A COMPARATIVE ANALYSIS OF TOLL PLAZAS SAFETY FEATURES IN PUERTO RICO AND MASSACHUSETTS USING A DRIVING SIMULATOR

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ABSTRACT

Driving simulators have been widely used in transportation research and have potential applications for toll plaza safety research. The University of Puerto Rico at Mayagüez (UPRM) and the University of Massachusetts Amherst (UMass-Amherst) performed a collaborative investigation using driving simulators to evaluate drivers' behavior in two toll plazas with different signage and lane configurations that operate under the USA jurisdiction. The studied toll roads were the Caguas South Toll Plaza in Puerto Rico (participants from Puerto Rico) and the West Springfield Toll Plaza in Massachusetts (participants from Massachusetts). The major safety issues identified in both toll roads were unexpected lane changes, sudden vehicle stops and variable speed patterns.

The purpose of this study was to exchange research scenarios between UPRM and UMass-Amherst to test drivers that are unfamiliar with the area of study and enlarge our scope. Assuming that the patterns of behavior are similar, this will suggest that drivers' behaviors from different regions depends largely on the geometry of the toll plaza and not the driving culture particular to a region. This will greatly add to the utility of driving simulator studies since the results reported from one region and one toll plaza arrangement should generalize to other regions around the country. Results showed that familiar drivers had a better driving performance, in terms of variability of lane position, when compared with unfamiliar drivers. However, the proposed treatments for each toll plaza improved road safety for both familiar and unfamiliar drivers.

Keywords: Driving Simulator, Toll Plaza Safety, Unfamiliar Drivers, Human Factors, Driving Behavior, Traffic Sign Configuration

INTRODUCTION

The construction and operation of toll plazas has been in continuous change due to the evolution of transportation technologies. Toll roads have been designed and used for more than five decades in the United States and Puerto Rico. However, there has been no real consistency across toll plazas in critical aspects of their design. Specifically, Traffic Control Devices (TCD's) and lane operations have varied considerably among operating agencies. Although the 2012 revision of the Manual on Uniform Traffic Control Devices (MUTCD) included a section dedicated to toll road signs (*1*), many toll plazas that were constructed before 2009 have not implemented these standardized signage configurations. Furthermore, emerging Intelligent Transportation Systems (ITS) applications such as Electronic Toll Collection (ETC) and Open Toll Road (OTR) have added to the complexity of the toll plaza environment and affected the safety of all road users. ETC lanes are automated toll collection systems that use wireless technologies for the transactions of moving vehicles. OTR utilizes ETC systems while drivers are traveling at normal highway speeds (1). Although, these payment methods do not require vehicles to completely stop at the toll plaza, therefore having an important role in reducing vehicle emissions and other environmental aspects (*2,3*), they raised the percent of total crashes in mainline toll plazas associated with ETC lanes (4).

The increase in vehicle crashes may be influenced by conflict points prior the toll plaza station, including merging movements, queuing, acceleration/deceleration rates, speed variations among drivers, the number of lanes and signage configuration (4). Yang et al. indicated that crashes are more likely to occur in multi-lane toll plazas as a consequence of conflict points generated by driver confusion when deciding which toll lane to use (*5*). In addition, the variation in drivers' speed in ETC lanes has increased the number of rear-end crashes, sideswipe crashes and vehicle collisions with toll plazas as compared with the period before the implementation of the E-ZPass lanes, which is a type of ETC system (*4*).

The sudden increase in the number of crashes that has occurred in toll plazas that operate multiple toll lane configurations has generated the need to study driving behavior (*6*,7). One of the research tools that can be utilized for toll plaza safety and human factors studies are driving simulators. Simulation studies are useful for the evaluation of emerging technologies and alternative solutions in transportation systems (*8*). For example, they have been used to study the effect of allowable permissive left-turn indications, effects of warning messages and variable speed limits, effectiveness of yield markings in midblock crosswalks, driving performance at high speeds, and the effect of alcohol, drugs and various medical treatments on drivers' performance (*8-12*). There are several types of simulators in which the cost and fidelity varies according to its screen projection systems, hardware, software and vehicle elements (*13*). One of the major advantages simulation provides is the ability to expose participants to potential hazardous situations without physically harming the subject driver, making it possible to evaluate dangerous scenarios with a high collision risk.

Given the above, studies have been undertaken using driving simulators in order to better understand the causes of crashes at toll plazas and to evaluate alternative treatments. For example, Valdés et al. found that overhead signing configuration had a better potential for crash reduction than roadside signage when providing information to drivers indicating the appropriate lane use and posted speed limits (*14,15*). They did so by using a driving simulator to evaluate Puerto Rican drivers in a simulation of the Caguas South Toll Plaza in Puerto Rico, where drivers' speed, acceleration noise, and lateral position of the vehicle were studied in different zones of interest prior the toll plaza.

First time users of a roadway or unfamiliar drivers may have a different driving behavior than those who are familiar drivers. Richard and Litchy created a method to determine driver expectations at interchanges and study how the complexity of interchanges affected driving behavior (16). Interestingly, the authors suggested that there could be a strong likelihood that unfamiliar drivers behave like familiar drivers if TCD's are provided in an effective manner, where drivers have a good understanding of what the situation is in the road.

This collaborative research is aimed at evaluating how a proposed solution for road safety issues on in-service toll plazas that operate ETC lanes and cash lanes can improve safety for unfamiliar drivers through the use of a driving simulator. In order to achieve this objective, virtual scenarios created in the research study at both UPRM and UMass-Amherst were exchanged to evaluate unfamiliar drivers. The studied toll stations are Caguas South Toll Plaza located in Puerto Rico and West Springfield Toll Plaza located in Massachusetts, where both toll roadways use the same fare structure with different lane configurations at the toll plaza. At each site, familiar users were compared with unfamiliar users to determine whether familiarity has an effect and to determine whether there is an interaction between familiarity and the location.

IN-SERVICE TOLL PLAZAS

Caguas South Toll Plaza is located in a freeway segment of PR-52 in the Municipality of Caguas. The specific three-lane freeway segment evaluated was in the southbound direction (SB) and widens to six lanes at the toll plaza. The first two lanes located at the left are used as E-ZPass lanes with a posted speed limit of 55 mph in which only passenger vehicles are allowed. The central lanes are arranged for all vehicles type that has E-ZPass accounts, where the maximum posted speed limit is 35 mph. The last two lanes located at the right are used as cash lanes where drivers have to stop at the toll plaza to either pay in cash or recharge their electronic account with mobile cash.

