Phase II Investigation of Safety at Toll Plazas Using Driving Simulation

SAFETY RESEARCH USING SIMULATION

UNIVERSITY TRANSPORTATION CENTER

Michael A. Knodler, PhD, PI
Professor
Department of Civil and Environmental Engineering

University of Massachusetts, Amherst

Foroogh Hajiseyedjavadi, PhD Candidate
Department of Civil and Environmental Engineering

University of Massachusetts, Amherst

Evaluation of Real-World Toll Plazas Using Driving Simulation

Michael A. Knodler, PhD, PI

Professor

Department of Civil and Environmental Engineering

University of Massachusetts, Amhurst

Foroogh Hajiseyedjavadi, PhD Candidate

Graduate Research Assistant

Department of Civil and Environmental Engineering

University of Massachusetts, Amhurst

A Report on Research Sponsored by

SAFER-SIM University Transportation Center

July 2018

Table of Contents

List of Figures

List of Tables

Abstract

1 Introduction

This report presents human behavior analysis at toll plazas through driving simulation. The same toll plaza from the first part of the study was modeled in Realtime Technologies Inc. (RTI) SimCreator software. The virtual world created for the simulator was a 600 m by 200 m (1968.5 ft by 656.168 ft) sketch of the West Springfield toll plaza. Five variables, including toll plaza lane configuration (i.e., which lanes were signed as E-ZPass and Cash), traffic queue (i.e., having a queue or not), traffic composition (i.e., having a leading heavy vehicle or not), origin-destination of the subject driver (i.e., right or left origin ramp, right or left destination ramp), and customer type (i.e., cash or E-ZPass driver), were defined, in order to find their effect on drivers' lane choice. The result of this simulation study is expected to give a better understanding of drivers' behavior at toll plazas and could lead to safer toll plaza designs. Also, the result could be used to modify and enhance drivers' behavior parameters in microsimulation software like VISSIM.

2 Driving Simulation

2.1 Participants

Twenty licensed drivers, ten females and ten males between the ages of 18 and 60 years, participated in this experiment. Subjects were recruited through the Arbella Human Performance Laboratory (HPL) general recruiting email list and through general flyers of the HPL driving simulation studies that were posted in the University of Massachusetts, Amherst (UMass Amherst) campus area.

Subjects needed to have a valid U.S. driver's license and no special physical or health conditions that might eliminate or affect their driving abilities. They were required not to have experienced motion sickness, either in their own car as a passenger or driver, or in other modes of transport.

Participants were compensated $20 following the completion of all the tasks in the experiment. Withdrawal from the experiment in the middle of the session was compensated proportionally.

2.2 Institutional Review Board Approval

This research was approved by the University of Massachusetts, Amherst Institutional Review Board. The protocol title is "Safer-Sim: Safety & Lane Configuration at Toll Plazas Protocol," and the protocol number is 2015-2563.

2.3 Methodology

Understanding drivers' lane choice behavior requires either a close scrutiny of their behavior in the field or the creation of a simulation environment similar to that of the field and looking at drivers' behavior in a controlled environment.

Real field study is more realistic but makes it hard to find the effect of each single variable independent of environmental conditions, since it is hard to keep all other variables constant in different experiments. Because of that, the toll plaza study site was created in the full-scale driving simulator to study subjects' behavior in a controlled environment.

This study looked at five factors affecting drivers' lane choice, including toll plaza lane configuration, origin and destination of the subject vehicle, traffic condition (i.e., having queue or not), traffic composition (i.e., having a lead heavy vehicle or not), and customer type (i.e., cash customer or electronic toll collection (ETC) customer).

2.3.1 Driving Simulator and Equipment

A virtual reality of a four-lane toll plaza environment was created in the HPL at UMass Amherst in order to test drivers' behavior in a simulated toll plaza environment. The simulation system was a full-scale driving simulator supported by Realtime Technologies Inc. (RTI) SimCreator technology.

The RTI fixed-base, full-cab Saturn driving simulator consists of four processing channels, namely the host, right, center, and left channels. The right, center, and left channels processed the image feed that was projected through the right, center, and left projectors, respectively, over three screens that provided a horizontal view of 150 degrees and vertical view of 30 degrees of the forward driving scene. The visuals projected on the screens were refreshed at a frequency of 60 Hz, and the display resolution of the image was 1024 by 768 dpi on each screen. The simulated sound tracks played via a surround sound system replicated the engine sound as well as the sound of the environment and ambient traffic. The sedan could be operated like a normal car (see Figure 2.1).

Figure 2.1 - Driving simulator at Human Performance Laboratory, UMass Amherst

The simulation environment was created through the Internet Scene Assembler (ISA), which has a library of roadway modules. Roadway structures that are not in the ISA library can be built in AutoCAD Civil 3D and/or SketchUp and Blender. Then the model is imported into ISA or added to the ISA library. The published world that is created in ISA can be run using the FullSim model in SimCreator technology from the host channel.

Since there was no toll plaza module in the ISA library, and considering that the geometry of the toll plaza needed to correspond to the field environment, the toll booths and the specific roadway geometry of the study site were built and added to the ISA library. In order to have a compatible output from all three graphical software packages, specific versions of each of the software were used: AutoCAD Civil 3D 2013, SketchUp Pro 2014, and Blender 2.49b.

An aerial image of the study site was imported into AutoCAD Civil 3D to copy the geometry of the road. Three frames of a 200 m by 200 m (656.168 ft by 656.168 ft) sketch of the roadway were created in AutoCAD Civil 3D. The plaza structure and the raised medians were created in SketchUp. Both Civil 3D and SketchUp drawings were then imported into Blender to be textured and exported with the right format for ISA. Blender has the feature to export .wrl file formats of the objects, which could be read by ISA after some changes to the files. Each closed polygon recognized as an object with a single texture was exported separately with .wrl format. The .wrl files keep the physical shape, texture, direction, and relative positions of the objects, so as they are imported in ISA, each object sits in its correct place and orientation relative to the other objects.

