INTEGRATION OF TOLL PLAZA MODELING INTO CORSIM

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To my family and friends who gave the support needed for me to finish

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LIST OF ABBREVIATIONS

ACM	Automatic Coin Machine
API	Application Programming Interface
AVI	Automatic Vehicle Identification
DVU	Driver Vehicle Units
ETC	Electronic Toll Collection
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
HCM	Highway Capacity Manual
ITS	Intelligent Transportation Systems
LOS	Level of Service
MOE	Measures of Effectiveness
NCHRP	National Cooperative Highway Research Program
OOCEA	Orlando-Orange County Expressway Authority
ORT	Open Road Tolling
P3	Public-Private Partnership
TPSIM	Toll Plaza Simulation Model
v/c	Volume to Capacity Ratio

Abstract of Thesis Presented to the Graduate School
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In the U.S. there currently exists a financial crisis for the funding of necessary roadway maintenance and expansion. It has thus become necessary to find other means to fund transportation based projects. One such solution is public-private partnerships (P3s) in which a private investor funds a public transportation project and in turn the government entity allows the private investor to collect tolls to recoup their investment. As this type of partnership becomes a more popular option it will become necessary to develop tools necessary to assist engineers in the planning and design of the toll plazas placed along these new roadways. Simulation software is one of these tools.

Simulation software such as CORSIM, Aimsun, and VISSIM, to name a few, are vital tools to the planning process of roadways as these programs allow engineers a means to analyze and visualize their proposed roadway designs under expected traffic conditions. This allows engineers an opportunity to develop the appropriate toll network design before construction even begins. This can greatly save federal, state, and local entities millions of dollars in expenses to correct or alter already started/completed

projects. Unfortunately, few of these simulation programs are capable of properly simulating traditional toll plazas.

CORSIM, one of the most widely utilized simulation programs in the U.S., does not currently allow for direct simulation of toll plaza facilities. This project resulted in the implementation of direct toll plaza modeling into CORSIM. This was accomplished through the development of new algorithms and modeling features. This document discusses the development, verification, and validation of the new toll plaza features implemented in CORSIM.

CHAPTER 1
INTRODUCTION

Background

Given the transportation financing challenges faced by government agencies in the U.S., toll roads are becoming a more common feature along freeway facilities. In Florida, there are over 700 miles of toll roads with more under construction and in the planning process. These toll roads provide a vital service by connecting portions of the state that may not have been connected by the Interstate Highway System or the Florida Strategic Intermodal System. Examples include connecting Naples to Miami via the Alligator Alley Expressway and Orlando to South Florida via the Florida Turnpike.

As the usage of toll roads in America continues to increase, there is a need to better understand the traffic operational characteristics of toll roads as well as how these operations impact the overall operations of the surrounding freeway corridor. The toll plaza segment has the greatest effect on freeway capacity compared to other segment types. This is because if the capacity of the toll plaza is below the capacity of the upstream segment, bottlenecking can occur, which in turn decreases the overall roadway's capacity (1). Given this issue, it is important to identify bottlenecks as soon as possible, preferably during the design process of the toll road. Because of this, it is vital for engineers to be able to analyze toll plazas during the planning process with minimal expenditures.

One way to analyze freeways at a low cost is to develop a simulation of the freeway using a traffic simulation program. By utilizing this software, engineers are capable of visually observing the network to determine problem areas. In addition to being able to visualize the freeway segments, simulation programs are also capable of providing large amounts of data useful for analysis. These data can include travel times, speeds, and delay.

Problem Statement

CORSIM is a well-established simulation program in the U.S., is the most commonly used microsimulation program in the U.S., and generally has a good reputation with respect to its underlying models and algorithms given its long history of development and testing. However, CORSIM currently does not directly accommodate toll plaza modeling. This has been a very common request of CORSIM users over the past few years. While it is possible to develop a basic toll plaza by utilizing stop control, these simulations do not take into account the variability of driver behavior, toll plaza transactions, etc. The creation of accurate simulation tools, such as CORSIM, for toll plazas will allow for more in-depth study on the subject. One area of study that the improved CORSIM program would be able to assist in is the development of an analytical method to analyze toll plazas. While methodologies exist to analyze toll plazas in isolation, all but one these methodologies base toll plaza performance on delay. One methodology estimates density for toll plazas, but this methodology was developed prior to the implementation of electronic toll collection lanes. All of the HCM freeway segment analysis methodologies, as well as the overall facility, base level of service on delay. Thus, existing methodologies for freeway facility analysis and toll plaza analysis use disparate performance measures. Consequently, a methodology does not exist by which the effect of toll plaza operations on extended lengths of freeway can be considered.

Research Objectives

The objectives of this research are to 1) integrate explicit toll plaza modeling into the CORSIM microscopic simulation program and 2) compare CORSIM's toll plaza simulation capabilities and results with field data. This will provide a valuable tool for engineers who need to evaluate the operations of existing toll plaza corridors and plan future toll plazas along freeway corridors.

The tasks that were conducted to achieve these objectives are as follows:

- Conducted a literature review on toll plaza design, and analytical and simulation-based methodologies developed for toll plazas.
- Evaluated existing toll plaza analysis methodologies to determine usability of methodologies for current research.
- Identified and recommended necessary revisions for CORSIM to allow for explicit toll plaza simulation.
- Implemented toll plaza simulation into CORSIM.
- Performed testing of CORSIM toll plaza modeling and compared to available field data.
- Developed toll plaza simulations to be utilized as examples for future CORSIM versions.
- Develop user guidelines for utilizing CORSIM to simulate toll plazas.

Document Organization

Chapter 2 presents the results of a literature review on the topics of toll plaza analysis, simulation, and design. Chapter 3 describes the implementation of direct toll plaza modeling into CORSIM. This includes discussion on newly developed inputs, added models/algorithms and revised models/algorithms needed to implement toll plaza modeling. Chapter 4 discusses the testing conducted to determine the validity of the CORSIM toll plaza modeling capabilities. Chapter 5 discusses the conclusions and recommendations developed from this research. This includes a discussion on limitations as well as recommendations for future improvements. Appendix A compiles all necessary information to properly simulate a toll plaza in CORSIM into a user guide. Appendix B provides the .trf files for three example problems

CHAPTER 2
LITERATURE REVIEW

Overview

This chapter summarizes the previous research conducted on toll plazas. This includes research conducted on the analysis of toll plazas, simulation of toll plazas, and the effect that ETC lanes have on toll plaza operations.

Analytical Approach

The analysis of toll plazas originates with the research conducted by Woo and Hoel (2). Their study resulted in the development of a methodology for analyzing toll plaza capacity and provided a LOS for toll plazas. Equations were developed by Woo and Hoel to calculate capacity and density; Equations 2-1 and 2-2 respectively.

Equation 2-1 for capacity of entire toll plaza:

$$C = \sum_{j=1}^{j} n_j c_j = n_1 \frac{3600}{t_{i1}} + n_2 \frac{3600}{t_{i2}} + \ldots + n_j \frac{3600}{t_{ij}} = \sum_{j=1}^{j} n_j \frac{3600}{t_{1j}} \qquad (2\text{-}1)$$

where,

C = capacity of toll plaza (veh/h)

n_j = toll booth with collection type j

c_j = capacity of toll booth with collection type j (veh/h)

t_{1j} = service time for vehicle type i and toll collection type j (s)

Equation 2-2 for the density of a toll plaza:

$$K = \frac{\sum Q_i T_i}{A} = \frac{2(Q_a T_a + Q_t T_t)}{(n_1 + n_2)L_1 + (n_2 + n_3)L_2} \qquad (2\text{-}2)$$

where,

K = density of toll plaza (veh/mi/ln)

Q = flow rate (*a* for automobiles, *t* for trucks)

T = average total time to travel through the toll plaza area (a for automobiles t for trucks)

A = Area of toll plaza segment

n_1 = number of arrival lanes

n_2 = number of toll booths

n_3 = number of departure lanes

L_1 = length of convergence section (ft)

L_2 = length of re-convergence section (ft)

In addition to the developed equations, field data (primarily traffic counts, including vehicle type, and vehicle time spent in the toll plaza) were then collected at eight toll plazas to test the validity of these equations. These data, along with regression analysis, were utilized to develop a relationship between the volume-to-capacity ratio (v/c) and density. This analysis provided evidence of a distinct relationship between density and v/c.

From the regression models and the collected data, LOS thresholds for toll plazas were created based on both density and v/c. In addition to establishing LOS thresholds for toll plazas Woo and Hoel also established average service times for cars and trucks; 5.11 sec to 5.47 sec and 12.87 sec to 14.88 sec. Capacity values were also determined by toll booth type, 600 veh/h for Automatic Coin Machine (ACM) booths with a gate, 665 to 745 veh/h ACM booths without a gate, and 650 to 705 veh/h for general cash booths. Table 2-1 presents the LOS findings from the work of Woo and Hoel. NCHRP Synthesis 240 (3) contains average toll lane capacities for a variety of payment methods. These values were obtained from a questionnaire sent out to toll plaza operators and represent operational capacity values. The results from this questionnaire are found in Table 2-2.

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Toll plaza capacity is an important determinant in the toll plaza operations. Capacity is a difficult value to obtain because a varying ETC penetration can significantly affect the plaza's capacity (4). In addition, the posted speed limit through the ETC-only lanes also can affect a toll plaza's capacity. In the case of Holland East Plaza in Orlando, Florida, it was observed that by decreasing the posted speed limit of the ETC lane from 55 mi/h to 35 mi/h, the processing rate of ETC vehicles decreased from 32 veh/min to 23 veh/min (5). This equates to a decrease in capacity of 540 veh/h per ETC lane. In order to determine the capacity of a toll plaza, Zarrillo proposed Equations 2-3 and 2-4.

$$C = J + K \tag{2-3}$$

where,

C = toll plaza capacity (veh/h)

J = capacity of single service lanes (veh/h)

K = capacity of mixed use lanes (veh/h)

$$K_{MTE} = N_{MTE} S_{MTE} = N_{MTE} \frac{100\%}{\frac{P_M}{S_M} + \frac{P_T}{S_T} + \frac{P_E}{S_E}} \tag{2-4}$$

where,

K = capacity of mixed use lanes (veh/h)

N = number of lanes of mixed use

S_i = vehicle processing rate for payment type *i* (veh/h)

P_i = percentage of vehicles utilizing payment method *i*

The vehicle processing rate *S* can be found Table 2-3.

Utilizing these equations and plaza traffic data from the Holland East Plaza in Orlando, Florida and Interchange 11A in Westborough, Massachusetts, Zarrillo evaluated the capacities of these toll roads. From this research, Zarrillo was able to conclude the following:

- The capacity of a toll plaza is dependent on the processing time and lane types of the toll plaza.
- The available capacity of a toll plaza increases as ETC lanes replace cash lanes, as long as appropriate levels of ETC usage are observed.
- Non-ETC semi-trucks are a major contributor to a facility’s delay and congestion.

A drawback of using simulation models is that there is a lack of data to compare the simulation outputs to the facility. The solution to this was to develop a methodology that could be used manually to calculate capacity, queuing patterns, and delay (6). The primary concern of these calculations was determining if the upstream segment capacity was more than the toll plaza capacity. If this was the case, a bottleneck will occur during an interval of high demand which would cause an overall decrease in the toll road’s capacity if a queue were to form at the toll plaza. In order to manually calculate toll plaza operations Aycin (6) proposed Equations 2-5, 2-6, 2-7, 2-9, and 2-10 for capacity, plaza queue, and delay for different toll booth payment options:

For capacity:

$$C_{ETC} = 3600\frac{V_{ETC}}{S} \tag{2-5}$$

$$C_{cash} = \frac{3600}{t_{service} + t_{moveup}} \tag{2-6}$$

$$C_{cash-ETC} = \frac{3600}{\sum_{j} \Delta t_j P_j} \tag{2-7}$$

$$C_{plaza} = N_{cash} \times C_{cash} + N_{ETC} \times C_{ETC} + N_{cash-ETC} \times N_{cash-ETC} \tag{2-8}$$

where,

C_i = capacity of toll booth for payment *i* (veh/h)

V_{ETC} = average ETC vehicle speed (ft/s)

S = average distance headway (ft)

$t_{service}$ = vehicle service time

t_{moveup} = time for next vehicle in queue to move to booth

Δt_j = transaction time of pair *j*

P_j = probabilities of possible leader-follower pairs given %ETC using mixed lane

To find the upstream roadway capacity, Acyin uses the established equation for a basic freeway segment from the 2000 Highway Capacity Manual (1):

$$C_{road} = v_p \times N \times f_{HV} \times f_p \tag{2-9}$$

where,

C_{road} = Capacity of upstream segment (veh/h)

v_p = 15-min peak passenger car equivalent flow rate (pc/h/ln)

N = number of lanes

f_{HV} = heavy vehicle factor

f_p = driver population factor

For queue:

$$Q_i = \Delta M_i - \frac{F_i}{V_{section}} \times X \quad (2\text{-}10)$$

where,

Q_i = number vehicles in plaza queue at time i

ΔM_i = cumulative vehicle demand (C_{plaza} – C) at time i (veh)

F_i = flow rate (veh/h)

$V_{section}$ = average section speed (mi/h)

X = distance between end of queue and automatic traffic recorder (mi)

For delay:

$$D = \frac{X_j}{S} \times \Delta t_j + \frac{(X_k)_{joined} \times n}{S} \times \frac{\Delta t_j}{B} \quad (2\text{-}11)$$

where,

D = queue delay (sec)

X_j = length of individual queue section for booth j (ft)

Δt = average headway time between completing transactions of successive cars (sec)

$(X_k)_{joined}$ = length of joined queue section for vehicle k in queue (ft)

S = average distance headway (ft)

n = number of queues in the joined area

B = number of available booths

Certain factors that can affect capacity were assumed. Some assumptions, including queues of different payment types, did not affect the arrival time of other vehicles. Perception-reaction lost time is accounted for by the separation distance and acceleration rates. With these mentioned assumptions, when compared to a simulation model, capacity, queuing, and delay were accurately calculated.

Simulation Approach

For toll roads in Florida, two computer simulation programs have been utilized for research, TPSIM and PARAMICS. The research efforts using these programs are described in the following sections.

TPSIM

TPSIM is a stochastic, discrete-event microscopic simulation program, written in Visual Basic 6 (8). TPSIM has been used extensively for research conducted on toll plaza operations in the Orlando, Florida area. Klodzinski and Al-Deek (9) investigated the various methodologies available for analyzing toll plazas using TPSIM. The methodologies investigated were based on traffic density, *v*/*c*, and vehicle delay. By doing this, the authors hoped to not only establish the best measure of effectiveness (MOE) to analyze toll plazas, but to also establish proper LOS criteria for the selected methodology.

Using traffic data obtained from field collection and TPSIM simulations, the three methodologies mentioned were evaluated. When evaluating the vehicle density methodology, it was determined that LOS based on vehicle density was not appropriate for toll plazas. This was because different lane transaction types produced varying vehicle densities. In addition, it was noted that ETC lanes can accommodate higher vehicle densities without an increase in plaza delay. The authors assert that this situation makes using vehicle density to determine LOS not viable because higher densities may not be an indicator of lower LOS.

The evaluation of *v*/*c* also proved to be an inaccurate indicator of LOS. A LOS based on *v*/*c* makes the assumption that the operating conditions of a roadway decreases as the roadway volume approaches the roadway's capacity. In the case of toll plazas, this may not always be the case. Toll plazas may run close to capacity but operating conditions may be acceptable. This is due to the effect of ETC penetration, which will be discussed later on.

Delay proved to accurately represent toll plaza LOS. According to the authors, “delay truly represents a driver’s level of inconvenience.” (8) Traffic delay at the plaza takes into account ETC lanes, geometry of the plaza, and upstream and downstream conditions. Using the traffic and simulation data collected, Klodzinski and Al-Deek [2002] further determined that cumulative delay better represented the data then average delay. This is because of the variation of delay distribution due to the peak hour.

With cumulative delay selected by Klodzinski and Al-Deek (8), the next step was to establish the LOS ranges for each LOS, starting with LOS A. Once the maximum allowed vehicle delay for LOS A was determined, the rest of the LOS levels were determined by a percent increase method that is provided in the HCM 2000 for signalized intersection delay. Table 2-4. contains the LOS values.

PARAMICS

Quadstone Paramics is a comprehensive microsimulation program (10). Paramics contains an application programming interface (API) that allows users to modify the behavior of the simulation. This allows users to expand the simulation capability of Paramics by creating new algorithms as needed. Nezamuddin and Al-Deek (11) wrote a component to simulate toll plazas that they integrated with Paramics through the API.

PARAMICS was used to simulate operations for individual toll plazas and for entire networks that included multiple toll plazas in Florida. PARAMICS utilizes what is referred to as driver vehicle units (DVU), which imitate individual driver characteristics based on input parameters. The PARAMICS toll plaza and toll road corridor model was developed by Nezamuddin and Al-Deek (11). Traffic data from the Orlando-Orange County Expressway Authority (OOCEA) toll road corridor and GEH statistic, a statistical value similar to the chi-squared test that compares hourly traffic values of a model to the hourly traffic values of field data, were utilized in the calibration of the model. To test the validity of the model, eight hypothetical scenarios were run using the model. During each scenario, the model acted within expectations. From this work, a successful simulation model was created that can properly analyze toll road corridors.

Effect of ETC Lanes

Dedicated ETC lanes are toll lanes where the vehicle typically does not stop to pay its toll, but rather continues through the toll plaza at regular or a reduced speed, with the toll transaction being done electronically. Sometimes electronic toll collection is allowed at the cash lanes as well, but in this case the vehicle must stop and wait for a gate to rise up. It is due to the characteristics of ETC-only lanes that make determining LOS for a toll plaza difficult, as these lane types create situations where density and *v/c* may not be clear indicators of poor operational conditions. (14) Shown in Table 2-5. for similar levels of *v/c,* but considerably different level of ETC-vehicle percentages, the level of delay can be considerably different. Additional work was conducted by Zarrillo (5) to investigate the affect ETC lanes have on capacity of a toll plaza. From the study it was determined that ETC-only lanes can greatly increase a plaza’s capacity. The results of the study are shown in Table 2-4. Table 2-5 and Table 2-6 illustrate that ETC vehicle penetration and ETC-only lanes can drastically change a toll plaza’s capacity and efficiency. Thus, understanding how ETC lanes effect a toll plaza’s capacity is vital to developing a valid methodology to analyze toll plazas.

While converting manual-payment toll booths to ETC-only lanes appears to be an obvious solution to increasing toll plaza capacity, it must be remembered that the number of ETC-only lanes must be balanced with the percentage of vehicles in the traffic stream that are equipped with electronic toll collection transponders. Switching manual-payment toll booths to ETC-only toll booths without adequate ETC penetration will cause a decrease in a plaza's overall performance (12). In addition, a 10% user shift from manual payment to ETC payment, when the manual lanes of the plaza are operating over capacity can decrease the total plaza queuing delay by 50%, reduce delay per vehicle by more than 90 seconds, and increases plaza flow by 20%. The increase of ETC users also causes a decrease in the simulated peak-hour delay (12).

Summary

Considerable research has been conducted on toll plaza operations. From the research discussed in this chapter, analytical methodologies have been developed that are capable of evaluating capacity, queuing, and delay by payment type. An LOS criterion has been developed based on vehicle delay at the toll plaza. Simulation programs, such as TPSIM and PARAMICS, have also provided a vital look into how ETC lanes affect the overall function of a toll plaza. Despite this research, however, there are still limitations—specifically with regards to integrating toll plaza analysis into freeway facility analysis. The main limitation is that a relationship between vehicle delay and traffic density for toll plazas with ETC-only lanes has not been created. Furthermore, the one existing methodology for estimating density at toll plazas (without ETC-only lanes) is approximately 20 years old, during which time toll plaza and traffic characteristics have possibly changed enough such that this methodology is less accurate than it once was. This has prevented toll plaza methodologies from being incorporated into the HCM freeway facilities analysis methodology.