West Springfield Toll Plaza is located in the City of Chicopee at Exit 4 of the Massachusetts Turnpike. The toll system has four lanes per direction, giving access to two major interstates (I-90 and I-91) and a primary State Route (SR-5). Lane configuration at the toll station is composed of two E-ZPass lanes positioned in the middle lanes and two cash only lanes located at each end of the toll plaza (*17*).

Existing conditions of both plazas are illustrated in Figure 1 along with the virtual versions created for this study. Although the studied toll plazas are located in different countries, major safety issues such as unexpected lane changes, sudden vehicle stops and variable speed patterns were identified. Proposed countermeasures for each toll plaza that have a potential to improve safety for drivers who are unfamiliar with the toll road are described and evaluated in this paper.

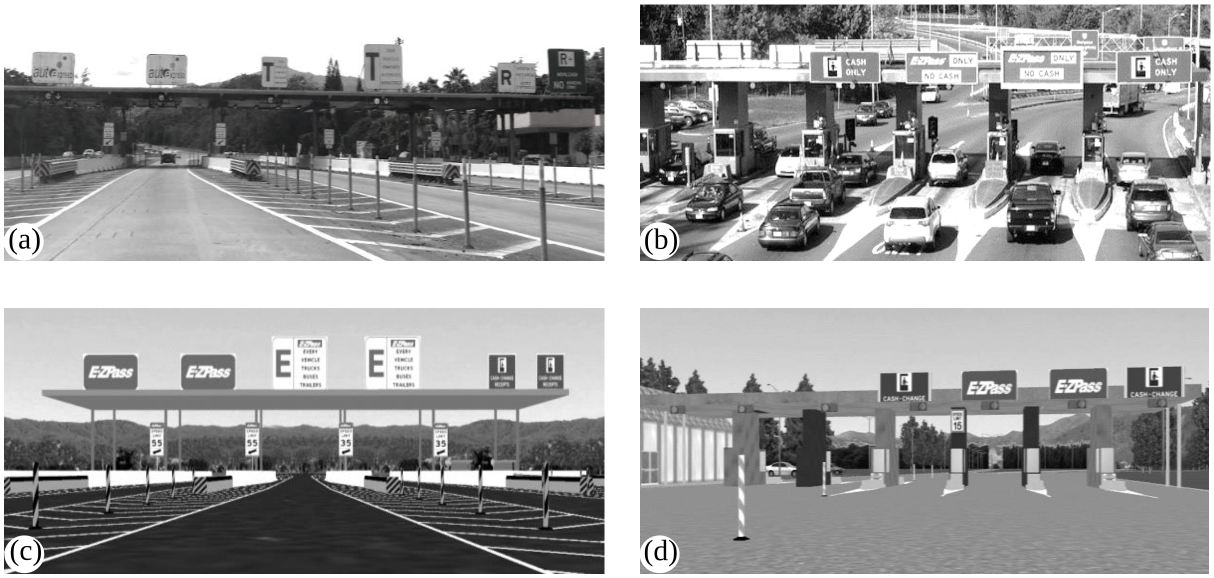


FIGURE 1 Existing Toll Plaza Configurations: (a) Caguas South Toll Plaza, (b) West Springfield Toll Plaza, (c) Virtual Scenario of Caguas South Toll Plaza, (d) Virtual Scenario of West Springfield Toll Plaza.

METHODOLOGY

The methodology followed in this research is illustrated in Figure 2 and described below. A Latin Square experimental design was used for each experiment to counterbalance the different possible configurations of treatments for the two toll plazas (*15*). The scenario layout varies between the two toll plaza experiments; the Caguas South Toll Plaza was divided in two configurations with 12 scenarios whereas West Springfield Toll Plaza experiment was divided in three configurations with 20 scenarios. A detailed explanation of configuration and scenarios for both toll plazas are presented in Table 2.

UPRM and UMass research teams recruited participants that served as *familiar subject drivers* in their respective generated scenarios and gathered the pertinent data. Once the experiments with *familiar subject drivers* were completed, all files and information related to the virtual scenarios developed by both UPRM and UMass research teams were exchanged. This information included questionnaires for subject drivers, Institutional Review Board (IRB) documents, detailed instructions, scenarios, and simulation scripts.

Unfamiliar subject drivers were recruited once all the exchanged scenarios and software within each campus were properly calibrated and validated. The collected raw data of all participants were exchanged between universities research teams in order to perform the respective driving simulation analysis. Finally, the conclusions and recommendations were made with respect to the effectiveness and significance of the proposed treatments for each toll plaza for both familiar and unfamiliar subject drivers. The configuration of familiar and unfamiliar subject drivers used for this collaborative research effort is shown in Table 1.

