean Plaza), a comparison of the actual toll plaza's Measure Of Effectiveness (MOEs) observed from the field to those resulting from the simulation package was conducted. The MOEs must be representative of the system performance of interest and characterize the essence of the system. For the purpose of TPSIM© testing, four different MOEs were selected. MOEs can be calculated for each lane, each lane type or the total plaza. For the purpose of this analysis, the MOEs were examined by 5-minute intervals and the entire hour for each lane type. These measures of effectiveness are summarized as follows:

***a) Throughput***

The vehicle count downstream of the plaza.

***b) Average Queuing Delay***

The time a vehicle spends waiting in a queue averaged over all vehicles in the queue upstream of the booth during the peak hour.

***c) Maximum Queuing Delay***

The maximum time a vehicle spends in the queue at the toll plaza booth during the peak hour.

***d) Total Queuing Delay***

The time spent by all vehicles waiting in the queue at the toll plaza booth during the peak hour.

## 1.5 MODEL CALIBRATION

### *1.5.1 EXPERIMENTAL DESIGN*

The experimental design was established using the process of first adjusting the input variables that least directly impact the individual operations of the vehicles. Therefore, the order of adjusting these parameters began with the plaza geometric data and then the global parameters. The default values of the model were chosen for the initial runs. Adjustments were made from these. These adjustments were based on testing the significant difference statistically between the model output and field MOEs. An adjustment to increase or decrease the applicable input variables was made to improve the statistical results. Once it was observed that no further improvements to the output results were realized, adjustments were made to another input variable. The final values for the adjusted parameters are documented in Table A1, Appendix A.

To begin the experimental design, August 17, 1994 data was chosen. Since there were two days from 1994, these days were chosen for evaluation first and then June 6, 2000. The experiment began by adjusting the approach lane length first and keeping all other parameters constant for August 17, 1994. Two or three runs using the same input variables were completed and the output of throughput analyzed. The values of the variables were adjusted according to the results. Each time a variable was concluded to be the best, it was held constant and another variable was adjusted. This iterative process was followed for all the calibration parameters. Once satisfactory results were obtained for August 17, September 14 was simulated using the concluded values of the calibration parameters. Now September 14 was taken through the same iterative process of adjusting the variables until satisfactory results were obtained for the throughput. Then, August 17 was simulated again. This process continued until both days had acceptable results (no significant difference in the throughput between the field and simulated values). Then, the calibration parameter values were applied to June 6, 2000 and the same process was followed but using all three days for the iterative process until acceptable results were obtained. After the throughput was completed, the MOEs for delay were analyzed using the same experimental design. The reason for the separation of the MOEs was to make the calibration parameters that affected one MOE more than another easy to identify.

The following parameters were used to calibrate the model:

- *Approach Lane Length*
  The length of the lanes upstream of the toll plaza before the transition zone. This is the section where the vehicle arrivals are generated in the simulation. Deceleration begins in this upstream section of the toll plaza area.
- *Average Approach Speed*
  The average speed of the vehicles as they approach the toll plaza before beginning to decelerate.
- *Approach Speed Standard Deviation*
  The standard deviation of the approach speed.
- *Average Deceleration Rate*
  The rate at which a vehicle decreases speed upon approach to the toll plaza area or a queued vehicle.

- *Deceleration Rate Standard Deviation*

  The standard deviation of the deceleration rate.
- *Average Acceleration Rate*

  The rate at which a vehicle increases speed after deceleration occurred. This value is applied to a vehicle once it has decelerated and it is necessary for the vehicle to speed up again (i.e. the vehicle was in a stopped queue and now must move to approach the toll plaza).
- *Acceleration Rate Standard Deviation*

  The standard deviation of the acceleration rate.
- *Clearance*

  The minimum and maximum spacing between two vehicles.
- *ETC Speed*

  The average speed of the vehicles using the dedicated ETC lane(s).
- *Service Time*

  The length of time a vehicle spends at the booth to pay a toll.

Some of the input data were required to be held constant because these are set values that do not have any variability. The toll lane and transition zone lengths were held constant as well as the lane widths. These values can be changed if a sensitivity analysis is conducted to evaluate the impacts of changes in the geometric design to a toll plaza.

Table A1 in Appendix A also lists the RONs used for the final TPSIM© runs. The reason for some variability in selection of the RON is sometimes this seed invokes extensive repetitive calculations in the algorithms that severely slow the simulation process. When this occurred, the run was terminated and another RON was chosen.

Following are descriptions of the variables used in the calibration process. The approach lane length was varied in 100 ft increments between 2000 and 3000 feet. The global parameters were adjusted next. The approach speed was varied between 55 and 65 mph in 5 mph increments and the standard deviation of the approach speed was varied between 5 and 10 mph in 1 mph increments. Since the deceleration rate of a vehicle occurs next upon approach to the toll plaza, this was the next variable investigated followed by the acceleration rate. The deceleration rate was varied between 3 and 5 ft/s$^2$ in 1 ft/s$^2$ increments and the standard deviation values used were 0.5 and 1.0 ft/s$^2$. The acceleration rate was varied from 3 and 6 ft/s$^2$ in 1 ft/s$^2$ increments and the standard deviation was varied from 0.4 and 1.0 ft/s$^2$ in 0.2 ft/s$^2$ increments. The clearance was varied from a minimum of 10 ft to a maximum of 60 ft in 10 ft increments. This was found to have some impact on the delay and throughput for individual lanes. The larger clearance can create longer queue lengths (in distance, not vehicles) thus somewhat impacting the lane selection algorithm but not to a significant degree in this analysis. This is possibly due to the low number of available toll lanes at this plaza. Therefore, the default values of 20 to 40 ft were concluded for this plaza.

Some difficulty obtaining acceptable results for the delay MOEs was encountered. Since the delay is directly impacted by the service time, examination of various service time distributions was done. The delay output was found to be highly sensitive to even slight adjustments in the service time (1 second). The service time is unique for each lane of the toll plaza being modeled. It was found to be the input value that most directly affects individual lane performance. Therefore, this was the last value to be adjusted in the calibration process. The model reacts to adjustments in the service time much like the traffic in the field upstream of a toll plaza. A slight increase or decrease in the service time at a tollbooth directly impacts all the vehicles queued in that lane and the approaching vehicles. The approaching vehicles select lanes not only based on their payment method but may also select which lane has the shortest queue thus providing the possibility of being processed through the toll plaza quicker. TPSIM© displayed similar reactions to slight adjustments in the service time (1 second) by producing a change in the outputs of the traffic volume distributions and individual lane delays. The service time collected from the field can inherently have some slight rounding errors over an entire hour as it is almost impossible to determine the service time with accuracy better than by the second. Because of this high sensitivity to service time, the field data was revisited for accuracy and some slight adjustments were made based on the observations of the toll collector's movements, the vehicle arrival and departure at the toll booths and the drivers paying the tolls. Slight variations were observed with some of the previously recorded service times so a final review of the service times in question was conducted and a final distribution of service times for each lane of each day concluded.

Service time distributions were documented both excluding and including outliers. Outliers were considered those service times that were significantly higher than the majority of the recorded service times. These service times are Tables A5, A6, and A7 in Appendix A.

# CHAPTER 2

# EVALUATION OF TPSIM© MODEL RESULTS

In order to evaluate the performance of the Dean Toll Plaza and compare the results to the Holland East Toll Plaza, the results for the two manual transaction lanes (lane 1 and 3) were averaged for the analysis. Though ETC was accepted on all lanes in June 2000, the lanes are labeled as the primary transaction type recorded (manual and ACM). For the simulation results, to account for the possible variability between individual simulation runs, an average of 10 runs from the TPSIM© model using the final calibration parameter values was used, see Table A1 in Appendix A. The analysis was done both macroscopically (entire one-hour study period) and microscopically (5-minute intervals). The first 5 minutes of the hour were excluded from the analysis because this was considered a warm up period for the simulation model. A warm up period is the time it takes the model to begin generating the actual results as realized from the field. In order for the algorithms to accurately simulate the occurrences in the field, entries in the simulation run database must be available for reference (e.g. accurate simulation of short queues at the beginning of a simulated hour require a queue build up in the model database). The statistical analysis was completed using both manual calculations and a statistical computing package to insure accuracy.

## 2.1. THROUGHPUT

The analysis for the throughput was chosen based on the value of measure. The volume is an integer counted from the field thus a Chi-Square analysis was chosen. A Chi-Square analysis tests if the differences are statistically significant, *Moore*, *1996*. These differences are between the field and simulated data. More specifically, it is a measure of the distance the field data is from the simulated data. The Chi-Square analysis tests the null hypothesis (Ho) that the distributions are identical as opposed to the alternative hypothesis (Ha) that there is a significant difference between the two groups of values.

Ho: The distributions are identical

Ha: There is a significant difference between the two distributions

The level of significance was tested at the 95% confidence level. If the p-value is greater than 0.05, then there is no evidence to support rejecting the null hypothesis. The Chi-Square value is used to determine the p-value based on the degrees of freedom, *Moore, 1996*. All three days for each lane type showed no significant difference between the field and simulated throughput. These results are documented in Table 2.01.

**Throughput**

| Date | Lane Type | Chi-square value | p-value | Results (reject if the p-value $\leq$ 0.05) | Conclusions |
|---|---|---|---|---|---|
| Aug. 17, 1994 | Manual | 3.5552 | 0.9652 | Do not reject $H_o$ | *Identical* |
| | ACM | 4.7633 | 0.9064 | Do not reject $H_o$ | *Identical* |
| Sept. 14, 1994 | Manual | 6.5878 | 0.7637 | Do not reject $H_o$ | *Identical* |
| | ACM | 10.0513 | 0.4360 | Do not reject $H_o$ | *Identical* |
| June 6, 2000 | Manual | 5.7708 | 0.8341 | Do not reject $H_o$ | *Identical* |
| | ACM | 4.3596 | 0.9297 | Do not reject $H_o$ | *Identical* |
| | ETC | 9.9993 | 0.4406 | Do not reject $H_o$ | *Identical* |

**Table 2.01: Statistical Results (Throughput)**

A comparison of the overall throughput is displayed in Figure 2.01. The throughput for each day in 5-minute intervals is shown in Tables 2.02, 2.03, and 2.04. Graphs comparing the distributions of the field and simulated throughput by lane type are shown for each of the three days in Figures 2.02, 2.03, and 2.04.