Once the objects were imported into ISA, the whole scene was published to run in SimCreator. During the experiment, an ASL mobile eye tracker was used to monitor and record eye movements of subject drivers. The mobile eye tracker had two cameras, one facing toward the scene that recorded at a frequency of 30 frames per second and an infrared optic facing toward the subject's eye that also recorded at a frequency of 30 frames per second. The interleaved videos recorded by the eye tracker included a crosshair that showed where the driver was looking on the virtual roadway during the experiment. The eye tracker has an accuracy of approximately 0.5 degrees of visual angle.

2.4 Scenario Layout

2.4.1 Variables

As described previously, five independent variables were defined, including lane configuration, origin-destination, queue (at the closest lane with the same payment type), traffic composition, and customer type. The description of the variables is given in Table 6. Considering all the possible combinations of those five variables, having a four-lane toll plaza would lead to 512 possible scenarios. To restrict the number of testing scenarios, the lane configuration variables were narrowed down to the ones represented in **Table 2.1**. As a result, the number of possible scenarios was reduced from 512 to 96 scenarios. Among those, 20 scenarios were chosen for further analysis in this study. The final scenarios are also summarized in Table 2.2 and described in more detail in the following sections of this report.

Table 2.1 - Lane configurations

Configuration 1	ETC–ETC–Cash–Cash
Configuration 2	ETC–Cash–ETC–Cash
Configuration 3	Cash–ETC–ETC–Cash

Table 2.2 - Description of factors

Factor	Description	Specifications
Lane Configuration	Combination of E-ZPass and cash lanes	Cash–E-ZPass–E-ZPass–Cash
		E-ZPass–Cash–E-ZPass–Cash
		E-ZPass–E-ZPass–Cash–Cash
Origin/Destination	On/off ramps	Right-to-right
		Right-to-left
		Left-to-right
		Left-to-left
Traffic Queues	Having queue or not	With queue
		Without queue
Traffic Composition	Having lead heavy vehicles or not	With lead heavy vehicle
		Without lead heavy vehicle
Customer Type	E-ZPass or cash customer	E-ZPass customer
		Cash customer

2.4.2 *Experimental Design*

Out of the 20 scenarios, 12 were E-ZPass scenarios and 8 were cash scenarios. The 12 E-ZPass scenarios were divided evenly among three lane configurations; each configuration was tested with different origins-destinations (O-D) and/or traffic compositions. The eight cash scenarios were evenly divided between two lane configurations; each configuration was tested with two different O-D and traffic queue conditions. Table 2.3 summarizes the testing scenarios.

Table 2.3 - Testing scenarios

Customer Type	Lane Configuration	Scenario Level*	Scenarios
Cash	Configuration 3	Left to left with queue	Scenario 1
		Left to left without queue	Scenario 2
		Right to right with queue	Scenario 3
		Right to right without queue	Scenario 4
	Configuration 2	Left to left with queue	Scenario 5
		Left to left without queue	Scenario 6
		Right to right with queue	Scenario 7
		Right to right without queue	Scenario 8
ETC	Configuration 3	Right to left with lead truck	Scenario 9
		Right to left without lead truck	Scenario 10
		Left to right with lead truck	Scenario 11
		Left to right without lead truck	Scenario 12
	Configuration 2	Right to left with lead truck	Scenario 13
		Right to left without lead truck	Scenario 14
		Left to right with lead truck	Scenario 15
		Left to right without lead truck	Scenario 16
	Configuration 1	Right to left with lead truck	Scenario 17
		Right to left without lead truck	Scenario 18
		Left to right with lead truck	Scenario 19
		Left to right without lead truck	Scenario 20

*If a factor is not listed, it is in the null state. So, for example, in Scenario 9, nothing is listed at the scenario level for Traffic Composition or Traffic Queue. This implies that the lead vehicle is a passenger car and that there is no queue.

Cash customer scenarios were designed to investigate the effect of a queue with different lane configurations on drivers' lane change behavior. With these scenarios, the closest lane to the subjects' path, considering their origin and destination, would be blocked by a queue of five vehicles, and the driver needed to decide between staying behind the queue and avoiding a lane change or choosing the farther lane to avoid the queue. Each of the queued scenarios had a similar base case scenario for comparison, in which all the variables were the same, except that there was no queue in the drivers' travel lane (see Figure 2.2).

Figure 2.2 - Sketch of two cash scenarios: Scenario 1 (left) and Scenario 2 (right)

E-ZPass customer scenarios are designed to study the effect of having a slow-moving lead heavy vehicle in front of the drivers' travel lane with different origin-destinations and three different lane configurations. Each lane configuration and origin-destination scenario is tested both with and without the slow-moving lead heavy vehicle to investigate whether or not drivers' lane choice would change due to having a truck ahead in the travel lane (see Figure 2.3).