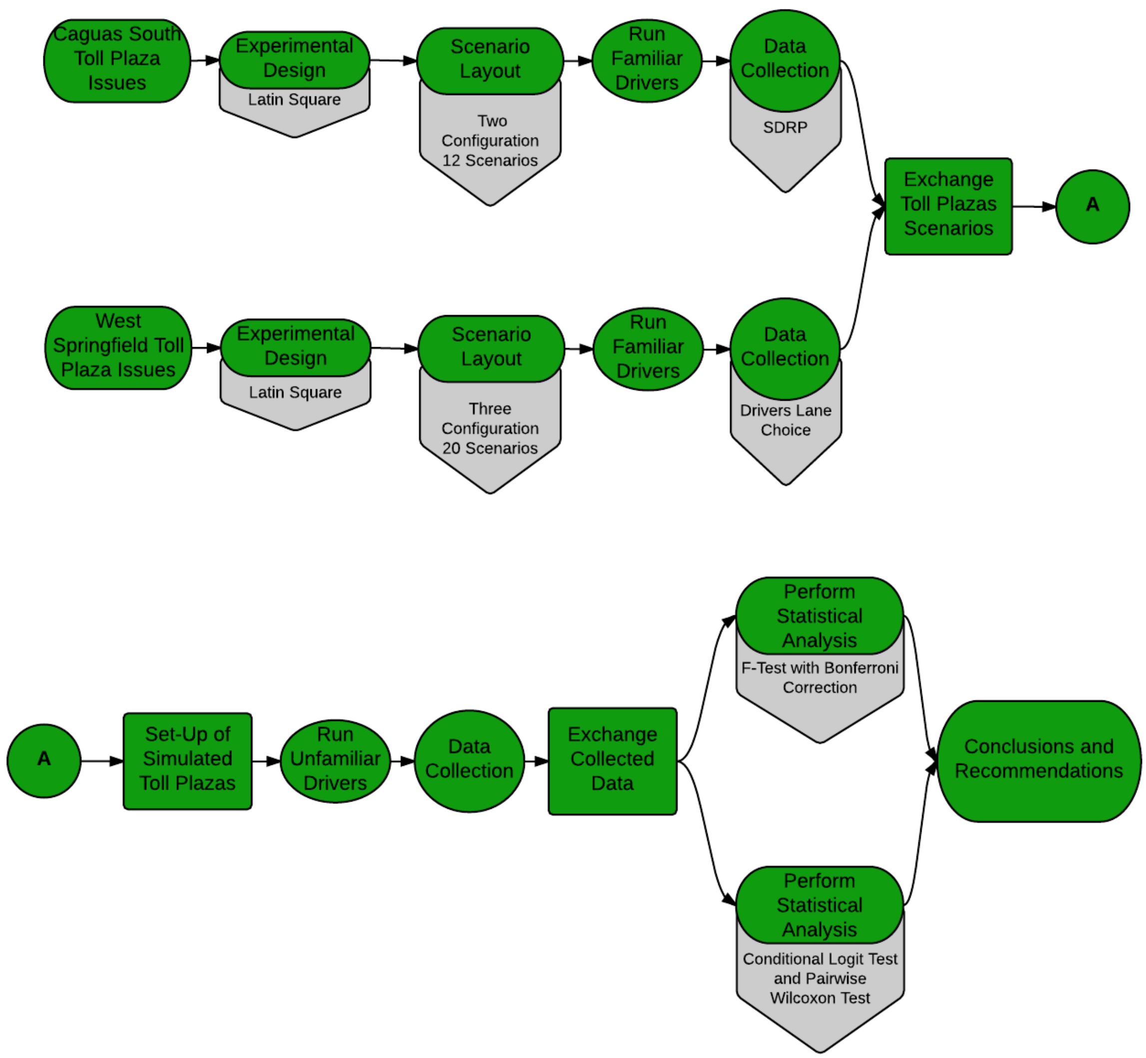


FIGURE 2 UPRM-UMass Toll Plaza Driving Simulator Methodology

TABLE 1 Configuration of Participants Used as Familiar and Unfamiliar Drivers for Each Toll Plaza

Location	Participants	Toll Plaza	Subject Driver Status
UPRM	Puerto Rico	Caguas South Toll Plaza	Familiar
UPRM	Puerto Rico	West Springfield Toll Plaza	Unfamiliar
UMass	Massachusetts	Caguas South Toll Plaza	Unfamiliar
UMass	Massachusetts	West Springfield Toll Plaza	Familiar

Descriptions of Driving Simulator

UPRM Driving Simulator

Consists of three major components; a vehicle cockpit made of wooden base (with six wheels for mobile applications) that includes the car seat, steering wheel, acceleration and brake pedals, signal and gear shifts; a visual display with three projectors and three squared screens that have a 10° deflection angle between screens (Figure 3a); computer hardware and software with NVIDIA graphics, RTI SimCreator/SimVista software package with Internet Scene Assembler (ISA) and audio system (18).

UMass Driving Simulator

Consists of three major components; a full size Saturn Sedan that has the same components of a fully functional vehicle (Figure 3b); a visual display with three projectors in three screens situated at 60° in the horizontal direction and 30° in the vertical direction; computer hardware and software (4 custom-built RTI servers with Sim Creator and ISA); and audio system.

FIGURE 3 Simulation Equipment: (a) UPRM Driving Simulator, (b) UMass Driving Simulator.

Experimental Design

A Latin Square experimental design was used to determine the order in which participants would drive through the 12 selected scenarios in Caguas South Toll Plaza. This design ensured that the order in which the participants were exposed to the simulation scenarios was counterbalanced across participants. Therefore, results obtained for each of the scenarios were independent from the order in which the participants ran the experiments (*15*).

The experimental design established for West Springfield Toll Plaza enclosed five independent variables, for which twenty scenarios were chosen for analysis. A Conditional Logit Test was used to determine significant differences in drivers' lane choice according to a given type of lane configuration. In addition, a Pairwise Wilcoxon Test was performed to identify significant differences between each two pairs of scenarios.

Description of Variables and Scenarios

Caguas South Toll Plaza

The dependent variable used to understand drivers' behavior of familiar and unfamiliar drivers in Caguas South Toll Plaza was the Standard Deviation of Roadway Position (SDRP). SDRP was obtained by calculating the standard deviation of the average position of the subject drivers in the roadway for each zone. This variable was analyzed using two signage configurations at five zones of interest located along the freeway and the toll plaza (Figure 4). Configuration 1 consisted of roadside signage, providing the distance to toll plaza and speed limits of each toll lane, whereas Configuration 2 includes the distance to the toll plaza with the addition of toll lane arrangement and the respective speed limits in an overhead design. The length of each zone was based in the MUTCD stipulated sight distance (1), which varies between 200m and 500m. The rationale of the five zones delimited for the study was to evaluate how adequate the time allotted for the location of each sign for subject drivers' response was (*15*).

Three independent variables were controlled for each virtual scenario, namely traffic flow condition, destination lane at the toll plaza and starting lane position. The four traffic flow conditions are: no traffic, only one lead vehicle in front of the test vehicle, traffic mix in the middle and right lanes, and traffic in all lanes. The two possible destination lanes at the toll plaza are: a pass through E-ZPass lane or through a cash lane. The two starting lane positions are the left or right lane. The description of the twelve scenarios selected is described in (Table 2).