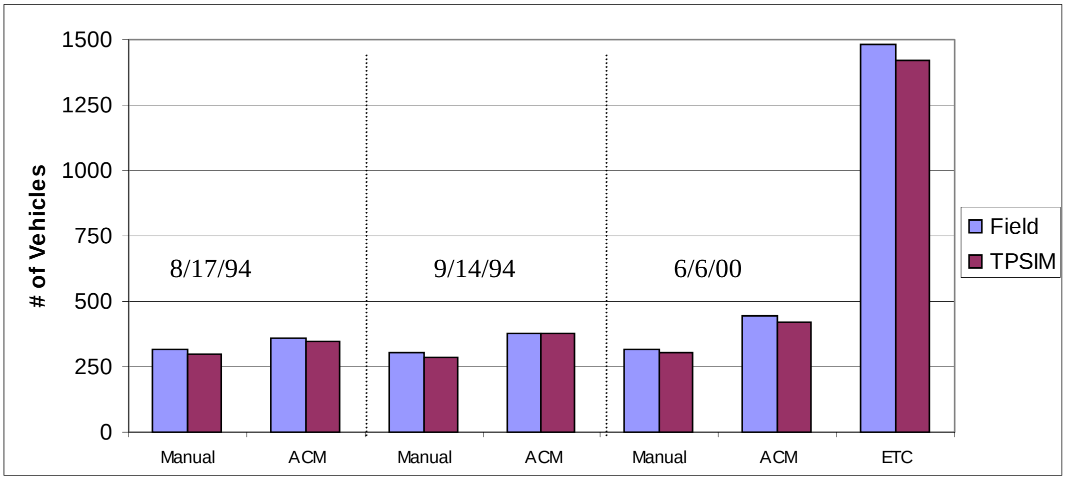



**Figure 2.01: Comparison of Actual and Simulated Throughput**

**Throughput**

| | Manual | | ACM | |
|---|---|---|---|---|
| | Field | TPSIM | Field | TPSIM |
| 7:05:00 | 28 | 24 | 26 | 27 |
| 7:10:00 | 30 | 26 | 32 | 30 |
| 7:15:00 | 30 | 28 | 36 | 35 |
| 7:20:00 | 25 | 30 | 37 | 32 |
| 7:25:00 | 32 | 30 | 37 | 37 |
| 7:30:00 | 34 | 31 | 46 | 38 |
| 7:35:00 | 32 | 30 | 36 | 35 |
| 7:40:00 | 29 | 30 | 30 | 33 |
| 7:45:00 | 26 | 25 | 24 | 28 |
| 7:50:00 | 24 | 24 | 30 | 27 |
| 7:55:00 | 28 | 24 | 23 | 28 |

**Table 2.02: August 17, 1994 Throughput (5-minute intervals)**

**Throughput**

| | Manual | | ACM | |
|---|---|---|---|---|
| | Field | TPSIM | Field | TPSIM |
| 7:05:00 | 29 | 23 | 28 | 32 |
| 7:10:00 | 24 | 28 | 37 | 37 |
| 7:15:00 | 27 | 26 | 37 | 36 |
| 7:20:00 | 31 | 26 | 45 | 34 |
| 7:25:00 | 32 | 28 | 43 | 41 |
| 7:30:00 | 29 | 28 | 44 | 40 |
| 7:35:00 | 30 | 28 | 43 | 36 |
| 7:40:00 | 27 | 28 | 36 | 37 |
| 7:45:00 | 21 | 24 | 18 | 25 |
| 7:50:00 | 30 | 23 | 22 | 28 |
| 7:55:00 | 27 | 25 | 25 | 30 |

**Table 2.03: September 14, 1994 Throughput (5-minute intervals)**

**Throughput**

| | Manual | | ACM | | ETC | |
|---|---|---|---|---|---|---|
| | Field | TPSIM | Field | TPSIM | Field | TPSIM |
| 7:05:00 | 22 | 26 | 40 | 37 | 143 | 123 |
| 7:10:00 | 31 | 28 | 42 | 39 | 135 | 136 |
| 7:15:00 | 33 | 28 | 40 | 39 | 129 | 127 |
| 7:20:00 | 28 | 30 | 44 | 40 | 144 | 139 |
| 7:25:00 | 35 | 30 | 45 | 42 | 138 | 138 |
| 7:30:00 | 36 | 31 | 50 | 43 | 155 | 152 |
| 7:35:00 | 32 | 32 | 46 | 44 | 146 | 143 |
| 7:40:00 | 27 | 27 | 31 | 38 | 141 | 127 |
| 7:45:00 | 26 | 24 | 41 | 36 | 105 | 115 |
| 7:50:00 | 27 | 25 | 33 | 33 | 133 | 113 |
| 7:55:00 | 23 | 25 | 33 | 32 | 115 | 108 |

**Table 2.04: June 6, 2000 Throughput (5-minute intervals)**

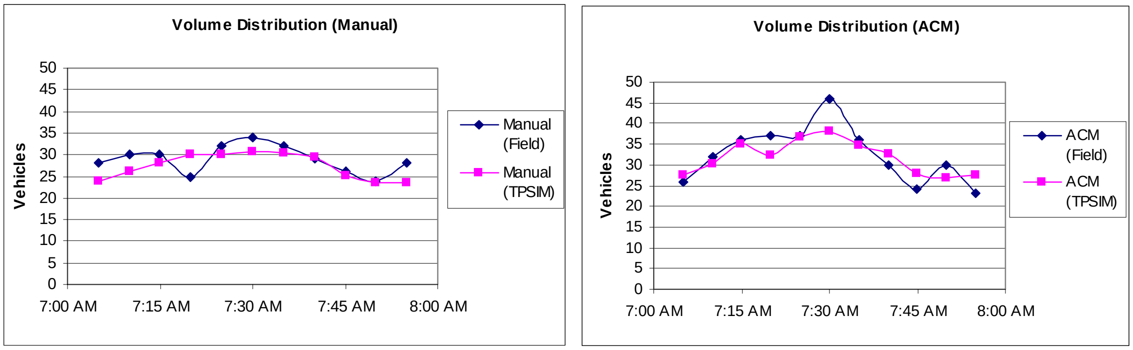



**Figure 2.02: August 17, 1994 Throughput**

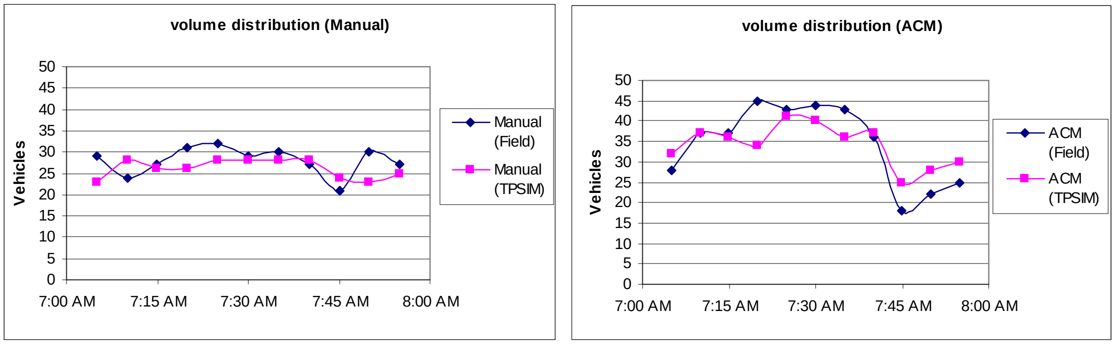



**Figure 2.03: September 14, 1994 Throughput**

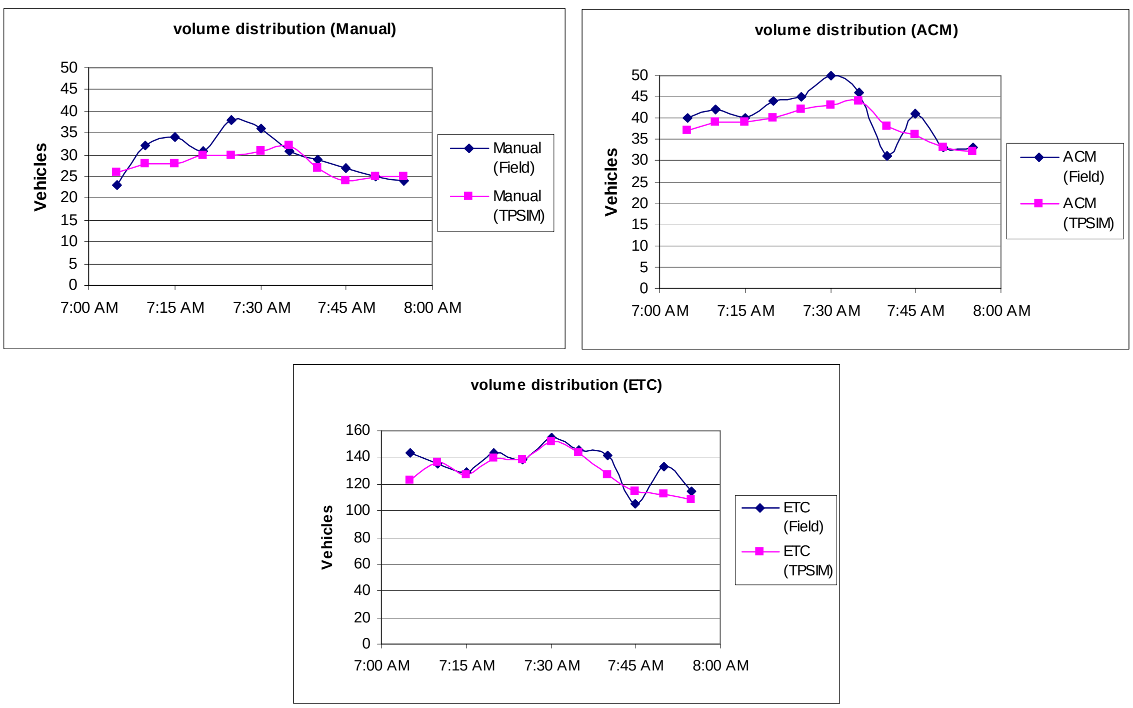



**Figure 2.04: June 6, 2000 Throughput**

## 2.2. AVERAGE QUEUING DELAY

The Wilcoxon Signed Rank Test was chosen for analysis of the delay MOEs because the delay is not a value counted in the field. The Wilcoxon Signed Rank analysis tests the hypothesis that the two population probability distributions are identical, *Mendenhall and Sincich, 1995*. More specifically, the differences between the measurements of each pair of values (field and simulated) are analyzed. If all of the differences are positive (or negative), the distributions are significantly different (one distribution is shifted a significant distance from the other). The data pairs (each value of field and simulated data for 5-minute intervals) analysis tests the null hypothesis (Ho) that the distributions are identical as opposed to the alternative hypothesis (Ha) that there is a significant difference between the two distributions.