Table 2-1. LOS thresholds for toll plazas

LOS	Density	v/c
A	< 12	0.24
B	< 20	0.4
C	< 30	0.57
D	< 42	0.74
E	< 67	1
F	> 67	---

Table 2-2. Typical toll lane capacities by method of collection and vehicle use

Types of Toll Payment/Lanes	Number of Responses	Actual Data Range (veh/h/ln)	Average Value (veh/h/ln)
Manual (Attended)			
Passenger vehicles only	22	240 - 500	416
Mixed use	24	180 - 550	360
ACM (Single Coin)			
Mixed use	2	550	550
ACM (multiple Coins)			
Mixed use	2	550	550
Ticket Entry			
Mixed use	4	425 - 600	506
Ticket Exit Payment			
Mixed use	2	275 - 465	370
ETC Express/Lanes	2	1200 - 1800	1500

Table 2-3. Processing rate at toll facilities by customer group

Customer-Group	Processing Rates (veh/h/ln)
Manual	498 ± 48
ACM	618 ±30
Trucks	138 ± 78
ETC 15 mi/h	900 ± 120
ETC 35 mi/h	1380 ± 120
ETC 55 mi/h	1920 ± 120

Table 2-4. LOS table based on delay

Level of Service	85th-percentile delay (s/veh)
A	≤ 14
B	> 14 - 28
C	> 28 - 49
D	> 49 - 77
E	> 77 - 112
F	> 112

Table 2-5. Delay and *v/c* ratio scenarios

Volume	% of ETC vehicle	% of ACM vehicle	% of manual vehicle	# of ETC lanes	# of ACM lanes	# of manual lanes	*v/c* ratio	Minimum % vehicles that have no delay
5000	0%	20%	80%	0	2	10	1.0	0%
5000	36%	20%	44%	1	2	6	0.96	36%
5000	72%	10%	18%	2	1	3	0.94	72%
5000	100%	0%	0%	3	0	0	0.93	100%

Table 2-6. Capacity evaluation of interchange 11A in Westborough, Massachusetts

Stage	For entire Plaza (%)			Entry to Turnpike Veh/h				*v/c* ratio	MSF
	P_E	P_T	N_E	*J*	*K*	*C*	*V*		
Before ETC	0	8.6	0	1440	1131	2571	2220	0.864	1900
After S_E = 15 veh/min	5	8	1	1542	492	2034	2200	>1.0	>2200
After S_E = 15 veh/min	25	6	1	2088	502	2590	2200	0.849	1870
After S_E = 23 veh/min	45	4	1	2820	606	3426	2200	0.642	1410

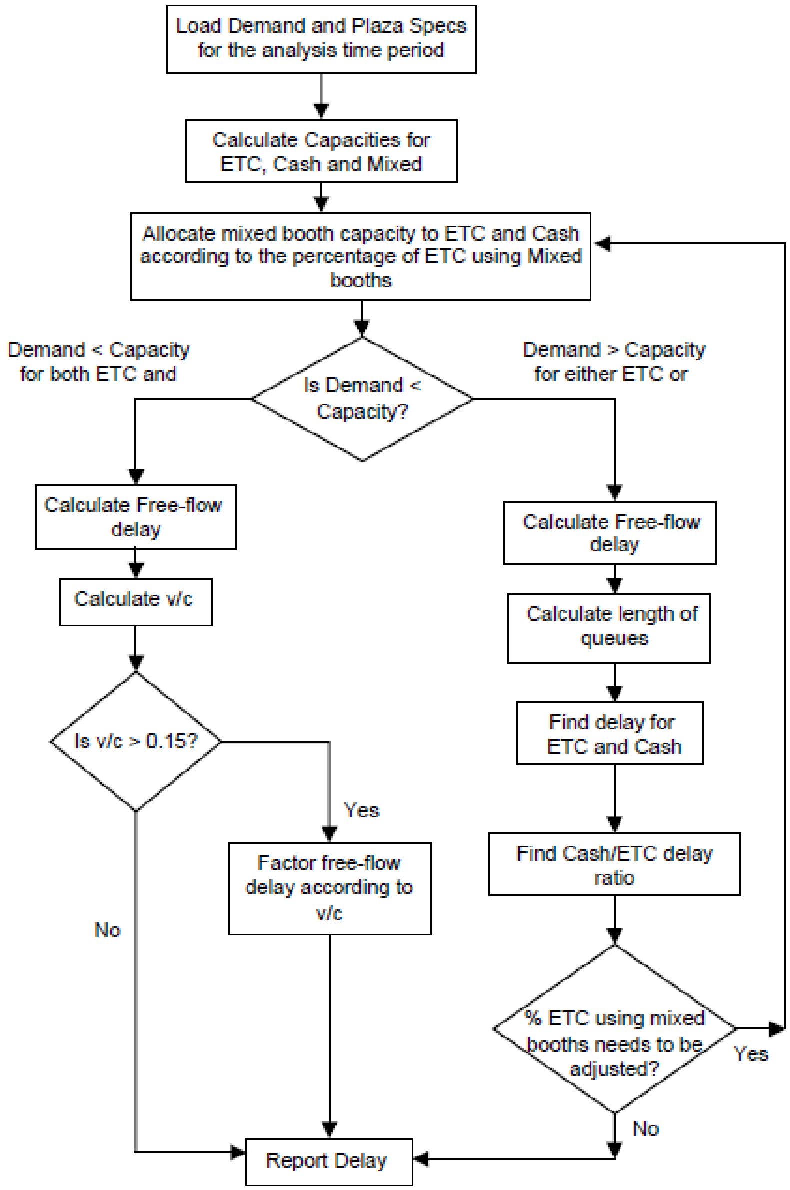


Figure 2-1. Flow chart that demonstrates the process to calculate toll plaza delay using the analytical methodology. [From Aycin et al. 2009. Development of Methodology for Toll Plaza Delay Estimation for Use in Travel Demand Model Postprocessor. In Transportation Research Record. (Page 3, Figure 1)]

CHAPTER 3
IMPLEMENTATION OF TOLL PLAZA MODELING IN CORSIM

Overview

Before implementing direct simulation of toll plazas into CORSIM, it is important to evaluate the current capabilities of CORSIM 6.2. This chapter will describe the current limitations with modeling toll plazas in CORSIM and then describe the revisions and additions made to CORSIM to allow for robust modeling of a variety of toll plaza configurations.

CORSIM Limitations

CORSIM 6.2 does not currently have the ability to directly model toll plazas. However, with the creative use of stop, yield, and/or signal control, it is possible for CORSIM 6.2 to indirectly model toll plazas. One drawback with this approach is that the stochastic nature of vehicle service times at the toll plaza cannot be taken into account, particularly with respect to how they can vary across different toll lanes with different payment methods. Using one of the stop control devices results in a constant service time for all vehicles across all lanes, which is not realistic at toll plazas, even if the same payment method was made in each lane. Typical toll plaza models allow for the input of an average service time along with an upper and lower service time range. This allows for the simulation program to vary the service time for each vehicle by randomly assigning a service time from the input range provided by the user, and according to the specified distribution (usually a normal or exponential distribution).

With the current methods used to model toll plazas in CORSIM, using stop and yield signs as the toll booths, lane selection at the toll booth is done in a more deterministic manner compared to what actually occurs at a toll plaza. In CORSIM, the only lane assignment restriction for a toll plaza is to utilize the toll booth that has the shortest queue. With toll plazas, queue length is probably the most significant factor, but likely not the only determining factor for why a particular toll booth is selected. Additionally, a driver needs to make sure they select a toll booth that is compatible with their desired form of payment (e.g., exact change). Unfortunately, CORSIM 6.2 currently cannot do this and operates as if all toll booths are able to accommodate all payment methods. A specialized lane selection algorithm is a vital part of a toll plaza simulation, as this algorithm allows for the creation of lane restrictions by vehicle payment type. In the case of toll plazas, this algorithm would prevent a cash vehicle from utilizing an ETC lane or an ACM (automatic coin machine, also known as 'exact change') vehicle from utilizing a cash lane. This toll plaza-specific lane-selection algorithm adds an additional layer to the simulation that promotes a more accurate representation of the toll plaza.

Changes to CORSIM

The research team worked with the Mc*Trans* Center to make the necessary improvements to CORSIM to explicitly model toll plaza operations. The main components that were added or revised in CORSIM 6.3 to accomplish the direct toll plaza modeling include:

- Developing a toll plaza control device
- Developing a toll plaza lane selection algorithm
- Adding toll plaza-specific input variables
- Adding performance measure outputs for the toll plaza link

Toll Plaza Control Device

The toll plaza control device was designed to be the heart of the new improvements to accommodate toll plaza simulation. The control device contains all the necessary inputs needed to properly simulate a toll plaza, primarily information concerning the traffic and toll booth characteristics.

Toll plaza characteristics

The toll plaza characteristics include toll booth status, average service time, and pull-up distance. The toll booth status information specifies whether the toll booth is open or closed, the payment types accepted at each toll booth, and the vehicle types allowed to use each toll booth. This is accomplished by using two binary coding strings, which will be discussed in more detail in Appendix A. This method currently allows each toll booth to accept up to four different payment types. Currently these payment types are named ACM, Manual, Ticket, and ETC. Even though each payment type is named after a specific payment, in reality they are interchangeable and can represent any payment type desired.

In addition to specifying how many of the four types of payments are accepted at each toll booth, a mean service time is also required for each payment type. This mean service time is used to place a delay on each vehicle as they stop at the toll booth, simulating the time it takes for a vehicle to pay the toll, or obtain a toll ticket. This delay is determined by utilizing a random number generated from a negative exponential distribution, as specified by the mean service time parameter. This value is also constrained by a minimum service time of one second. Typical values for each payment type, as determined from toll plaza field data obtained from FDOT, can be seen in Table 3-1. It is important to note two things from these values. It should be noted that the typical service time shown for the TICKET payment type is based on average service times for vehicles entering a ticket-based toll network. A significantly higher service time, around 15 to 16 seconds, would need to be utilized for the exit toll plaza for a ticket-based toll road.

Toll plaza’s capacity is affected by the pull up distance between the vehicle at the toll booth and the first vehicle in queue for that booth. This distance is usually established by the toll authority as a safety measure for toll workers and vehicles interacting with the plaza. This distance varies by toll authority; thus, it was included as a user input in CORSIM. A default value of 25 feet is utilized by CORSIM.

Traffic characteristics

To properly simulate a toll plaza, information concerning the traffic characteristics is necessary. There are two traffic characteristics needed to simulate a toll plaza; the percentile distribution of payment types within the traffic flow and the percentage of ETC users that do not utilize ETC-only lanes. It should be noted that traffic volume is not a necessary input, as a toll plaza segment is a closed traffic segment; thus, the traffic volume entering the toll plaza segment will be a function of upstream traffic volume inputs.

To address the payment distribution issue, an input was added such that the user can specify the percentage of vehicles in the traffic stream for each payment type (e.g., ETC, change required). This allows the user to utilize any combination of the four available payment types. Currently these four payment types are labeled ACM, ETC, Manual, and Ticket after the four most commonly accepted toll payment types in Florida.

In addition to the payment distribution information, it is also important to distinguish what percentage of ETC-eligible vehicles will use the dedicated ETC lane (in which vehicles do not have to stop) versus a standard toll booth lane in which ETC and other payment methods might be accepted (in these lanes vehicles will have to stop and wait for a gate to raise) The modeling of dedicated ETC lanes is discussed in more detail in the section “Accommodating Dedicated ETC Lanes”.

It should be noted that, in theory, acceleration and deceleration rates should also be considered as inputs, as it is possible that drivers use different deceleration and acceleration rates in toll plaza areas than along other roadway facilities; however, determining this is outside the scope of this research. Thus, the default acceleration and deceleration values in CORSIM will be utilized.

Toll Lane Selection Algorithm

To determine toll plaza lane selection in CORSIM, previously developed toll lane selection algorithms were considered and evaluated. One option is a heuristic algorithm similar to the method developed by Al-Deek et al. (2) for the TPSIM toll plaza simulator. This methodology is a two-step process. The first step occurs in the approach zone of the toll plaza. As a vehicle enters this zone of the toll plaza, the program scans the toll plaza to identify toll lanes that match the vehicle’s assigned payment type. Based on the identification process, toll plaza lanes are designated open or closed based on the vehicle’s payment type. After identifying the available toll lanes, the program then selects a toll lane with the shortest available queue. This becomes the desired toll lane the driver wants to use. The second step of this process occurs as the vehicle leaves the approach zone and enters the transition zone. The second step rechecks the original lane selection to determine the final lane selection. This allows for a more accurate model that takes into account the varying conditions that occur at a toll plaza as a vehicle approaches the plaza. When looking at this process it would appear that the first step is not necessary. However, it may become impossible for the vehicle to get to the desired toll lane due to other vehicles in the network. It is also possible that conditions at the originally selected toll lane have changed and now make another toll lane more favorable.

Another existing approach to simulating toll plazas was developed for PARAMICS. Developed by Nezamuddin and Al-Deek (11) the PARAMICS approach utilizes the existing driver vehicle units (DVU) and four features already available in PARAMICS to simulate a toll plaza. First, to assist with visual identification, the vehicle type manager was adjusted to suit the needs for toll plaza simulation. The vehicle type manager algorithm implements a color coding for vehicles based on their payment type. The vehicle type manager also adds payment type identifiers to each DVU. This allows for the restriction manager, next-lane allocation, and lane choice rule algorithms to properly interact with each DVU. The next feature used is the restriction manager. In this case the restriction manager dictates which lanes are available for each payment type and prevents vehicles from utilizing the wrong toll lane based on payment type. The next feature adjusted to accommodate toll plaza simulation was the next lane allocation tool. This tool is used to assist with smoother transitions when lanes are added. The tool works by overriding the default lane mapping used in PARAMICS. This prevents the unrealistic tendency of vehicles not utilizing the newly added lanes. The primary tool used to move the vehicles to the correct toll lanes is the lane choice rule. This is done by overriding the default lane use rules. In the case of the toll plaza simulation, the lane choice rule assigns vehicles to toll lanes based first on payment type accepted at the booth and then on queue length.

After researching existing lane selection algorithms, a heuristic algorithm similar to Al-Deek et al. (2) was developed. The modified heuristic algorithm utilizes a two-step process to determine the preferred toll lane based on existing conditions. Refer to Figure 3-1 for the developed algorithm for toll lane selection implemented in CORSIM. To implement this toll lane selection algorithm, a specific point upstream of the plaza serves as the point at which the toll lane selection algorithm is invoked for each vehicle passing this point. This point essentially serves as a driver reaction the reaction point that informs the vehicle that it is approaching a toll plaza. It is also at this point that a payment method is randomly assigned to a vehicle, as a function of the user-specified distribution of payment percentiles. CORSIM uses a default value of 1500 feet, but this value can also be user-specified.

The heart of the toll lane selection algorithm is the following equation for calculating the desirability of a given toll lane. This equation is a function of relative queue length and the number of lane changes required to reach a given toll lane. The equation to determine desirability is as follows:

$$TLD_j = \frac{\Delta Q}{LC^{SF}} \tag{3-1}$$

where,

TLD_j = Toll lane desirability of toll lane *j*

ΔQ = Difference in queue length between vehicle’s current toll lane Q_i and toll lane Q_j

LC = Number of lane changes required for vehicle to reach toll lane *j*

SF = Lane change sensitivity factor

With regard to the lane change sensitivity factor, this value can range from 0 to 3 and provides the user with the ability to adjust the importance of the number of lane changes to a driver's perception of the desirability of a given toll lane. The default value is 0.7, based on trial-and-error experimentation and what seemed reasonable to the research team. See Appendix A for a more in-depth discussion on the toll lane selection equation.

Additional Improvements to CORSIM

In the process of implementing toll plaza simulation into CORSIM, previous limitations were observed and corrected. One such limitation observed deals with the interface node that connects FRESIM links to NETSIM links. Before the recent changes to CORSIM, the interface node was limited to a maximum of five lanes (due to an unintended consequence of the original separate development tracks of FRESIM and NETSIM). The maximum number of lanes for an interface node was changed to nine, now consistent with the maximum number of lanes allowed for NETSIM links.

Accommodating Dedicated ETC Lanes

While developing the toll plaza capabilities for CORSIM it was determined that implementing ETC payment into the traditional toll lanes was easily accommodated. The same cannot be said for dedicated ETC lanes. This is mainly due to the speed differential witnessed between dedicated ETC lanes and the traditional toll lane. CORSIM was unable to accommodate multiple desired speeds within the same link. It was then determined this that the best way to overcome this obstacle was to simulate dedicated ETC lanes as independent parallel link separate to the toll plaza link. This would allow the ETC link to operate at free flow speed or reduced speeds as necessary. It is important to note that the ability to simulate dedicated ETC lanes was not a change to CORSIM more of a solution to a new problem using existing tools already found in CORSIM. Additional information concerning the simulation of dedicated ETC lanes can be found in Appendix A.

Changes Made to TRAFVU

In addition to the changes made to CORSIM, changes were also made to the TRAFVU graphic processor. TRAFVU provides users a visual depiction of the CORSIM simulation. The changes made to TRAFVU assist the user in visually identifying important features of the toll plaza. This includes vehicle payment assignment and payment type acceptance at each toll booth.

To allow users to visually recognize vehicles by their assigned payment method, a new color scheme was developed in TRAFVU. To complement the new vehicle color scheme developed for toll plaza segments, a toll payment section was added to the TRAFVU legend. Figure 3-2 and Figure 3-3 show the improved legend and vehicle color scheme for toll plaza segments.

The other addition to TRAFVU concerns the visualization of the toll plaza. This involves additions to pavement markings and signage. The addition to signage allows for a visual representation of the toll plaza control device. The new pavement markings, which utilize a matching color scheme as used for vehicles, display the various payment types accepted at each toll lane. The pavement markings also denote if the booth is open or closed. Figure 3-4 provides a description of what each pavement marker color represents.

Performance Measures

The new toll plaza link created in CORSIM will produce outputs that can be utilized to evaluate the overall operations and capacity of the toll plaza, as well as the operations and capacity of individual toll lanes. Two new performance measures were developed for toll plaza analysis: TOLLBOOTH and TOLLPAYMENT. The toll plaza link performance measures include delay, speed, density, discharge total, service time average, and toll booth utilization by payment type. The performance measures are discussed in detail in Appendix A.

Implementation of New Record Types in CORSIM

To accommodate direct toll plaza simulation in CORSIM, new record types were implemented for the CORSIM program. These new record types contain and organize the necessary input data needed for toll plaza simulation. In depth discussion of the new record types is contained in Appendix A.

Table 3-1. Typical FDOT service times/processing rates of toll payment types

Payment Type	Mean Service Time (s/veh)	Mean Processing Rate (s/veh)
ACM	2.5	7.0
Manual	5.5	9.0
Ticket	2.5	7.0
ETC	1.0	4.5

Table 3-2. Color coding for toll booth markings

Color	Description
Yellow Marking	ACM
Brown Marking	Manual
Blue Marking	Ticket
Green Marking	ETC
White Marking	All payment types
Three Red Markings	Booth Closed