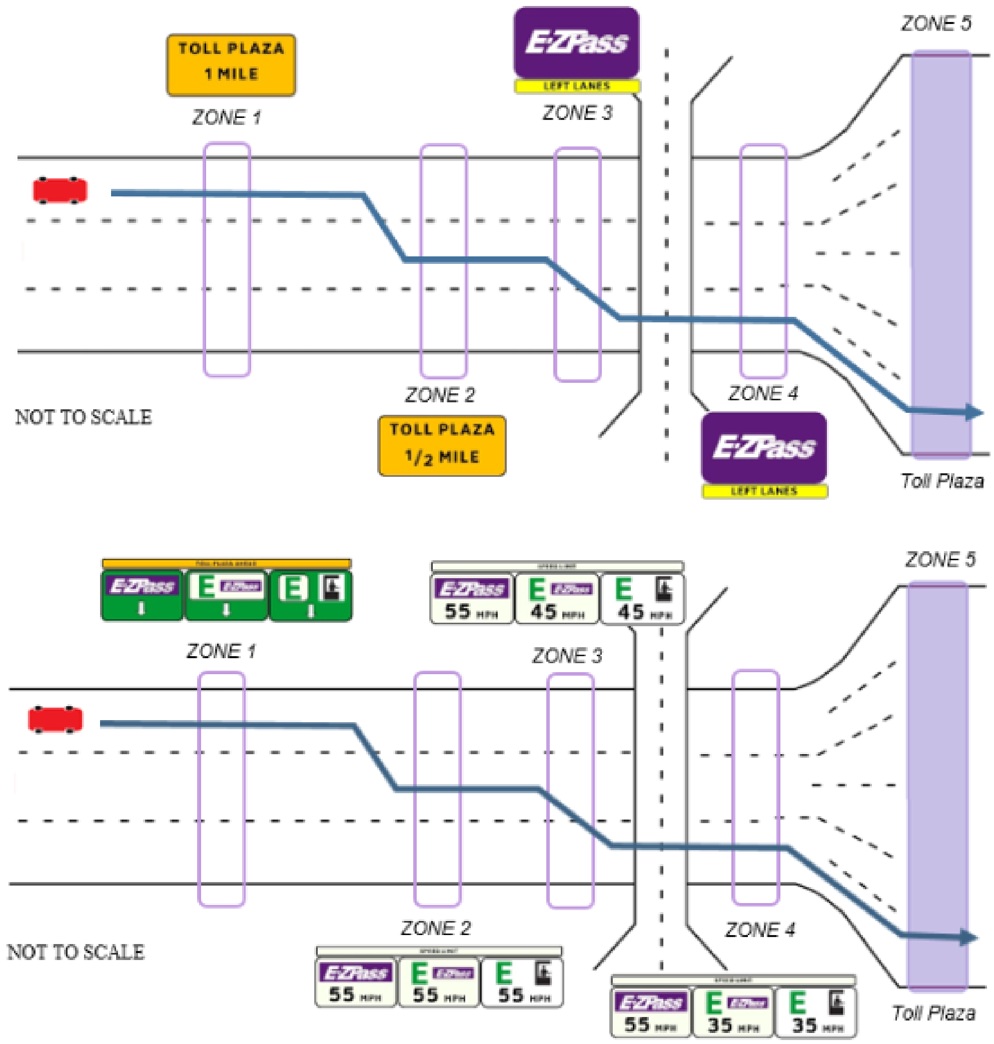


FIGURE 4 Zones of Interest Used in this Study with Each Corresponding Sign: (a) Configuration 1 Example with Roadside Signage in Scenario 6; (b) Configuration 2 Example with Overhead Sign in Scenario 11. Note: The Solid Lines Perpendicular to the Axis of the Travel Lanes Represents a Bridge that Allows Vehicles to Pass Over the Travel Lanes Just Before the Toll Plaza.

West Springfield Toll Plaza

The dependent variable analyzed in order to evaluate drivers' behavior of familiar and unfamiliar drivers in West Springfield Toll Plaza was the subject's lane decision of toll lane. This variable was evaluated using three lane configurations at the toll plaza: E-ZPass-E-ZPass-Cash-Cash, E-ZPass-Cash-E-ZPass-Cash and Cash-E-ZPass-E-ZPass-Cash. The following independent variables were regulated to understand driver behavior: lane configuration, origin-destination, queue, traffic composition and customer type. Scenario layout of all selected scenarios are described in Table 2.

TABLE 2 Developed Scenarios for Caguas South Toll Plaza and West Springfield Toll Plaza

Caguas South Toll Plaza Scenarios			
Customer Type	**Traffic Flow Condition**	**Description**	**Scenario**
E-Z Pass	No Traffic	Start in the Left and Finish Left	1
	Lead Vehicle Only in the Left	Start in the Left and Finish Left	2
	Traffic in Middle and Left Lanes	Start in the Left and Finish Left	3
	Traffic in All Lanes	Start in the Left and Finish Left	4
Cash Lane	No Traffic	Start in the Left and Finish Right	5
	Lead Vehicle Only in the Left	Start in the Left and Finish Right	6
	Traffic in Middle and Left Lanes	Start in the Left and Finish Right	7
	Traffic in All Lanes	Start in the Left and Finish Right	8
E-Z Pass	No Traffic	Start in the Right and Finish Left	9
	Lead Vehicle Only in the Left	Start in the Right and Finish Left	10
	Traffic in Middle and Left Lanes	Start in the Right and Finish Left	11
	Traffic in All Lanes	Start in the Right and Finish Left	12
West Springfield Toll Plaza Scenarios			
Customer Type	**Lane Configuration**	**Description**	**Scenario**
Cash Customer Scenario	Cash-E-ZPass-E-ZPass-Cash Configuration 3	Left-to-Left with Queue	1
		Left-to-Left without Queue	2
		Right-to-Right with Queue	3
		Right-to-Right without Queue	4
	E-ZPass-Cash-E-ZPass-Cash Configuration 2	Left-to-Left with Queue	5
		Left-to-Left Without Queue	6
		Right-to-Right with Queue	7
		Right-to-Right without Queue	8
E-ZPass Customer Scenario	Cash-E-ZPass-E-ZPass-Cash Configuration 3	Right-to-Left	9
		Right-to-Right	10
		Left-to-Left	11
		Left-to-Right	12
	E-ZPass-Cash-E-ZPass-Cash Configuration 2	Right-to-Left with Truck	13
		Right-to-Left without Truck	14
		Left-to-Right with Truck	15
		Left-to-Right without Truck	16
	E-ZPass-E-ZPass-Cash-Cash Configuration 1	Right-to-Left with Truck	17
		Right-to-Left without Truck	18
		Left-to-Right with Truck	19
		Left-to-Right without Truck	20

Hypotheses

The two general hypotheses of this collaborative research are:

1. *Familiar drivers would have a better driving performance than unfamiliar drivers at the same toll plaza.*
2. *The proposed treatments will have similar effects for familiar and unfamiliar drivers.*

Subject Drivers

A criterion was established for the recruitment of subject drivers in order to participate in the research study. This included having an active driving license, at least 18 months of driving experience and an age between 18 and 70 years old. Three age groups were considered at each plaza experiment: 18-25, 26-40 and 41-60 for West Springfield Toll Plaza and 18-25, 26-45 and 46-70 for Caguas South Toll Plaza. As part of the study protocol, participants were given a consent form and a questionnaire to gathered information related to their demographics and simulation sickness history.