Ho: The distributions are identical

Ha: There is a significant difference between the two distributions (one distribution is shifted to the right or left of the other)

The analysis was completed for the 95% confidence level. The $T_+$ and $T_-$ values indicate the positive and negative ranking values. The smaller of the two rank values is compared to $T_o$. If the chosen rank value is greater than $T_o$, there is no evidence to support rejection of the null hypothesis (Ho). $T_o$ is a value derived from a statistical table based on the number of matched-pair samples, *Mendenhall and Sincich, 1995*. The p-value is another statistical reference. Any p-value greater than 0.05 indicates no significant difference at the 95% confidence level. All three days were found to have no significant difference in the distributions for average queuing delay for the manual and ACM lanes, see Table 2.05.

**Average Queuing Delay**

| Date | Lane Type | T+ | T- | $T_0$ | p-value | Results (reject if the smaller of $T_-$ or $T_+ \leq T_0$) | Conclusions |
|---|---|---|---|---|---|---|---|
| Aug. 17, 1994 | Manual | 40 | 26 | 11 | 0.532 | Do not reject $H_o$ | *Identical* |
| | ACM | 26.5 | 28.5 | 8 | 0.919 | Do not reject $H_o$ | *Identical* |
| Sept. 14, 1994 | Manual | 49 | 17 | 11 | 0.155 | Do not reject $H_o$ | *Identical* |
| | ACM | 14 | 41 | 8 | 0.168 | Do not reject $H_o$ | *Identical* |
| June 6, 2000 | Manual | 12 | 43 | 8 | 0.112 | Do not reject $H_o$ | *Identical* |
| | ACM | 28 | 38 | 11 | 0.656 | Do not reject $H_o$ | *Identical* |

**Table 2.05: Statistical Results (Average Queuing Delay)**

A macroscopic analysis of the average queuing delay for each lane type from each of the three days is shown in Figure 2.05. For the microscopic analysis, the average queuing delay for each day in 5-minute intervals is shown in Tables 2.06, 2.07, and 2.08. Graphs comparing the distributions of average queuing delay are in Figures 2.06, 2.07, and 2.08.

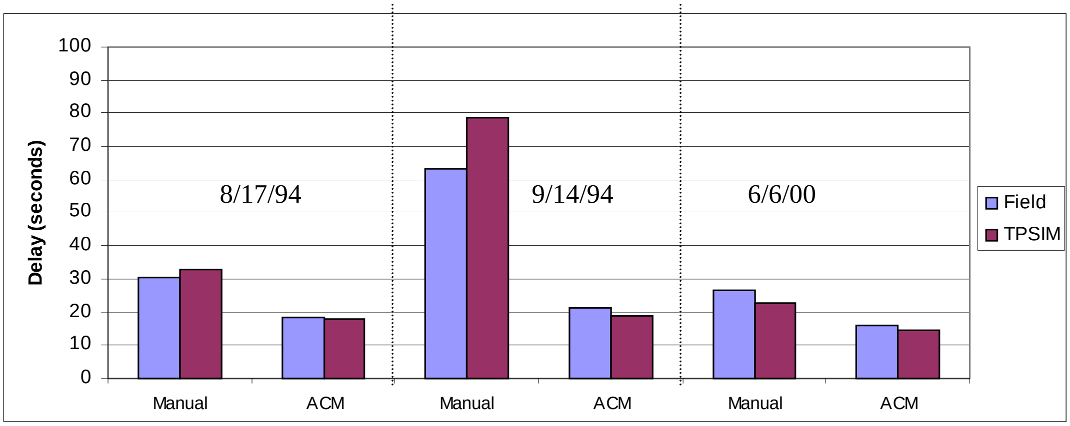



**Figure 2.05: Comparison of Actual and Simulated Average Queuing Delay**

**Average Queuing Delay**

| | Manual | | ACM | |
|---|---|---|---|---|
| | Field | TPSIM | Field | TPSIM |
| 7:05:00 | 29 | 21 | 21 | 13 |
| 7:10:00 | 21 | 25 | 13 | 12 |
| 7:15:00 | 29 | 35 | 17 | 18 |
| 7:20:00 | 34 | 36 | 20 | 16 |
| 7:25:00 | 44 | 40 | 31 | 23 |
| 7:30:00 | 68 | 56 | 47 | 32 |
| 7:35:00 | 27 | 39 | 18 | 23 |
| 7:40:00 | 20 | 43 | 12 | 22 |
| 7:45:00 | 19 | 24 | 7 | 13 |
| 7:50:00 | 15 | 21 | 10 | 10 |
| 7:55:00 | 27 | 21 | 8 | 16 |

**Table 2.06: August 17, 1994 Average Queuing Delay (5-minute intervals)**

**Average Queuing Delay**

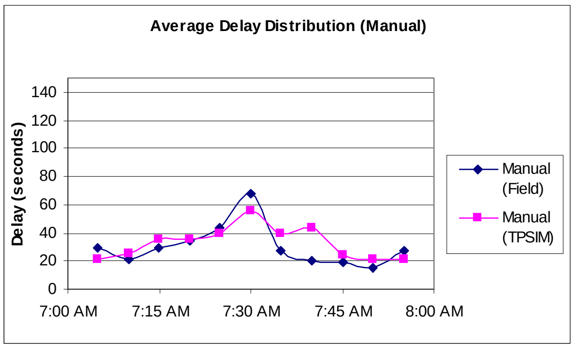
| | Manual | | ACM | |
|---|---|---|---|---|
| | Field | TPSIM | Field | TPSIM |
| 7:05:00 | 39 | 33 | 13 | 11 |
| 7:10:00 | 102 | 52 | 21 | 13 |
| 7:15:00 | 109 | 68 | 22 | 13 |
| 7:20:00 | 55 | 62 | 17 | 14 |
| 7:25:00 | 62 | 80 | 24 | 19 |
| 7:30:00 | 108 | 119 | 32 | 29 |
| 7:35:00 | 95 | 155 | 41 | 44 |
| 7:40:00 | 38 | 139 | 17 | 33 |
| 7:45:00 | 23 | 75 | 25 | 10 |
| 7:50:00 | 39 | 40 | 14 | 13 |
| 7:55:00 | 24 | 45 | 10 | 10 |

**Table 2.07: September 14, 1994 Average Queuing Delay (5-minute intervals)**

**Average Queuing Delay**

| | Manual | | ACM | |
|---|---|---|---|---|
| | Field | TPSIM | Field | TPSIM |
| 7:05:00 | 20 | 22 | 16 | 12 |
| 7:10:00 | 26 | 24 | 9 | 16 |
| 7:15:00 | 25 | 26 | 11 | 14 |
| 7:20:00 | 39 | 21 | 10 | 14 |
| 7:25:00 | 28 | 28 | 25 | 15 |
| 7:30:00 | 24 | 32 | 22 | 20 |
| 7:35:00 | 34 | 28 | 18 | 17 |
| 7:40:00 | 23 | 21 | 28 | 14 |
| 7:45:00 | 24 | 19 | 14 | 11 |
| 7:50:00 | 24 | 16 | 9 | 11 |
| 7:55:00 | 23 | 15 | 11 | 13 |

**Table 2.08: June 6, 2000 Average Queuing Delay (5-minute intervals)**



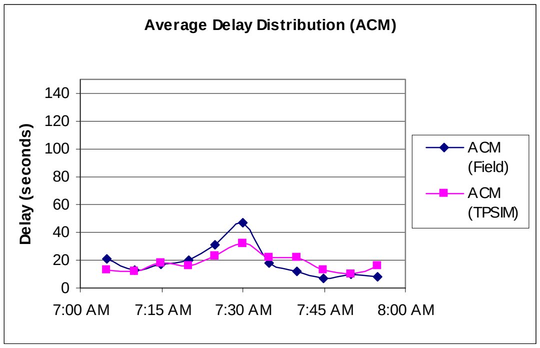




**Figure 2.06: August 17, 1994 Average Queuing Delay**

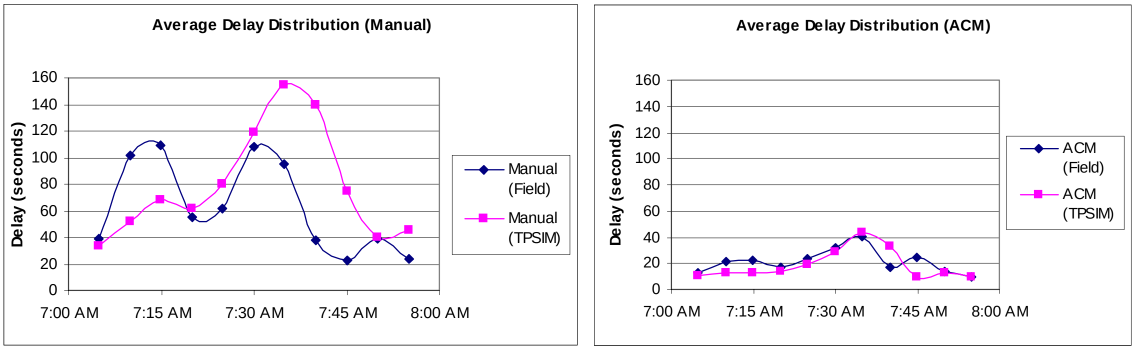



**Figure 2.07: September 14, 1994 Average Queuing Delay**

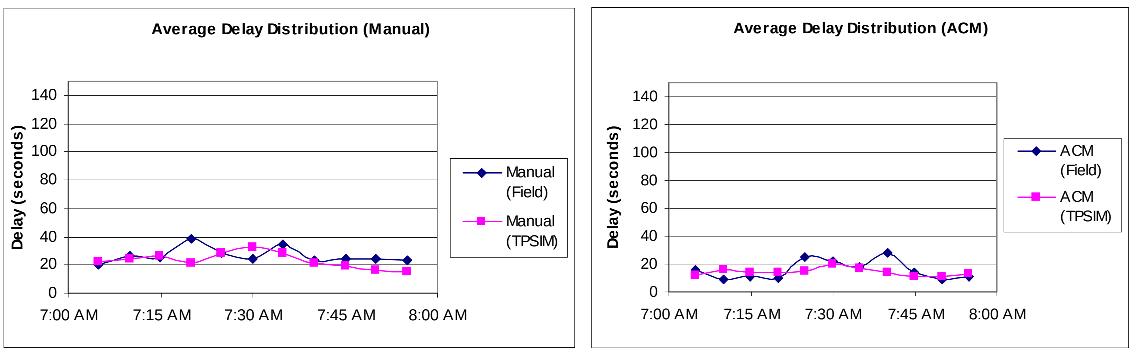



**Figure 2.08: June 6, 2000 Average Queuing Delay**

## 2.3. MAXIMUM QUEUING DELAY

The Wilcoxon Signed Rank Test results at the 95% confidence level are shown in Table 2.09 for the maximum queuing delay. The data pairs (each value of field and simulated data for 5-minute intervals) were tested with the same conclusions for the null hypothesis (Ho) and alternative hypothesis (Ha).

