Operational and Safety-Based Analyses of Varied Toll Lanes

SAFETY RESEARCH USING SIMULATION

UNIVERSITY TRANSPORTATION CENTER

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Acronyms

DOT	Department of Transportation
ETC	Electronic Toll Collection
FHWA	Federal Highway Administration
IRB	Institutional Review Board
ITS	Intelligent Transportation Systems
MPH	Miles per Hour
MUTCD	Manual on Uniform Traffic Control Devices
ORT	Open Road Tolling
PDO	Property Damage Only
RITA	Research and Innovative Technology Administration
SDRP	Standard Deviation of Roadway Position
TCD	Traffic Control Devices
UPRM	University of Puerto Rico at Mayagüez
UTC	University Transportation Center
VMS	Variable Message Signs
WHO	World Health Organization

Sponsorship

This project is part of Safety Research using Simulation Center (SAFER-SIM) program that was established in 2013 and sponsored by the Research and Innovative Technology Administration (RITA). The investigation program brings together transportation safety research from multiple educational institutions with the goal of analyzing and addressing safety issues on America's roads. The following universities comprise the consortium:

University of Iowa, Iowa City, IA (UI)

The University of Iowa was founded in 1847 and is a major national research university with 30,000 students that are spread through 11 colleges. UI offers education in Engineering, Medicine, Pharmacy, Public Health and Liberal Arts and Sciences, along with six research centers that carry out transportation- related research projects.

University of Central Florida – Orlando, FL (UCF)

The University of Central Florida, founded in 1963, offers college education to approximately 60,000 students among 183 bachelors and 29 master's degrees and doctoral programs. This institution has a Center for Advanced Transportation Systems Simulation (CATSS) in which driving simulators and traffic data sensing technology has been used for road safety research. This Center has students from civil engineering, computer science, kinesiology, and psychology.

University of Massachusetts –Amherst, MA (UMass)

The University of Massachusetts provides education to nearly 30,000 students. Installed in 1980 was the Arbella Insurance Human Performance Lab (HPL), a laboratory that realized transportation-related investigations to address safety and driving behavior using a driving simulator.

University of Wisconsin – Madison, WI (UW)

The University of Wisconsin was founded in 1848 and has over 42,000 students enrolled under 150 bachelors and master's degrees and 100 doctoral programs. UW has transportation related research with faculties from Civil Engineering, Industrial Engineering, Computer Science, Medicine, Public Health, Urban Planning, Geography, Psychology and Law.

University of Puerto Rico – Mayagüez. PR (UPRM)

The University of Puerto Rico at Mayagüez is a recognized minority serving institution established in 1911. It is a bilingual college that offers studies to approximately 12,000 students in Agricultural Science, Arts and Science, Business Administration, Engineering, and Division of Continuing Education and Professional Studies. The Civil Engineering and Surveying Department offers a BS in Civil Engineering and Surveying, MS in Construction Management, Environmental Engineering, Geotechnical Engineering, Structural Engineering and Transportation Engineering. In addition, PhDs in Transportation, Structures and Environmental are offered at this institution.

Abstract

Over the past decades, fatal crashes and severe injuries have been observed to increase in highway facilities. This has created a big concern among different transportation agencies and other organizations such as State Departments of Transportation (DOT) and the World Health Organization (WHO). One of the most important components of highway operations that is affected by the increase in crashes are toll road systems.

Recent toll plaza designs have changed drastically due to the implementation of new technologies such as Electronic Toll Collection (ETC). Although these emerging features are developed to improve toll plaza operations, it has altered driver behavior and increased crash frequency as a result of driver confusion and difficult merging scenarios that occur when approaching toll plazas with alternative payment methods. Driving simulators are cost-efficient devices that can be used to understand how these changes affect driving behavior and safety issues in toll roads without endangering the health of the participants. Past studies have used driving simulators to evaluate the effectiveness of pavement markings, crash cushions, traffic control devices, Variable Message Signs (VMS) and other emerging technologies.