Subjects were exposed to a scenario unrelated with the study as a trial run in which drivers could familiarize themselves with the simulator equipment and identify their sensitivity to simulation sickness. The familiarization scenario used consisted of a highway facility with moderate traffic and lasted 5 to 10 minutes. A total of 20 familiar and 20 unfamiliar subject drivers divided among three age groups was proposed for each study, which was approved by the IRB of both Universities. However, four of the participants that served as unfamiliar drivers for UPRM could not complete all the scenarios as consequence of simulation sickness and difficult recruitment of subjects for the replacement of these participants. The time duration of experiments for each participant was approximately 60 minutes.

ANALYSIS OF RESULTS

Caguas South Toll Plaza Analysis

Twelve unique scenarios were analyzed and compared in two different signage configurations at five different zones using familiar and unfamiliar subject drivers. Driver's lane movements became smoother as values of the SDRP became lower for any evaluated zone, indicating that subjects were less confused when determining which lane was the correct one. The SDRP analysis was performed using the F-test analysis at a 95% confidence level to compare the variance of the sample data of each zone within the two configurations. The average position of each participant was determined to calculate the sample variance within the roadway and make the comparisons between configurations. The F-Test was conducted to compare if the recommended treatment was significant for each group unfamiliar and familiar. Additionally, a second F-Test was performed to compare in each configuration how the familiarity of the subjects with the toll plaza was significant. Furthermore, a Bonferroni correction with a P-value less than 0.0102 was applied for both F-Tests to eliminate the familywise error (*15*).

$$F - Test = \frac{S_x^2}{S_y^2} \quad \text{[Eq.1]}$$

Where:

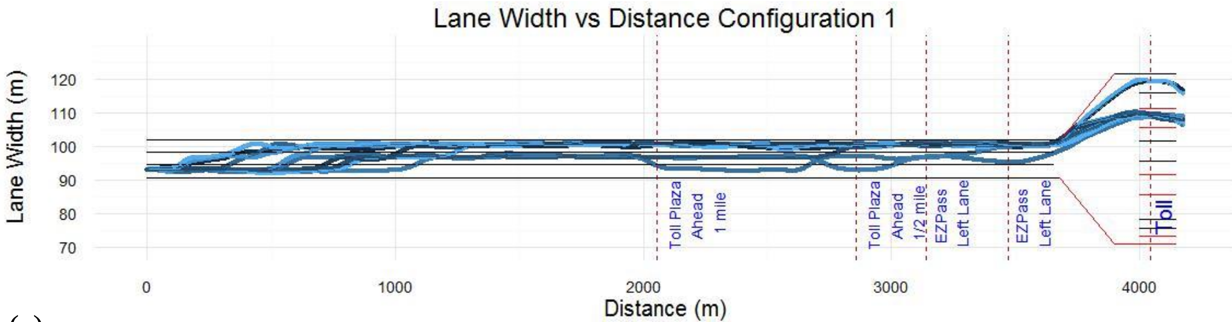
S_x^2 = Variance of subjects in group 1
S_y^2 = Variance of subjects in group 2

Results indicated that the SDRP of unfamiliar drivers was less significant than for familiar drivers that drove through the same configurations and scenarios. Table 3 shows the P-values of the SDRP, where familiar and unfamiliar drivers were compared for each Configuration and for all zones of interest. Figure 5a illustrates the trajectory of familiar drivers in scenario 11, where comparisons between configurations were the most significant. Zones 3, 4 and 5, which is located at the toll plaza, resulted the most significant for familiar drivers. Similarly, Figure 5b displays unfamiliar drivers trajectory on scenario 6 when approaching the toll plaza and how they drove with the signage configuration located on the freeway. These scenarios were the most significant, in which familiar and unfamiliar subjects changed lanes in a smoothly and harmonized course when exposed to overhead signage. In terms of unfamiliar drivers, Zones 3 and 4 were the most significant. Overhead signage configuration improved driving performance of familiar drivers in 66.67% of the scenarios tested (with at least one significant zone) whereas unfamiliar drivers had a driving performance improvement in 33%. This indicates that Configuration 2 has a potential of improving driving behavior at least by 30%, therefore improve safety when both familiar and unfamiliar drivers use the toll facilities.

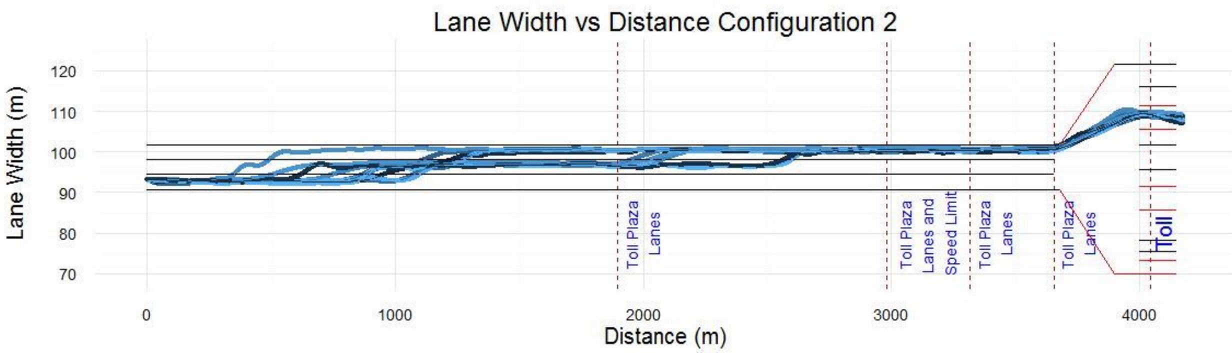
TABLE 3 Comparison of SDRP for Familiar and Unfamiliar between Configurations