Ho: The distributions are identical

Ha: There is a significant difference between the two distributions (one distribution is shifted to the right or left of the other)

All three days were found to have no significant difference in the distributions for maximum queuing delay for both the manual and ACM lanes.

**Maximum Queuing Delay**

| Date | Lane Type | T+ | T- | $T_0$ | p-value | Results (reject if the smaller of $T_-$ or $T_+ \leq T_0$) | Conclusions |
|---|---|---|---|---|---|---|---|
| Aug. 17, 1994 | Manual | 27 | 28 | 8 | 0.959 | Do not reject $H_o$ | *Identical* |
| | ACM | 27 | 39 | 11 | 0.594 | Do not reject $H_o$ | *Identical* |
| Sept. 14, 1994 | Manual | 49 | 17 | 11 | 0.155 | Do not reject $H_o$ | *Identical* |
| | ACM | 30.5 | 35.5 | 11 | 0.824 | Do not reject $H_o$ | *Identical* |
| June 6, 2000 | Manual | 12 | 43 | 8 | 0.114 | Do not reject $H_o$ | *Identical* |
| | ACM | 32 | 34 | 11 | 0.929 | Do not reject $H_o$ | *Identical* |

**Table 2.09: Statistical Results (Maximum Queuing Delay)**

A macroscopic analysis of the maximum queuing delay for each lane type from each of the three days is shown in Figure 2.09. For the microscopic analysis, the maximum queuing delay for each day in 5-minute intervals is shown in Tables 2.10, 2.11, and 2.12. Graphs comparing the distributions of maximum queuing delay are in Figures 2.10, 2.11, and 2.12.

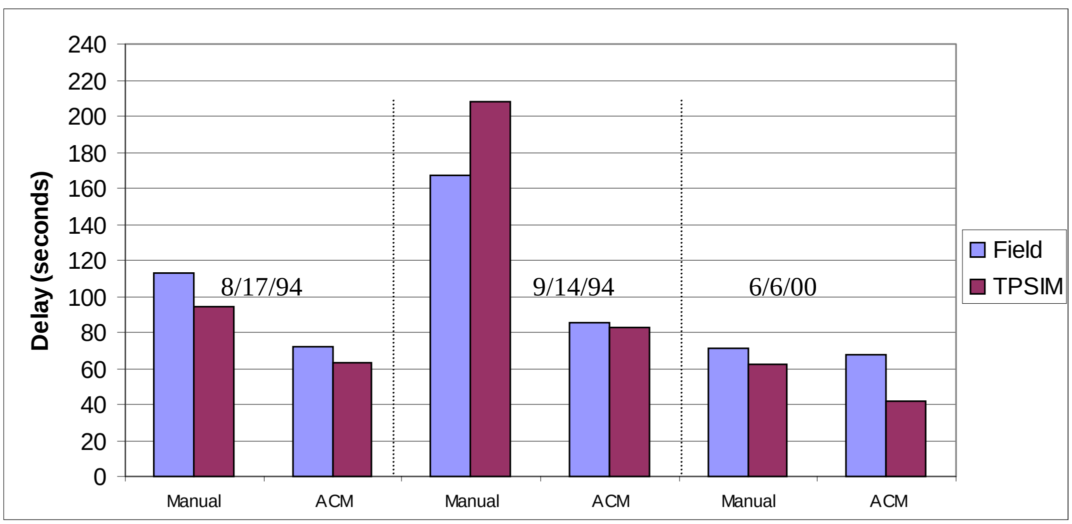



**Figure 2.09: Comparison of Actual and Simulated Maximum Queuing Delay**

**Maximum Queuing Delay**

| | Manual | | ACM | |
|---|---|---|---|---|
| | Field | TPSIM | Field | TPSIM |
| 7:05:00 | 60 | 48 | 46 | 27 |
| 7:10:00 | 46 | 53 | 24 | 27 |
| 7:15:00 | 53 | 63 | 34 | 41 |
| 7:20:00 | 81 | 72 | 58 | 37 |
| 7:25:00 | 113 | 76 | 68 | 48 |
| 7:30:00 | 107 | 94 | 72 | 64 |
| 7:35:00 | 54 | 78 | 52 | 44 |
| 7:40:00 | 43 | 78 | 31 | 45 |
| 7:45:00 | 54 | 54 | 16 | 29 |
| 7:50:00 | 33 | 48 | 24 | 29 |
| 7:55:00 | 67 | 47 | 18 | 35 |

**Table 2.10: August 17, 1994 Maximum Queuing Delay (5-minute intervals)**

**Maximum Queuing Delay**

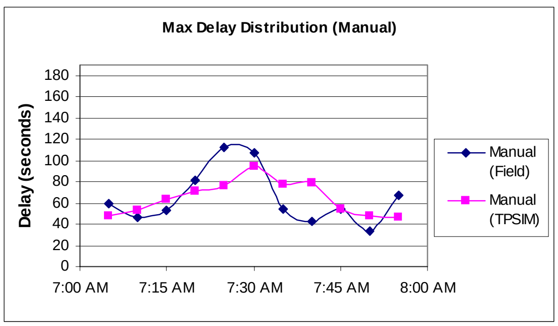
| | Manual | | ACM | |
|---|---|---|---|---|
| | Field | TPSIM | Field | TPSIM |
| 7:05:00 | 64 | 65 | 19 | 25 |
| 7:10:00 | 167 | 89 | 46 | 31 |
| 7:15:00 | 143 | 107 | 49 | 30 |
| 7:20:00 | 85 | 98 | 34 | 35 |
| 7:25:00 | 98 | 117 | 46 | 45 |
| 7:30:00 | 135 | 166 | 85 | 62 |
| 7:35:00 | 119 | 208 | 70 | 83 |
| 7:40:00 | 66 | 207 | 32 | 70 |
| 7:45:00 | 41 | 137 | 59 | 27 |
| 7:50:00 | 78 | 74 | 22 | 30 |
| 7:55:00 | 70 | 82 | 14 | 26 |

**Table 2.11: September 14, 1994 Maximum Queuing Delay (5-minute intervals)**

**Maximum Queuing Delay**

| | Manual | | ACM | |
|---|---|---|---|---|
| | Field | TPSIM | Field | TPSIM |
| 7:05:00 | 33 | 41 | 43 | 34 |
| 7:10:00 | 59 | 49 | 16 | 36 |
| 7:15:00 | 50 | 50 | 25 | 33 |
| 7:20:00 | 71 | 45 | 28 | 35 |
| 7:25:00 | 59 | 54 | 56 | 35 |
| 7:30:00 | 47 | 62 | 47 | 41 |
| 7:35:00 | 61 | 56 | 38 | 42 |
| 7:40:00 | 47 | 50 | 68 | 35 |
| 7:45:00 | 54 | 41 | 31 | 27 |
| 7:50:00 | 69 | 36 | 20 | 24 |
| 7:55:00 | 63 | 34 | 20 | 31 |

**Table 2.12: June 6, 2000 Maximum Queuing Delay (5-minute intervals)**



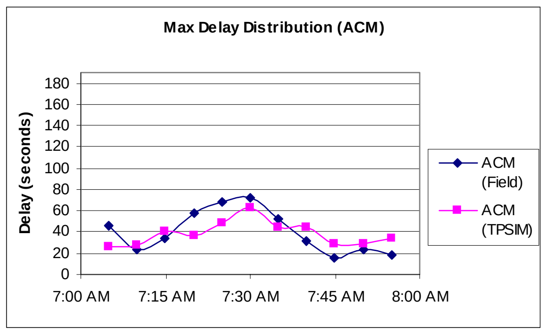
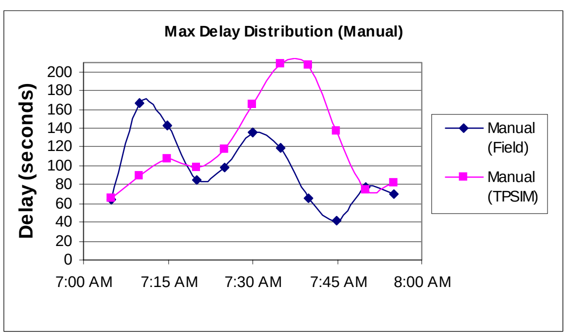




**Figure 2.10: August 17, 1994 Maximum Queuing Delay**



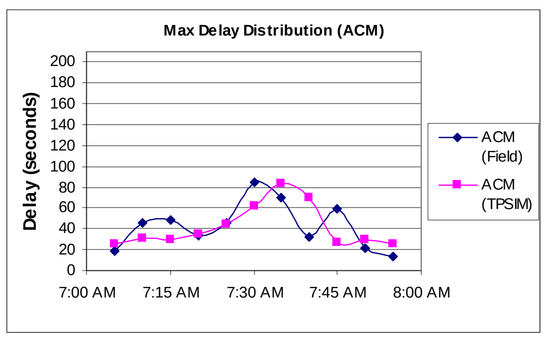
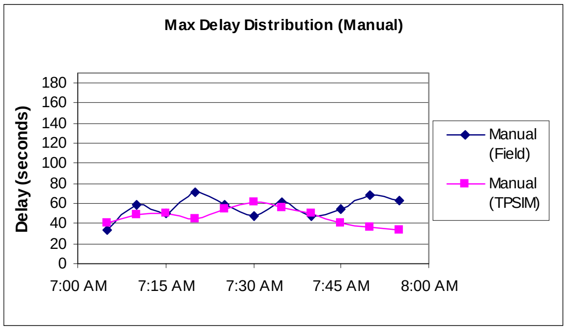