This research presents the first mobile driving simulator in Puerto Rico used to address safety issues related to driver behavior and toll plaza design, which is located in the Transportation Laboratory of the University of Puerto Rico at Mayaguez (UPRM). The purpose of this research is to evaluate the effectiveness of two different signage configurations of Caguas Sur Toll Plaza using a virtual simulation environment. The first configuration contained roadside signage that corresponded to the existing sign conditions, while the second configuration consisted of the proposed overhead signage.

Both signage configurations provided information regarding the speed limits and lane purpose before approaching the toll plaza. A sample of subject drivers was selected to drive through different scenarios to evaluate the effectiveness of both signage configurations. The variables used for analysis were standard deviation of roadway position (SDRP), average speed and acceleration noise, which were calculated in different locator references prior to the toll plaza.

The outcome of the research indicated that the configuration with the proposed conditions had a statistically significant reduction of acceleration noise, which was used as a surrogate measure of safety. This was a result of the reduction in lane-changing patterns. It was found that subject drivers of scenarios containing overhead signage changed lanes smoothly and reduced vehicle velocity with anticipation when approaching the toll plaza. Significant difference was found between the signage configurations when analyzing acceleration noise in the Toll Plaza Locator Reference.

In conclusion, this study provides strong evidence that driving simulators can be used as an effective and low-cost technology to identify alternative signage configurations at toll plazas without exposing drivers to dangerous situations. These results are expected to contribute both to the understanding of driving behavior and the safety of new features used in the operation of toll facilities around the world.

CHAPTER 1 INTRODUCTION

This chapter provides background information regarding safety issues that have influenced the urge for the development of research in toll plazas. Generally, the problem being attended in the investigation is associated with the diversity of toll plaza signage designs and how road safety has been affected by this component of highway operations. Therefore, a hypothesis is analyzed to determine if a change in the existing signage configuration can positively influence driving behavior, with the use of the driving simulator, and contribute to road crash reduction in toll plazas.

1.1 Background

Different organizations and state DOTs are concerned with the increment of fatal crashes and severe injuries related to highway facilities that have occurred during the recent decades. According to WHO, the ninth cause of disease or injury in 1990 was road traffic injuries (Peden et al., 2004), and it is estimated to rank third by the year 2020 with an approximate forecast of 1.9 million deaths per year (WHO, 2013). Different highway systems, such as toll roads, are being highly affected by the increase of crash frequency as a consequence of the development of new transportation technologies. Even though toll road systems have been designed and operated in the United States for more than 50 years, there is no recognized design standard that addresses the uniformity of toll plaza design and safety issues (Brown et al., 2006). The lack of uniformity among different toll plazas has altered drivers' speed and lane changing patterns when approaching toll facilities that affect toll plaza safety. New innovative technologies and lane modifications in toll plazas, such as ETC and Open Road Tolling (ORT), have amplified driving confusion and challenging merge scenarios that have resulted in unexpected driving behavior. Driving simulators have been used in different transportation studies to analyze how human factors and road safety are related in a virtual environment. This type of simulation can be used to understand driving behavior under different scenarios where drivers are in a hazardous situation without the subject driver being exposed to physical injury.

Driving simulators can be a cost-effective solution to study emerging technologies and lane modifications that are currently used or will be implemented in toll plazas. Scenarios can be created to understand how signage configuration and the number of lanes with different types of toll collection affects toll plaza safety. The purpose of this research is to recreate toll plaza scenarios in a virtual environment using an RTI (Realtime Technologies Inc.) cockpit driving simulator and evaluate if the proposed signage configuration has the potential to improve road safety of an existing toll road. The toll plaza selected for this study is Caguas Sur Toll Plaza, which is located on PR-52 within the municipality of Caguas, Puerto Rico. Therefore, the main goal of this investigation is to determine which of the following signage configurations has a lower likelihood of road crashes: existing conditions (roadside signage) or proposed conditions (overhead signage).

A methodology for the construction of toll plaza scenarios was developed in the Transportation Engineering Laboratory located in the University of Puerto Rico at Mayaguez (UPRM) with the collaboration of the University of Massachusetts Amherst and the University of Wisconsin in Madison. The research included three variables: standard deviation of roadway position (SDRP), average speed, and acceleration noise. Studies have demonstrated that acceleration noise distributions can be used as surrogate measures of road safety (Boonsiripant, 2009; Chung and Gartner, 1973). Average speed and acceleration noise were determined in four locator references while SDRP was determined in five locator references prior to the toll plaza. The variables were analyzed for both signage configurations using 12 different scenarios in which three different factors were controlled: traffic flow condition, starting lane position, and destination lane at the toll plaza. In addition, daylight and nighttime conditions were compared to determine how both situations affect driving behavior.