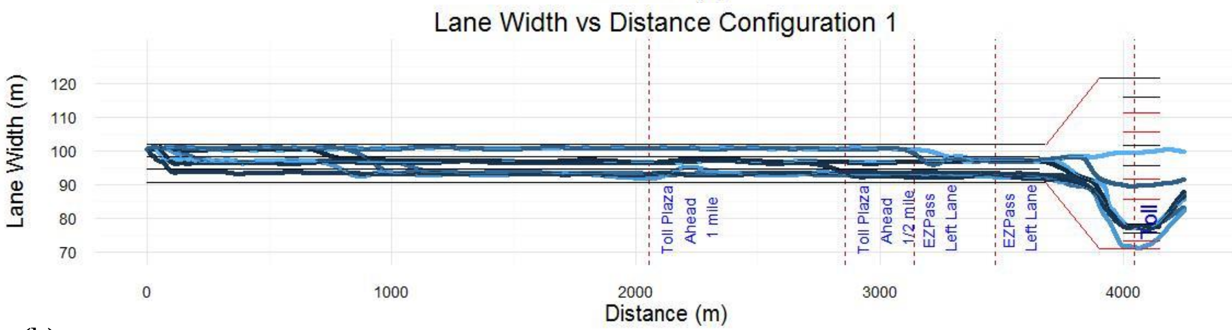
Scenario	**P-value of the F-Test for the Standard Deviation of the Roadway Position (SDRP) Comparisons between Configuration 1 (roadside sign) and Configuration 2 (overhead sign)**									
	Familiar Subjects (UPRM Participants)					**Unfamiliar Subjects (UMass Participants)**				
	Zone 1	**Zone 2**	**Zone 3**	**Zone 4**	**Zone 5**	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 4**	**Zone 5**
1	0.9575	0.6740	0.4075	0.1028	0.4314	0.1996	0.3941	0.4753	0.9864	0.4444
2	0.8516	0.9463	0.4461	0.8822	<0.0001*	0.2103	0.2668	0.3141	0.7060	0.5895
3	0.0005**	0.0002**	0.7273	0.4537	0.3305	0.4910	0.9388	0.9404	0.7006	0.9540
4	0.3724	0.3588	0.0051*	<0.0001*	0.2487	0.6983	0.6691	0.4603	0.6068	0.7900
5	0.5402	0.9401	0.5329	0.0010*	0.4905	0.1030	0.0248	<0.0001*	0.0001*	0.1155
6	0.3670	0.3156	<0.0001*	0.3219	0.0353	0.0075*	<0.0001*	<0.0001*	0.0020*	<0.0001*
7	0.2948	0.3790	0.0792	0.6081	0.0006**	0.6940	0.2998	<0.0001*	0.0008*	0.0033*
8	0.5856	0.7618	0.5363	<0.0001*	0.0031*	0.0450	0.0001*	<0.0001*	<0.0001*	0.0005*
9	0.5015	0.0820	<0.0001*	0.0013*	0.0002*	0.5522	0.3576	0.3726	0.7498	0.7133
10	0.8682	0.7362	0.3290	<0.0001*	0.3150	0.7540	0.1992	0.0920	0.7174	0.6554
11	0.4715	<0.0001*	<0.0001*	<0.0001*	<0.0001*	0.3684	0.0197	0.0150	0.1332	0.2142
12	0.3782	0.0033*	<0.0001*	0.2468	<0.0001*	0.5301	0.9528	0.8264	0.7835	0.9819

P-value <0.0102 with Bonferroni Correction.
** Configuration 2 had less variance in lane position.*
*** Configuration 1 had less variance in lane position.*



(a)





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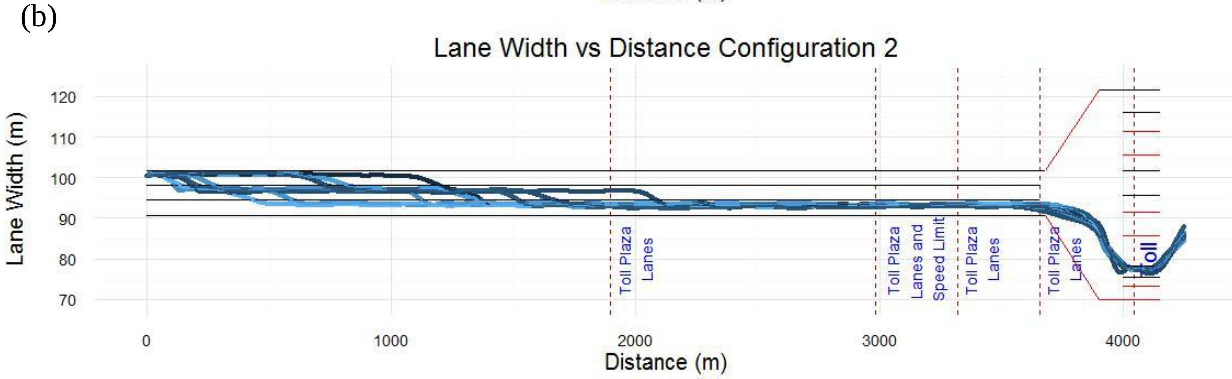

FIGURE 5 Roadway Position of Subject Drivers:
(a) Familiar Drivers in Scenario 11;
(b) Unfamiliar Drivers in Scenario 6.

The results of the SDRP of Configuration 2 were more significant than Configuration 1 for the analysis between familiar and unfamiliar drivers. Table 4 displays the P-values of the SDRP of familiar vs. unfamiliar drivers for all zones of interest in each configuration. Scenario 3 in Configuration 1 and scenario 11 in Configuration 2 were the most significant for this analysis. Furthermore, familiar drivers had less variability in lane position in 50% of the evaluated scenarios (with at least one significant zone) than unfamiliar drivers, resulting in a better driving performance. However, when exposed to Configuration 2, unfamiliar drivers improved the variability in lane position in 25% of the scenarios whereas familiar drivers had a better driving performance in 58.33% of the scenarios. Therefore, both subject samples had a better driving performance, in terms of lane changing movements, when exposed to overhead signage configuration along the freeway.

The proposed treatment for Caguas South Toll Plaza has a great potential for reducing the number of lane movement prior the toll plaza for both familiar and unfamiliar subject drivers. However, significant scenarios and zones were not always similar for familiar and unfamiliar drivers. Therefore, driving behavior in toll facilities may be affected by cultural aspects and not only by familiarity with the toll facility.