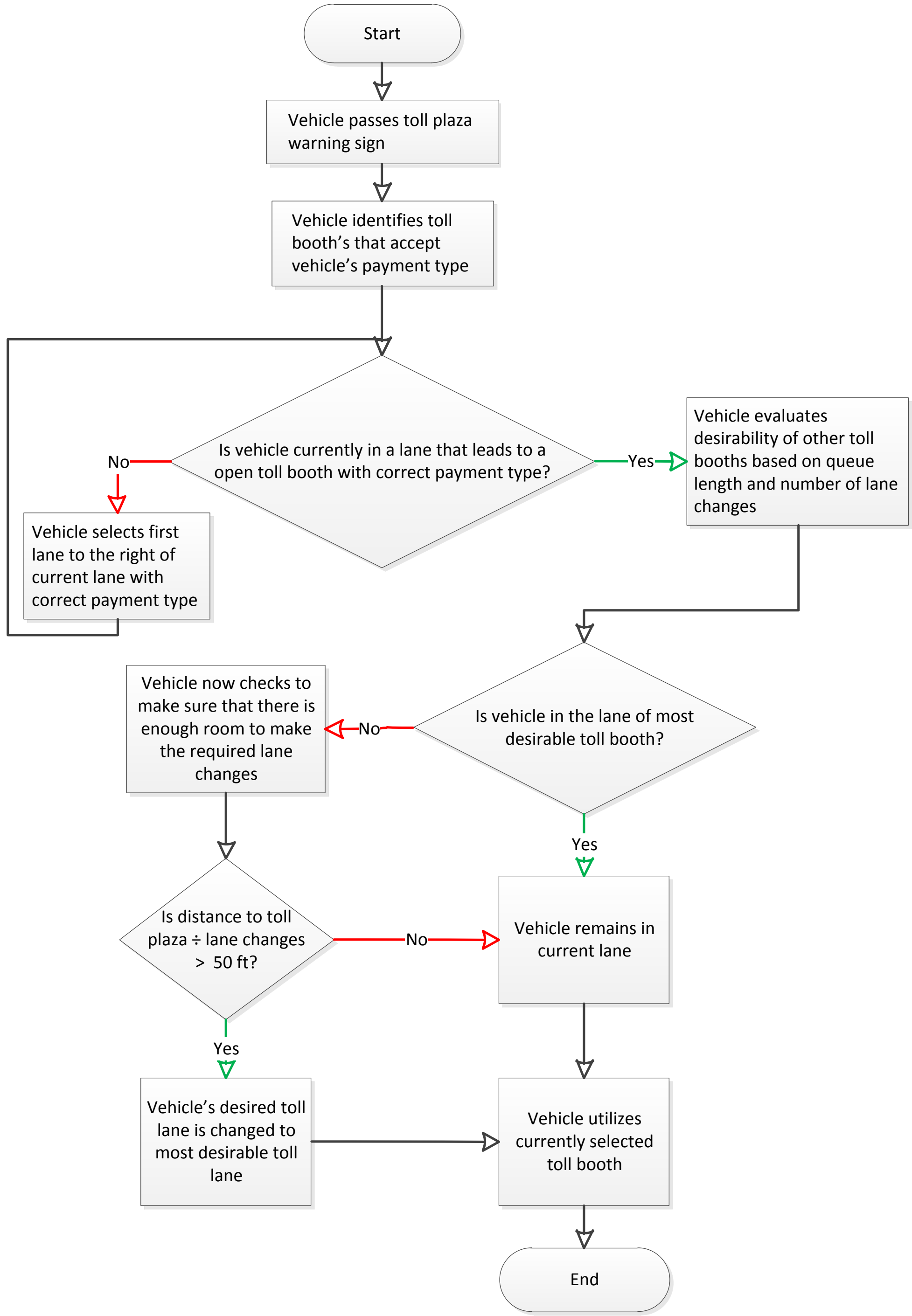


Figure 3-1. Generalized Toll lane selection algorithm

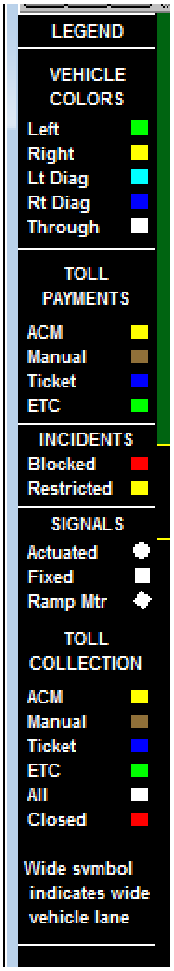


Figure 3-2. New legend depicting vehicle color scheme for toll plaza segments

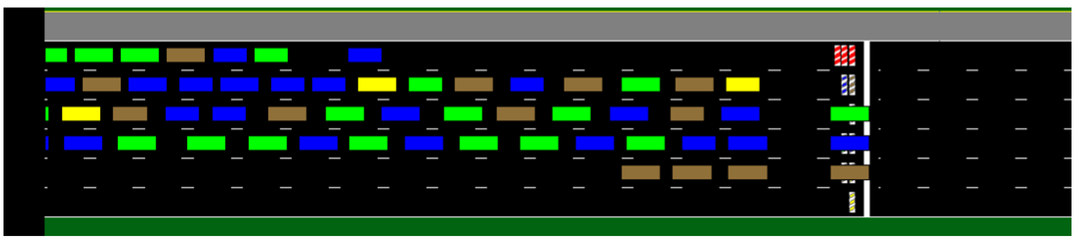


Figure 3-3. New vehicle color scheme for toll plaza segments

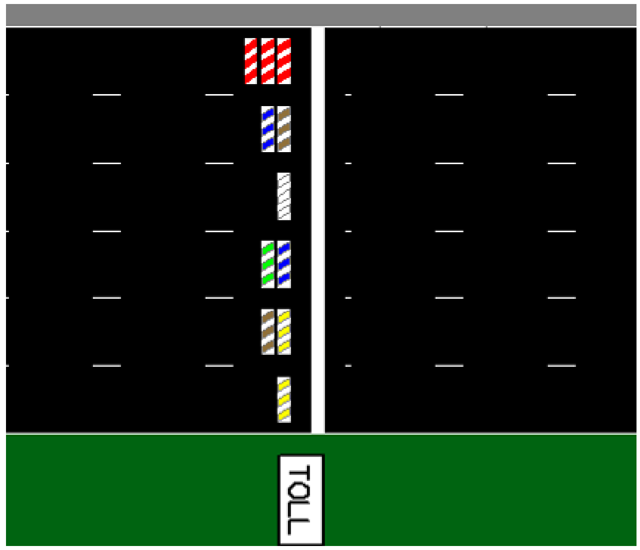


Figure 3-4. New lane markings and signage depicting payment types accepted at each toll booth

CHAPTER 4
VERIFICATION AND VALIDITY TESTING OF CORSIM SIMULATION

Verification of CORSIM Improvements

The first step in evaluating the improvements made to CORSIM is the verification process. During the verification process, the improvements to CORSIM were run through a variety of test scenarios to determine that all improvements are working correctly and produce reasonable results. This was accomplished by individually varying the input values of the new variables. All bugs identified during this testing process were relayed back to the programmer for correction.

For the toll plaza improvements, five CORSIM algorithms were tested to confirm that the inputs functioned correctly. These inputs included:

- Payment distribution
- Service time
- Payment restrictions at toll booth
- Vehicle type restrictions at toll booth
- Toll booth status changes during multiple time period simulation

General Assumptions for Verification Process

Before starting the verification process it is important to identify variables that can affect the results of the verification process. To ensure that these variables only have minimal effects on the verification process, they must have their impact minimized. There are two variables capable of affecting the verification process: toll plaza geometry and the toll lane selection algorithm. One hour simulations were used to produce volume outputs instead of flow rates.

To ensure that the effects of the toll plaza geometry and toll lane selection algorithms were minimal, two generic toll plazas were designed for the verification testing. The generic toll plazas were designed based off a traditional toll plaza design without the typical lane additions and drops seen at traditional plazas. This prevents additional lane changes that are due to lane additions or drops typically seen as vehicles fan out/merge to utilize available lanes. To ensure equal availability of each payment type, an eight lane generic toll plaza was utilized for testing the payment distribution. This was not an issue for testing the service time algorithm; thus, a smaller, six-lane toll plaza was utilized.

In addition to the number of lanes, care was also taken in determining the length of the approach segment. This was to ensure that the toll lane selection algorithm does not interfere with testing. The warning sign utilized to start the toll lane selection algorithm was placed at 2000 feet. By establishing the starting point of the toll lane selection algorithm far enough upstream, the lane changes due to the toll lane selection algorithm would be at a minimum near the toll booths. This distance was determined based off of measurements of existing toll plazas which typically have an approach length of a half-mile. See Figure 4-1 for the link-node design of the plaza and Figure 4-2 and Figure 4-3 for the visual depiction of the six lane and eight lane generic toll plaza designs.

Verification of payment distribution

To verify that the payment distribution input was working correctly, twelve scenarios were run with varying payment distributions. These scenarios cover a wide range of situations, from single payment type scenarios to all four payment types being utilized. This ensures that the payment distribution works for all cases. Using the developed generic toll plaza, each scenario was run ten times using CORSIM’s multiple run processor and the average values of the ten runs were evaluated. The twelve test scenarios developed for this testing are shown in Table 4-1.

When conducting the verification of the payment distribution, it became evident that this testing could be broken up into two distinct tests. The first test was to determine that when the user specified only one payment type, the payment distribution algorithm only assigned vehicles to the defined payment type. The second test was to determine that the payment distribution algorithm properly distributed the user-specified payment percentiles for a wide variety of scenarios.

For the first portion of testing, four scenarios that utilized 100 percent of a single payment type were tested, with one scenario for each payment type. To ensure minimal variance in these tests, variables such as service time and traffic volume, were kept uniform throughout the four scenarios. For these scenarios, an entering traffic volume of 2000 veh/h and an average service time of 10 seconds/veh were utilized. Each scenario was simulated ten times and results were obtained from the average of these ten runs. The results of this testing are found in Table 4-2, Table 4-3, Table 4-4, and Table 4-5. From this testing, it was determined that the payment type distribution algorithm properly identified that only one payment type was utilized and only assigned vehicles to that payment type.

After testing individual payment types, the next step was to confirm that the payment distribution algorithm properly assigned the correct percentiles of multiple payment types to the traffic flow. To accomplish this, eight scenarios utilizing a variety of payment distributions were run. These tests could not be performed in exactly the same way as the four scenarios used to test the individual payment types because vehicles left in the toll plaza queue at the end of the simulation would affect the results of these particular tests. Even though different payment percentages were specified for each payment type if queuing were to exist at the plaza for the entire simulation, scenarios could arise where the volumes of each payment type would be greatly different from the expect volumes and percent distribution. This is caused by the queuing at the toll plaza not being cleared by the end of the simulation. These vehicles that did not clear the toll plaza would not be counted towards the total volume of vehicles exiting the plaza. Thus, the entering traffic volumes had to be adjusted on a scenario by scenario basis to ensure that no, or very minimal, queuing existed at the end of each scenario, which would ensure that all vehicles that entered the network were accounted for in the final analysis.

To obtain the desired network conditions at the end of each scenario, it was determined that the network entering volume should be adjusted by time period, with each time period having a duration of fifteen minutes. This approach would allow a significant number of vehicles to enter the network at the beginning of the simulation, and as the simulation progresses decrease the volume of traffic entering the network until the volume was low enough to where the queuing at the plaza was cleared before the end of the simulation period. Results for these scenarios are shown in Table 4-6 through Table 4-13. From the results of these test scenarios, it was determined that the payment distribution algorithm is working correctly.

Verification of service time

The verification process of service time inputs follows a similar approach used for the verification of the payment distribution input. For this testing, seven scenarios were developed for testing; three scenarios to test the FDOT typical values for each payment type, and four scenarios to test a wide range of user specified inputs. Only three of the four payment types need to be tested as the ACM and Ticket payment type have the same typical service time. This testing utilized the six lane generic toll plaza segment. For this process a single payment type was utilized across all toll lanes. This approach eliminated the interaction between vehicles with different payment reducing potential variability of each simulation. The test scenarios developed for testing are shown in Table 4-14.

In addition to utilizing only one payment type, care was taken in establishing a volume of vehicles entering the network. Different volumes were utilized for each scenario. The reason for this was to ensure that the toll plaza was operating under constant queuing conditions. This ensures that each toll booth is operating at capacity for the specified service time of that scenario.

Generally, assuming constant queuing, average service time for a toll lane can be calculated using Equation 4-1.

$$S = \frac{3600}{V_i} \tag{4-1}$$

where,

S = average service time (seconds/veh)

V_i = Volume of vehicles exiting toll booth *i* (veh/h)

Strictly speaking, however, the time calculated in Equation 4-1 also includes the time a vehicle spends pulling up from the first position in queue to a position immediately adjacent to the booth. Thus, the time calculated in Equation 4-1 will be referred to as the overall processing time, and the service time is considered to be just the time a vehicle spends immediately adjacent to the toll booth. The difference between the overall processing time and average service time will be referred to as the pull-up time. Pull-up time is the time it takes the first vehicle in the queue to pull up to the toll booth. This usually accounts for three to four seconds of the total processing time. Accounting for pull up time is discussed in the following section.

Testing to verify service time followed the original experimental design. As mentioned previously, testing would be conducted on both user-specified average service times and default average service times to determine how accurately the outputs correspond to the inputs. The FDOT typical service times for the four payments, as well as four scenarios designed to test various levels of average service times, were created. For this testing, each toll booth was analyzed individually; producing six data points averaged over ten runs for each simulation. To ensure that the largest number of vehicles possible would be processed for a given service time, each scenario was set up to operate with constant queuing. This would ensure that the maximum throughput was achieved with the given service time.

Testing of the user-specified average service time inputs showed good results. For low to medium-low service times, 1 to 6 seconds, average service times were found to be typically within one tenth of a second from the desired average service time, with a standard deviation of under 0.1 seconds. Typically, for these lower average service times, the average service times resulting from the simulation tended to be slightly higher than the average. This is a result of a required minimum service time of one second that is imposed on all vehicles entering a toll booth. The one second minimum also produces a larger error for smaller service times. At higher average service times, the observed range of error for the average service times jumped from one tenth of a second to two tenths of a second for service times ranging from 7 to 10 seconds. Service times over 10 seconds produce averages within three tenths of a second of the desired average service time. Results for the testing of user-specified service times are shown in Table 4-15, Table 4-16, Table 4-17, and Table 4-18.

Testing was also conducted on the FDOT typical service times. Since ACM and Ticket payment types have the same average service time, only one simulation was run for the two of them. At this time, it should be noted that an exact processing rate for ETC payment utilizing a standard toll booth has not been determined, so an estimate of 4.5 seconds was utilized. This was based on 3.5 seconds observed for pull-up time and an additional 1 second needed for the toll arm to rise. Results for the testing of the FDOT typical service times are shown in Table 4-19, Table 4-20, and Table 4-21.

In addition to the testing previously mentioned, testing was also conducted on a 0-second service time scenario. This scenario was designed to test the “tolls lifted” scenario typically observed during hurricane evacuations or other high-volume situations. To test this scenario, a simulation was developed utilizing ACM, Manual, and ETC payments types. Each of these payment types’ average service time were assigned to 0 seconds. Service time and average speed for each toll booth was obtained from the CORSIM output processor. From this testing, it was determined that the evacuation scenario works properly, with vehicles traveling through the plaza at or near the free flow speed specified for the toll link. Results for this test can be seen in Table 4-22.

Development of toll plaza pull-up time equation

Pull up time typically accounts for three to four seconds of the processing time. This time is vehicle/driver type specific, as it is a function of vehicle acceleration/deceleration rates and driver reaction times. Because pull-up time is vehicle/driver specific, an approximation equation was developed so that a general estimate of pull-up time (an average for the given traffic stream) could be obtained and applied, along with the average service time, to obtain an estimate of the processing rate. To develop this equation, 30 toll-plaza scenarios with varying queue setback distances and truck percentages were developed. This testing was similar to the verification testing for the single payment type in the fact that each scenario utilized the six-lane generic toll plaza and was simulated with constant queuing to insure that maximum throughput for each toll booth. Each scenario was simulated ten times in CORSIM. The CORSIM output processor was utilized to collect the exiting traffic volume and the average service time for each toll booth. These outputs allowed for the calculation of the processing rate and pull-up time for each toll booth. Using these collected data, a three-axis plot was created using truck percentage, queue-setback distance, and pull-up time. From this plot, it was seen that the relationship between the dependent variable of pull-up time and the independent variables of truck percentage and queue-setback distance was approximately linear. Thus, a linear-regression analysis was performed for these three variables, and Equation 4-2 was obtained:

$$PullupTime = 3.222 + 0.056 \times QueueSetbackDist + 0.015 \times \%Trucks \qquad (4\text{-}2)$$

where,

QueueSetbackDist = distance between stopped vehicle position immediately adjacent to toll booth and stopped position of first vehicle in queue (measured from front bumper to front bumper), in feet

%Trucks = Percent of heavy vehicles in the traffic stream

This equation produces an adjusted R^2 value of 0.806. The t-statistics showed that the independent variables are significant at the 99% confidence level.

Verification of payment restrictions

The verification testing of the payment restrictions tests to make sure that each vehicle is only utilizing toll booths that accept their assigned payment type. This testing was not done by a quantitative method, but instead a visual confirmation approach was utilized. This was accomplished by running simulations and observed using TRAFVU to determine if the restrictions were working correctly. To determine this, attention was focused on randomly selected vehicles. These vehicles were observed from the time their payment type was assigned to when they entered the toll booth. At this point, careful attention was paid to make sure that the vehicle in question utilized a toll lane that accepted its payment type. This testing showed that the payment restriction capabilities were working correctly.

Testing was also conducted to the test the open/closed status of a toll booth. This was to ensure that vehicles would not utilize closed toll booths during high volume scenarios. To test this, scenarios were developed with multiple toll booth closures and traffic volumes well over the capacity of the available toll booths. This testing also relied on a combination of visual confirmation of the results and exiting volume collection from the CORSIM output processor. From this testing it was determined that even in high-demand, low-capacity scenarios, vehicles would not pass through a closed toll booth. Visualization of this validation testing can be found in Figure 4-4. Numerical results of this testing can be found in Table 4-23.

Verification of vehicle type restrictions

To verify that the vehicle type restriction functioned properly, three simulations were developed. These simulations were developed to test two realistic scenarios and one hypothetical scenario. Scenario one restricts all heavy vehicles to the far right toll booth; there are no restrictions for car vehicle types. For scenario two, all heavy vehicles were restricted to the two far right toll lanes and car vehicle types were restricted to the remaining four toll booths. The third scenario is based on a hypothetical scenario that utilizes six vehicle types and assigns vehicle types 1 and 2 to toll booths 1 and 2, vehicle types 3 and 4 to toll booths 3 and 4, and vehicle types 5 and 6 to toll booths 5 and 6.. To ensure that adequate volumes for each vehicle type were observed, the vehicle type percentages were adjusted so that each vehicle type would have the same probability of being assigned to a vehicle entering the network. Results for these three scenarios can be found in Table 4-24, Table 4-25, and Table 4-26. From this testing it was determined that the algorithms limiting vehicle types to specific toll booths was working properly.

Verification of multiple time period toll booth changes

The verification testing of multiple time period plaza changes tests the new CORSIM features to ensure that the simulation is properly implementing changes to the toll booths during multiple time period simulations. To test this, a single CORSIM simulation was developed. This simulation consisted of four time periods. Each time period utilized a different number of open toll booths. See Table 4-27 for the plaza configuration for each time period. Results for this simulation were averaged over ten runs. Results for this testing can be found in Table 4-28. From this testing it was determined that the toll booth changes implemented during each time period worked properly.

Summary

Verification testing was conducted on five essential toll plaza algorithms to ensure they functioned correctly. From this testing it was determined that the payment distribution algorithm, payment restriction algorithms, vehicle restriction algorithm, and multiple time periods algorithm, operated as expected. The service time algorithm tends to produce average service times that are slightly higher than desired for smaller service times. This is due to the enforced 1-second minimum service time that shifts the average service time slightly upward.

Validation of CORSIM Improvements

After the verification process, in which errors were identified and corrected, the performance measure results were further scrutinized for consistency. This was accomplished by testing to see if the toll plaza features in CORSIM could replicate field conditions of a real toll plaza. For this effort, data were obtained from the FDOT. The data obtained included the following:

- Video footage of two toll plazas
- Daily average traffic volumes
- Average ETC penetration
- Average capacity volumes and processing rates for various payment types

These data are found in Table 4-29, Table 4-30, Table 4-31, and Table 4-32. This information provided valuable resources to determine default values for a variety of toll plaza inputs and expected outputs allowing for CORSIM to be calibrated based on these values.

Calibration

To confirm the accuracy of the improvements made to CORSIM, it is important to test the validity of the simulation. For this, two toll plazas were selected from the list of toll plazas currently in use in Florida. The two toll plazas were selected to provide calibration for two of the three styles of toll plazas seen in Florida. The two plaza types that were simulated were the traditional toll plaza and the hybrid plaza that combines open road tolling (ORT), any type of tolling system that does not require a vehicle to come to a complete stop, with traditional tolling into one plaza. The third toll plaza type, open-road tolling-only plaza was not simulated, as the plaza is simply a basic freeway segment that operates at normal freeway speeds. In the case of ORT toll plazas, the toll plaza tools developed in CORSIM would not be needed. These two plazas were selected based on geometry, traffic volumes, and researcher's familiarity with the plazas. The two plazas selected for this testing were the Leesburg Plaza and the Beach Line-West toll plaza. The locations of these toll plazas can be seen in Figure 4-10.

Video Data Collection

In addition to the basic traffic data, FDOT also was able to provide video footage for the Leesburg Toll Plaza and the Beach Line-West Toll Plaza. A total of about 1 hour and 15 minutes of operations at each plaza was recorded. It was decided to use a 15-minute interval from each video recording for the toll plaza operations validation. The 15-minute interval chosen was the one with the heaviest traffic demand. However, one 15-minute interval for the Leesburg Toll Plaza was not considered because the number of open booths changed during this interval.

Leesburg plaza data collection

The video footage was of the southbound approach of the Leesburg plaza. It was observed that during the selected 15-minute interval, the plaza had three manual-payment lanes open and one dedicated-ETC lane open. The dedicated-ETC lane has a posted speed limit of 25 mi/h; however, Turnpike personnel indicated that many vehicles travel through the plaza in this lane at speeds up to 40 mi/h. During the 15-minute interval, steady queuing of one to two vehicles was observed with a maximum queue of two to three vehicles at each of the three manual payment lanes. See Figure

4-11 for a screen shot of the traffic conditions at the Leesburg plaza. A fairly steady flow of vehicles entering the ETC-only lane was also observed. A summary of the minute by minute traffic counts of the selected 15-minute interval is in Table 4-33.

Beach Line-West plaza data collection

The video footage was of the westbound approach. It was observed that during the selected 15-minute interval, the plaza had three manual payment lanes open and three ORT dedicated-ETC lanes open. Typically, queuing at this toll plaza was nonexistent. However an instance of a two-vehicle queue was observed at one manual lane. See Figure 4-12 for a screen shot of the traffic conditions at the Beachline-West plaza. Concerning the ORT lane, congestion was not an issue as vehicles were traveling near or at free-flow speed. A summary of the minute by minute traffic counts of the selected 15-minute interval is in Table 4-34.