1.2 Problem Description

In the beginning, toll plazas were designed and constructed using cash-only systems for all lanes. Toll roads have been modified to mixed systems that operate cash lanes and ETC lanes with different posted speed limits. Caguas Sur Toll Plaza uses the extreme left lanes as ETC lanes for passenger cars only with a posted maximum speed of 55 mph. Similarly, center lanes operate as ETC lanes for general use, allowing both passenger cars and heavy vehicles to travel at a maximum speed of 35 mph. Lastly, lanes located at the extreme right are used as cash-only and recharge lanes, where drivers have to stop their vehicles in the toll plaza to perform the transaction.

Safety problems with toll plaza systems increased after the implementation of technologies with automatic tolling in combination with cash-only lanes. Although the Manual on Uniform Traffic Control Devices (MUTCD) added a section for toll plaza signage, toll roads prior to the release of the manual have not updated their signage configurations to fulfill the requirements (MUTCD 2009). Therefore, the potential for driving confusion increases when drivers have to decide which lane to use in a system that has diverse operating speeds at the same time.

1.3 Hypothesis

The general hypothesis for this research is that drivers of scenarios created with the proposed signage configuration would have a better performance, in terms of SDRP, average speed and acceleration noise, than those presented the scenario with the existing signage configuration. This hypothesis is used for the evaluation and comparison of three driving behaviors: first, the distribution of acceleration noise when subject drivers are exposed to both signage configurations; second, the difference in average speed and acceleration noise between participants who drive through the electronic toll lane or cash lane; and third, the difference between subject drivers in scenarios that include daytime or nighttime conditions. The performance measures used to evaluate driving behavior were obtained from the differences of SDRP, average speed, and acceleration noise between both signage configurations. The experimental design was based on the Latin square principle to counterbalance the order of subject drivers throughout the 12 scenarios and obtain results that are not dependent on the order in which participants saw each scenario. In addition, drivers were allowed to use the simulator in scenarios that were not related to the investigation to ensure their understanding of the equipment prior to the beginning of the experiments. However, participants that suffered from simulation sickness were excluded from analysis. This research was approved by the UPRM Institutional Review Board (IRB) protocol number 20141109, which represents a low risk under category 7 of 45CFR46.110.

This report is composed of the following chapters. Chapter 2 summarizes the literature used to understand safety in toll roadways, toll plaza signage configuration, and driving simulators. Chapter 3 includes the methodology used to develop the investigation (including the experimental design and subject drivers), driving simulator description, signage configurations, scenario- developing process, variables evaluated, and locator references used to acquire data. Chapter 4 describes the results of the investigation, analysis of the variables taken into consideration, and the discussion of results. Chapter 5 provides conclusions, recommendations, and acknowledgements. Lastly, references and appendices are included at the end of the report.

CHAPTER 2 LITERATURE REVIEW

This chapter consists of a review of studies over the past years that are related to safety in toll roadways, signage configuration at tolls, and the use of driving simulators in transportation- related studies. Road safety in toll plazas has created a huge concern among public and private transportation agencies due to the increase in road crashes. One element that can be negatively affecting safety in toll roads is the lack of uniformity in traffic control devices. Therefore, these sections were studied to understand how driving simulation could be used to evaluate safety of signage configurations in toll plazas that operate electronic toll collection systems in the Commonwealth of Puerto Rico.

2.1 Safety in Tollway Facilities

Fatal, injury, and property damage only (PDO) crashes are frequently associated with lane changes and speed variations on highway facilities. Road users have involuntarily modified driving behavior when approaching toll plazas as a consequence of the evolution and implementation of new technologies. The increase of fatal and injury crashes during highway operations has created safety awareness among different public and private agencies that manage toll plazas. Although toll plaza operations are crucial for highway facilities, design standards for toll systems that address the uniformity of traffic control devices (TCD) and road safety have been under slow development. Benda et al. (2009) stated that toll plaza operations and the accompanying TCDs used to facilitate their operation have varied widely from agency to agency.