**Figure 2.11: September 14, 1994 Maximum Queuing Delay**



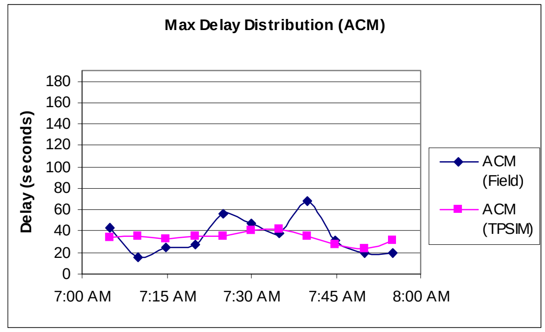




**Figure 2.12: June 6, 2000 Maximum Queuing Delay**

## 2.4. TOTAL QUEUING DELAY

The Wilcoxon Signed Rank Test results at the 95% confidence level are shown in Table 2.13 for the total queuing delay. The data pairs (each value of field and simulated data for 5-minute intervals) were tested with the same conclusions for the null hypothesis (Ho) and alternative hypothesis (Ha).

Ho: The distributions are identical

Ha: There is a significant difference between the two distributions (one distribution is shifted to the right or left of the other)

All three days were found to have no significant difference in the distributions for total queuing delay for both the manual and ACM lanes.

**Total Queuing Delay**

| Date | Lane Type | T+ | T- | $T_0$ | p-value | Results (reject if the smaller of $T_-$ or $T_+ \leq T_0$) | Conclusions |
|---|---|---|---|---|---|---|---|
| Aug. 17, 1994 | Manual | 37 | 29 | 11 | 0.722 | Do not reject $H_o$ | *Identical* |
| | ACM | 28 | 38 | 11 | 0.657 | Do not reject $H_o$ | *Identical* |
| Sept. 14, 1994 | Manual | 41 | 25 | 11 | 0.477 | Do not reject $H_o$ | *Identical* |
| | ACM | 16 | 50 | 11 | 0.131 | Do not reject $H_o$ | *Identical* |
| June 6, 2000 | Manual | 14 | 52 | 11 | 0.091 | Do not reject $H_o$ | *Identical* |
| | ACM | 26.5 | 39.5 | 11 | 0.563 | Do not reject $H_o$ | *Identical* |

**Table 2.13: Statistical Results (Total Queuing Delay)**

A macroscopic analysis of the total queuing delay for each lane type from each of the three days is shown in Figure 2.13. For the microscopic analysis, the total queuing delay for each day in 5-minute intervals is shown in Tables 2.14, 2.15, and 2.16. Graphs comparing the distributions of total queuing delay are in Figures 2.14, 2.15, and 2.16.

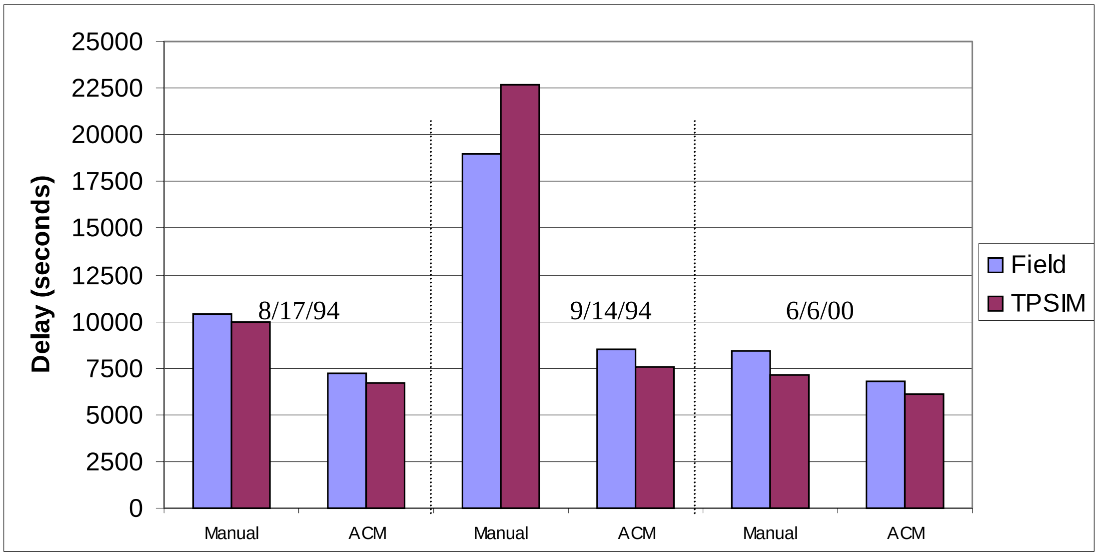



**Figure 2.13: Comparison of Actual and Simulated Total Queuing Delay**

**Total Queuing Delay**

| | Manual | | ACM | |
|---|---|---|---|---|
| | Field | TPSIM | Field | TPSIM |
| 7:05:00 | 660 | 479 | 561 | 381 |
| 7:10:00 | 671 | 647 | 400 | 358 |
| 7:15:00 | 844 | 965 | 646 | 623 |
| 7:20:00 | 900 | 1042 | 756 | 510 |
| 7:25:00 | 2584 | 1136 | 1252 | 866 |
| 7:30:00 | 1660 | 1656 | 1870 | 1199 |
| 7:35:00 | 898 | 1152 | 650 | 802 |
| 7:40:00 | 530 | 1249 | 375 | 799 |
| 7:45:00 | 515 | 608 | 172 | 383 |
| 7:50:00 | 318 | 503 | 356 | 282 |
| 7:55:00 | 803 | 492 | 155 | 464 |

**Table 2.14: August 17, 1994 Total Queuing Delay (5-minute intervals)**

**Total Queuing Delay**

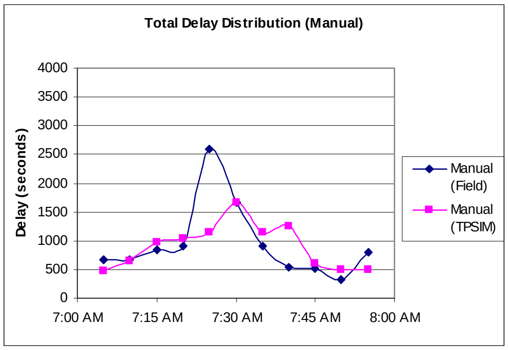
| | Manual | | ACM | |
|---|---|---|---|---|
| | Field | TPSIM | Field | TPSIM |
| 7:05:00 | 1216 | 756 | 349 | 346 |
| 7:10:00 | 2997 | 1380 | 897 | 460 |
| 7:15:00 | 2556 | 1703 | 786 | 483 |
| 7:20:00 | 1526 | 1592 | 664 | 492 |
| 7:25:00 | 2099 | 2149 | 1077 | 763 |
| 7:30:00 | 3136 | 3274 | 1549 | 1136 |
| 7:35:00 | 2338 | 4190 | 1722 | 1664 |
| 7:40:00 | 848 | 3733 | 483 | 1332 |
| 7:45:00 | 478 | 1877 | 454 | 246 |
| 7:50:00 | 1169 | 918 | 313 | 351 |
| 7:55:00 | 641 | 1106 | 251 | 305 |

**Table 2.15: September 14, 1994 Total Queuing Delay (5-minute intervals)**

**Total Queuing Delay**

| | Manual | | ACM | |
|---|---|---|---|---|
| | Field | TPSIM | Field | TPSIM |
| 7:05:00 | 406 | 590 | 471 | 439 |
| 7:10:00 | 887 | 653 | 357 | 627 |
| 7:15:00 | 783 | 738 | 455 | 555 |
| 7:20:00 | 1248 | 627 | 431 | 556 |
| 7:25:00 | 883 | 820 | 1156 | 643 |
| 7:30:00 | 838 | 995 | 1023 | 842 |
| 7:35:00 | 983 | 882 | 795 | 765 |
| 7:40:00 | 669 | 586 | 952 | 546 |
| 7:45:00 | 636 | 462 | 487 | 386 |
| 7:50:00 | 610 | 403 | 317 | 347 |
| 7:55:00 | 504 | 362 | 343 | 430 |