Traditional toll plaza

To simulate the traditional toll plaza, the Leesburg Plaza located along the Florida Turnpike, latitude 28.66 deg longitude -81.84 deg, was utilized. The southbound approach of this plaza is a two-lane approach which fans out to accommodate seven toll booths. These seven toll lanes are comprised of one ETC-only lane and six cash/ETC lanes. In the case of this plaza, the ETC-only lane is not a full speed lane as seen in the open road tolling plaza. Instead, speed limits are reduced as the vehicle approaches the plaza until the vehicle reaches the plaza, at which point the posted speed limit is 25 mi/h. It is also important to note that of the six lanes available for non-ETC vehicles; typically only three to four of them are open during normal traffic conditions. A fifth toll lane is opened only during higher than normal traffic conditions, and the sixth cash lane is only opened during extremely high demand periods such as when tolls are lifted during emergencies or before or after a major holiday. An aerial photograph and configuration for the northbound approach of the plaza are shown in Figure 4-5 and Figure 4-6, respectively.

Hybrid plaza

In the case of the hybrid scenario, the Beach Line-West toll plaza located along the Beachline Expressway (State Road 528), latitude 28.44 deg longitude -81.38 deg, was utilized. The Beach Line-West toll plaza contains seven toll lanes for each direction and is broken up into two distinct segments. The first segment is the ORT portion of the plaza, which has a posted speed limit of 55 mi/h. In this segment there are three ETC ORT lanes. The second part of the plaza contains a traditional toll plaza configuration, with four cash toll lanes for users not utilizing the ETC ORT lanes. The aerial photographs and configuration of the Beach Line-West toll plaza are shown in Figure 4-7, Figure 4-8, and Figure 4-9, respectively.

Results of Validation Testing

To confirm the accuracy of the CORSIM improvements, video data for the Leesburg and Beach Line-West Plaza was analyzed. Using the collected data as inputs, an attempt was made to recreate a 15-minute time period observed in the video footage using CORSIM. To produce a more accurate representation of this 15-minute interval, three time periods of five minutes each were utilized for each simulation. The summarized 5-minute interval data can be found in Table 4-35 and Table 4-36. These vehicle counts were then converted to hourly rates to be used as inputs. To confirm that the simulations are accurately portraying the field data, each toll plaza model was simulated twelve times and the average values obtained from the simulations were compared to the field data.

Network Model Development

When developing toll plaza network models in CORSIM a certain amount of planning needs to be done first. This is especially the case when developing network models that contain toll plazas with ETC-only lanes. The reason for this is that the presence of ORT lanes requires a split to occur to separate the ETC-only lanes from the traditional toll plaza. This is done by utilizing a FRESIM link with an off-ramp. Care needs to be taken when determining which portion of the toll plaza, ETC-only portion or traditional portion is incorporated into the off-ramp.

For the Beachline-West toll plaza, it was decided that the traditional portion of the toll plaza would utilize the off-ramp portion of the network model. This was decided based on the geometry of the plaza and regulatory speeds of the ORT lanes. To simulate the ORT lanes, the regulatory speed limit was high enough to allow the utilization of FRESIM links for the entire ORT portion. See Figure 4-13 and Figure 4-14 for the developed network model of the Beachline-West toll plaza.

In the case of the Leesburg toll plaza, it was decided that the ETC-only lane of the toll plaza would utilize the off-ramp portion of the network model. The reason for this decision was due to the number of manual booths at this toll plaza. In the case of the ETC-only lane for this plaza, a combination of FRESIM and NETSIM links were utilized for the network. This was due to regulatory speed limit placed on the ETC-only lane as it passed through the plaza. The regulatory speed of 25 mi/h cannot be accommodated by FRESIM links. As such, NETSIM links were utilized as the ETC-only lane approached the toll plaza. See Figure 4-15 and Figure 4-16 for the developed network model of the Leesburg toll plaza.

Results

With the network models for Leesburg and Beachline-West toll plazas created, they were simulated using the collected field data as inputs. Each toll plaza was simulated twelve times. Utilizing the output processor, the following three traffic characteristics were collected:

- Traffic volume by vehicle type exiting the toll plaza
- Maximum queue length
- Average queue length

Leesburg toll plaza results

The simulation results for the Leesburg toll plaza appear to be very promising. The Leesburg network model was found to be capable of producing passenger vehicle volumes that were within three to four vehicles of the five minute volumes collected in the field. Simulation results of the truck volume were even more accurate, within one to two vehicles of the five minute volumes collected from the field data.

Testing for the queuing averages and maximum queue length also produced promising results. The average queue lengths obtained from the video footage were a rough approximation. Even with this being the case, the CORSIM model produced average queue lengths within the range observed from the video footage. In addition to the average queue lengths, the maximum queue length observed in CORSIM, which averaged around three to four vehicles, matched up to the observed four vehicle maximum queue from the video footage. Results for this testing can be found in Table 4-37 and Table 4-38.

Beachline-West toll plaza results

The Beachline-West toll plaza produced similar results seen in the Leesburg toll plaza. Traffic volume did not match up as well as the Leesburg model. Even with this being the case, the Beachline-West simulation was still typically within six vehicles of the five minute volumes obtained from the video footage.

Concerning the average queue length and maximum queue length, the results were in the expected range. One observation that reinforces the validity of the CORSIM network model created is that the average queue length increases as the 15- minute interval passes. During the 15-minute interval, the video footage showed a progressive increase in the traffic volumes on the roadway. This increase in traffic resulted in a slight increase to the average queuing observed. Results for this testing can be found in Table 4-39 and Table 4-40.

Table 4-1. Verification scenarios for payment distribution input

Scenario	ACM	Manual	Ticket	ETC
1	100%	0%	0%	0%
2	0%	100%	0%	0%
3	0%	0%	100%	0%
4	0%	0%	0%	100%
5	0%	0%	50%	50%
6	50%	50%	0%	0%
7	10%	10%	0%	80%
8	15%	15%	50%	20%
9	20%	20%	20%	40%
10	10%	60%	10%	20%
11	20%	20%	50%	10%
12	5%	85%	5%	5%

Table 4-2. Results 100% ACM payment

	ACM	Manual	Ticket	ETC	Total
Volume (Vehicles)	1940.8	0	0	0	1940.8
Percent Distribution	100.00%	0.00%	0.00%	0.00%	100.00%
Expected Distribution	100.00%	0.00%	0.00%	0.00%	100.00%
Absolute Difference	0.00%	0.00%	0.00%	0.00%	
Percent Difference	0.00%	0.00%	0.00%	0.00%	

Table 4-3. Results 100% Manual payment

	ACM	Manual	Ticket	ETC	Total
Volume (Vehicles)	0	1940.8	0	0	1940.8
Percent Distribution	0.00%	100.00%	0.00%	0.00%	100.00%
Expected Distribution	0.00%	100.00%	0.00%	0.00%	100.00%
Absolute Difference	0.00%	0.00%	0.00%	0.00%	
Percent Difference	0.00%	0.00%	0.00%	0.00%	

Table 4-4. Results 100% Ticket payment

	ACM	Manual	Ticket	ETC	Total
Volume (Vehicles)	0	0	1991.4	0	1991.4
Percent Distribution	0.00%	0.00%	100.00%	0.00%	100.00%
Expected Distribution	0.00%	0.00%	100.00%	0.00%	100.00%
Absolute Difference	0.00%	0.00%	0.00%	0.00%	
Percent Difference	0.00%	0.00%	0.00%	0.00%	

Table 4-5. Results 100% ETC payment

	ACM	Manual	Ticket	ETC	Total
Volume (Vehicles)	0	0	0	1940.8	1940.8
Percent Distribution	0.00%	0.00%	0.00%	100.00%	100.00%
Expected Distribution	0.00%	0.00%	0.00%	100.00%	100.00%
Absolute Difference	0.00%	0.00%	0.00%	0.00%	
Percent Difference	0.00%	0.00%	0.00%	0.00%	

Table 4-6. Results 0% ACM, 0% Manual, 50% Ticket, 50% ETC payment distribution

	ACM	Manual	Ticket	ETC	Total
Volume (Vehicles)	0	0	542.3	559.6	1101.9
Percent Distribution	0.00%	0.00%	49.21%	50.79%	100.00%
Expected Distribution	0.00%	0.00%	50.00%	50.00%	100.00%
Absolute Difference	0.00%	0.00%	0.79%	0.79%	
Percent Difference	0.00%	0.00%	1.58%	1.56%	

Table 4-7. Results 50% ACM, 50% Manual, 0% Ticket, 0% ETC payment distribution

	ACM	Manual	Ticket	ETC	Total
Volume (veh)	542.3	559.6	0	0	1101.9
Percent Distribution	49.21%	50.79%	0.00%	0.00%	100.00%
Expected Distribution	50.00%	50.00%	0.00%	0.00%	100.00%
Absolute Difference	0.79%	0.79%	0.00%	0.00%	
Percent Difference	1.58%	1.56%	0.00%	0.00%	

Table 4-8. Results 5% ACM, 85% Manual, 5% Ticket, 5% ETC payment distribution

	ACM	Manual	Ticket	ETC	Total
Volume (veh)	45.8	737.4	40.5	43.2	866.9
Percent Distribution	5.28%	85.06%	4.67%	4.98%	100.00%
Expected Distribution	5.00%	85.00%	5.00%	5.00%	100.00%
Absolute Difference	0.28%	0.06%	0.33%	0.02%	
Percent Difference	5.51%	0.07%	6.79%	0.34%	

Table 4-9. Results 10% ACM, 10% Manual, 0% Ticket, 80% ETC payment distribution

	ACM	Manual	Ticket	ETC	Total
Volume (veh)	97.8	94.6	0	773.2	965.6
Percent Distribution	10.13%	9.80%	0.00%	80.07%	100.00%
Expected Distribution	10.00%	10.00%	0.00%	80.00%	100.00%
Absolute Difference	0.13%	0.20%	0.00%	0.07%	
Percent Difference	1.28%	2.05%	0.00%	0.09%	

Table 4-10. Results 10% ACM, 60% Manual, 10% Ticket, 20% ETC payment distribution

	ACM	Manual	Ticket	ETC	Total
Volume (veh)	97.7	589.4	95.8	188.7	971.6
Percent Distribution	10.06%	60.66%	9.86%	19.42%	100.00%
Expected Distribution	10.00%	60.00%	10.00%	20.00%	100.00%
Absolute Difference	0.06%	0.66%	0.14%	0.58%	
Percent Difference	0.55%	1.10%	1.41%	2.93%	

Table 4-11. Results 15% ACM, 15% Manual, 50% Ticket, 20% ETC payment distribution

	ACM	Manual	Ticket	ETC	Total
Volume (veh)	143	143	491.2	188.6	965.8
Percent Distribution	14.81%	14.81%	50.86%	19.53%	100.00%
Expected Distribution	15.00%	15.00%	50.00%	20.00%	100.00%
Absolute Difference	0.19%	0.19%	0.86%	0.47%	
Percent Difference	1.30%	1.30%	1.70%	2.39%	

Table 4-12. Results: 20% ACM, 20% Manual, 20% Ticket, 40% ETC payment distribution

	ACM	Manual	Ticket	ETC	Total
Volume (veh)	193.8	184.6	192.1	389.1	959.6
Percent Distribution	20.20%	19.24%	20.02%	40.55%	100.00%
Expected Distribution	20.00%	20.00%	20.00%	40.00%	100.00%
Absolute Difference	0.20%	0.76%	0.02%	0.55%	
Percent Difference	0.97%	3.89%	0.09%	1.36%	

Table 4-13. Results: 20% ACM, 20% Manual, 50% Ticket, 10% ETC payment distribution

	ACM	Manual	Ticket	ETC	Total
Volume (veh)	193.7	185.7	484.3	94.4	958.1
Percent Distribution	20.22%	19.38%	50.55%	9.85%	100.00%
Expected Distribution	20.00%	20.00%	50.00%	10.00%	100.00%
Absolute Difference	0.22%	0.62%	0.55%	0.15%	
Percent Difference	1.08%	3.14%	1.09%	1.48%	

Table 4-14. Verification scenarios for mean service time input

Payment Type	Mean Service Time
ACM	FDOT Typical – 2.5 sec
Manual	FDOT Typical – 5.5 sec
Ticket	FDOT Typical – 2.5 sec
ETC	FDOT Typical – 1 sec
ACM	4 sec
ACM	7 sec
ACM	9 sec
ACM	13 sec

Table 4-15. Results for 4 second service time testing

	Lane 1	Lane 2	Lane 3	Lane 4	Lane 5	Lane 6
Expected Service Time	4	4	4	4	4	4
CORSIM Service Time	4.1203	4.1185	4.0719	4.1476	4.1495	4.144
Difference (seconds)	-0.12	-0.119	-0.072	-0.148	-0.15	-0.144
Percent Difference	2.96%	2.92%	1.78%	3.62%	3.67%	3.54%

Table 4-16. Results for 7 second service time testing

	Lane 1	Lane 2	Lane 3	Lane 4	Lane 5	Lane 6
Expected Service Time	7	7	7	7	7	7
CORSIM Service Time	7.1403	7.2994	6.9962	7.0208	7.0065	7.1711
Difference (seconds)	-0.14	-0.299	0.0038	-0.021	-0.007	-0.171
Percent Difference	1.98%	4.19%	0.05%	0.30%	0.09%	2.42%

Table 4-17. Results for 9 second service time testing

	Lane 1	Lane 2	Lane 3	Lane 4	Lane 5	Lane 6
Expected Service Time	9	9	9	9	9	9
CORSIM Service Time	9.1043	9.1868	9.3161	9.2429	8.8427	8.8973
Difference (seconds)	-0.104	-0.187	-0.316	-0.243	0.1573	0.1027
Percent Difference	1.15%	2.05%	3.45%	2.66%	1.76%	1.15%

Table 4-18. Results for 13 second service time testing

	Lane 1	Lane 2	Lane 3	Lane 4	Lane 5	Lane 6
Expected Service Time	13	13	13	13	13	13
CORSIM Service Time	13.077	13.177	12.918	12.889	13.427	12.686
Difference (seconds)	-0.077	-0.177	0.0822	0.1111	-0.427	0.3143
Percent Difference	0.59%	1.36%	0.63%	0.86%	3.23%	2.45%

Table 4-19. FDOT typical testing ACM and Ticket payment

	Lane 1	Lane 2	Lane 3	Lane 4	Lane 5	Lane 6
Volume	609.1	607.2	611.4	610.5	609.4	608.4
Expected Processing Rate	9	9	9	9	9	9
CORSIM Processing Rate	5.9104	5.9289	5.8881	5.8968	5.9074	5.9172
Expected Service Time	3.0896	3.0711	3.1119	3.1032	3.0926	3.0828
CORSIM Service Time	2.2253	2.2468	2.2002	2.2148	2.2147	2.2384

Table 4-20. FDOT typical testing Manual payment

	Lane 1	Lane 2	Lane 3	Lane 4	Lane 5	Lane 6
Volume	403.4	397.3	404.4	404.3	400.8	406
Expected Processing Rate	9	9	9	9	9	9
CORSIM Processing Rate	8.9241	9.0612	8.9021	8.9043	8.982	8.867
Expected Service Time	5.3	5.3	5.3	5.3	5.3	5.3
CORSIM Service Time	5.4037	5.5261	5.3869	5.3748	5.4526	5.3157

Table 4-21. FDOT typical testing ETC payment

	Lane 1	Lane 2	Lane 3	Lane 4	Lane 5	Lane 6
Volume	690.6	688.4	693.4	690.8	688.2	691.7
Expected Processing Rate	4.5	4.5	4.5	4.5	4.5	4.5
CORSIM Processing Rate	5.2129	5.2295	5.1918	5.2113	5.231	5.2046
Expected Service Time	1	1	1	1	1	1
CORSIM Service Time	1.3693	1.39	1.3571	1.3759	1.3841	1.3629

Table 4-22. 0 second service time scenario

	Toll Booth					
	1	2	3	4	5	6
Average Service Time	0.0	0.0	0.0	0.0	0.0	0.0
Average Speed	42.4	42.5	42.7	42.5	42.4	41.9

Table 4-23. Payment restriction testing

	Lane 1	Lane 2	Lane 3	Lane 4	Lane 5	Lane 6
Status	Closed	Open*	Open*	Open*	Closed	Closed
Expected Volume	0	277	277	277	0	0
CORSIM Volume	0	278	277.1	275.6	0	0

* Assuming 13 second processing rate

Table 4-24. Results Trucks restricted to one lane no car restrictions

	Vehicle type					
	1	2*	5	6*	7*	8*
Booth 1	259.7	22.0	88.5	27.6	17.3	6.0
Booth 2	291.2	0.0	103.1	0.0	0.0	0.0
Booth 3	292.2	0.0	92.3	0.0	0.0	0.0
Booth 4	280.1	0.0	96.7	0.0	0.0	0.0
Booth 5	299.0	0.0	94.0	0.0	0.0	0.0
Booth 6	320.1	0.0	109.0	0.0	0.0	0.0

* Denotes heavy vehicle vehicle types

Table 4-25. Results Trucks restricted to two lanes cars restricted to four lanes

	Vehicle type					
	1	2*	5	6*	7*	8*
Booth 1	0.0	98.8	0.0	112.0	72.1	24.8
Booth 2	0.0	92.9	0.0	103.7	69.2	29.5
Booth 3	320.9	0.0	113.8	0.0	0.0	0.0
Booth 4	326.2	0.0	111.0	0.0	0.0	0.0
Booth 5	333.6	0.0	109.7	0.0	0.0	0.0
Booth 6	357.1	0.0	117.9	0.0	0.0	0.0

* Denotes heavy vehicle vehicle types

Table 4-26. Results two vehicle types to two toll booths assignment

	Vehicle type					
	1[a]	2[a]	5[b]	6[b]	7[c]	8[c]
Booth 1	287.0	112.6	0.0	0.0	0.0	0.0
Booth 2	253.1	107.2	0.0	0.0	0.0	0.0
Booth 3	0.0	0.0	271.7	114.9	0.0	0.0
Booth 4	0.0	0.0	272.7	114.1	0.0	0.0
Booth 5	0.0	0.0	0.0	0.0	112.9	118.5
Booth 6	0.0	0.0	0.0	0.0	105.8	108.3

[a] Denotes vehicle types restricted to Booths 1 & 2

[b] Denotes vehicle types restricted to Booths 3 & 4

[c] Denotes vehicle types restricted to Booths 5 & 6

Table 4-27. Multiple time period verification scenario

		Toll Booth							
		1	2	3	4	5	6	7	8
Time Period	1	Open	Open	Open	Open	Open	Open	Open	Open
	2	Open	Open	Open	Open	Open	Open	Closed	Closed
	3	Closed	Open	Open	Open	Open	Open	Open	Open
	4	Open	Open	Closed	Closed	Open	Open	Open	Open

Table 4-28. Results of multiple time period testing

		Toll Booth Volumes (vph)							
		1	2	3	4	5	6	7	8
Time Period	1	25.1	22.8	29.3	46.5	75.1	94.4	100.1	104.3
	2	52.2	51.3	74.4	92.9	110	118.2	0*	0*
	3	0*	6.1*	19.1	50.1	88.5	111.6	114.4	111.7
	4	51.3	54.4	0*	0*	45.1	87.8	123.1	139.6

* Denotes that toll booth was closed during time period

Table 4-29. Traffic volumes for Beachline West toll plaza

			Manned Booths		Open Road ETC	
			Cash	SunPass	Cash*	SunPass
Weekend	PM	Average	8,845	62	920	11,221
		Total	70,757	494	7,363	89,771
	AM	Average	4,495	30	502	6,814
		Total	35,962	239	4,016	54,516
Weekday	PM	Average	4,426	30	914	12,246
		Total	101,790	699	21,017	281,653
	AM	Average	7,970	53	581	10,757
		Total	183,321	1,208	13,370	247,414
Entire Weekend		Average	13,340	92	1,422	18,036
		Total	106,719	733	11,379	144,287
Entire Weekday		Average	12,396	83	1,495	23,003
		Total	285,111	1,907	34,387	529,067
All Days		Average	12,640	85	1,476	21,721
		Total	391,830	2,640	45,766	673,354

* These vehicles are toll violators

Table 4-30. Traffic volume for Leesburg toll plaza

			Manned Booths		Dedicated ETC	
			Cash	SunPass	Cash*	SunPass
Weekend	PM	Average	2,905	50	136	2,842
		Total	66,823	1,160	3,117	65,361
	AM	Average	5,114	151	191	4,538
		Total	117,632	3,474	4,397	104,373
Weekday	PM	Average	8,827	71	237	5,707
		Total	70,619	565	1,897	45,659
	AM	Average	3,954	34	117	2,368
		Total	31,633	273	938	18,945
Entire Weekend		Average	8,020	201	327	7,380
		Total	184,455	4,634	7,514	169,734
Entire Weekday		Average	12,782	105	354	8,076
		Total	102,252	838	2,835	64,604
All Days		Average	9,249	177	334	7,559
		Total	286,707	5,472	10,349	234,338

* These vehicles are toll violators

Table 4-31. Standard toll plaza capacities and rates along Florida toll roads (single payment type lane)

Lane Type	Capacity (vph)	Rate veh/s
High Speed SunPass only	2100	1.71
Dedicated SunPass (Mainline)	1700	2.12
Dedicated SunPass (Ramps)	1300	2.77
Automatic coin	500	7.2
Manual/automatic	400	9
Manual booth	400	9
Manual ticket entry	500	7.2
Manual ticket exit	180	20