Initially, cash payments were the only tolling method used in every toll road in the United States and Puerto Rico. At this moment, all lanes in the station served the same purpose. Later, automatic coin collectors were implemented in toll plazas to reduce time travel and enhance toll operation. Still, each driver had to completely stop their vehicle in one of the lanes approaching the toll plaza to either insert the coins in the coin machine or make the transaction with one of the toll workers. Although the automatic coin collector achieved faster transaction time than the traditional payment method, long travel time and heavy traffic congestion were still affecting toll road operations. The design and construction of toll plazas drastically changed as a consequence of other emerging technologies such as Electronic Toll Collection (ETC) and Open Road Tolling (ORT). ETC is an efficient Intelligent Transportation Systems (ITS) application that has numerous benefits such as lower transaction time, reduced air pollution and fuel consumption due to the fact that drivers do not need to stop the car at the station (Coelho et al., 2005; Venigalla and Krimmer, 2006). Likewise, ORT consists of high-speed ETC lanes that allow drivers to automatically pay tolls in an electronic way without the need for a significant speed reduction (Yang et al., 2013).

However, these design modifications and other elements used to improve toll plaza systems have altered drivers' reaction-perception time. Yang et al. (2013) indicated that adverse safety issues in barrier toll plazas were caused by the mix of different lanes with alternative payment methods. For example, drivers in traditional toll plaza configurations can generate acceleration-deceleration patterns and complex lane movements as a consequence of the variety of lanes with alternative payment options that are available. These issues are observed in Caguas Sur Toll Plaza, where the toll system operates both ETC and cash-only lanes.

Figure **2.1** illustrates how toll plazas in Puerto Rico have shifted from automatic coin collection and cash-only lanes into a hybrid toll system that combines ETC and cash lanes. Abuzwidah et al. (2014) reveal that toll plazas with varied tolling systems raise the potential for hotspots and crashes as result of acceleration-deceleration patterns and difficult merging scenarios of vehicles traveling at different speeds. These issues produce conflict points prior to toll plazas that result in unexpected lane change movements and fluctuations in drivers' speeds. The increase in crashes that take place in toll road systems has created the necessity for studying driving behavior when approaching toll plazas (Abdelwahab et al., 2002; Mckinnon, 2013).

a)

b)

Figure 2.1 Changes in Lane Configuration Usage and Toll Collection Payment in Caguas Sur Toll Plaza, Puerto Rico (a) Year 2004 and (b) Year 2015 (Source: Google Earth)

2.2 Toll Plaza Signage Configuration

Over the past decades, toll plaza systems were designed and constructed among transportation agencies without the use of a guideline that maintained consistency and uniformity in TCD's messages, color, placement and dimensions (Schaufler, 1997). Previous versions of the MUTCD did not include signage standards for toll plazas, resulting in a vast diversity of signage configurations and placement among different agencies who operate toll plazas in United States and Puerto Rico. In 2004, the Federal Highway Administration (FHWA) started to study existing conditions in toll plazas and developed a design standard that could facilitate toll plaza operations and improve road safety (Brown et al., 2006). In the year 2009, Chapter 2F "Toll Road Signs" was incorporated in the MUTCD to address signage requirements on toll roads where all lanes were used for payment. According to the MUTCD, signage should be located in such a manner that drivers can process the information illustrated in the sign and perform better with changes that occur in the approximation of a toll plaza. One of the key elements considered for signage location is the driver's perception-reaction time. This expression is defined as the time needed to detect, recognize, decide, and react to a situation. MUTCD indicates that toll pay warning signs should be located at an approximated distance of 1 mile and ½ mile before approaching the toll plaza in an overhead structure (MUTCD, 2012). Incorporating warning signs at a distant location from the condition for which the information is provided can cause drivers to forget the warning as a consequence of road-related distractions. Though two revisions of the MUTCD 2009 have been published, existing toll plazas still have signage configurations that do not fulfill the manual requirements, affecting the safety of road users in toll roads (Dutta et al., 2014). Benda et al. (2009) found that participants of their study considered that signage configurations should be improved in ORT systems. Some of the suggestions given were better signs for toll plaza fare, incorporation of arrows that indicate lane use, and additional warning signs when approaching the toll plaza. Although vehicle speeds at toll plazas are generally lower than other highway operations, they still cause a considerable number of injuries and PDO crashes. However, these modifications in toll plaza designs affect the reaction of drivers and, consequently, the safety of all road users, leaving space for researchers to study and provide solutions.