**Table 2.16: June 6, 2000 Total Queuing Delay (5-minute intervals)**



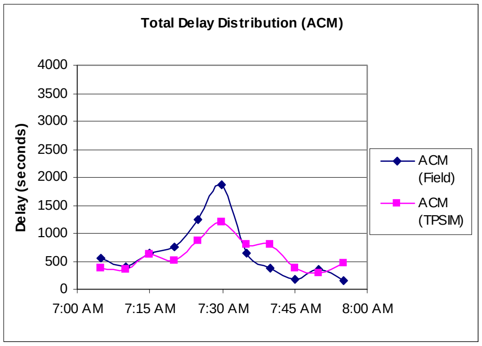




**Figure 2.14: August 17, 1994 Total Queuing Delay**

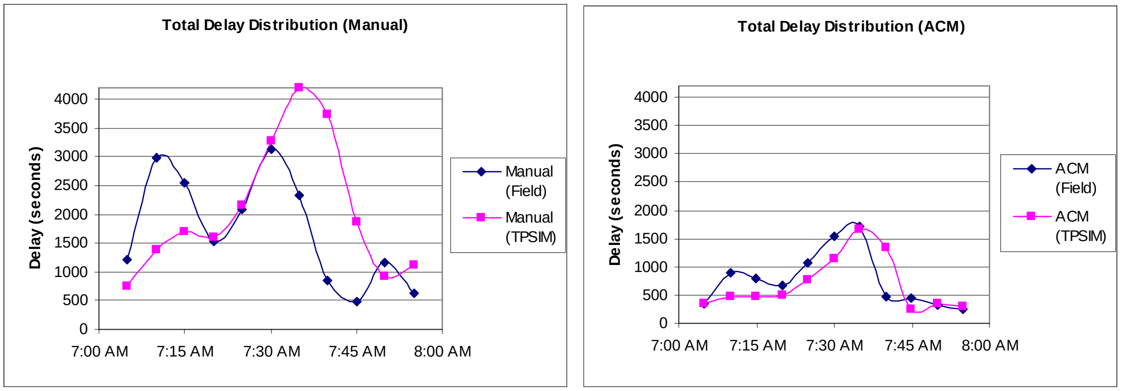



**Figure 2.15: September 14, 1994 Total Queuing Delay**

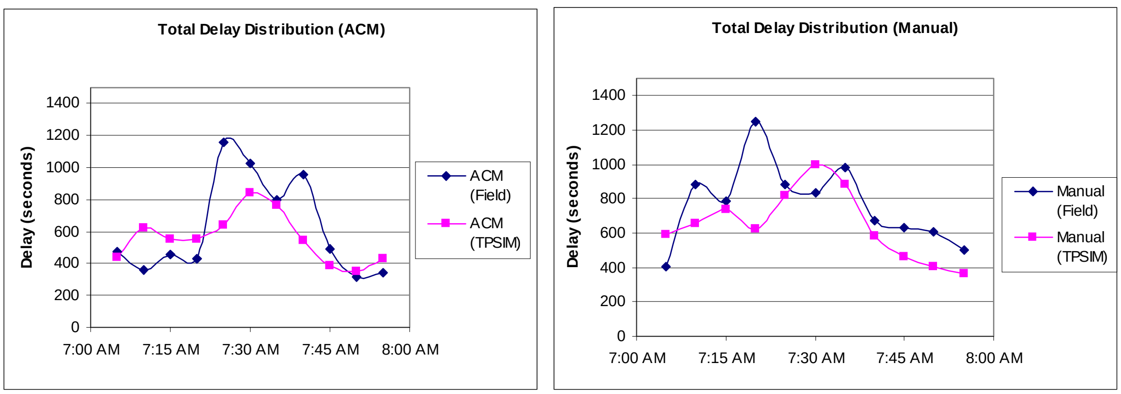



**Figure 2.16: June 6, 2000 Total Queuing Delay**

## 2.5. COMPARISON OF DEAN PLAZA AND HOLLAND EAST PLAZA RESULTS

Both Holland East and Dean Plazas showed no significant difference for the comparison of each lane type for the identified MOEs of throughput, average queuing delay, maximum queuing delay, and total queuing delay. Holland East Plaza was analyzed for data collected in 1995 and 1996 and Dean Plaza was analyzed for data collected in 1994 and 2000. In 1995, Holland East had one dedicated ETC lane that compares to the one ETC lane at Dean Plaza in 2000. This analysis of Dean Plaza also identifies the fact that the model cannot only be applied to a different toll plaza, but different operations as well. Dean Plaza in 1994 had no ETC payment option at all.

Table 2.17 compares some of the traffic characteristics and toll plaza configurations for both plazas.

| | Holland East | | Dean | | |
|---|---|---|---|---|---|
| | June 8, 1995 | July 9, 1996 | Aug. 17, 1994 | Sept. 14, 1994 | June 6, 2000 |
| # of Approach Lanes | 4 | 4 | 3 | 3 | 4 |
| # of Manual Lanes | 6* | 5* | 2 | 2 | 2* |
| # of ACM Lanes | 2* | 2* | 1 | 1 | 1* |
| # of ETC Lanes | 1 | 2 | 0 | 0 | 1 |
| Plaza Volumes | 5113 | 5546 | 1061 | 1044 | 2807 |
| % of Manual Payments | 51% | 40% | 64% | 62% | 25% |
| % of ACM Payments | 24% | 20% | 36% | 38% | 17% |
| % of ETC Payments | 25% | 40% | 0% | 0% | 58% |
| % of Trucks | 1% | 1% | 1% | 1% | 2% |

* indicates ETC payment also accepted

**Table 2.17: Traffic and Plaza Characteristics - Holland East and Dean Plazas**

Some adjustments to certain input parameters were required to produce acceptable results for the simulation of Dean Plaza. These adjustments were based on testing the statistically significant difference between the model output and field MOEs. An adjustment to increase or decrease the applicable input variables was made to improve the statistical results. Once it was observed that no further improvements to the output results were realized, adjustments were made to another input variable. Adjustment to the input parameters accomplished the calibration of the model for a 95% confidence level between the model output and the field MOEs. The parameter values for both Holland East and Dean Plazas are identified in Table 2.18. Service time is not included in the table because it is recorded from the field and may vary from plaza to plaza depending on the manual lane operator(s), time of day, or other individual location characteristics.

**Input Parameter Values**

| Parameter | Holland East* | Dean |
|---|---|---|
| Approach Lane Length | 3000 ft | 2500 ft |
| ETC Speed | 40 mph | 40 mph |
| Average Approach Speed | 60 mph | 60 mph |
| Average Approach Speed (Standard Deviation) | 5 mph | 8 mph |
| Deceleration Rate | 3 ft/s$^2$ | 3.5 ft/s$^2$ |
| Deceleration Rate (Standard Deviation) | 0.5 ft/s$^2$ | 0.5 ft/s$^2$ |
| Acceleration Rate | 5.5 ft/s$^2$ | 3.5 ft/s$^2$ |
| Acceleration Rate (Standard Deviation) | 0.5 ft/s$^2$ | 0.4 ft/s$^2$ |
| Clearance | 20-40 ft | 20-40 ft |

* from phase I final report

**Table 2.18: Input Parameter Values for Holland East and Dean Plazas**

# CHAPTER 3

# TPSIM© ANIMATION

## 3.1 ANIMATION DEVELOPMENT

The animation capabilities coincide with an individual simulation run. In order to execute the animation features, a simulation run must be completed first. This is because in order to accurately display the animation, the calculations from the model must be completed for the animation to run properly.

Vehicles are displayed in different colors, with each color representing a specific vehicle payment type. Manual vehicles are green, automatic coin machine vehicles are blue, and ETC vehicles are purple. Trucks are displayed as a longer vehicle as indicated in Figure 3.03. The time is displayed at the lower left of the animation window. The unit of measure is seconds. The calculation is based on 12:00:00 AM being equal to 3600 seconds. Therefore, 7:00:00 AM = 7*3600 seconds or 25200 seconds. The time displayed on the window snapshot in Figure 3.01 of 25700 corresponds to 7:08:20 AM. The animation is in real-time. Every second of animation corresponds to every second that would occur in the field. To display the animation after a simulation is completed, select "View" from the TPSIM© menu bar, and then select "Animation" from the "View" drop down menu. Figure 3.01 shows an upstream section of the animation where the approach lanes diverge into the toll lanes. The center section is the transition zone as noted in the figure. The window also shows a scale for visualizing lengths in the animation. The distance measurement is in 100-foot increments. Figure 3.02 shows the toll plaza structure on the right and the labeled lane types selected based on the input from the user.

The animation capabilities include approach, car following, lane changing and lane type choice up to approach of the toll plaza. Table 3.01 is taken from the field data observed from the videotape for a three-minute interval. The indicated arrival or departure value is totaled for the entire minute. The animation window, Figure 3.02, is a snapshot of one second. Calculation of the differences between the arrivals and departures indicates that there should be virtually no queuing conditions for this time period that is captured in this animation snapshot. The field calculations are just a sample and do not indicate the previous arrivals or departures thus accounting for the additional departures in the table compared to the arrivals. This table is just to provide a general observation of the comparison between the simulation and field observations. Because each simulation is of a random nature, it will not match exactly but the animation window does provide adequate visualization of the low traffic expected during this time period in the field.

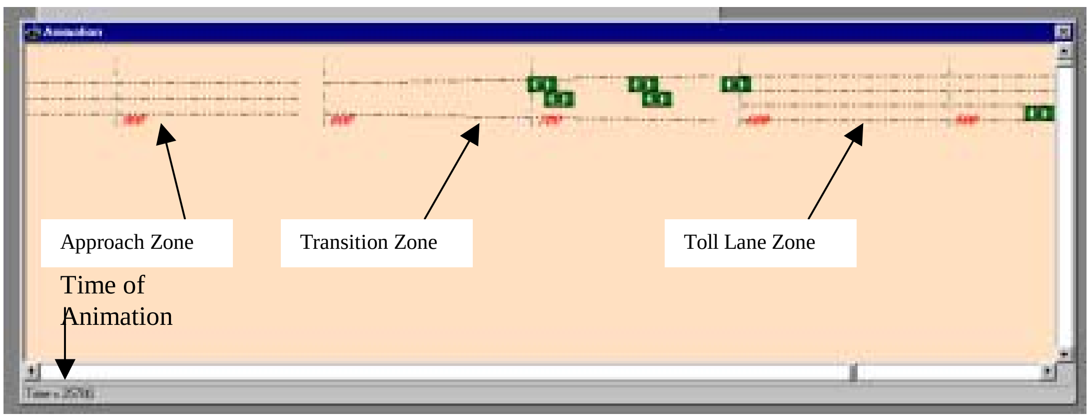



**Figure 3.01: Animation Window for Dean Plaza (Aug 17, 1994, 7:08:20 AM)**

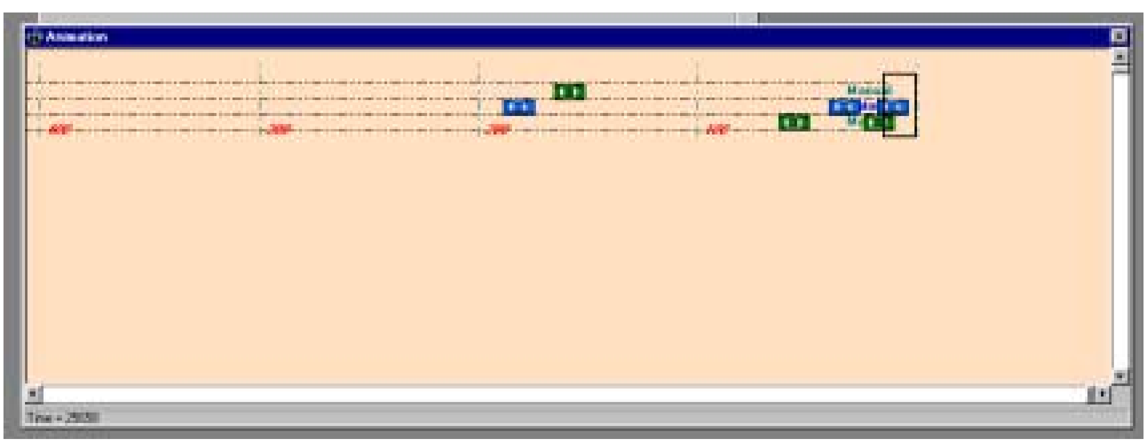


**Figure 3.02: Animation Window for Dean Plaza (Aug. 17, 1994, 7:07:38 AM)**

| | arrivals | | | departures | | |
|---|---|---|---|---|---|---|
| | lane 1 | lane 2 | lane 3 | lane 1 | lane 2 | lane 3 |
| 7:06:00 | 7 | 5 | 2 | 7 | 6 | 5 |
| 7:07:00 | 6 | 7 | 5 | 6 | 8 | 6 |
| 7:08:00 | 4 | 7 | 7 | 4 | 9 | 6 |