Table 4-32. SunPass's impact on mixed use lane capacity along Florida's toll roads

System	Type	Assumed SunPass Rate	Capacity (veh/h)
Northern Coin	Cash/ETC	64%	718
South Ticket (MP 88-142)	ME/ETC	74%	918
	MX/ETC	74%	621
North Ticket (MP 142-236)	ME/ETC	59%	785
	MX/ETC	59%	478
Southern Coin	Cash/ETC	70%	776
BeachLine West	Cash/ETC	60%	684
Sawgrass	Cash/ETC	79%	883
Seminole	Cash/ETC	75%	832
Veterans	Cash/ETC	68%	756
Southern Connector	Cash/ETC	65%	727
Polk Pkwy	Cash/ETC	55%	646
Suncoast Pkwy	Cash/ETC	67%	746

Table 4-33. Leesburg 15 minute traffic data

	Total Volume/Car Volume/Truck Volume			
	ETC Lane	Manual 1	Manual 2	Manual 3
46:00-47:00	14/14/0	1/1/0	3/3/0	8/8/0
47:00-48:00	16/14/2	5/5/0	0/0/0	3/2/1
48:00-49:00	22/22/0	6/6/0	7/7/0	1/1/0
49:00-50:00	17/17/0	6/6/0	2/2/0	7/7/0
50:00-51:00	13/13/0	7/7/0	2/1/1	1/1/0
51:00-52:00	11/9/2	4/4/0	3/3/0	5/4/1
52:00-53:00	10/9/1	5/5/0	1/1/0	1/1/0
53:00-54:00	16/12/4	6/6/0	5/5/0	6/6/0
54:00-55:00	21/21/0	2/2/0	3/3/0	3/3/0
55:00-56:00	13/12/1	3/3/0	6/6/0	4/1/3
56:00-57:00	12/11/1	6/6/0	3/3/0	1/0/1
57:00-58:00	7/7/0	5/5/0	4/4/0	3/2/1
58:00-59:00	20/20/0	6/6/0	4/4/0	4/4/0
59:00-1:00:00	17/16/1	7/7/0	3/3/0	5/4/1
1:00:00-1:01:00	16/16/0	5/5/0	5/5/0	2/2/0
Total Volume	225/213/12	51/51/0	51/50/1	54/46/8

Table 4-34. Beachline West 15 minute traffic data

	Total Volume/Car Volume/Truck Volume			
	ETC Lane	Manual 1	Manual 2	Manual 3
01:00-02:00	37/33/4	4/4/0	5/5/0	6/6/0
02:00-03:00	27/26/1	4/4/0	1/1/0	2/2/0
03:00-04:00	32/31/1	2/2/0	4/4/0	2/2/0
04:00-05:00	27/27/0	2/2/0	0/0/0	1/1/0
05:00-06:00	45/40/5	2/2/0	3/3/0	3/3/0
06:00-07:00	42/41/1	2/2/0	3/3/0	5/5/0
07:00-08:00	38/37/1	5/5/0	3/3/0	4/4/0
08:00-09:00	39/38/1	4/4/0	2/2/0	3/3/0
09:00-10:00	26/24/2	3/3/0	5/5/0	2/2/0
10:00-11:00	39/33/3	4/4/0	3/3/0	3/3/0
11:00-12:00	45/42/3	4/4/0	3/3/0	2/2/0
12:00-13:00	46/41/5	5/5/0	5/5/0	3/2/1
13:00-14:00	62/61/1	4/4/0	5/5/0	4/4/0
14:00-15:00	38/38/0	4/3/1	5/5/0	6/6/0
15:00-16:00	31/30/1	3/3/0	5/5/0	3/2/1
Total Volume	574/545/29	52/51/1	52/52/0	49/47/2

Table 4-35. Five minute interval data for Leesburg Toll Plaza

	Entry Volume			ETC Only Volume			Toll Plaza Volume		
	Total	Car	Truck	Total	Car	Truck	Total	Car	Truck
Interval 1	141	137	4	82	80	2	59	57	2
Interval 2	128	116	12	71	63	8	57	53	4
Interval 3	135	130	5	72	70	2	63	60	3

Table 4-36. Five minute interval data for Beachline-West Toll Plaza

	Entry Volume			ETC Only Volume			Toll Plaza Volume		
	Total	Car	Truck	Total	Car	Truck	Total	Car	Truck
Interval 1	209	198	11	168	157	11	41	41	0
Interval 2	235	224	11	184	173	11	51	51	0
Interval 3	283	270	13	222	212	10	61	58	3

Table 4-37. Volume comparison Leesburg Toll Plaza

		Toll Plaza Volumes			ORT Volumes		
		Total	Cars	Trucks	Total	Cars	Trucks
Interval 1	Field Data	59.0	57.0	2.0	82.0	80.0	2.0
	CORSIM Results	57.1	55.1	2.0	81.7	79.6	2.1
Interval 2	Field Data	57.0	53.0	4.0	71.0	63.0	8.0
	CORSIM Results	59.7	55.6	4.1	73.4	66.3	7.1
Interval 3	Field Data	63.0	60.0	3.0	72.0	70.0	2.0
	CORSIM Results	63.0	60.3	2.8	70.3	67.6	2.7

Table 4-38. Queuing comparison Leesburg Toll Plaza

	Interval 1	Interval 2	Interval 3	Expected Queue
Booth 1	0.44	0.46	0.78	1-2
Booth 2	0.82	0.82	1.22	1-2
Booth 3	1.22	1.16	1.63	1-2
Avg Max Queue	3.25	3.17	4.08	3-4

Table 4-39. Volume comparison Beachline-West Toll Plaza

		ORT Volumes			Toll Plaza Volumes		
		Total	Cars	Trucks	Total	Cars	Trucks
Interval 1	Field Data	168.0	157.0	11.0	41.0	41.0	0.0
	CORSIM Results	167.3	157.4	9.9	39.8	39.8	0.0
Interval 2	Field Data	184.0	173.0	11.0	51.0	51.0	0.0
	CORSIM Results	176.7	166.1	10.6	52.9	52.9	0.0
Interval 3	Field Data	222.0	212.0	10.0	61.0	58.0	3.0
	CORSIM Results	210.8	201.4	9.4	62.0	59.1	2.9

Table 4-40. Queuing comparison Beachline-West Toll Plaza

	Interval 1	Interval 2	Interval 3	Expected Queue
Booth 1	0.34	0.51	0.78	≤1
Booth 2	0.71	0.91	1.25	≤1
Booth 3	1.02	1.13	1.48	≤1
Avg Max Queue	3.00	3.16	3.67	2-3

Figure 4-1. Link-node diagram of generic toll plaza

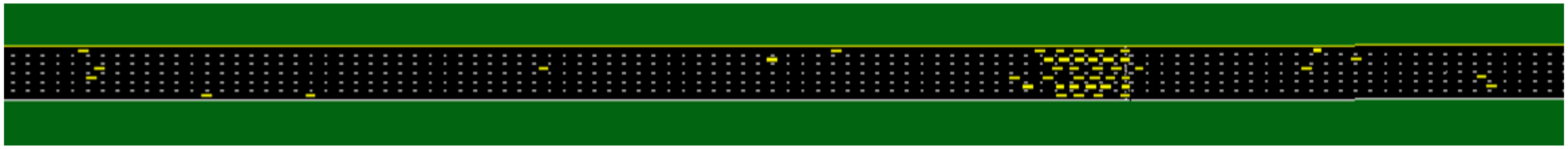


Figure 4-2. Six lane generic toll plaza developed for service time verification

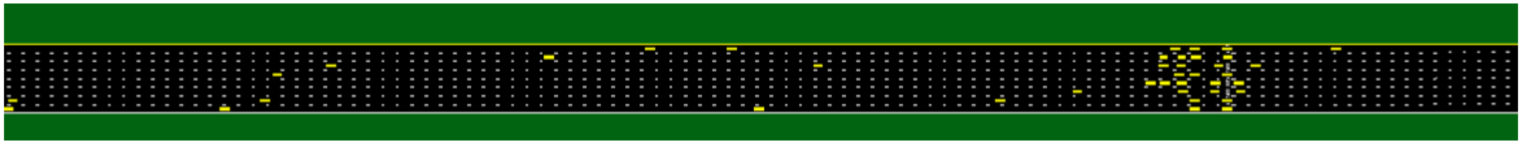


Figure 4-3. Eight lane generic toll plaza developed for payment distribution verification

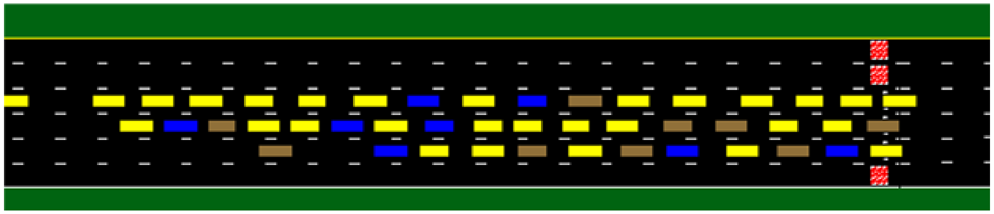


Figure 4-4. Verification testing results for toll booth restrictions

Figure 4-5. Aerial view of Leesburg toll plaza

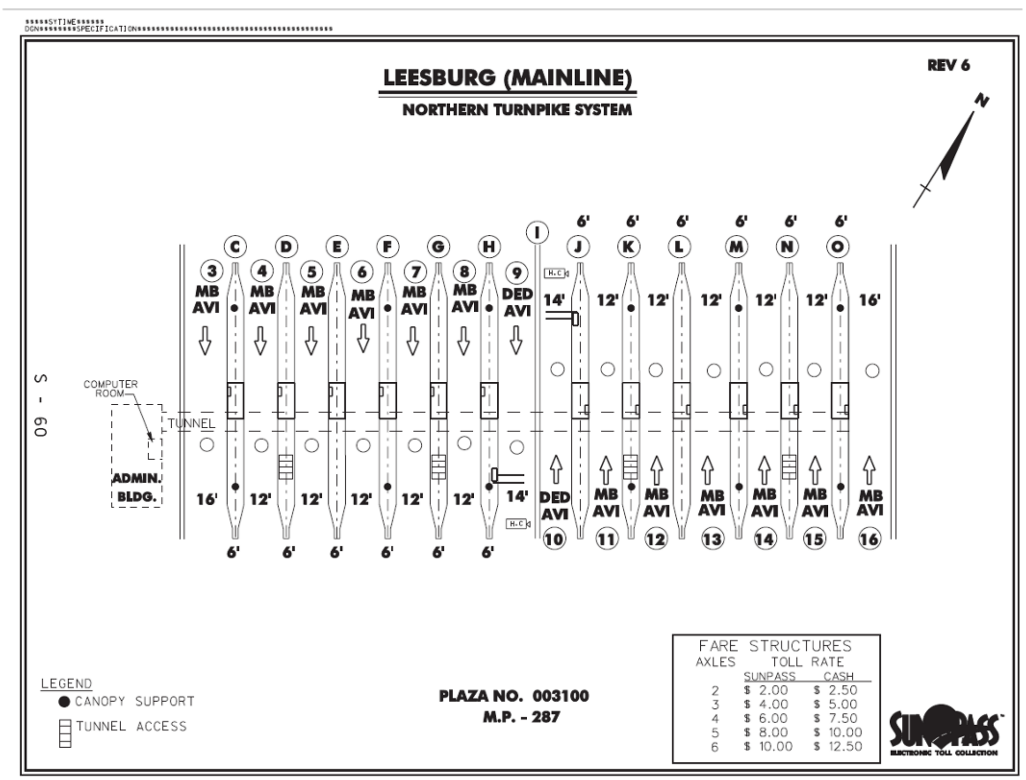
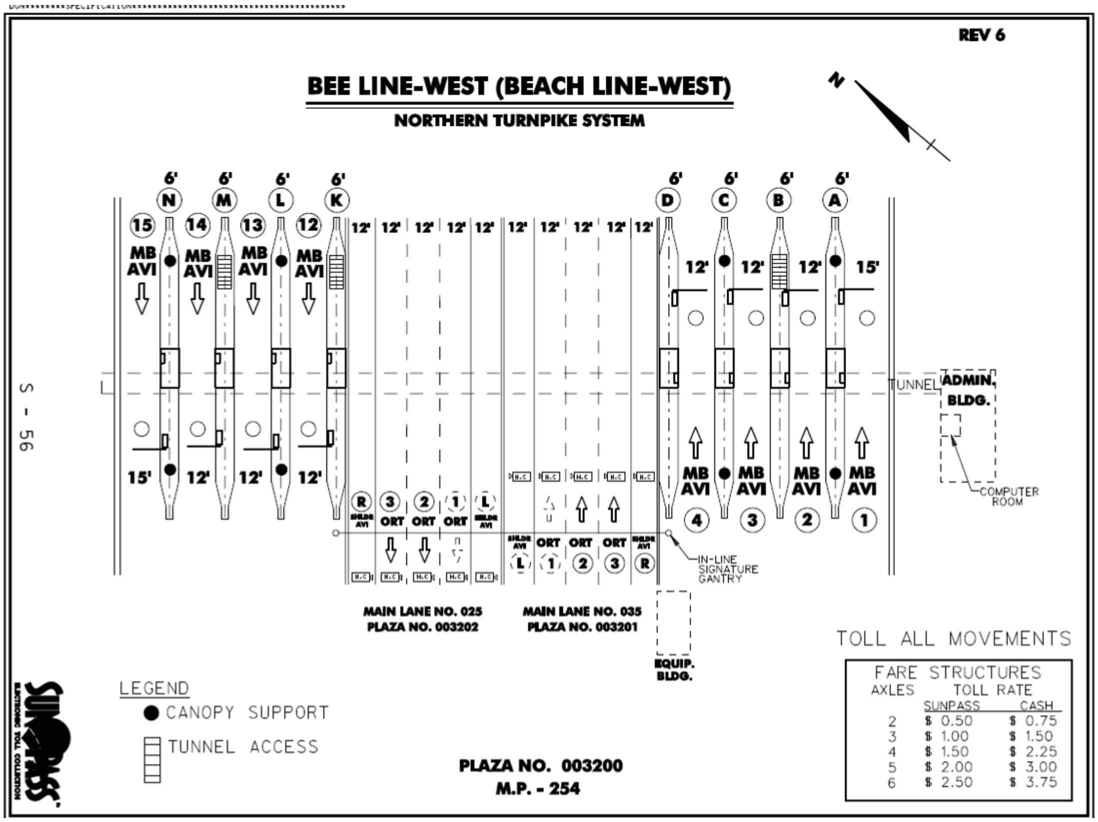


Figure 4-6. Toll booth configuration for Leesburg toll plaza (Courtesy of FDOT)

Figure 4-7. Aerial view of Beach Line-West toll plaza eastbound approach

Figure 4-8. Aerial view of Beach Line-West toll plaza westbound approach



FARE STRUCTURES		
AXLES	TOLL RATE	
	SUNPASS	CASH
2	$ 0.50	$ 0.75
3	$ 1.00	$ 1.50
4	$ 1.50	$ 2.25
5	$ 2.00	$ 3.00
6	$ 2.50	$ 3.75

Figure 4-9. Toll booth configuration for Beach Line-West toll plaza (Courtesy of FDOT)

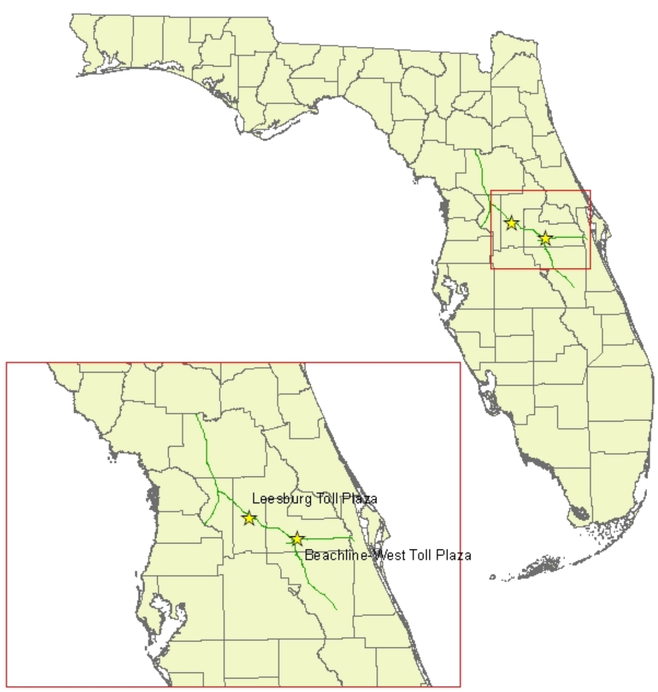


Figure 4-10. Location map of toll plazas for study

Figure 4-11. Traffic conditions at Leesburg toll plaza during study period

Figure 4-12. Traffic conditions at Beachline-West toll plaza during study period

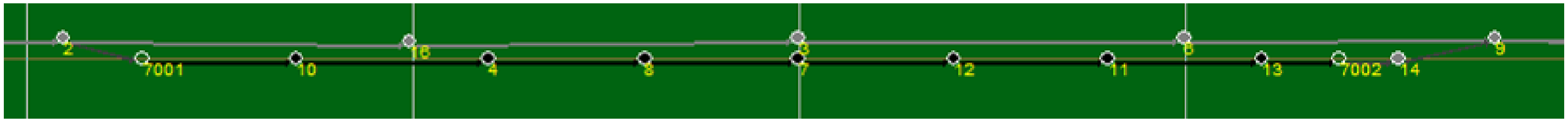


Figure 4-13. CORSIM node-link diagram for Beachline-West Toll Plaza

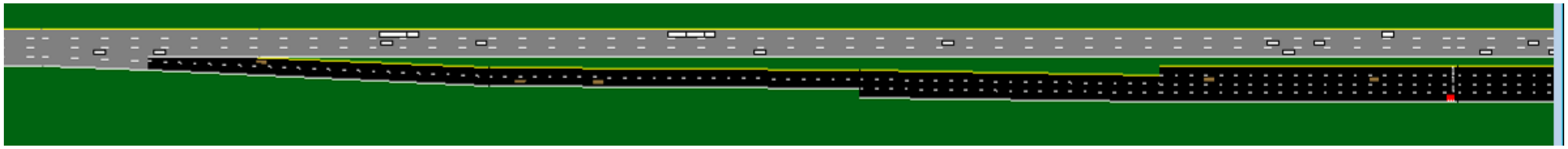


Figure 4-14. CORSIM model of the Beachline-West Toll Plaza

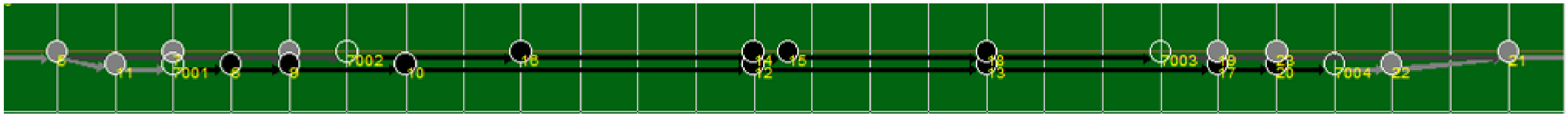


Figure 4-15. CORSIM node-link diagram for Leesburg Toll Plaza

Figure 4-16. CORSIM network model of the Leesburg Toll Plaza

CHAPTER 5
SUMMARY AND RECOMENDATIONS

Summary

The results of this study produced the integration of toll plaza modeling into CORSIM. To accomplish this, new algorithms were developed for CORSIM. These new algorithms and their required inputs were then verified for accuracy and constancy during the verification testing. During this testing, various experiments were developed to test each algorithm and input individually. Once it was determined that the toll plaza features were working correctly, two toll plaza along Florida's network of toll roads were chosen to be simulated by CORSIM as a means to validate the simulation tool. Traffic data and video footage for these two toll plazas were obtained from FDOT. This information was input into the developed CORSIM network models for the two toll plazas to see if CORSIM would produce similar outputs. From this testing, it was determined that CORSIM could accurately model real life traffic conditions at toll plazas. This was determined by comparing the outputs produced by CORISM to various traffic data collected at the toll plazas. From this, it was determined that the two CORSIM toll plaza models and real toll plazas had very similar volume and queuing characteristics

To assist users in simulating toll plazas, research was also conducted on establishing reasonable default values for various toll plaza inputs for CORSIM. These default values give users fairly accurate inputs without the need for expensive traffic studies and data collection. This research led to the creation of default service times for four payment types commonly found in Florida, as well as default values for queue setback distance and lane change sensitivity.

This research also led to the development of an equation to estimate pull-up time. Pull-up time is the time it takes a vehicle in the first queue position at a toll booth to accelerate, decelerate, and stop immediately adjacent to the toll booth. This pull-up time equation allows users to estimate an average service time input for CORSIM for any payment type based to obtain the desired processing rate.