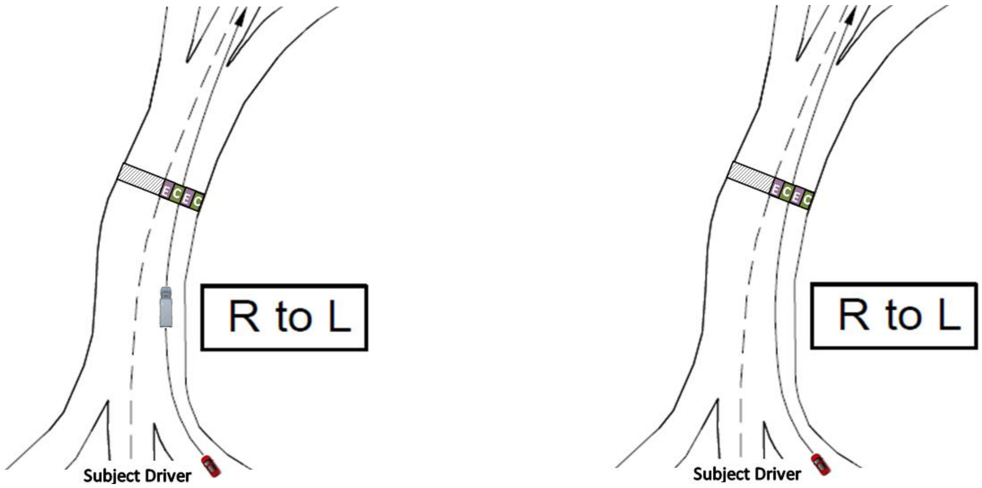

Figure 2.3 - Sketch of two E-ZPass scenarios: Scenario 13 (left) and Scenario 14 (right)

This study used 20 subjects in total, and each subject participated in all 20 scenarios. Half of the subjects started with the E-ZPass scenario set and completed all the scenarios in that set before switching to the cash scenarios, and half of them started with the cash scenario set and completed it before switching to the other one. This arrangement was set to counterbalance the learning effect due to the order of presentation. The experiment was designed in such a way that each two sequenced scenarios would have different lane configurations and differ in scenario level, either in terms of O-D or in terms of having/not having queue (having/not-having trucks in the E-ZPass cases). The above algorithm was coded in MATLAB in order to generate the described pseudo-random scenario configurations.

2.5 Procedure

Each participant took part in one session experiment at the HPL (ELab I Building, Room 110), located at the College of Engineering at UMass Amherst. The session was approximately 40 to 50 minutes. Once a participant arrived at the lab, he or she was asked to read and sign a consent form that explained the experiment and asked about his or her willingness to participate in the study. Then, participants were given one questionnaire on their demographic information and one on their physical conditions, and asked if they had motion sickness history. A very similar simulator sickness questionnaire was given to them after they finished the experiment. Upon the completion of the forms, each participant was moved to the vehicle, the eye tracker was set on the participant, and complementary instructions were given. A sample practice drive was shown to enable the participant to become familiar with the environment and the vehicle. Participants were asked to drive at 35 mph on ramps, stop at cash lanes, and reduce their speed to 15 mph at E-ZPass lanes.

3 Results

Data used in this study were collected from an ISA head-mounted eye tracker and subject drivers' lane choice behavior that was observed by the experimenter. Among the 20 subjects, 1 person dropped out of the study after completing the cash set of scenarios, due to simulation sickness symptoms. Drivers' lane choice was captured, as well as the number of glances at the toll signs and the duration of travel in the final target lane, as a measure of timeliness/lateness of drivers' lane decision making.

Drivers had two lane choices in each scenario. The scored lane choice behavior was defined as a binary variable, in the sense that if the driver picked the closest possible lane to his or her driving path upstream of the plaza, the "path distance" variable was scored as 0, and if he or she chose the farthest lane, the variable was scored as 1. The objective was to find a trend in drivers' lane decision making.

3.1 Summary of Results

Two types of statistical tests were done on the drivers' lane choice: conditional logit tests to find the effect of different variables and also sets of pairwise t-tests to compare each pairs of scenarios separately. Three sets of conditional logit tests and 12 sets of pairwise Wilcoxon tests were conducted on data.

Before moving to the statistical tests, some comparisons on drivers' performance in different scenarios are provided in Figure 3.1 through Figure 3.5.

According to the results, drivers are more prone to choose the right lane than the left lane (Figure 3.1 through Figure 3.5). In Scenario 2, with lane configuration 3 and O-D both on the left ramp, 90% of drivers chose the closest left lane and still 10% of drivers chose the farthest right lane, which cost them three lane crossings before the plaza and three lane crossings after the plaza to get back to the left lane to take the left ramp. However, in Scenario 4, by keeping all the conditions the same as those of Scenario 2 except changing O-D to be on the right, all of the drivers chose the closest lane on the right end, without any exception. Comparing Scenarios 6 and 8 in Figure 3.2 also shows that with lane configuration 2 and O-D on left ramp, 5% of drivers still chose the right end lane, at the cost of two lane crossings. However, with the same condition but having O-D on the right, all the drivers chose the right end lane without exception. Comparing Figure 3.1 and Figure 3.2 shows that once the left end cash lane is shifted to the right, fewer drivers would cross lanes aiming for the right lane.