TABLE 4 Comparison of SDRP for both Configurations between Familiar and Unfamiliar Drivers

Scenario	P-value of the F-Test for the Standard Deviation of the Roadway Position (SDRP) Comparisons between Familiar and Unfamiliar Drivers									
	Configuration 1					Configuration 2				
	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
1	0.0248	0.0349	0.2341	0.1597	0.1850	0.3530	0.4180	0.7142	0.7086	0.2524
2	0.2799	0.0206	0.0581	0.2153	0.9232	0.9131	0.9917	0.7857	0.6482	<0.0001 [u]
3	<0.0001 [f]	<0.0001 [f]	0.0002 [f]	0.0001 [f]	0.4054	0.4331	0.1859	0.0006 [u]	<0.0001 [u]	0.1481
4	0.2057	0.4569	0.0029 [f]	0.0001 [f]	0.8267	0.9901	0.5618	0.6049	0.6137	0.1757
5	0.8851	0.3383	0.0127	0.0051 [f]	0.0001 [f]	0.2037	0.1195	<0.0001 [u]	0.7193	0.0079 [u]
6	0.1620	0.0593	0.0643	<0.0001 [f]	0.0001 [f]	0.4062	0.0001 [u]	0.2275	0.0703	0.1057
7	0.4835	0.1217	0.2289	0.5420	0.0001 [f]	0.4756	0.0885	<0.0001 [u]	0.0002 [u]	0.0068 [u]
8	0.9656	0.5246	0.2616	0.0770	0.0428	0.1181	0.0005 [u]	0.0001 [u]	0.6179	0.8487
9	0.8134	0.5921	0.3562	0.6825	0.1946	0.8297	0.8532	0.0004 [u]	0.0004 [u]	<0.0001 [u]
10	0.2362	0.1554	0.2393	0.7068	0.5985	0.1056	0.7379	0.8111	<0.0001 [u]	0.0903
11	0.1940	0.1959	0.0362	0.1270	0.0635	0.3191	0.0002 [u]	0.0001 [u]	0.0003 [u]	<0.0001 [u]
12	0.8749	0.0066 [f]	<0.0001 [f]	<0.0001 [f]	0.5841	0.9757	0.7892	0.7166	0.0002 [u]	<0.0001 [u]

P-value <0.0102 with Bonferroni Correction.
[f] *Familiar drivers had less variance in lane position.*
[u] *Unfamiliar drivers had less variance in lane position.*

West Springfield Toll Plaza Analysis

Three sets of conditional logit test, at a 95% confidence level, were conducted to determine significant differences in drivers' lane choice throughout cash scenarios, E-ZPass scenarios of lane configuration type 1 and 2, and all E-ZPass scenarios without trucks. The dependent variable, define as "Path Distance", is the binary variable of choosing either the longest or the shortest path upstream of the toll plaza. The results of the conditional logit test are shown in Table 5 and described below.

The *first conditional logit test* was conducted for cash lanes (scenarios 1 to 8) where the independent variables were origin-destination, queue, and lane configuration. Origin-destination was evaluated from left-to-left and right-to-right, where there was a queue of 5 vehicles or no queue within two lane configurations. The results showed that:

- queue had a statistically significant effect on drivers' lane choice, which occurred for both familiar and unfamiliar drivers.
- familiar and unfamiliar drivers showed the same behavior toward origin-destination, queue, and lane configurations.

The *second conditional logit test* was done for E-ZPass lanes (scenarios 13-20) where the independent variables were origin-destination, having leading truck and lane configuration. Origin-destination was evaluated from left-to-right and right-to-left, where there was a leading heavy vehicle within two lane configurations. The results showed that:

- origin-destination had a statistically significant effect on drivers' lane choice for both familiar and unfamiliar subjects.
- drivers were more likely to switch to the right lane upstream of the plaza when origin-destination was left-to-right.
- drivers were inclined to switch into the left downstream of the plaza when origin-destination was right-to-left.
- considering the fact that drivers are more likely to choose the right lane, trucks are located in the right lane regardless of the origin-destination of the subject driver.

The *third conditional logit test* was performed in E-ZPass lanes with no leading heavy vehicle (Scenarios 9, 12, 14, 16, 18 and 20), where the independent variables were origin-destination and lane configuration. Lane configurations were tested using origin-destination from left-to-right and right-to-left. The results showed that:

- origin-destination had a statistically significant effect on drivers' lane choice. The outcome was similar to the previous two conditional logit tests, where drivers switched to the right lane after the toll plaza for left-to-right origin-destination.
- when origin-destination was from right-to-left, drivers were likely to stay within the closest lane of the origin and would switch to the left downstream of the plaza.
- unlike familiar drivers, lane configuration affected lane decision for unfamiliar drivers. Unfamiliar drivers would choose longer distance in configuration 2 as compared to configurations 1 and 3.

TABLE 5 Conditional Logit Test for Familiar and Unfamiliar Drivers

Path Distance	Familiar				Unfamiliar			
Cash Scenarios (1-8)								
	Coefficient	**Standard Error**	**Z**	**P>|z|**	**Coefficient**	**Standard Error**	**Z**	**P>|z|**
Origin-Destination	0.79295	0.5841	1.36	0.175	0.56605	0.4074	1.39	0.165
Queue	4.09191	0.79000	5.18	<0.001*	1.48092	0.42873	3.45	0.001*
Configuration	0.15632	0.55993	0.28	0.780	0.40519	0.40532	1.00	0.317
E-ZPass Scenarios (13-20)								
Path Distance	**Familiar**				**Unfamiliar**			
	Coefficient	**Standard Error**	**Z**	**P>|z|**	**Coefficient**	**Standard Error**	**Z**	**P>|z|**
Origin-Destination	1.81533	0.43751	4.15	<0.001*	1.82765	0.43047	4.25	<0.001*
Truck	-0.32592	0.40534	-0.80	0.421	-0.78812	0.39712	-0.20	0.843
Configuration	0.48739	0.40676	1.2	0.231	0.23632	0.39787	0.59	0.553
E-ZPass Scenarios without truck (9, 12, 14, 16, 18, 20)								
Path Distance	**Familiar**				**Unfamiliar**			
	Coefficient	**Standard Error**	**Z**	**P>|z|**	**Coefficient**	**Standard Error**	**Z**	**P>|z|**
Origin-Destination	3.68277	0.77852	4.73	<0.001*	4.63928	1.10591	4.19	<0.001*
Configuration 2	0.64843	0.66856	0.97	0.332	1.70552	0.84238	2.02	0.043*
Configuration 3	-0.39460	0.63248	-0.62	0.533	-1.08098	0.77760	-1.39	0.164

***** *Significant P-value at 0.05*

A comparison was conducted for all scenarios to check whether there was any significant difference between each two pair of scenarios. Since all variables are categorical, a Pairwise Wilcoxon test was used (Table 6). The results showed that:

- Pairwise Wilcoxon test results comply with the conditional logit test results.
- the only difference detected was the effect of having a leading truck on E-ZPass scenarios, which was expected to occur.

The effect of having a leading truck could not have been tested through conditional logit test. However, according to the Wilcoxon test, having a lead truck has a statistically significant effect on drivers' lane choice.