**Table 3.01: Dean Plaza Field Data (August 17, 1994)**

Depending upon the time of capture for the animation window, some variation in the queue length compared to the field values will occur because of the perceptible possibilities of the simulation model output varying from the actual field observations. However, observations from the field do show the arrivals and departures are similar to what is observed in the animation window for the same time periods, thus providing good simulated representations with the animation of the field traffic conditions. Keep in mind that the windows in the figures are snapshots showing only a second of the values for the total minute in the corresponding tables. Figures 3.03 and 3.04 with corresponding Tables 3.02 and 3.03 display some of these comparisons for September 14, 1994.

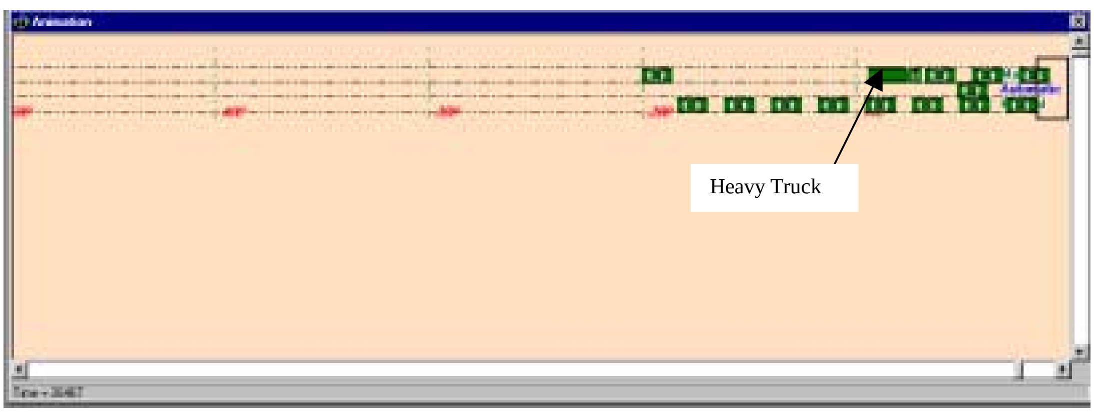



**Figure 3.03: Animation Window for Dean Plaza (Sept. 14, 1994, 7:21:07 AM)**

**Figure 3.04: Animation Window for Dean Plaza (Sept. 14, 1994, 7:22:59 AM)**

| | arrivals | | | departures | | |
|---|---|---|---|---|---|---|
| | lane 1 | lane 2 | lane 3 | lane 1 | lane 2 | lane 3 |
| 7:19:00 | 4 | 13 | 2 | 5 | 8 | 6 |
| 7:20:00 | 5 | 7 | 4 | 7 | 10 | 4 |
| 7:20:00 | 5 | 7 | 4 | 7 | 10 | 4 |
| 7:21:00 | 4 | 10 | 4 | 5 | 9 | 6 |
| 7:22:00 | 7 | 7 | 5 | 7 | 10 | 8 |
| 7:23:00 | 9 | 8 | 9 | 5 | 7 | 6 |

**Table 3.02: Dean Plaza Field Data (September 14, 1994)**

# CHAPTER 4

# CONCLUSIONS AND RECOMMENDATIONS

Application of the TPSIM© computer model on other toll plazas is possible based on the results of this analysis. Three days from Dean Mainline Toll Plaza on the OOCEA toll road network were selected for analysis using the TPSIM© model. Dean Plaza was selected based on the significant difference in the plaza layout compared to Holland East Plaza (the first plaza analyzed in Phase I) and the availability of detailed historical data. Dean Plaza has a total of only eight lanes in both directions whereas Holland East Plaza has fourteen lanes for both directions. The historical data provided detailed data of two days from 1994, which had only three operational lanes at the time, and no ETC payment option. The third day collected in 2000 provided data for simulating Dean Plaza with a fourth lane (dedicated ETC) and ETC payment capabilities on the three other lanes.

An experimental design was outlined and followed in order to accurately account for each trial simulation run during the calibration process. Over four hundred individual simulation runs were completed for the analysis. The service time was determined to have the most significant impact on the simulation model much in the same manner as it does in the field. Therefore, accuracy of determining the service time for a toll plaza to be simulated is important. The four measures of effectiveness (MOEs) chosen to evaluate TPSIM© were throughput, average queuing delay, maximum queuing delay, and total queuing delay. These measurements represent the important traffic operational conditions at the toll plaza for the engineer, planner and toll road user. The simulation results are from an average of ten individual runs for each of the three days. This was done to account for the variation in output for a single simulation run. A Chi-Square Statistical Test was used to compare the field and simulated throughput for all three days because the throughput is counted from field observations. At the 95% confidence level, there was no significant difference between the field and simulation throughput. For the queuing delay, a Wilcoxon Signed Rank Statistical Test was applied because these values are not counted directly from the field. At the 95% confidence level, there was no significant difference between the field and simulation values for average, maximum and total queuing delay for each lane type of all three days. Comparison of the Holland East and Dean Plaza results indicates that the TPSIM© simulation model is transferable to another toll plaza with different configurations than the Holland East Plaza.

The ability of TPSIM© to display accurate animation for the toll plaza being simulated has been accomplished. Execution of the animation allows the user to simulate the operational conditions at the toll plaza under analysis. This provides the analyst with a visual description of the operations including vehicle type (by payment option and classification), approach volumes, queues and time of occurrence.

The accuracy in which TPSIM simulates a selected plaza depends on the amount of available field data. The minimum suggested input values are the plaza geometric values, traffic volume, traffic conditions and the lane service times. The smaller the traffic volume intervals, the more detailed the analysis could be conducted. In order to conduct calibration, throughput should at least be collected for a MOE evaluation variable. Again, the more intervals collected and the shorter the intervals, the more data points available for the statistical analysis. Then, depending upon the desired significance level input parameter adjustments might be required. It is suggested to follow the same adjustment sequence as described in Section 1.5.1. It may not be necessary to measure the global parameters in the field. The default values may be used and adjusted during the calibration process for the desired precision in the simulation. For further calibration, collection of delay measurements is suggested. This will depend upon the desired accuracy. TPSIM© has the ability to produce graphical representations of the output variables that could also be used as a visual comparison to field data to determine if a simulation run is acceptable to the user. These graphical figures include histograms of throughput and delay.

The TPSIM© microscopic toll plaza simulation model accurately produces results comparable to field values. TPSIM© can be utilized to simulate conditions at any toll plaza for the present or for forecasted growth. It can also be used to show impacts to changes in the geometric or lane configurations of a toll plaza. Determining when a new dedicated ETC lane should be opened or a change in an existing lane be done is also easy to do with this model. It is a useful tool for engineers and planners to determine possible need for improvements to a toll facility.

## REFERENCES

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Moore, D. S. The Basic Practice of Statistics, 4th Printing. W.H. Freeman and Company, New York, 1996.