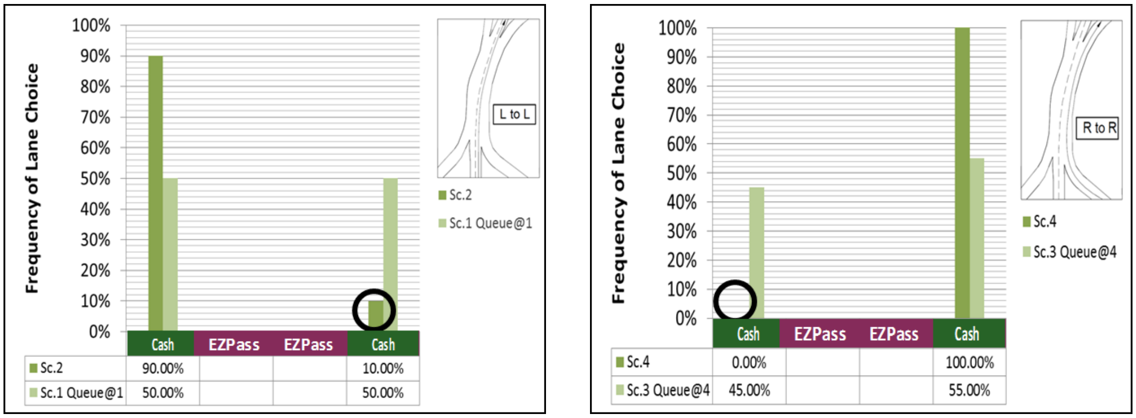

Figure 3.1 - Frequency of lane choice in Scenarios 1 to 4

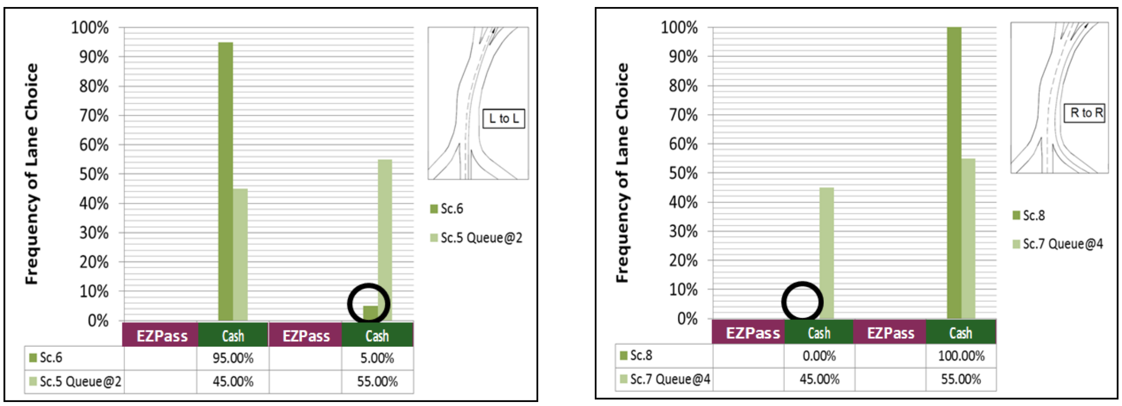

Figure 3.2 - Frequency of lane choice in Scenarios 5 to 8

Comparing E-ZPass Scenarios 14 to 16 and Scenarios 18 to 20 shows that, under the same conditions and regardless of lane configuration, drivers have more incentive to pick the right lane than the left (Figure 3.3 and Figure 3.4).

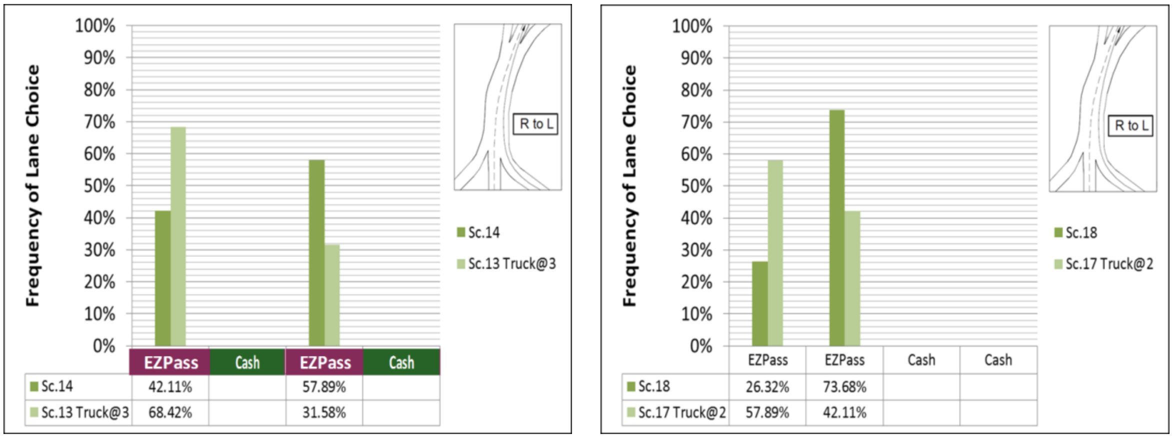

Figure 3.3 - Frequency of lane choice in Scenarios 13, 14, 17, and 18

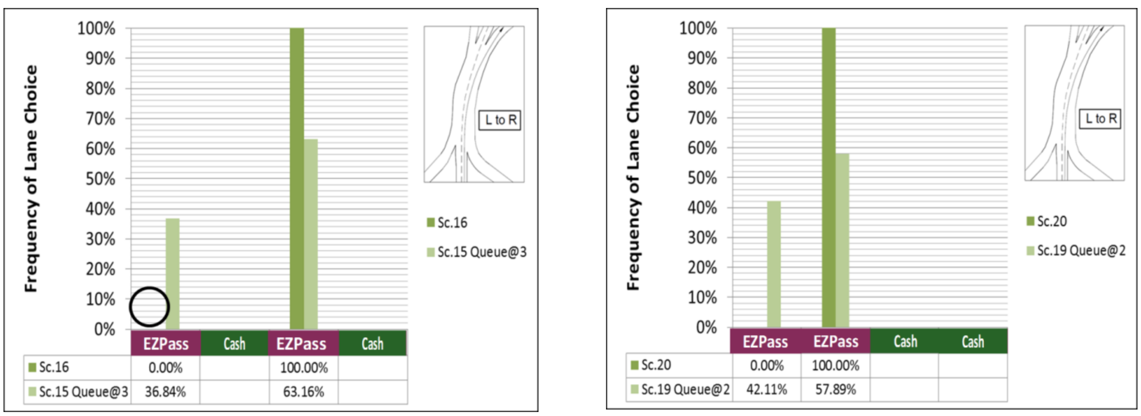

Figure 3.4 - Frequency of lane choice in Scenarios 15, 16, 19, and 20

Comparing Scenarios 9 to 12, with equal O-D conditions, more drivers pick the right lane than the left (see Figure 3.5). In Scenario 11, with O-D both on the left, 10% of the drivers still switch to the right. However, with similar conditions having O-D on the right, only 5% of drivers switch to the left lane. This could support the idea that drivers are more willing to switch to the right lane (Figure 3.5).