2.3 Driving Simulation

Due to being an efficient and cost-effective instrument to address road safety in several transportation studies, the demand for driving simulators has increased. Simulators provide researchers the opportunity to investigate driving behavior on both existing and future roadway conditions in a more secure manner, meaning that human subjects can be exposed to potentially hazardous scenarios without physically harming the participant.

A wide variety of driving simulator styles are being used in transportation-related studies to evaluate human factors on transportation facilities. The type of simulator varies depending on different elements, such as: screen systems, adapted audio systems, and simulation software that employs each of its elements to recreate the driving experience. Non-motion simulation systems like desktop and cockpit simulators provide an adequate and realistic experience of what happens in real-life situations. Desktop simulators consist of a set of screens or monitors, a steering wheel, acceleration and brake pedals, a sound system, and other features that are used for driving maneuvers. For example, Benda et al. (2009) used a desktop driving simulator to evaluate the effectiveness of ORT under different signage scenarios. On the other hand, cockpit simulators include features similar to desktop simulators with the addition of a vehicular seat that is positioned along with controls similar to those found in a real vehicle. However, the fidelity and comfort of the simulation is restricted by the available budget and equipment compatibility. For example, driving simulations with motion systems and real car body kits provide feedback far closer to the effect of the real driving experience at a higher cost than non-motion simulations.

Therefore, driving simulators can be used as efficient research instruments to investigate safety issues in existing or future transportation facilities. Researchers have used driving simulation to analyze driving behavior and skills, such as: driver distraction, impairment, novice training, and fatigue, among other factors (Varkaki et al., 2014; Oron et al., 2014). In addition, simulation has been of great value for evaluating the effectiveness of road design, Variable Message Signs (VMS), crash cushions, and other emerging TCD (Watson et al., 2006; Fitzpatrick et al., 2013; Jeihani et al., 2014). Driving simulation has also been used to address human factor issues, making it an effective tool not only for transportation but other disciplines, such as: psychology, medicine, and computer science (Fisher et al., 2011). However, this technology has not been used to evaluate driving behavior in toll plaza systems with multiple lanes and alternative tolling methods. This provides an opportunity for researchers to develop studies that involve signage configuration on toll roads with lanes that serve different purposes.

CHAPTER 3 METHODOLOGY

This chapter presents the methodology followed to accomplish the objectives of this research project. The experimental design, subject drivers, participant selection criteria, study protocol, instrument for data collection, scenarios, and configuration descriptions are presented in the different sections of this chapter.

3.1 Methodology Description

The methodology followed in this research project is illustrated in Figure 3.1 and described below. First, a literature review was conducted, focusing on three major aspects, namely toll plaza signage configurations, safety in tollway facilities and driving simulations. Second, the Latin Square experimental design, which consisted of 20 subjects divided into two groups, was selected for this research. Third, representing scenarios of the Caguas Sur Toll Plaza were developed using AutoCAD Civil 3D, Blender 2.49b, Google Sketch-Up and Sim Creator. Fourth, subjects had to satisfy certain criteria in order to be eligible as a participant for this study. Fifth, data collection and analysis was performed after all participants completed the designated scenarios. Sixth, an integrated analysis was conducted using the F-Test and ANOVA with Tukey comparison test for the three variables under evaluation. Lastly, results and conclusions were made.