Recommendations

During the process of completing this research, some additional improvements for toll plaza modeling in CORSIM were thought of, but were outside of the scope of this project. It is recommended that further research be conducted on the following items.

User Specified Acceleration and Deceleration Rates for Toll Plaza Links

As mentioned previously, it is believed that vehicles approaching and departing a toll plaza use higher acceleration/deceleration rates than typically observed at other control devices (e.g., signalized intersections). While CORSIM allows a user to modify the acceleration/deceleration rates for an entire network, it does not allow these rates to be varied at a link level. The higher acceleration and deceleration rates would possibly lead to more accurate values of control delay.

Integration of ORT Lanes into Toll Plaza Link

One current inconvenience that would be nice to address is having to code ETC-only lanes separate from the toll plaza link Currently, the toll plaza link cannot handle an ETC-only lane built into the toll plaza link. Instead, a separate link, parallel to the toll plaza link, is used to simulate ETC-only lanes. This is because ETC-only lanes are not stop controlled and operate at either the free flow speed of the freeway or at a reduced speed, usually 25 mph to 35 mph as specified by regulatory signs. To accomplish this it will be necessary to make two improvements within the CORSIM framework to allow ETC-only lanes to be integrated into the toll plaza link.

First, changes will need to be made to the toll plaza stop control device that will allow the user to individually specify which lanes to apply the toll plaza stop control device. It is possible to bypass this issue by assigning a service time of 0 seconds for one payment type. This would allow the selected payment type to bypass stopping at the toll booth. However, by utilizing this method the user is unable to adjust the speed of the ETC-only lanes. This prevents this method from being used for ORT lanes. To fully integrate ORT/ETC-only lanes it would be necessary to improve NETSIM links to allow for multiple free-flow speeds along a single link. Currently, CORSIM only allows a user to specify one free-flow speed for each link. By making this change it would allow a user to specify the thru speed for the ORT lane and the approach speed for the traditional toll lanes.

As nice as this improvement would be, it is not always desirable to incorporate the ORT lanes into the toll plaza. This is due to the fact that many of the newly developed toll plazas have a distinct separation between the toll plaza and the ORT lanes. However, for cases where there is no physical separation between the ORT lanes and the toll plaza, integrating the ORT lanes into the toll plaza link would likely increase the accuracy of the simulation.

Logit Model for Toll Lane Selection

In the future, one possible improvement that could be made to the developed CORSIM model would be to implement a multinomial logit model to determine toll plaza lane selection. Logit models are well suited to the modeling of unordered discrete choices. The basis of the Logit model, the utility equation, would likely be a function of variables such as payment method, number of lanes between the vehicle's current lane and a given toll plaza lane, queue length at toll plaza lane, and number of trucks in queue. From the developed utility equation, utility values would be calculated for each toll lane. Based on the calculated utility values, the probability of selecting each toll lane would be calculated. The probability values would be compared to uniformly-generated random numbers to determine the lane selection.

However, any improvement in the accuracy of toll lane selection due to a Logit model must be weighed against increases in computation time due to more mathematical calculations.

APPENDIX A
CORSIM USER GUIDE FOR TOLL PLAZA MODELING

Overview

This appendix serves as a guide for CORSIM users to learn how to properly code a toll plaza section into CORSIM 6.3. This guide includes detailed discussion on the necessary input values, description of the new record types and fields, allowable ranges and default values, and the proper formatting of the .trf code. The end of this guide will include a step-by-step walkthrough of coding a toll plaza into CORSIM 6.3.

Toll Plaza Data Discussion

Before getting into the discussion on each toll plaza record type and where each item of input data is entered into CORSIM, it is important to understand the necessary data needed to properly simulate any given toll plaza. This information can be broken up into two categories; essential toll plaza data and secondary toll plaza data.

Essential Toll Plaza Data

Essential toll plaza data is data that is absolutely necessary to adequately simulate a toll plaza in CORSIM. Not inputting this information into CORSIM will cause fatal errors when a simulation of a network containing toll plazas is attempted. This information includes traffic and toll plaza characteristics.

When attempting to simulate a toll plaza, there is one primary traffic characteristic needed by CORSIM: the percentile distribution of each payment type within the traffic stream. This information is necessary for CORSIM to simulate a toll plaza because CORSIM utilizes these percentile inputs to properly distribute all the available payment types to the vehicles entering the toll plaza segment. In addition to the basic percentile distribution, additional information concerning the ETC payment type may be needed.

This is only necessary if ETC-only lanes are available at the toll plaza. When ETC-only lanes are available, a percentile distribution is needed of ETC users utilizing the ETC-only lane(s) and ETC users utilizing the traditional toll lanes. The reason for this will be discussed in more detail in the “Simulating ORT Lanes” section

In addition to the traffic characteristics just discussed, there is an essential datum needed concerning the toll plaza characteristics. This datum concerns the payment types accepted at each toll booth. Currently there exist a wide variety of payment configurations utilized at toll plazas, such as ETC only, mixed use, ETC, and ACM to name a few. In addition to this, a single toll plaza can utilize a different payment combination for each of its toll booths. To accommodate this wide variety of toll plaza configurations, it was determined that the user would have to specify the payment types accepted at each toll booth. To ensure that all applicable payment types are accepted at the plaza, a fatal error will occur if a payment type specified by the payment distribution input is not accepted at the toll plaza.

Secondary Toll Plaza Data

Secondary toll plaza data is additional information concerning the toll plaza that is not absolutely necessary to simulate a toll plaza. This information adds additional data that will improve the accuracy of the simulation; however, default values for these inputs are already specified in CORSIM. Failure to input this data will not result in a fatal error. There are currently four toll plaza inputs that fall into this category of secondary data; inputs include queue setback distance, payment average service time, , “toll plaza ahead” warning sign reaction point, where the toll lane selection algorithm takes effect, and vehicle sensitivity to lane changes for toll booth selection.

Queue setback distance

Toll plazas typically do not allow vehicles to queue bumper to bumper directly behind the vehicle at the toll booth. Instead, a sign is usually used to inform the first vehicle in the queue where they are required to stop. This setback distance is utilized to provide additional safety to the toll booth workers. To accommodate this issue, a queue setback distance input was incorporated into CORSIM. This value provides the user with the ability to define what the required pull up distance is in feet, and is a factor in the pull-time time discussed in the next section. The default value for this input is 25 feet with an input range of 0-99 feet.

Average service time

Ideally, for modeling existing toll plazas, average service times should be measured in the field. However, when this is not possible or a future toll plaza is being simulated, typical service times for four payment types commonly found Florida were identified. See for the service times for each payment type. These service times were obtained from average processing rates for four payment types obtained from FDOT. The FDOT information provides basic service times for four payment types utilized on toll roads statewide. It should be noted that the “Ticket” payment type service time is based on the average service time for vehicles entering a ticket toll system; the service time for an exit toll booth is much higher, around twenty seconds instead of seven seconds. It is important to note that there is a distinct difference between service time and processing rate. The processing rate of a toll booth or payment type is the combination of the pull-up time and the service time. If only the processing rate was obtained, use the following equation to estimate what portion of the processing rate can be attributed to the pull-up time:

$$PullupTime = 3.222 + 0.056 \times QueueSetbackDist + 0.015 \times \%Trucks \quad \text{(A-1)}$$

By knowing the processing rate and estimating the pull-up time, the service time can be determined.

Reaction point for toll plaza warning sign

To ensure that vehicles have adequate distance to get to their desired toll booth, a user-specified reaction point distance input was created for toll plazas. This reaction point can be loosely translated into real world terms as the first road sign informing drivers that they are approaching a toll plaza. This sign would also contain information directing what payment type is accepted at each toll booth. It is after vehicles pass this reaction point that they are randomly assigned a payment type based on the payment distribution input previously mentioned. It is at this point that vehicles start to identify which toll booth is preferred (based on whether it is open, accepts the driver's payment type, queue length, and number of required lane changes). In the case of the user not specifying an input for the reaction point, the reaction point distance is established by either a default distance of fifteen hundred feet or if the link containing the toll plaza is directly connected to an interface node the interface node would serve as the reaction point.

Lane change sensitivity to toll lane selection

When the toll lane selection process is being applied to a vehicle, the toll lane selection algorithm utilizes an equation that evaluates each toll lane relative to the toll lane a vehicle is currently in. This equation utilizes relative queue length, required number of lane changes, and a sensitivity factor. The sensitivity factor is a variable that affects a driver's willingness to make a lane change to save one queue space. The input range for this value is 0 to 3 with 0 meaning a vehicle is very willing to make a lane change and 3 less likely to make a lane change. If no value is input then a default sensitivity of 0.7 is utilized by CORSIM. The equation used to assist with toll lane selection is as follows:

$$TLD_j = \frac{\Delta Q}{LC^{SF}} \tag{A-1}$$

where,

TLD_j = Toll lane desirability of toll lane *j*

ΔQ = Difference in queue length between vehicle’s current toll lane Q_i and adjacent toll lane Q_j

LC = Number of lane changes required for vehicle to reach toll lane *j*

SF = Lane change sensitivity factor (default value = 0.7)

To better understand how the toll lane desirability equation is used, a hypothetical toll plaza scenario was developed. See Figure A-1 for the visual representation of the toll plaza. For this configuration, the subject vehicle would first identify that toll booth 5 is closed and remove it from consideration. Next, each toll lane is evaluated, relative to the vehicle’s current lane, starting with the left-most toll lane. If that toll lane accepts the vehicle’s payment type, Eq. 3-1 is applied. For example, for lane 1 in Figure A-1, the subject vehicle approaches in lane 3, so the difference in queue is 2 vehicles and the number of lane changes to move to that lane would be 2. Thus, the *TLD* value is calculated as follows,

$$TLD_j = \frac{2}{2^{0.7}} = 1.23 \tag{A-2}$$

Note that if the current lane the vehicle is in has a queue length less than or equal to the queue length of any other toll lane, the vehicle will continue in that lane. The results from applying Eq. 3-1 to the other lanes are shown in Table A-1. Based on these results, the subject vehicle would choose toll booth 1 as its desired toll booth.

Output Processor

For toll plaza simulation, two new MOE categories were developed to collect data concerning the toll plaza portion of the network. In the output processor window, these outputs are referred to as "TOLLBOOTH" and "TOLLPAYMENT".

The "TOLLBOOTH" MOE contains the majority of the toll plaza outputs available, including average service time, exit volumes, density, average speed, and average delay per vehicle. It should be noted that the service time output produces an output of an average service time for each toll lane. This means that the service time output will be based on the weighted average of the service times of the payment types assigned to that toll booth.

The "TOLLPAYMENT" MOE only contains one output. This output produces the traffic volumes exiting each toll booth by each payment type. This means that if a user wishes to gather information concerning the traffic volumes for each payment type at each toll booth, this MOE would be utilized.

Record Type Discussion

To fully understand how the toll plaza modeling functions, it is necessary to describe in detail the record types pertaining to toll plaza simulation. For toll plaza simulation, three record types are utilized by CORSIM to specify the necessary input data. It should be noted that each of these record types can be modified in different time periods.

Record Type 82

Record Type 82 contains information concerning the mean service times for all four payment types and the location upstream of the toll plaza where drivers react to a “toll plaza ahead” warning sign. To properly input the mean service time for each toll payment type, it is important to remember that service time is input as tenths of a second. This means that a desired service time of 7 seconds would be represented by 70 in the .trf format. Concerning the toll warning sign input, this value is specified in feet in the .trf format. Formatting for Record Type 82 can be found in Figure A-2. The input range for each service time is 0-9999 tenths of a second.

Record Type 83

Record Type 83 contains information pertaining to the status of the toll booth. This information includes payment types accepted at each toll booth, vehicle types allowed to utilize each toll booth, queue setback distance at the toll booth, and the lane changing sensitivity factor.

It was determined that the best way to implement payment acceptance and toll booth status, open or closed, for a toll booth into CORSIM was to combine both values into one input. This was done by utilizing a four digit binary code to tell CORSIM what payment type is accepted at each toll booth. In this binary format, a “zero” tells CORSIM the payment type is not accepted at the booth and “one” tells CORSIM the payment type is accepted at the booth. Each toll booth has its own binary code allowing the user a high level of customization to fit the user’s needs. In the case of no payment type being accepted at a toll booth, that is, 0 for all payment types, the toll booth in question is considered to be closed and no vehicles will utilize it. See Table A-1 for payment location within the binary code.

A binary coding configuration was also utilized for the vehicle restriction input. For this input a sixteen digit binary code is utilized to represent the sixteen vehicle types available in CORSIM. For this coding, a 0 represents that the vehicle type can utilize the toll booth and a 1 means the vehicle type cannot use the toll booth. Refer to the CORSIM user manual for a detailed description of each vehicle type.

Record Type 83 also contains the input information for the queue setback distance and the lane changing sensitivity factor. The units for queue setback distance are feet. The value for queue setback distance can range from 0 to 99 feet. The lane changing sensitivity factor corresponds to the willingness of a driver to make a lane change to save time in the queue. This value is input in tenths of a second and ranges 0 to 30 (i.e., 0 to 3 seconds). Formatting and input locations for Record Type 83 can be found in Figure A-3.

Record Type 84

Record Type 84 contains the payment distribution information for the four payment types. The payment distribution for each payment type is represented by a whole number from 0 to 100. A fatal error is produced from this record type if the sum of the various payment distributions does not add up to 100. Formatting for Record Type 84 can be found in Figure A-4.

Simulating ORT Lanes

Simulating ORT lanes creates an interesting challenge when trying to model a toll plaza. The main issue with ORT lanes is that vehicles do not have to reduce their speed to travel through the plaza. This creates a dilemma for one reason. First, a single CORSIM link cannot currently accommodate different speeds for each lane.

To resolve these issues, it was determined that currently the best solution to accommodate ORT lanes was to create ORT lanes on a link parallel to the toll plaza. By knowing the overall ETC penetration and percentage of ETC vehicles that utilize mixed-used payment lanes at a toll plaza, a diagonal turning movement can be coded into CORSIM. To ensure that ETC vehicles assigned to the ORT lanes utilize the proper lane, record type 81 is utilized. Record type 81 is utilized to specify in percent how cooperative the subject vehicle is to allowing a vehicle making lane changes. By inputting a high cooperation value vehicles are more likely to allow other vehicles to make lane changes into the ORT/ETC-only lanes.

To simulate ORT and ETC-only lanes, both NETSIM and FRESIM links can be used. Typically a FRESIM link is desired as it can handle diagonal lane changes much better than NETSIM links; however, this should not be the deciding factor in using FRESIM over NETSIM links. To determine which type of CORSIM link to utilize, the speed and type of the ORT lanes should be looked at. A FRESIM link should be utilized for the following scenarios; when no deceleration is required to go thru the ORT lanes, the ORT lanes are integrated into the mainline freeway and operate at the same regulation speed as the freeway containing the toll plaza, or there is a distinct physical separation between the ORT/ETC-only lanes and the toll plaza. NETSIM links on the other hand should be utilized when the speed thru the ORT is not the speed of the freeway or there is no separation between the ORT lanes and the toll plaza. See Figure A-5 and Figure A-6 for depiction on when to use FRESIM or NETSIM links to simulate ORT lanes. See Figure A-7 and Figure A-8 for depiction of networks utilizing ORT lanes.

Example Problems

This section provides three examples on how to code toll plazas into CORSIM 6.3. These examples include a basic, complex, and multi-time period toll plaza models. Since there is no plan to incorporate the toll plaza inputs into TRAFED, graphical user input concerning toll plaza inputs are provided by TSIS Next, the newest version of CORSIM that integrates TRAFED and TRAVU into one program. All other visual inputs are provided by TRAFED of CORSIM 6.3. At the end of this section, the .trf formatted simulations are provided for the three examples.

Example 1

This example is based on a traditional toll plaza without ORT lanes. The inputs are as followed:

- Simulation length of 15 minutes
- Traffic volume of 2000 vehicles per hour
- Assume there are no heavy vehicles
- Two lane approach and departure
- Approach length of 1500 feet
- Departure length of 1500 feet
- Four lane toll plaza
- Payment types accepted at the plaza are ETC and Manual
- Toll booth 1 accepts ETC
- Toll booth 2 and 3 accepts ETC and Manual
- Toll booth 4 accepts Manual
- Payment distribution is 70% ETC 30% Manual
- Manual payment type service time is 5.5 seconds/vehicle
- ETC payment type service time is 1.5 seconds/vehicle
- Queuing offset of 5 feet
- Lane change sensitivity factor of 0.7

Simulation and network setup

Similar to setting up a normal CORSIM simulation the first step is setting up the network properties inputs and network inputs. The network properties screen is the first input screen seen when opening a new TSIS Next model. This includes the simulation length, number of time periods, and simulation start time. For this example the only input that needs to be adjusted is the simulation length, which is input as 900 seconds. See Figure A-9 for screen shot of network properties input screen.

With the network properties input the next step is to build the network. For this example only NETSIM nodes and links are needed. For this network each node is spaced 500 feet apart and connected by a link. Using a multiple link approach for a toll plaza allows the user to incrementally increase the number of lanes on each link until the number of lane of the link matches the number of toll lanes of the plaza. When increasing the number of lanes make sure that the lane alignment matches the desired direction of lane fanning out. Figure A-10, Figure A-11, and Figure A-12 provide node and link configuration for Example 1. After building the network the entry traffic volume is entered into the entry node.

Toll plaza setup

Now that the simulation and network have been setup, the next step is to setup the toll plaza inputs. In TSIS Next this is found in the “edit link” input window. For this example link [3,4] contains the toll plaza. With the “edit link” window open bring up the toll plaza tab, within this tab contains all the inputs needed to code the toll plaza. These inputs are greyed out until the “toll plaza exists” icon is selected. Once the icon is selected the toll plaza inputs can be changed. First to bit of information to be added to this section is payment types accepted at each toll booth. Each box correlates to a toll booth and payment type. The numbering for toll booths starts from right to left, this means that the far left lane is toll booth 1. In the .trf format coding of the toll booths is right to left. After configuring the toll booths, the next step is to input the service times and payment distribution values. At this point, if there were desired processing rates for each payment type the pull up equation would be utilized to calculate the actual service for each payment type. For this example a service time was provided so this step is skipped and service times and payment distribution values are input. Finally, the last inputs entered into this window are the setback distance and lane change sensitivity values. See Figure A-13 for a screen shot of the completely input toll plaza tab for this example. With this information input the model is built and ready to be run. Figure A-14 and Figure A-15 provide examples of the toll plaza simulation based on the inputs provided.

Output processor

With the toll plaza model created data can now be collected from the simulation using the output processor. For this example the output processor is going to be used to determine lane utilization by payment type for the entire fifteen minute simulation. To do this open up the output processor and under the MOE section select “TOLLPAYMENT” and under the object section select all objects under the “TOLLPAYMENT” category. Under the “format and options” section select the format option of a CVS file. It is important that the CVS file format is selected as this is the only file type available that outputs toll plaza information. See Figure A-16 for a visual of the output processor configuration. With the output processor configured, the multiple run tool is utilized to collect the desired information. Table A-3 has the results of this testing. The formatting for Example 1 can be found in Appendix B. This concludes Example 1.

Example 2

Example 2 utilizes a real life toll plaza. For this example the Beachline-West toll plaza along the Beachline Expressway was utilized. This is a much more complex network that requires the implementation of ORT lanes. For this example service time and exiting volumes will be collected. Inputs used for this simulation are below:

- Simulation length of 15 minutes
- Traffic volume of 3000 vehicles per hour
- Assume there are no heavy vehicles
- Four lane approach
- Three lane departure
- Approach length of 1500 feet
- Departure length of 1500 feet
- Four lane toll plaza
- Three lane ORT segment
- Payment types accepted at the plaza are ETC, ACM, and Manual payment types
- Toll booth 1, 2,3, and 4 accepts ETC, ACM, and Manual payment types
- Payment distribution is 80% ORT ETC users and 20% traditional toll plaza users with 60% ETC, 30% Manual, and 10% ACM
- Manual payment type processing rate is 10 seconds/vehicle
- ETC payment type processing rate is 5 seconds/vehicle
- ACM payment type processing rate is 7 seconds/vehicle
- Queuing offset of 5 feet
- Lane change sensitivity factor of 0.7

Simulation and network setup

As the basics of developing a network for toll plaza have already been discussed in detail this section will look more at implementation of ORT lanes into a toll plaza simulation. When coding toll plazas with ORT lanes the user must first determine which part of the toll plaza will be the mainline portion. This is typically determined by either the number of ORT lanes or the location of the ORT lanes. In the case of this scenario the ORT lanes are the mainline. As it can be observed in Figure A-17, the aerial provided demonstrates the reason that the ORT lanes were chosen for the mainline portion. In this case the reason was because of ORT lane's location. When compared to the traditional toll plaza location it appears that the lanes to the traditional plaza appear to be an off ramp. If this was the Leesburg toll plaza the traditional portion of the plaza would be the mainline. Figure A-18 depicts the network split and Figure A-19 provides the completed node and link diagram for this network. Note that in the node and link diagram the toll plaza node, node 7, matches up with a node along the ORT section, node 3. This network design can assist the user in collecting data for the toll plaza as both nodes would be located in the same spatial position allowing for accurate collection of volumes during multiple time periods.