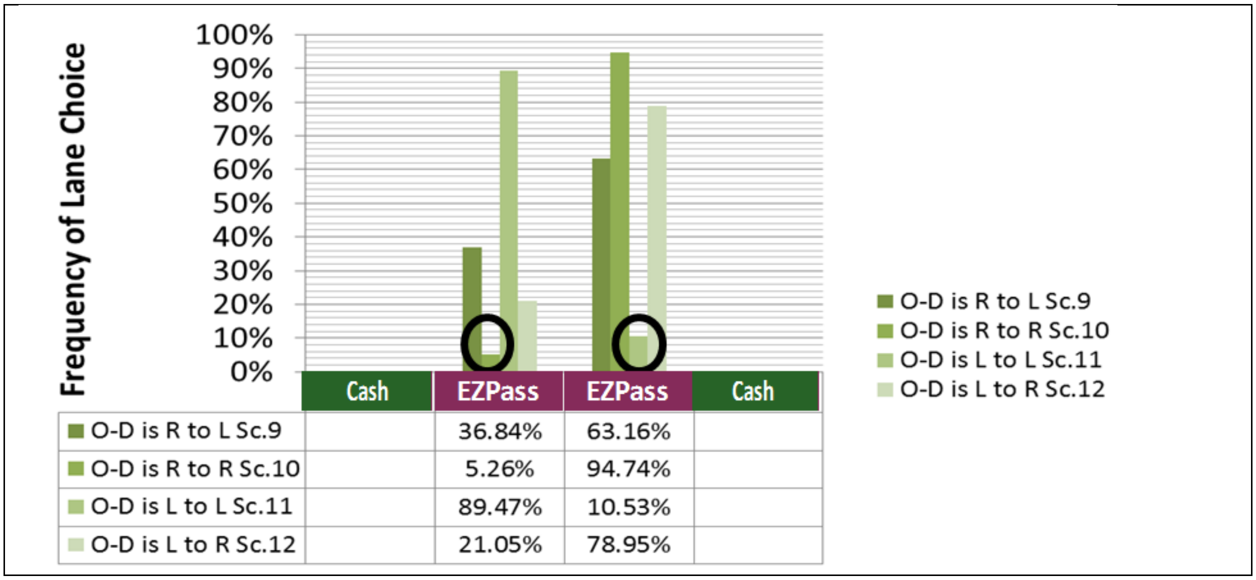

Figure 3.5 - Frequency of lane choice in Scenarios 9 to 12

3.2 Conditional Logit Test

To determine the significant difference in drivers' lane choices across different scenarios, three sets of conditional logit tests were conducted comparing cash scenarios, E-ZPass scenarios of lane configuration types 1 and 2, and E-ZPass scenarios across all lane configurations, excluding truck scenarios. The confidence interval was 5%. The dependent variable in all three sets was the binary variable of choosing the longest or shortest path upstream of the plaza. The variable is called path distance, and it would be 1 if the subject chose longest path upstream of the plaza, and 0 otherwise. The independent variables changed in each set.

3.2.1 Cash Scenarios (Scenarios 1 to 8)

The independent variables were O-D, queue, and lane configuration. Origin-destination in cash scenarios were either from left to left or from right to right. Left to left was set to 1, and right to right was set to 0. Queue variable was 1 if there was a queue of five vehicles in the closest lane to the subject's lane, and it was 0 if there was no queue. Cash scenarios were tested over two lane configurations (i.e., configuration 2 and configuration 3). The configuration variable was 1 if it was lane configuration 2, and 0 otherwise.

Based upon the result of the test, with 5% confidence interval, only queue had a statistically significant effect on drivers' lane choice (see Table 3.1).

Table 3.1 - Cash scenarios conditional logit table

Path Distance	Coefficient	Standard Error	z	P>|z|	[95% Confidence Interval]	
Origin-Destination	0.79295	0.5841	1.36	0.175	-0.35181	1.93771
Queue	4.09191	0.79000	5.18	0.000	2.54352	5.64029

Configuration	0.15632	0.55993	0.28	0.780	-0.94112	1.25375

3.2.2 E-ZPass Configurations 1 and 2 (Scenarios 13 to 20)

The independent variables were O-D, having a leading truck, and lane configuration. Origin-destination in E-ZPass scenarios with configurations 1 and 2 was either from left to right or from right to left. Left to right was set to 1, and right to left was set to 0. Truck variable was 1 if there was a slow lead heavy vehicle in the scenario, and 0 otherwise. The configuration variable was 1 if it was lane configuration 2, and 0 otherwise.

The results of the test, with 5% confidence interval, show that only O-D has a statistically significant effect on drivers' lane choice (see Table 3.2). It appeared that if origin was on the left ramp and destination was on the right exit, then drivers were more likely to switch to the right lane upstream of the plaza. However, if origin was on the right ramp and destination was on the left ramp, drivers stayed within the closest lane before the plaza and would switch to the left downstream of the plaza. It appears that drivers are more comfortable driving closer to the right side of the roadway.