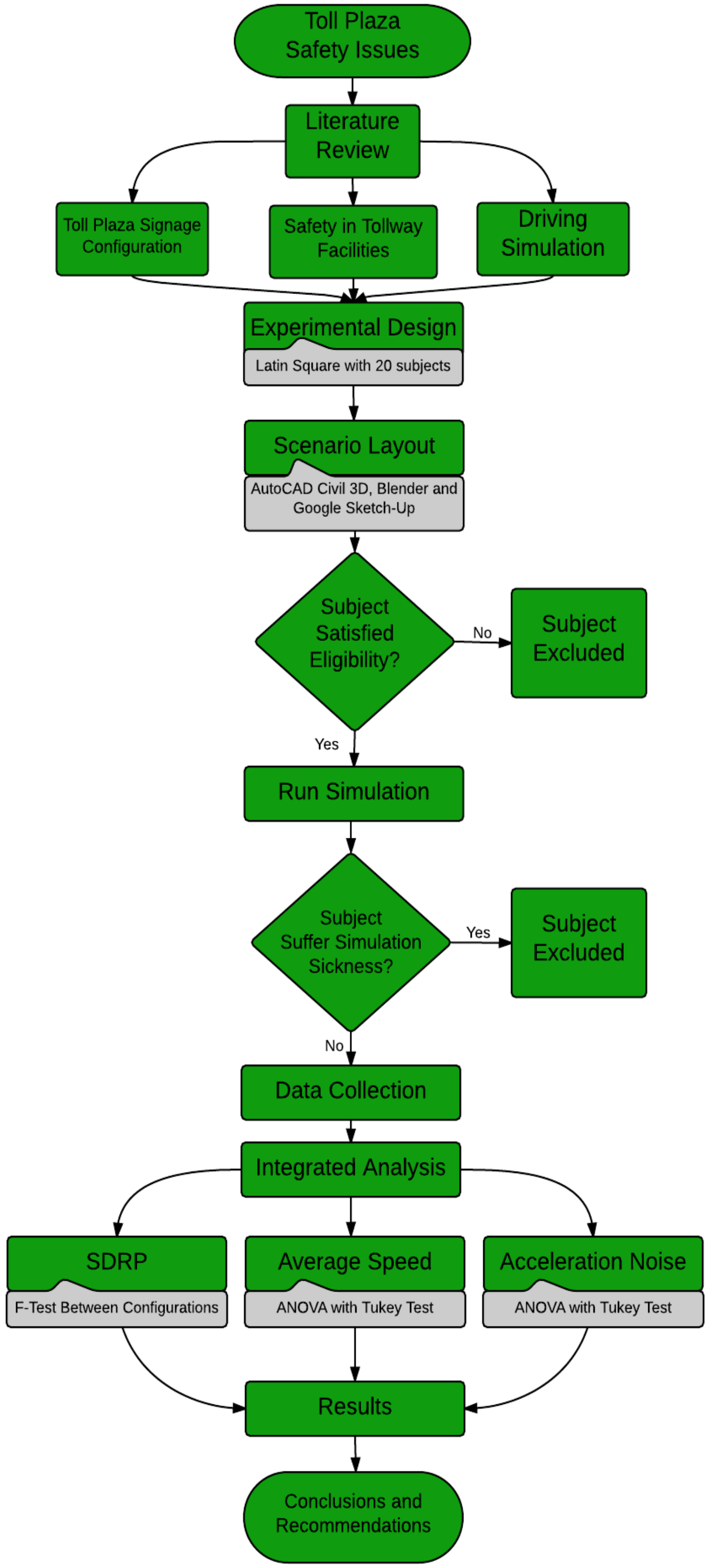


Figure 3.1 UPRM Research Methodology

3.2 Experimental Design

Ten of the subjects drove 12 scenarios with the current roadside signage configuration, and the other 10 subjects drove 12 scenarios with a proposed overhead signage configuration. Within each group of participants, a Latin Square was used to counterbalance the order of the 12 scenarios. This design ensured that the order in which the participants were exposed to the 12 simulation scenarios was counterbalanced across participants. Therefore, results obtained for each of the scenarios were not dependent on the order in which the participants saw the scenarios. As noted above, twelve different scenarios were created for each of the two configurations. The scenarios were the same between the two signage configurations, making signs the only aspect that varied between them. The twelve scenarios are presented Table 3.1.

Table 3.1 Scenarios Description.