TABLE 6 Pairwise Wilcoxon test results for Familiar and Unfamiliar Drivers

Null Hypothesis (H_0)	z	P>|z|	Effect on Drivers' Lane Choice	Comply with Conditional Logit Test
Familiar Drivers				
Sc.1 = Sc.2	2.828	0.0047*	Queue has a statistically significant effect	Yes
Sc.3 = Sc.4	3.000	0.0027*	Queue has a statistically significant effect	Yes
Sc.5 = Sc.6	2.887	0.0039*	Queue has a statistically significant effect	Yes
Sc.7 = Sc.8	3.162	0.0016*	Queue has a statistically significant effect	Yes
Sc.13 = Sc.14	2.236	0.0253*	Truck has a statistically significant effect	No
Sc.15 = Sc.16	-2.646	0.0082*	Truck has a statistically significant effect	No
Sc.17 = Sc.18	2.121	0.0339*	Truck has a statistically significant effect	No
Sc.19 = Sc.20	-2.828	0.0047*	Truck has a statistically significant effect	No
Sc.2 = Sc.11	0.000	1.000	Customer type has not a statistically significant effect	--
Sc.4 = Sc.10	-1.000	0.3173	Customer type has not a statistically significant effect	--
Sc.14 = Sc.16	-3.317	0.0009*	Origin-destination has a statistically significant effect	Yes
Sc.18 = Sc.20	-3.742	0.0002*	Origin-destination has a statistically significant effect	Yes
Unfamiliar Drivers				
Sc.1 = Sc.2	-.577	0.5637	Queue has not a statistically significant effect	No
Sc.3 = Sc.4	2.646	0.0082*	Queue has a statistically significant effect	Yes
Sc.5 = Sc.6	2.111	0.0348*	Queue has a statistically significant effect	Yes
Sc.7 = Sc.8	2.121	0.0339*	Queue has a statistically significant effect	Yes
Sc.13 = Sc.14	-0.598	0.5498	Truck has not a statistically significant effect	Yes
Sc.15 = Sc.16	2.819	0.0048*	Truck has a statistically significant effect	No
Sc.17 = Sc.18	-2.121	0.0339*	Truck has a statistically significant effect	No
Sc.19 = Sc.20	1.000	0.3173	Truck has not a statistically significant effect	Yes
Sc.2 = Sc.11	0.372	0.7098	Customer type has not a statistically significant effect	--
Sc.4 = Sc.10	1.000	0.3173	Customer type has not a statistically significant effect	--
Sc.14 = Sc.16	-2.527	0.0115*	Origin-destination has a statistically significant effect	Yes
Sc.18 = Sc.20	-3.464	0.0005*	Origin-destination has a statistically significant effect	Yes

***** *Significant P-value at 0.05*

CONCLUSIONS

This joint research between UPRM and UMass aimed at evaluating how a proposed solution for road safety issues on in-service toll plazas that operate ETC lanes and cash lanes can improve safety for unfamiliar drivers through the use of a driving simulator.

The conclusions applicable to *Caguas South Toll Plaza* for familiar and unfamiliar drivers in terms of overhead signage configuration for SDRP are summarized below (refer to Tables 3 and 4 for P-values of F-Test):

- SDRP between familiar and unfamiliar drivers was more significant for Configuration 2, which means that drivers behavior improved for both types of drivers when exposed to overhead signage.
- Driving performance of subjects in Configuration 2 improved by 67% and 33% for familiar and unfamiliar drivers, respectively.
- Overhead signage configuration has the potential to improve the variability of lane position by 50% in the scenarios evaluated for both familiar and unfamiliar drivers in toll plazas.
- Cultural aspects of subject drivers may influence driving behavior whether or not the driver is a frequent or first time user of a particular toll plaza.

Safety improvements are represented by a reduced variability in lane position, thereby reducing the number of conflict points and crash frequency. In the case of Caguas South Toll Plaza, Configuration 2 reduced the variability in lane position in at least 60% of the scenarios for familiar drivers and 30% for unfamiliar drivers. However, familiar drivers had a better driving performance when exposed to both signage configurations. Still, Configuration 2 improved driving behavior for both familiar and unfamiliar.

This means that even a slightly improvement in safety may contribute in saving lives in transportation facilities. Therefore, overhead signage configuration provides a better visual explanation of which type of toll lane use is ahead along with the corresponding speed limits. As a result, the possibility of a driver to be involved in a crash nearby a toll plaza may be reduced with appropriate overhead signage.

The conclusions applicable to *West Springfield Toll Plaza* for familiar and unfamiliar drivers in terms of drivers' lane choice using three sets of the Conditional Logit Test and a Pairwise Wilcoxon Test are summarized below (refer to Tables 6 and 7 for P-values):

- For the first logit test (cash scenarios), queue had significant effects on drivers' lane choice for both familiar and unfamiliar subjects.
- For the second logit test (E-ZPass scenarios), Origin-Destination had a significant effect on drivers' lane choice for both familiar and unfamiliar subjects.
- Both familiar and unfamiliar drivers changed to the right lane prior to the toll plaza left-to-right scenario configuration whereas in right-to-left scenarios the drivers tended to use the shortest path and change lanes after the toll plaza.
- For the third logit test (E-ZPass scenarios without trucks), there was a statistically significant effect of the Origin-Destination variable for both familiar and unfamiliar subjects. Drivers in left-to-right configurations were inclined to choose the longest path whereas drivers in right-to-left configurations tended to use the closest path.

- Drivers’ lane decision was affected by the lane configuration only for unfamiliar drivers in Configuration 2, where the longest path was the most common approach.
- A Wilcoxon test showed that having a leading truck has a statistically significant effect on drivers’ lane choice, which was expected to occur for E-ZPass scenarios.

One of the limitations in this collaborative research was that some of the participants suffered of simulation sickness, which may occur for many factors including when subjects perform abrupt braking while driving through the simulation. In particular, simulation sickness dropouts were a factor that affected subject drivers in the 26-40 age group that were exposed to the Caguas South Toll Plaza simulation scenarios. Therefore, the number of scenarios simulated and the time exposed to the simulation should be taken into consideration for future research experiments. Nevertheless, the trend with the familiar and unfamiliar participants was sufficiently robust in terms of statistical significance to draw conclusion relevance to first time drivers in toll plazas facilities in different jurisdiction. Further research is needed to evaluate cultural characteristics of subject drivers that were out of the scope of this collaborative study.
Additionally, the research conducted at each site will continue and additional variables such as velocity and acceleration noise will be explored to continue reinforcing the results found with the current analysis.

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