The design of the truck variable in the experiments was not necessarily to block the shortest path to the driver, but considering the fact that drivers were more prone to pick the right lane as shown in the previous results and also in the E-ZPass scenarios without truck, trucks were located in the right lane regardless of O-D of the subject driver.

In other words, since a slow leading truck is not necessarily located in the closest lane to the subject, it might not necessarily be a potential incentive to pick a longer path, and its effect could not be captured by this test. However, its effect was analyzed through a pairwise Wilcoxon test later in this report.

Table 3.2 - E-ZPass scenarios with configuration 1 and 2 conditional logit table

Path Distance	Coefficient	Standard Error	z	P>|z|	[95% Confidence Interval]	
Origin-Destination	1.81533	0.43751	4.15	0.000	0.95782	2.6728
Truck	-0.32592	0.40534	-0.80	0.421	-1.12036	0.46853
Configuration	0.48739	0.40676	1.2	0.231	-0.30985	1.2846

3.2.3 E-ZPass Scenarios without Trucks (Scenarios 9, 12, 14, 16, 18, and 20)

The independent variables were O-D and lane configuration. Scenarios 9, 12, 14, 16, 18, and 20 were base E-ZPass scenarios without any slow leading heavy vehicle. The only variables between these sets of scenarios were lane configurations (i.e., configurations 1, 2, and 3) and O-D. Origin-destination in these scenarios was either from left to right or from right to left. Left to right was set to 1, and right to left was set to 0. The configuration 2 variable was 1 if it was lane configuration 2, and 0 otherwise. The configuration 3 variable was 1 if it was lane configuration 3, and 0 otherwise.

The result of the test, with 5% confidence interval, showed that only O-D had a statistically significant effect on drivers' lane choice (see Table 3.3). The result was very similar to the result of the previous test (E-ZPass scenarios with truck). It appeared that if drivers entered from the left ramp and wanted to exit to the right after the plaza (i.e., O-D was 1), they were more likely to switch to the right lane upstream of the plaza or, in other words, pick the longest path. But when they entered from the right ramp and wanted to exit to the left ramp after the plaza, they stayed with the closest lane to their current lane and switched to the left downstream of the plaza. Lane configuration in this case did not have any effect on drivers' lane decision.

Table 3.3 - E-ZPass scenarios without truck conditional logit table

Path Distance	Coefficient	Standard Error	z	P>|z|	[95% Confidence Interval]	
Origin-Destination	3.68277	0.77852	4.73	0.000	2.15689	5.2086
Configuration 2	0.64843	0.66856	0.97	0.332	-0.66193	1.9588
Configuration 3	-0.39460	0.63248	-0.62	0.533	-1.6342	0.84504

3.3 Pairwise Wilcoxon Test

A pairwise comparison was conducted on scenarios to find out if there was any significant difference between each two pairs of scenarios. Since all of the variables were categorical, the pairwise Wilcoxon test was used. The results are summarized in Table 3.4. It is shown that the pairwise Wilcoxon test results comply with the conditional logit test results. The only difference is with the effect of leading truck on E-ZPass scenarios, which was expected to be so. As explained in the previous section, the effect of truck could not have been tested through conditional logit test. However according to the Wilcoxon test, having truck has a statistically significant effect on drivers' lane choice.

Table 3.4 - Pairwise Wilcoxon test results

H0	z	P>|z|	Note	Comply with Cond. Logit
Sc.1 = Sc.2	2.828	0.0047	Queue has a statistically significant effect on lane choice	Yes
Sc.3 = Sc.4	3.000	0.0027	Queue has a statistically significant effect on lane choice	Yes
Sc.5 = Sc.6	2.887	0.0039	Queue has a statistically significant effect on lane choice	Yes
Sc.7 = Sc.8	3.162	0.0016	Queue has a statistically significant effect on lane choice	Yes
Sc.13 = Sc.14	2.236	0.0253	Truck has a statistically significant effect on lane choice	No
Sc.15 = Sc.16	-2.646	0.0082	Truck has a statistically significant effect on lane choice	No

Sc.17 = Sc.18	2.121	0.0339	Truck has a statistically significant effect on lane choice	No
Sc.19 = Sc.20	-2.828	0.0047	Truck has a statistically significant effect on lane choice	No
Sc.2 = Sc.11	0.000	1.000	Customer type does not have a statistically Significant effect on lane choice	--
Sc.4 = Sc.10	-1.000	0.3173	Customer type does not have a statistically significant effect on lane choice	--
Sc.14 = Sc.16	-3.317	0.0009	Origin-dest. has a statistically significant effect on lane choice	Yes
Sc.18 = Sc.20	-3.742	0.0002	Origin-dest. has a statistically significant effect on lane choice	Yes

3.4 Eye Tracker Data Analysis

Eye-tracking videos were coded manually to find the number of glances drivers made at toll lane signs to investigate if there was any trend with drivers' lane decision making and their glance pattern at the signs, and if the trend changed across cash and E-ZPass drivers.

Of the 20 subjects, 1 dropped the study after the cash set of scenarios due to simulation sickness symptoms. Some of the eye-tracking videos were partially or completely impaired. In total ,17 subject videos of the cash set of scenarios and 15 subject videos of the E-ZPass set of scenarios were used for the analysis.

In all the scenarios, drivers had only two lane options to pick that matched their payment method (i.e., two cash lanes and two E-ZPass lanes). Subject drivers who chose to stay behind the queue of five vehicles during the cash-scenarios-with-queue experienced a longer drive because of the time they spent in the queue. The chance of having a higher number of glances at each lane can potentially increase because of the increase of the exposer time. To take care of that effect, the scorers eliminated the random glances that were not part of the drivers' lane decision making process and did not count them in the number of glances.

Figure 3.6 shows the average number of glances drivers made as a cash customer with two conditions, and as an E-ZPass customer.