Toll plaza setup

Implementing a toll plaza into this network follows the same steps described in Example 1. The only difference being that the service time for each payment type needs to be determined based on the desired processing rate provided. This is done by utilizing the pull up equation. From this equation a pull up time of 3.5 seconds was calculated for this plaza. Subtracting this value from the desired processing rate produces approximate service times for each payment type.

In addition to determining the service times for each payment, the volume split needs to be determined. This split determines the vehicle utilization of the two different parts of the toll plaza. As mentioned in the input data 80%, 2400 vph, of the vehicles utilize the ORT lanes and 20%, 600 vph, utilize the traditional toll plaza. This information is input at the node where separation between the traditional toll plaza and the ORT lanes occurs. Figure A-20 shows the inputs for the network split.

Output processor

With the toll plaza model created data can now be collected from the simulation using the output processor. For this example the output processor is going to be used to determine the average service rate for each lane and exiting volume of each lane during the fifteen minute simulation. To do this open up the output processor and under the MOE section select “TOLLBOOTH” and select “average service time” and “vehicle discharge total”. For the object section select all objects under the “TOLLBOOTH” category. In addition to the MOEs for the toll plaza, MOEs also need to be selected for the ORT segment. Like the other toll plaza MOE used in Example one go to the “format and options” section select the format output option as a CVS file. Results of the output processor can be found in Table A-4 and Table A-5. The .trf format for Example 2 can be found in Appendix B. This concludes Example 2.

Example 3

This example is based on a traditional toll plaza without ORT lanes to demonstrate CORSIM 6.3’s ability to simulate multiple toll plaza scenarios within one simulation. This example is based on the same network used for Example 1. The inputs are as followed:

- Simulation uses two 10 minutes time periods
- Traffic volume of 2000 vph during first 10 minute period
- 1500 vph during second 10 minute period
- Assume there are 5% heavy vehicles for both time periods
- Heavy vehicles restricted to toll booth 4
- Two lane approach and departure
- Approach length of 1500 feet
- Departure length of 1500 feet
- Four lane toll plaza
- Payment types accepted at the plaza are ETC and Manual

- Toll booth 1 accepts ETC
- Toll booth 2 accepts Manual
- Toll booth 3 and 4 accepts ETC and Manual
- Toll booth 3 closes during second time period
- Payment distribution is 70% ETC 30% Manual
- Manual payment type service time is 5.5 seconds/vehicle
- ETC payment type service time is 1.5 seconds/vehicle
- Queuing offset of 5 feet
- Lane change sensitivity factor of 0.7

Simulation and network setup

As mentioned previously, Example 3 utilizes the same network configuration and simulation setup as Example 1. As such the setup of this simulation will not be discussed. Please refer to Example 1 for a detailed description on how to create this network.

Toll plaza setup

The setup of the toll plaza for this example follows the same approach as Example 1 with the addition of the heavy vehicle input and the second time period. The heavy vehicle input is found in the entry node. Adding the additional time period can be done one of two ways. One way is for the user to specify that there are two time periods when first creating the simulation file. The other way is by going into the network properties and adding the second time period. See Figure A-21 for the network properties input screen.

With the network fully set up the next step is to incorporate the toll plaza information into the .trf file. For a simulation that uses multiple time periods the toll plaza record types need to be included in each time period only when information concerning the toll plaza changes. In the case of this example, the toll plaza record types do need to be included as a toll booth is closed during the second time period.

The final step is to implement the vehicle restrictions. For this simulation only the far right toll lane can accommodate heavy vehicles. To input this into CORSIM the binary coding for vehicle restrictions in RT 83 needs to restrict vehicle types that are classified as trucks. In NETSIM, vehicle types 2, 6, 7, and 8 are classified as truck class vehicles. Changing the 0 to 1 for these four vehicle types in the binary code for vehicle types ensures heavy vehicles do not utilize toll booths 2, 3, and 4. The finalized .trf file for Example 3 can be found in Appendix B.

Output processor

For this example outputs will be obtained to determine toll booth utilization by vehicle type. To accomplish this, the VEHICLETYPE_LANE MOE will be utilized. The objects selected are all the vehicle types for the four lane on link [3,4]. Similar to the toll booth MOE's, the output file format should be in a .csv format. Results from the output processor can be found in Table A-6 and Table A-7.

Additional Application of CORSIM Improvements

The new toll plaza capability greatly increases the ability of CORSIM to simulate a wide variety of roadway networks. The new toll plaza capability also allows CORSIM to simulate a variety of other applications that are similar to a toll plaza. One such application that can be found for these improvements is border crossings. Like a toll plaza, border crossings utilize a multi booth system to facilitate the flow of traffic through the border crossing and into the country. When looking at the basic characteristics of a border crossing, the only significant difference between the two are the service times. In the case of a toll plaza, services times tend to be in the magnitude of seconds, whereas border crossing service times tend to be in the minutes. The difference in magnitudes for service times produces a large capacity difference between toll plaza booths and border crossing booths. To remedy this issue, border crossings usually provide a larger number of open booths for users. Each CORSIM toll plaza link can accommodate up to a nine lanes. However, multiple toll plaza links can be used “in parallel” as necessary.

.

Table A-1. Lane selection example toll lane desirability

	Booth 1	Booth 2	Booth 3	Booth 4	Booth 5
TLD	1.23	1.00	1.00	-1.00	Closed

Table A-2. Binary Code Use for Payment Acceptance

Numerical Location	Payment Type
1XXX	ACM
X1XX	Manual
XX1X	Ticket
XXX1	ETC

Table A-3. Example 1 lane utilization by payment type

	Lane 1	Lane 2	Lane 3	Lane 4
Manual	89.8	39.2	20.5	0
ETC	0	95	95.8	158.3

Table A-4. Example 2 exiting volumes results

	ORT Lanes	Toll Plaza
Expected Volume	600	150
CORSIM Volume	593.2	155.2

Table A-5. Example 2 average service time by toll booth

	Booth 1	Booth 2	Booth 3	Booth 4
Expected Service Time	3.4	3.4	3.4	3.4
Actual Service Time	4.1823	3.3836	3.7677	3.5695

Table A-6. Example 3 toll booth utilization by vehicle type time period 1

	1	2	5	6	7	8
Booth 1	48.4	4.8	16.5	7.3	4.1	1.3
Booth 2	65.1	0.0	24.6	0.0	0.0	0.0
Booth 3	40.4	0.0	15.0	0.0	0.0	0.0
Booth 4	79.8	0.0	24.2	0.0	0.0	0.0

Table A-7. Example 3 toll booth utilization by vehicle type time period 2

	1	2	5	6	7	8
Booth 1	45.5	4.2	14.8	5.7	2.8	1.2
Booth 2	58.9	0.0	19.2	0.0	0.0	0.0
Booth 3*	0.0	0.0	0.0	0.0	0.0	0.0
Booth 4	76.7	0.0	24.8	0.0	0.0	0.0

* Closed during time period 2

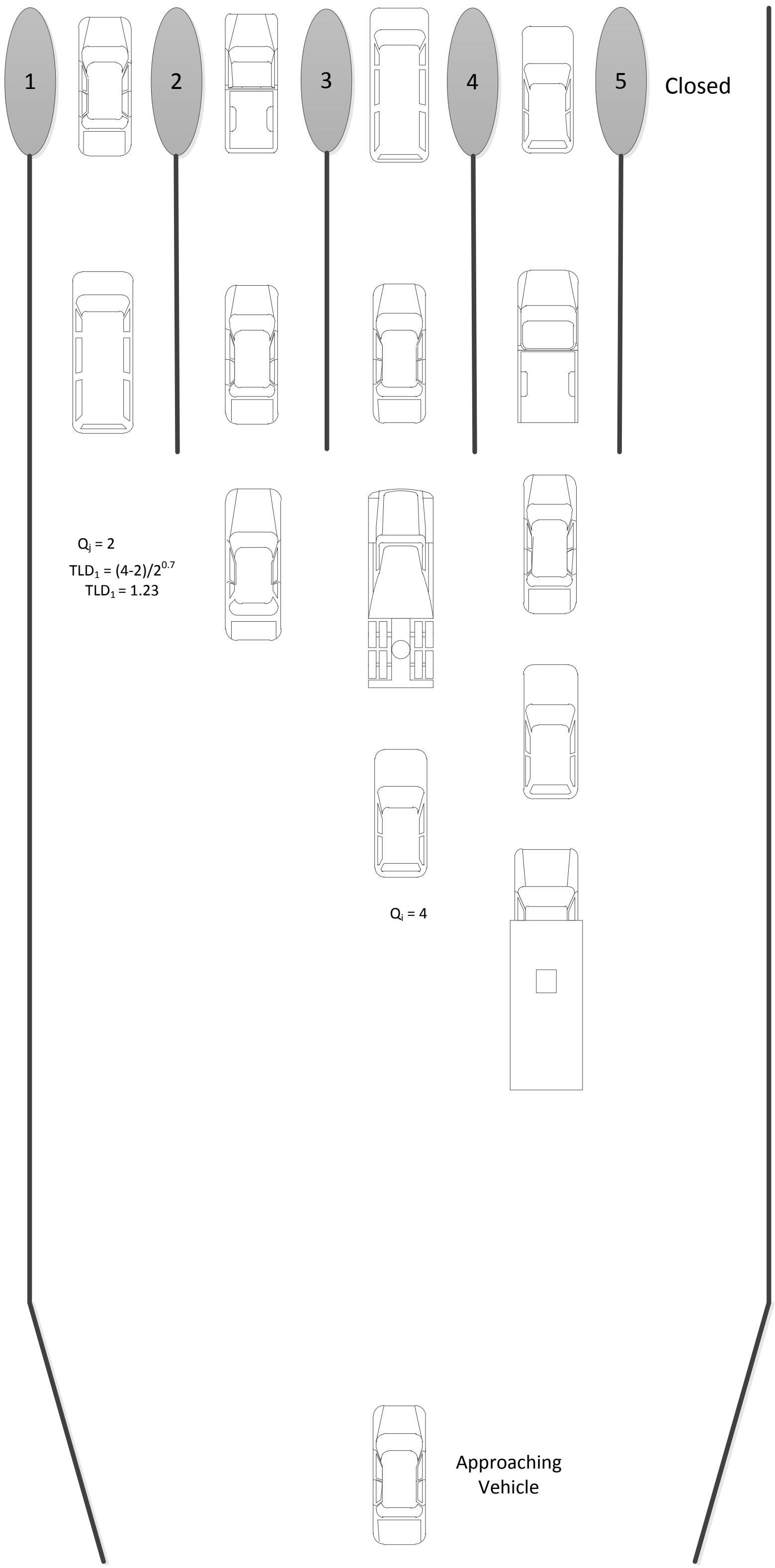


Figure A-1. Lane change selection example

```
RT 82 Mean Service Time by form of payment
upnode
dwnode
mean service time by form of payment
reaction dist
setback
sensitivity parameter
   2 102  25  50  25  101500   5   7                                          82
```

Figure A-2. .trf format for record type 82

```
RT 83 Payment Type by Lane
upnode
dwnode
lane
accepted payment type codes
vehicle restriction codes
   2 102   1  1111          0011111111111111                                 83
   2 102   2  1111          0011111111111111                                 83
   2 102   3  1111          1111001111111111                                 83
   2 102   4  1111          1111001111111111                                 83
   2 102   5  1111          1111110011111111                                 83
   2 102   6  1111          1111110011111111                                 83
```

Figure A-3. .trf format for record type 83

```
RT 84 Distribution of Vehicle Payment Types
upnode, dwnode, distribution of types
   6 102  25  25  25  25                                                     84
```

Figure A-4. .trf format for record type 84

Figure A-5. Toll plaza that should utilize a combination of FRESIM and NETSIM links to simulate ORT lanes note that there is no separation between the toll plaza and the ORT lane

Figure A-6. Toll plaza that should utilize FRESIM link to simulate ORT lanes note separation between toll plaza and ORT lanes

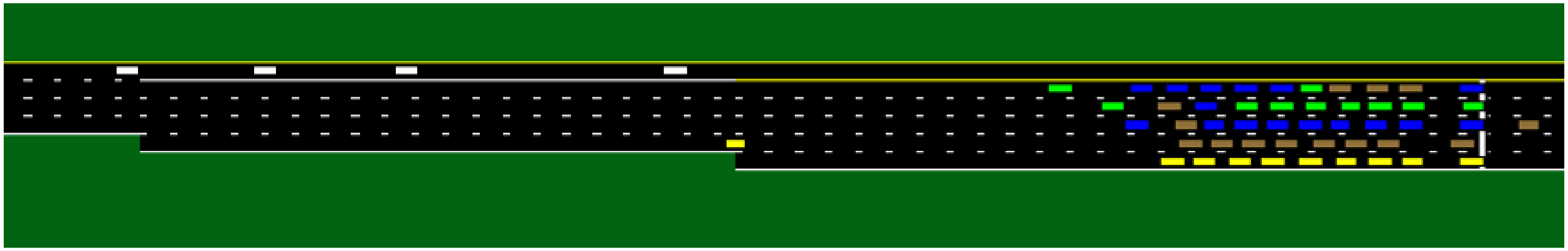


Figure A-7. ORT lane utilizing NETSIM link (ORT lane is top lane)

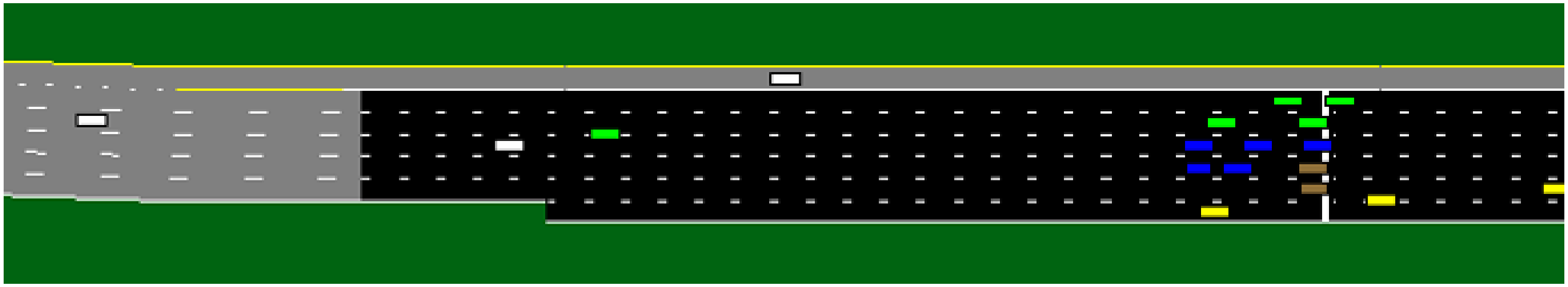


Figure A-8. ORT lane utilizing FRESIM link (ORT lane is top lane)