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# APPENDIX

# TPSIM© Input Data

| | | | | | | | Approach Speed | | | Deceleration Rate | | | Acceleration Rate | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Run #** | **Data Set** | **RON** | **Approach Lane Length** | **Toll Lane Length** | **Transition Zone Length** | **ETC Speed** | **distribution** | **Average** | **Std Dev** | **distribution** | **Average** | **Std Dev** | **distribution** | **Average** | **Std Dev** |
| **August 17, 1994** | | | | | | | | | | | | | | | |
| 417 | 2g | 14 | 2500 | 600 | 200 | N/A | normal | 60 mph | 8 | normal | 3.5 ft/s/s | 0.5 | normal | 3.5 ft/s/s | 0.4 |
| 418 | 2g | 2 | 2500 | 600 | 200 | N/A | normal | 60 mph | 8 | normal | 3.5 ft/s/s | 0.5 | normal | 3.5 ft/s/s | 0.4 |
| 419 | 2g | 13 | 2500 | 600 | 200 | N/A | normal | 60 mph | 8 | normal | 3.5 ft/s/s | 0.5 | normal | 3.5 ft/s/s | 0.4 |
| 420 | 2g | 4 | 2500 | 600 | 200 | N/A | normal | 60 mph | 8 | normal | 3.5 ft/s/s | 0.5 | normal | 3.5 ft/s/s | 0.4 |
| 421 | 2g | 18 | 2500 | 600 | 200 | N/A | normal | 60 mph | 8 | normal | 3.5 ft/s/s | 0.5 | normal | 3.5 ft/s/s | 0.4 |
| 422 | 2g | 5 | 2500 | 600 | 200 | N/A | normal | 60 mph | 8 | normal | 3.5 ft/s/s | 0.5 | normal | 3.5 ft/s/s | 0.4 |
| 423 | 2g | 3 | 2500 | 600 | 200 | N/A | normal | 60 mph | 8 | normal | 3.5 ft/s/s | 0.5 | normal | 3.5 ft/s/s | 0.4 |
| 424 | 2g | 6 | 2500 | 600 | 200 | N/A | normal | 60 mph | 8 | normal | 3.5 ft/s/s | 0.5 | normal | 3.5 ft/s/s | 0.4 |
| 425 | 2g | 1 | 2500 | 600 | 200 | N/A | normal | 60 mph | 8 | normal | 3.5 ft/s/s | 0.5 | normal | 3.5 ft/s/s | 0.4 |
| 426 | 2g | 7 | 2500 | 600 | 200 | N/A | normal | 60 mph | 8 | normal | 3.5 ft/s/s | 0.5 | normal | 3.5 ft/s/s | 0.4 |
| **September 14, 1994** | | | | | | | | | | | | | | | |
| 401 | 3c | 14 | 2500 | 600 | 200 | N/A | normal | 60 mph | 8 | normal | 3.5 ft/s/s | 0.5 | normal | 3.5 ft/s/s | 0.4 |
| 402 | 3c | 13 | 2500 | 600 | 200 | N/A | normal | 60 mph | 8 | normal | 3.5 ft/s/s | 0.5 | normal | 3.5 ft/s/s | 0.4 |
| 403 | 3c | 2 | 2500 | 600 | 200 | N/A | normal | 60 mph | 8 | normal | 3.5 ft/s/s | 0.5 | normal | 3.5 ft/s/s | 0.4 |
| 404 | 3c | 4 | 2500 | 600 | 200 | N/A | normal | 60 mph | 8 | normal | 3.5 ft/s/s | 0.5 | normal | 3.5 ft/s/s | 0.4 |
| 405 | 3c | 18 | 2500 | 600 | 200 | N/A | normal | 60 mph | 8 | normal | 3.5 ft/s/s | 0.5 | normal | 3.5 ft/s/s | 0.4 |
| 406 | 3c | 5 | 2500 | 600 | 200 | N/A | normal | 60 mph | 8 | normal | 3.5 ft/s/s | 0.5 | normal | 3.5 ft/s/s | 0.4 |
| 407 | 3c | 3 | 2500 | 600 | 200 | N/A | normal | 60 mph | 8 | normal | 3.5 ft/s/s | 0.5 | normal | 3.5 ft/s/s | 0.4 |
| 408 | 3c | 6 | 2500 | 600 | 200 | N/A | normal | 60 mph | 8 | normal | 3.5 ft/s/s | 0.5 | normal | 3.5 ft/s/s | 0.4 |
| 409 | 3c | 1 | 2500 | 600 | 200 | N/A | normal | 60 mph | 8 | normal | 3.5 ft/s/s | 0.5 | normal | 3.5 ft/s/s | 0.4 |
| 410 | 3c | 7 | 2500 | 600 | 200 | N/A | normal | 60 mph | 8 | normal | 3.5 ft/s/s | 0.5 | normal | 3.5 ft/s/s | 0.4 |
| **June 6, 2000** | | | | | | | | | | | | | | | |
| 316 | 4d | 5 | 2500 | 600 | 200 | 40 | normal | 60 mph | 8 | normal | 3.5 ft/s/s | 0.5 | normal | 3.5 ft/s/s | 0.4 |
| 317 | 4d | 9 | 2500 | 600 | 200 | 40 | normal | 60 mph | 8 | normal | 3.5 ft/s/s | 0.5 | normal | 3.5 ft/s/s | 0.4 |
| 318 | 4d | 2 | 2500 | 600 | 200 | 40 | normal | 60 mph | 8 | normal | 3.5 ft/s/s | 0.5 | normal | 3.5 ft/s/s | 0.4 |
| 319 | 4d | 6 | 2500 | 600 | 200 | 40 | normal | 60 mph | 8 | normal | 3.5 ft/s/s | 0.5 | normal | 3.5 ft/s/s | 0.4 |
| 328 | 4d | 1 | 2500 | 600 | 200 | 40 | normal | 60 mph | 8 | normal | 3.5 ft/s/s | 0.5 | normal | 3.5 ft/s/s | 0.4 |
| 329 | 4d | 7 | 2500 | 600 | 200 | 40 | normal | 60 mph | 8 | normal | 3.5 ft/s/s | 0.5 | normal | 3.5 ft/s/s | 0.4 |
| 330 | 4d | 13 | 2500 | 600 | 200 | 40 | normal | 60 mph | 8 | normal | 3.5 ft/s/s | 0.5 | normal | 3.5 ft/s/s | 0.4 |
| 331 | 4d | 4 | 2500 | 600 | 200 | 40 | normal | 60 mph | 8 | normal | 3.5 ft/s/s | 0.5 | normal | 3.5 ft/s/s | 0.4 |
| 332 | 4d | 12 | 2500 | 600 | 200 | 40 | normal | 60 mph | 8 | normal | 3.5 ft/s/s | 0.5 | normal | 3.5 ft/s/s | 0.4 |
| 333 | 4d | 11 | 2500 | 600 | 200 | 40 | normal | 60 mph | 8 | normal | 3.5 ft/s/s | 0.5 | normal | 3.5 ft/s/s | 0.4 |

**Table A1: TPSIM© Input Parameters (Final Runs)**

| Traffic Volumes | | | |
|---|---|---|---|
| **Time Interval** | **Aug. 17, 1994** | **Sept. 14, 1994** | **June 6, 2000** |
| **7:00 - 7:05** | 77 | 68 | 230 |
| **7:05 – 7:10** | 76 | 90 | 222 |
| **7:10 - 7:15** | 91 | 102 | 247 |
| **7:15 – 7:20** | 96 | 83 | 233 |
| **7:20 – 7:25** | 91 | 95 | 256 |
| **7:25 – 7:30** | 117 | 114 | 248 |
| **7:30 – 7:35** | 90 | 111 | 280 |
| **7:35 – 7:40** | 104 | 85 | 252 |
| **7:40 – 7:45** | 86 | 74 | 229 |
| **7:45 – 7:50** | 77 | 60 | 203 |
| **7:50 – 7:55** | 77 | 83 | 211 |
| **7:55 – 8:00** | 79 | 79 | 196 |

**Table A2: TPSIM© Input (Volumes)**

| Percentage of Transaction Type Usage | | | |
|---|---|---|---|
| **Transaction Type** | **Aug. 17, 1994** | **Sept. 14, 1994** | **June 6, 2000** |
| **Manual** | 64% | 62% | 25% |
| **Automatic** | 36% | 38% | 17% |
| **ETC** | 0% | 0% | 58% |

**Table A3: TPSIM© Input (Transaction Type Percentages)**

| Percentage of Vehicle Type | | | |
|---|---|---|---|
| **Vehicle Type** | **Aug. 17, 1994** | **Sept. 14, 1994** | **June 6, 2000** |
| **Passenger Car** | 99% | 99% | 98% |
| **Heavy Truck** | 1% | 1% | 2% |

**Table A4: TPSIM© Input (Vehicle Type Percentages)**

**August 17, 1994 Service Time (Data Set 2g)**

| Seconds | Lane 1 Percent | Lane 2 Percent | Lane 3 Percent |
|---|---|---|---|
| 1 | 1% | 1% | 6% |
| 2 | 4% | 7% | 24% |
| 3 | 13% | 30% | 20% |
| 4 | 13% | 27% | 12% |
| 5 | 12% | 17% | 8% |
| 6 | 7% | 8% | 3% |
| 7 | 6% | 4% | 4% |
| 8 | 8% | 2% | 3% |
| 9 | 4% | 2% | 3% |
| 10 | 4% | | 2% |
| 11 | 4% | 2% | 3% |
| 12 | 4% | | 3% |
| 13 | 2% | | 2% |
| 14 | 3% | | 1% |
| 15 | 3% | | 2% |
| 16 | 3% | | 1% |
| 17 | 1% | | 1% |
| 18 | 1% | | |
| 19 | 1% | | |
| 20 | 1% | | 1% |
| 21 | 1% | | 1% |
| 22 | | | |
| 23 | 1% | | |
| 24 | 1% | | |
| 25 | 1% | | |
| 32 | 1% | | |

**Table A5: TPSIM© Input (Aug. 17, 1994 Service Time Distribution)**

**September 14, 1994 Service Time (Data Set 3c)**

| Seconds | Lane 1 Percent | Lane 2 Percent | Lane 3 Percent |
|---|---|---|---|
| 1 | 0% | 9% | 0% |
| 2 | 0% | 21% | 11% |
| 3 | 4% | 32% | 15% |
| 4 | 10% | 21% | 17% |
| 5 | 18% | 11% | 8% |
| 6 | 9% | 3% | 6% |
| 7 | 7% | 1% | 4% |
| 8 | 4% | 2% | 6% |
| 9 | 6% | 0% | 7% |
| 10 | 5% | 0% | 5% |
| 11 | 4% | | 4% |
| 12 | 5% | | 5% |
| 13 | 3% | | 3% |
| 14 | 3% | | 2% |
| 15 | 4% | | 1% |
| 16 | 3% | | 2% |
| 17 | 2% | | 1% |
| 18 | 3% | | |
| 19 | 2% | | 1% |
| 20 | 2% | | |
| 21 | 2% | | |
| 22 | 1% | | |
| 23 | | | 1% |
| 24 | 2% | | |
| 25 | 1% | | |
| 26 | | | |
| 27 | | | 1% |

**Table A6: TPSIM© Input (Sept. 14, 1994 Service Time Distribution)**

**June 6, 2000 Service Time (Data Set 4d)**

| Seconds | Lane 1 Percent | Lane 2 Percent | Lane 3 Percent |
|---|---|---|---|
| 0 | 4% | 6% | 1% |
| 1 | 0% | 3% | 2% |
| 2 | 0% | 24% | 9% |
| 3 | 4% | 32% | 13% |
| 4 | 12% | 21% | 24% |
| 5 | 21% | 8% | 18% |
| 6 | 19% | 2% | 12% |
| 7 | 12% | 1% | 5% |
| 8 | 6% | 1% | 2% |
| 9 | 5% | | 3% |
| 10 | 3% | | 2% |
| 11 | 3% | | 1% |
| 12 | 1% | | 1% |
| 13 | 1% | 1% | 1% |
| 14 | 1% | | 1% |
| 15 | 1% | | 1% |
| 16 | 1% | | 1% |
| 17 | 1% | | 1% |
| 18 | 1% | | 1% |
| 19 | 1% | | 1% |
| 20 | | | |
| 21 | | | |
| 22 | | | |
| 23 | 1% | 1% | |
| 24 | | | |
| 25 | | | |
| 26 | 1% | | |
| 27 | 1% | | |

**Table A7: TPSIM© Input (June 6, 2000 Service Time Distribution)**