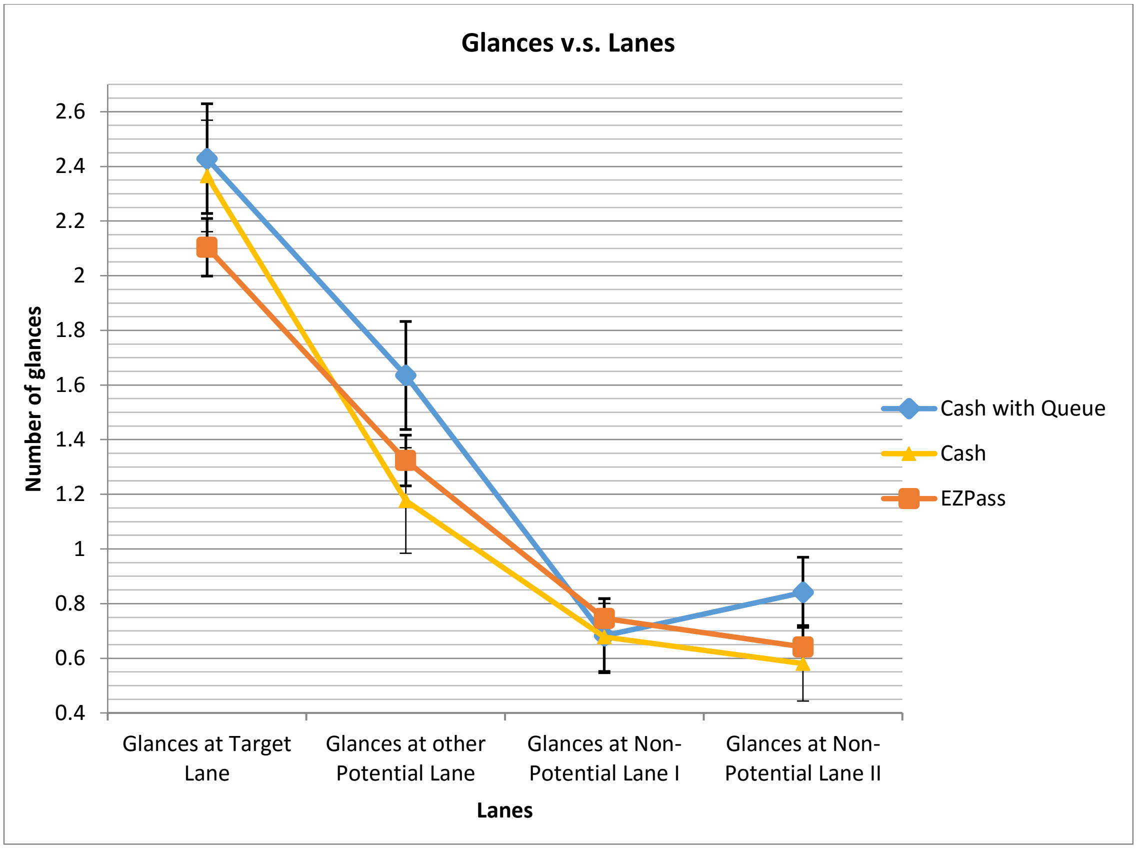

Figure 3.6 - Number of glances at lanes

In the figure, "target lane" is the driver's final lane choice at the toll plaza, and "other potential lane" is the lane that has the same payment method and could have been chosen by the driver. "Non-potential lane I" and "Non-potential lane II" are the two lanes with different payment methods than that of the drivers' type.

The average number of glances that a cash driver took at his or her target lane (M=2.37, SE=.2) was statistically similar to that of E-ZPass drivers (M=2.10, SE=.11) and to queue conditions (M=2.43, SE=.20). Also, the number of glances taken at "other potential lane" was statistically similar for cash (M=1.18, SE=.19) and E-ZPass (M=1.32, SE=.09) drivers. However, the presence of queue increased this percentage significantly (M=1.63, SE=20). The number of glances taken at either of the non-potential lanes was less than 1 for all cash (M=0.68, SE=.12 and M=0.58, SE=.14), E-ZPass (M=.75, SE=.07 and M=.64, SE=0.08), and queue scenarios (M=.68, SE=.14 and M=.84, SE=.13).

The comparison of the results of glances for queued cash scenarios and the rest of the scenarios showed significant difference. The Wilcoxon rank-sum (or Mann–Whitney–Wilcoxon (MWW)) test showed that once the driver is facing a queue in front of his or her path at the toll booth, the frequency of glances at the other potential lane (the cash lane which had less utility to be picked by the driver) is significantly higher. Driver scanning the other lane more frequently can be an indicator that deciding between two options causes more workload as the utilities of the two options (farther lane without queue and the closer lane with queue) get closer with the presence of queue compared to previous condition (no queue at either lanes).