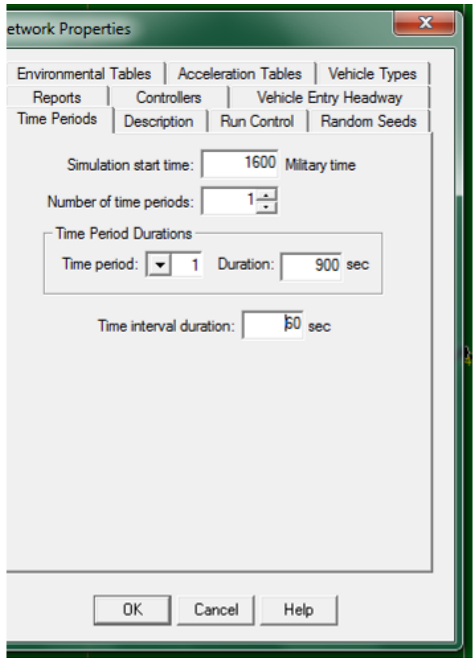


Figure A-9. Network properties input screen for Example 1

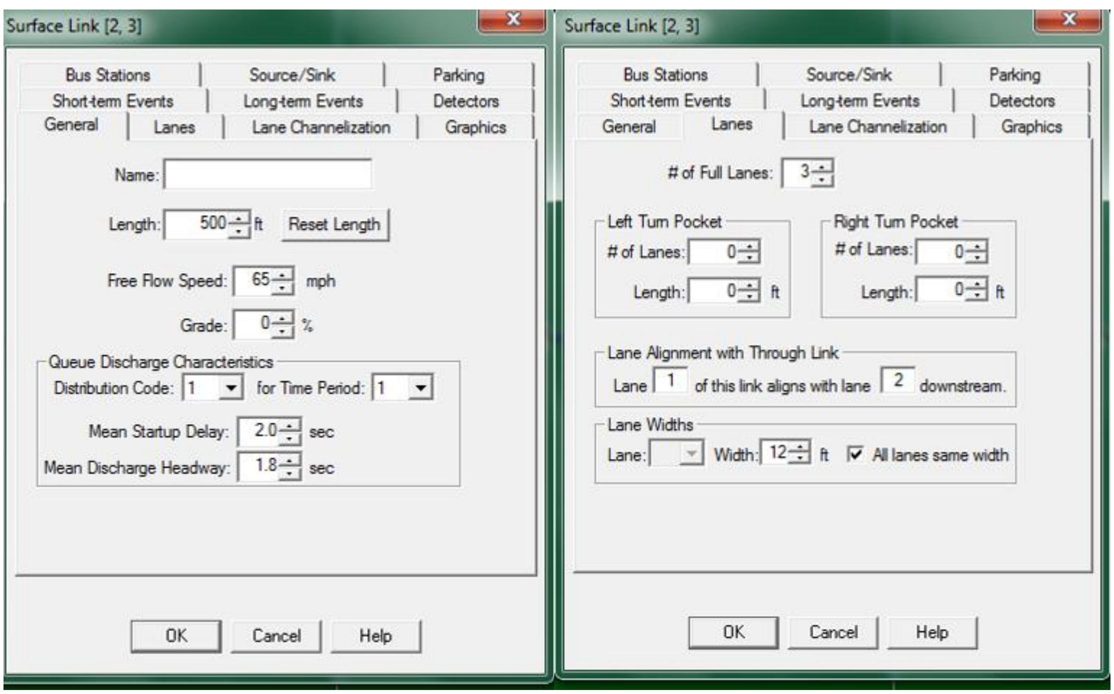


Figure A-10. Link input screens for Example 1

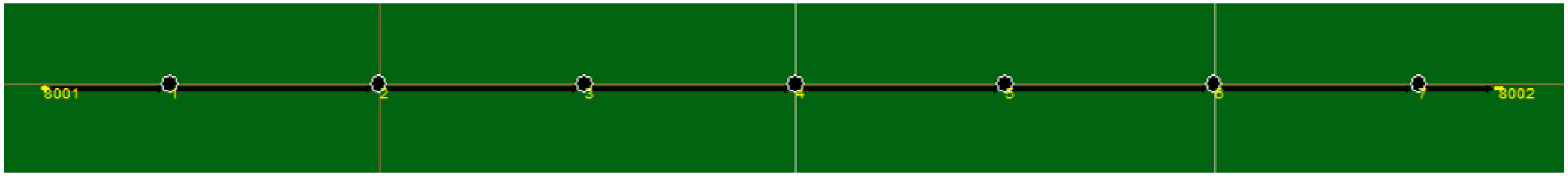


Figure A-11. Node and ink diagram of Example 1

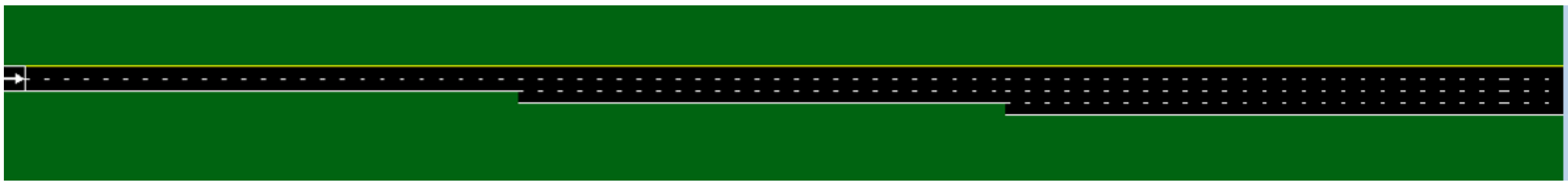


Figure A-12. Example 1 approach

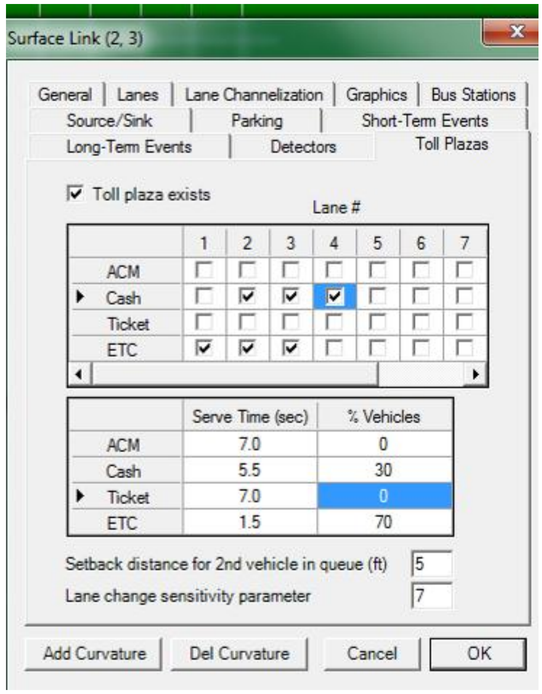


Figure A-13. Toll plaza input screen coded for Example 1

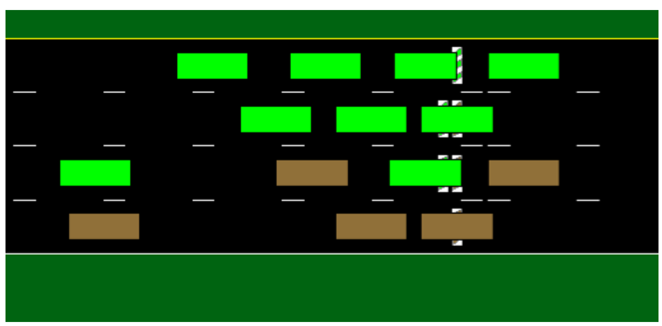


Figure A-14. Toll plaza developed in Example 1

Figure A-15. Toll plaza approach for Example 1

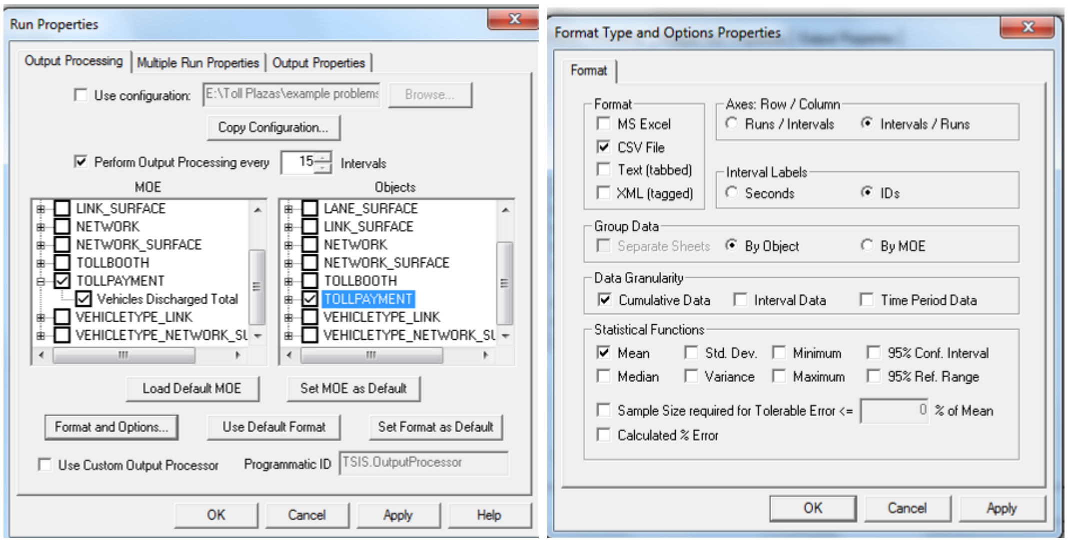


Figure A-16. Output processor configuration for Example 1

Figure A-17. Aerial of Beachline-West Toll Plaza

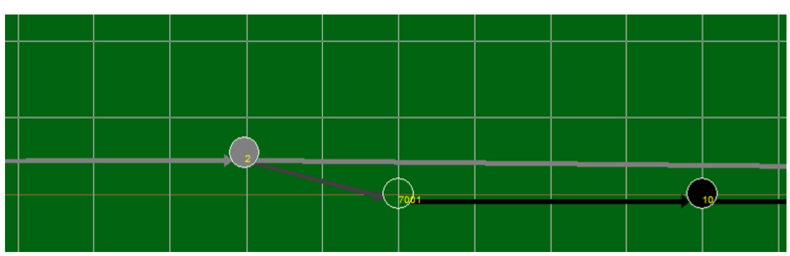


Figure A-18. Example 2 network split (bottom portion leads to traditional plaza)

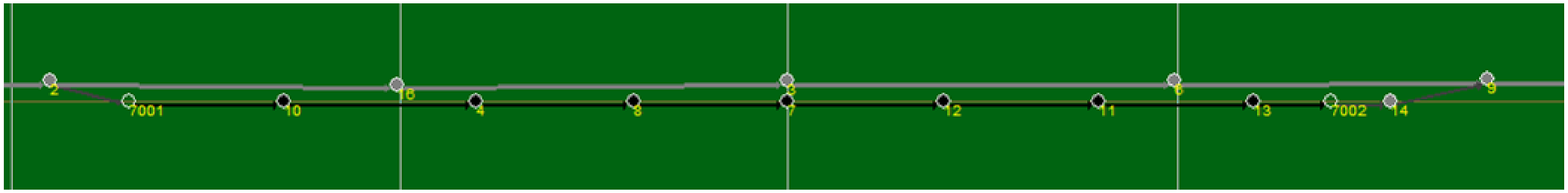


Figure A-19. Node and link diagram for Example 2

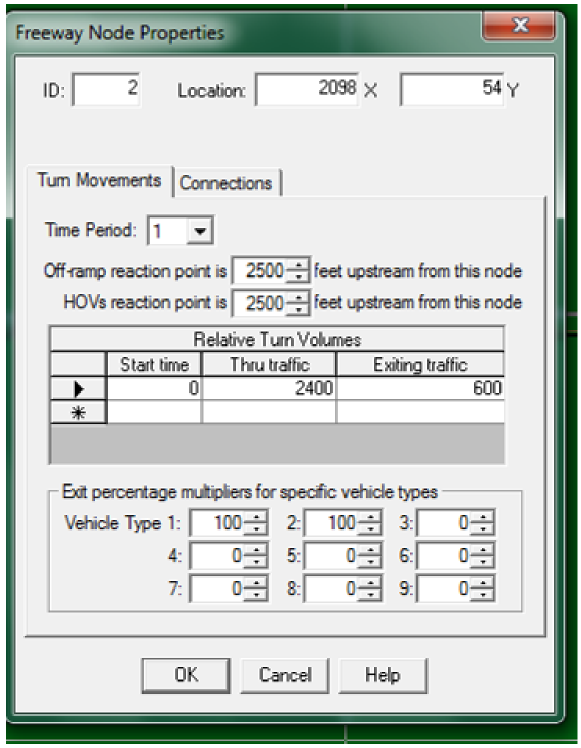


Figure A-20. Off ramp inputs for traditional toll plaza Example 2

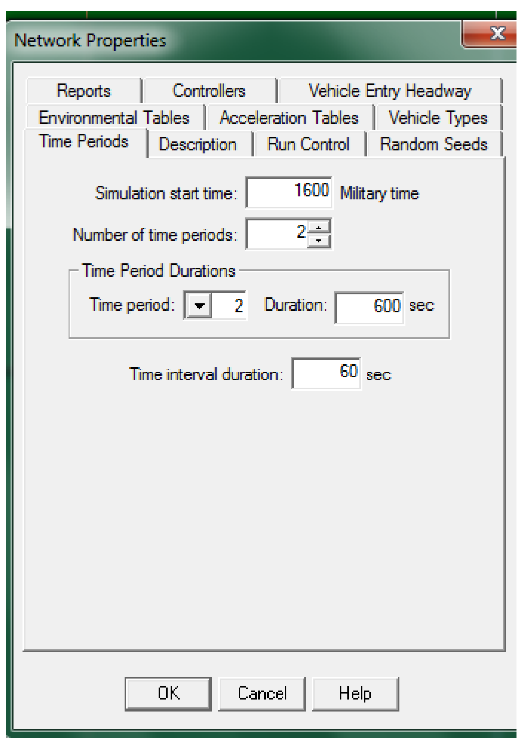


Figure A-21. Network properties input for Example 3

APPENDIX B
EXAMPLE PROBLEMS FILE FORMATS

Example 1

```
Created by TSIS Wed Mar 09 17:41:30 2011 from TNO Version 65
12345678 1 2345678 2 2345678 3 2345678 4 2345678 5 2345678 6 2345678 7 234567
                                       3   92011                           0   1
       1   0   0  10 97165909 0000  0              31600    6799963041456717   2
 900                                                                           3
           1      60                                                           4
   0       0   0   0   0   0   0   0   0   0   0   0                           5
   1   2 500         2     01              3              20  18  30  012     11
   2   3 500         3     01              4              20  18  65  012     11
   3   4 500         4     01              5              20  18  65  0       11
   4   5 500         4     01              6              20  18  65  043     11
   5   6 500         3     01              7              20  18  30  032     11
   6   7 500         2     01           8002              20  18  30  0       11
8001   1             2     01              2              20  18      0       11
   1   2     100                                                              21
   2   3     100                                                              21
   3   4     100                                                              21
   4   5     100                                                              21
   5   6     100                                                              21
   6   7     100                                                              21
8001   1     100                                                              21
   1    8001                                                                  35
   2       1                                                                  35
   3       2                                                                  35
   4       3                                                                  35
   5       4                                                                  35
   6       5                                                                  35
   7       6                                                                  35
   1 1                                                                        36
   2 1                                                                        36
   3 1                                                                        36
   4 1                                                                        36
   5 1                                                                        36
   6 1                                                                        36
   7 1                                                                        36
8001   12000   0   0  100                                                     50
   3   4  90  55  60  151200   5   7                                          82
   3   4   1  0100           0000000000000000                                 83
   3   4   2  0101           0000000000000000                                 83
   3   4   3  0101           0000000000000000                                 83
   3   4   4  0001           0000000000000000                                 83
   3   4   0  30   0  70                                                      84
   0                                                                         170
8001       0       0                                                         195
8002    3480       0                                                         195
   1     300       0                                                         195
   2     800       0                                                         195
   3    1294       0                                                         195
   4    1800       0                                                         195
   5    2300       0                                                         195
   6    2800       0                                                         195
   7    3290       0                                                         195
   1   0   0                                                                 210
```

Example 2

```
Created by TSIS Thu Mar 10 00:52:34 2011 from TNO Version 65
12345678 1 2345678 2 2345678 3 2345678 4 2345678 5 2345678 6 2345678 7 234567
                                       3   12011                           0   1
       1   0   0 120 97165909 0000  0              32100    6799963041456717   2
 900                                                                           3
           1      60                                                           4
   0       0   0   0   0   0   0   0   0   0   0   0                           5
  11  13 398         2     01          7002              20  18  65  0        11
  12  11 400         3     01            13              20  18  65  0        11
   7  12 400         4     01            11              20  18  65  021      11
   8   7 400         4     01            12              20  18  65  0        11
   4   8 404         3     01             7              20  18  65  0        11
  10   4 496         2     01             8              20  18  65  012      11
7001  10 400         2     01             4              20  18  65  0        11
  137002 202         1     01                            20  18  65           11
   4   8   8   7   1  1                                                       14
   4   8   8   7   2   1                                                      14
   4   8   8   7   3    1                                                     14
  10   4   4   8   1  1                                                       14
  10   4   4   8   2   1                                                      14
  11  13      100                                                             21
  12  11      100                                                             21
   7  12      100                                                             21
   8   7      100                                                             21
   4   8      100                                                             21
  10   4      100                                                             21
7001  10      100                                                             21
  137002      100                                                             21
   4      10                                                                  35
   7       8                                                                  35
   8       4                                                                  35
  10    7001                                                                  35
  11      12                                                                  35
  12       7                                                                  35
  13      11                                                                  35
   4 1                                                                        36
   7 1                                                                        36
   8 1                                                                        36
  10 1                                                                        36
  11 1                                                                        36
  12 1                                                                        36
  13 1                                                                        36
   8   7  40  60  60  201200   5   7                                          82
   8   7   1  1101          0000000000000000                                  83
   8   7   2  1101          0000000000000000                                  83
   8   7   3  1101          0000000000000000                                  83
   8   7   4  1101          0000000000000000                                  83
   8   7  10  30   0  60                                                      84
   8                                                                         170
   5   2  17 11000 3 93 1100                 1 9                              19
  16   3   6 10060 3                         1                                19
   1   5   2 13990 4                         9                                19
   3   6   9  9980 3                         1                                19
   6   9  15  8040 3                         1                                19
  14   9  15  2561 1                         9                                19
   9  158003  4940 3 91  200                 1                                19
   27001      2091 2                         1                                19
7002  14   9  1501 1                         1                                19
8001   1   5     0 4                         1                                19
  17  16   3  4320 3                         1                                19
   2  17  16  4620 3                         1                                19
```

```
   5   2 0 0   0 11065       2500      2500                          100      20
  16   3 0 0   0 11065                                               100      20
   1   5 0 0   0 11065                                               100      20
   3   6 0 0   0 11065                                               100      20
   6   9 0 0   0 11065                                               100      20
  14   9 0 0   0 11065                                               100      20
   9  15 0 0   0 11065                                        431500 100      20
   27001 0 0   0 11065                                               100      20
7002  14 0 0   0 11065                                               100      20
8001   1 0 0   0 11065                                                        20
  17  16 0 0   0 11065                                               100      20
   2  17 0 0   0 11065                                               100      20
   5   2   3   0                                                              24
   5   2   4   0                                                              24
   5   2   5   0                                                              24
   5   2   6   0                                                              24
   5   2   7   0                                                              24
   5   2   8   0                                                              24
   5   2   9   0                                                              24
   5   2  1724007001 600                                                      25
  16   3   6 100                                                              25
   1   5   2 100                                                              25
   3   6   9 100                                                              25
   6   9  15 100                                                              25
  14   9  15 100                                                              25
   9  158003 100                                                              25
7002  14   9 100                                                              25
8001   1   5 100                                                              25
  17  16   3 100                                                              25
   2  17  16 100                                                              25
8001   13000   0   0  100                                    25 25 25 25      50
   0                                                                         170
8003    7608      50                                                         195
8001       0      50                                                         195
   4    3896       0                                                         195
   7    4700       0                                                         195
   8    4300       0                                                         195
  10    3400       0                                                         195
  11    5500       0                                                         195
  12    5100       0                                                         195
  13    5898       0                                                         195
   1     299      51                                                         195
   2    2798      54                                                         195
   3    4698      54                                                         195
   5    1698      52                                                         195
   6    5696      54                                                         195
   9    6500      56                                                         195
  14    6250       0                                                         195
  15    6994      54                                                         195
7001    3000       0                                                         195
7002    6100       0                                                         195
  16    3692      44                                                         195
  17    3260      50                                                         195
   1   0   0                                                                 210
```

Example 3

```
Created by TSIS Sat Apr 09 22:32:55 2011 from TNO Version 65
12345678 1 2345678 2 2345678 3 2345678 4 2345678 5 2345678 6 2345678 7 234567
                                       3   92011                           0   1
       1   0   0  10 97165909 0000  0              31600    6799963041456717   2
```

```
 600 600                                                                        3
           1      60                                                            4
   0       0   0   0   0   0   0   0   0   0   0   0                            5
   1   2 500         2     01              3              20  18  30  012      11
   2   3 500         3     01              4              20  18  65  012      11
   3   4 500         4     01              5              20  18  65  0        11
   4   5 500         4     01              6              20  18  65  043      11
   5   6 500         3     01              7              20  18  30  032      11
   6   7 500         2     01           8002              20  18  30  0        11
8001   1             2     01              2              20  18      0        11
   1   2     100                                                               21
   2   3     100                                                               21
   3   4     100                                                               21
   4   5     100                                                               21
   5   6     100                                                               21
   6   7     100                                                               21
8001   1     100                                                               21
   1    8001                                                                   35
   2       1                                                                   35
   3       2                                                                   35
   4       3                                                                   35
   5       4                                                                   35
   6       5                                                                   35
   7       6                                                                   35
   1 1                                                                         36
   2 1                                                                         36
   3 1                                                                         36
   4 1                                                                         36
   5 1                                                                         36
   6 1                                                                         36
   7 1                                                                         36
8001   12000   5   0  100                                                      50
   5  14         100                      25   0   0   0                  130  58
   1  16         100                      75   0   0   0                  130  58
   2  35         120                       0  31   0   0                  120  58
   6  53         120                       0  36   0   0                  120  58
   7  53         120                       0  24   0   0                  120  58
   8  64         120                       0   9   0   0                  120  58
   3   4  90  55  60  151200   5   7                                           82
   3   4   1  0101           0000000000000000                                  83
   3   4   2  0101           0100011100000000                                  83
   3   4   3  0100           0100011100000000                                  83
   3   4   4  0001           0100011100000000                                  83
   3   4   0  30   0  70                                                       84
   0                                                                          170
8001       0       0                                                          195
8002    3480       0                                                          195
   1     300       0                                                          195
   2     800       0                                                          195
   3    1294       0                                                          195
   4    1800       0                                                          195
   5    2300       0                                                          195
   6    2800       0                                                          195
   7    3290       0                                                          195
   0   3                                                                      210
8001   11500   5   0  100                                                      50
   3   4  90  55  60  151200   5   7                                           82
   3   4   1  0101           0000000000000000                                  83
   3   4   2  0101           0100011100000000                                  83
   3   4   3  0000           0100011100000000                                  83
   3   4   4  0001           0100011100000000                                  83
   3   4   0  30   0  70                                                       84
   0                                                                          170
```

1 0 0 210

LIST OF REFERENCES

1. *Highway Capacity Manual*. TRB, National Research Council, Washinton, D.C., 2000. Print.

2. Woo, T, and Lester Hoel. "Toll Plaza Capacity and Level of Service." *Transportation Research Record*. 1320. (1991): 119-127. Print.

3. Schaufler, Alberte. *NCHRP Synthesis 240 – Toll Plaza Design*. Transportation Research Board, 1996. Print.

4. Zarrillo, Marguerite, A Radwan, and Joseph Dowd. "Toll Network Capacity Calculator." *Transportation Research Record*. 1781. (2002): 49-55. Print.

5. Zarrillo, Marguerite. "Capacity Calculation for Two Toll Facilities: Two Experiences in ETC Implementation." *79th Transportation Research Board Annual Meeting*. (2000): 1-11. Print.

6. Aycin, Murat. "Simple Methodology for Evaluating Toll Plaza Operation." *Transportation Research Record*. 1988. (2006): 92-101. Print.

7. Al-Deek, Haitham, Ayman Mohamed, and Essam Radwan. "New Model for Evaluation of Traffic Operations at Electronic Toll Collection Plazas." *Transportation Research Record*. 1710. (2000): 1-10. Print.

8. Klodzinski, Jack, and Haitham Al-Deek. "New Methodology for Evaluating a Toll Plaza's Level of Sevice." *ITE Journal*. 27.2 (2002): 34-43. Print.

9. Klodzinski, Jack, and Haitham Al-Deek. "New Methodology for Defining Level of Service at Toll Plaza." *Journal of Transportation Engineering*. 128.2 (2002): 173-181. Print.

10. "Freeways and Highways". Quadstone Paramics Ltd. 7/8/2010 http://www.paramics-online.com/freeways-and-highways.php

11. Nezamuddin, N, and Haitham Al-Deek. "Developing Microscopic Toll Plaza and Toll Road Corridor Model with PARAMICS." *Transportation Research Record*. 2047. (2008): 100-110. Print.

12. Al-Deek, Haitham. "Analyzing Performance of ETC Plazas Using New Computer Software." *Journal of Computing in Civil Engineering*. 15.4 (2001): 309-319. Print.

13. Aycin, Murat, Keith Kiskel, Vassilis Papayannoulis, and Gary Davies. "Development of Methodology for Toll Plaza Delay Estimation for Use in Travel Demand Model Postprocessor." *Transportation Research Record*. 2133. (2009): 1-10. Print.

14. Klodzinski, Jack, and Haitham Al-Deek. "Transferability of a Stochastic Toll Plaza Computer Model." *Transportation Research Record*. 1811. (2002): 40-49. Print.

15. Klodzinski, Jack, and Haitham Al-Deek. "Evaluation of Toll Plaza Performance After Addition of Express Toll Lanes at Mainline Toll Plaza." *Transportation Research Record*. 1867. (2004): 107-115. Print.

BIOGRAPHICAL SKETCH

Brett Allen Fuller, the only child of Chris and Cliff Fuller, grew up in Okeechobee, Florida graduating from Okeechobee High School in 2005. He began his post-secondary education at the University of Miami (Florida) in the fall of 2005 graduating in the spring of 2009 with a Bachelor of Science in Civil Engineering. He is a licensed Engineering Intern in the State of Florida. In August 2009, he began work on his master's degree in civil engineering at the University of Florida and graduated in May 2011.