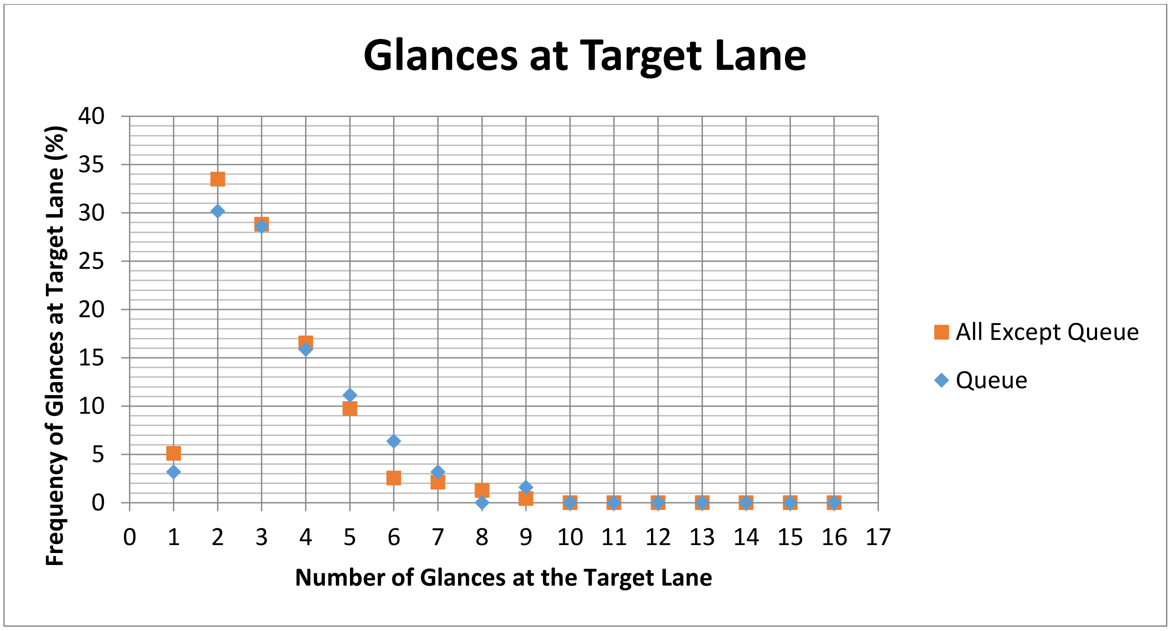

Figure 3.7 - Glance frequency at target lane

Also, the graph of the frequency of glances at target lane in Figure 3.7 shows a similar distribution for queued scenarios and the rest of the scenarios. It is shown that in the presence of a queue, the distribution of drivers' glances at the target lane gets thicker right tail (i.e., mostly higher frequency for more than 4 number of glances is observed with queue scenarios).

4 Conclusions

This study proved the feasibility of modeling traffic conditions at a toll plaza and evaluating its safety using VISSIM and SSAM. Also, traffic safety was evaluated in different lane configurations at the toll plaza.

In general, it seems that fewer lane choices and fewer incentives to change lanes would increase safety at the site.

It seems that if lanes with the same tolling system were grouped together and separated from other toll lane types, the severity of collisions would decrease on average but the probability or number of conflicts might increase. This type of design that has clustered lane types might be infeasible under some conditions, due to the considerable increase in the weaving maneuvers required for vehicles to take the proper exit after the plaza.

Based on the microsimulation study, an all-ETC lanes design and use of both combo lanes as well as ETC lanes, are found as the safest and second-safest configurations, respectively. The third-safest condition is the design that separates different toll lane types (i.e., cash and E-ZPass lanes) from each other.

Based on the driving simulation data, it seems that the right lanes have potentially higher utility for the drivers, and in the similar conditions (between lanes), drivers are more prone to choose the lane that is closer to the right edge of the road. This is regardless of the payment type the driver is going to pick (i.e., cash or E-ZPass).

The glance distribution shows that drivers glance more frequently at the other lane (the lane with less utility) when the queue exists. This indicates that the driver is going through a higher workload to decide between the two options as the utilities of the two options (farther lane without queue and the closer lane with queue) gets closer with the presence of queue compared to previous condition (no queue at either lanes).

References

Mohamed, A. A., M. Abdel-Aty, and J. G. Klodzinski. Safety Considerations in Designing Electronic Toll Plazas: Case Study. ITE Journal, Vol. 71, no. 3, 2001, pp. 20–33.

1. Ding, J., F. Ye, and J. Lu. Impact of ETC on Traffic Safety at Toll Plaza. Plan, Build, and Manage Transportation Infrastructure in China. Presented at Seventh International Conference of Chinese Transportation Professionals Congress (ICCTP), Shanghai, China, 2007, pp. 695–701.

2. McKinnon, I. A. Operational and Safety-Based Analyses of Varied Toll Lane Configurations. MSc Thesis, University of Massachusetts, Amherst, Amherst, MA, May 2013.

3. Sze, N. N., S. C. Wong, and W. F. Chan. Traffic Crashes at Toll Plazas in Hong Kong. Proceedings of the ICE-Transport, Vol. 161, no. TR2, May 2008, pp. 71–76.

4. Mudigonda, S., B. Bartin, and K. Ozbay. Microscopic Modeling of Lane Selection and Lane Changing at Toll Plazas. In Transportation Research Board 88th Annual Meeting. CD-ROM. Washington, D.C., 2009, p. 18.

5. Russo, C. S. The Calibration and Verification of Simulation Models for Toll Plazas. MSc Thesis, University of Central Florida, Orlando, FL, 2008.

6. Wong, S. C., N. N. Sze, W. T. Hung, B. P. Y. Loo, and H. K. Lo. The Effects of a Traffic Guidance Scheme for Auto-Toll Lanes on Traffic Safety at Toll Plazas. Safety Science, Vol. 44, no. 9, 2006, pp. 753–770.

7. Smith, R. F., and Wilbur Smith Associates. State of the Practice and Recommendations on Traffic Control Strategies at Toll Plazas. Manual of Uniform Traffic Control Devices. Federal Highway Administration, Federal Highway Administration. FHWA, U.S. Department of Transportation, June 2006. http://mutcd.fhwa.dot.gov/rpt/tcstoll/index.htm. Accessed July 27, 2014.

8. Gettman, D., L. Pu, T. Sayed, and S. G. Shelby. Surrogate Safety Assessment Model and Validation: Final Report. FHWA-HRT-08-051, Federal Highway Administration, U.S. Department of Transportation, 2008.