Scenario	Traffic[a]				Start Lane		Toll Lane		Environment	
	1	2	3	4	Left	Right	E-ZPass	Cash	Day	Night
1	√				√		√		√	
2		√			√		√		√	
3			√		√		√		√	
4				√	√		√		√	
5	√				√			√	√	
6		√			√			√	√	
7			√		√			√	√	
8				√	√			√	√	
9	√					√	√		√	
10		√				√	√		√	
11			√			√	√		√	
12				√	√		√			√

3.3 Subject Drivers

A total of 9 female and 11 male subjects were used in this research. The age distribution amongst all participants was the following: 8 subjects from 18 to 25 years old, 7 subjects from 26 to 55 years old and 5 subjects from 56 to 70 years old. All subjects had to meet the following criteria:

Have a driver's license

Be in good health and free from any condition that could be aggravated by the simulation

Be between 18 and 70 years of age.

The mean age for the population used in the research was 34 years old. Figure 3.2 presents the subjects' distribution by age.

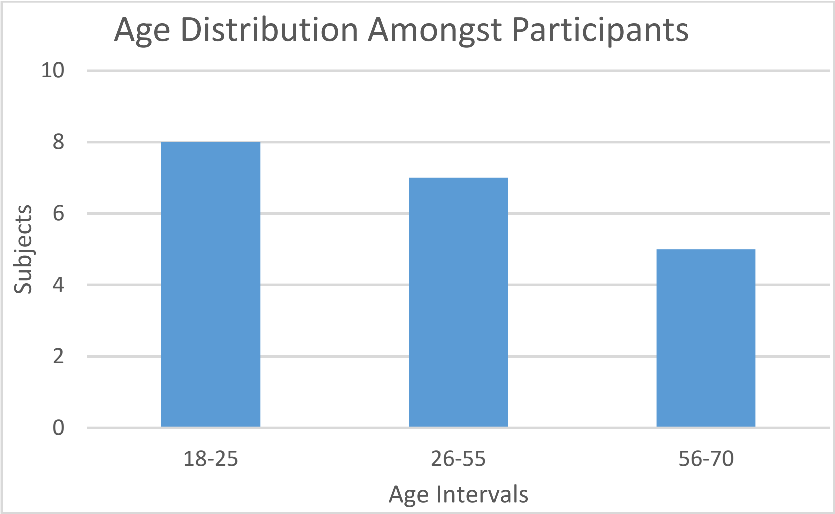


Figure 3.2 Subjects' Age Distribution Amongst Participants

3.4 Study Protocol

The risks involved in using the driving simulator were explained to participants as soon as they arrived at the study area. They were given the Informed Consent Form along with a detailed explanation of the study and the questionnaire form. Research assistants were available for answering any question that the participants had. Those subjects that did not sign the Informed Consent Form were excluded from the study. On the other hand, those subjects that signed the form started the simulation study only if they met the participation requirements.

When the subjects sat at the simulators, each of the components they would be using was explained to them. In addition, it was emphasized that driving in this equipment would feel different from the one they use to drive on a daily basis. Before running the research simulation, subjects ran a generic simulation until they felt comfortable driving the simulation. At that point the researchers answered any questions the subjects had. However, research assistants had to make it clear that no questions were to be answered during the run of each scenario related to the investigation. Before beginning the experiments, each subject was told what they would find in the simulation along with other brief instructions. It was also explained to them that they would drive through a toll road and he/she would interact with the toll lanes of E-ZPass, Every Traffic E-ZPass, and cash lanes. In addition, subjects were not allowed to listen to music at any time during the study. The researcher did not talk to the subject during any scenario simulations. At the beginning of each scenario, the researcher told the subject which lane he/she would pass through at the toll plaza depending on the scenario the subject was running (as shown in Table 3.2).

Table 3.2 Toll Plaza Final Destination Depending on the Scenario

Scenario	Lane in Toll Plaza
1-4	E-ZPass
5-8	Cash lane
9-12	E-ZPass

3.5 Runtime Setup Instruction

The information provided in the simulation, before clicking “Run Simulation”, is an essential part when analyzing the data. For this reason, the values placed in each space were standardized. The “Experiment Name” space has to be in position “1” when using Configuration 1 scenarios and “2” for Configuration 2 scenarios. The “Participant ID” space is for the subject’s number, which was assigned to the subject when he or she filled out the questionnaire form. The “Drive ID” space is for the scenario number that the subject is running. An example of this is shown in Figure 3.3.

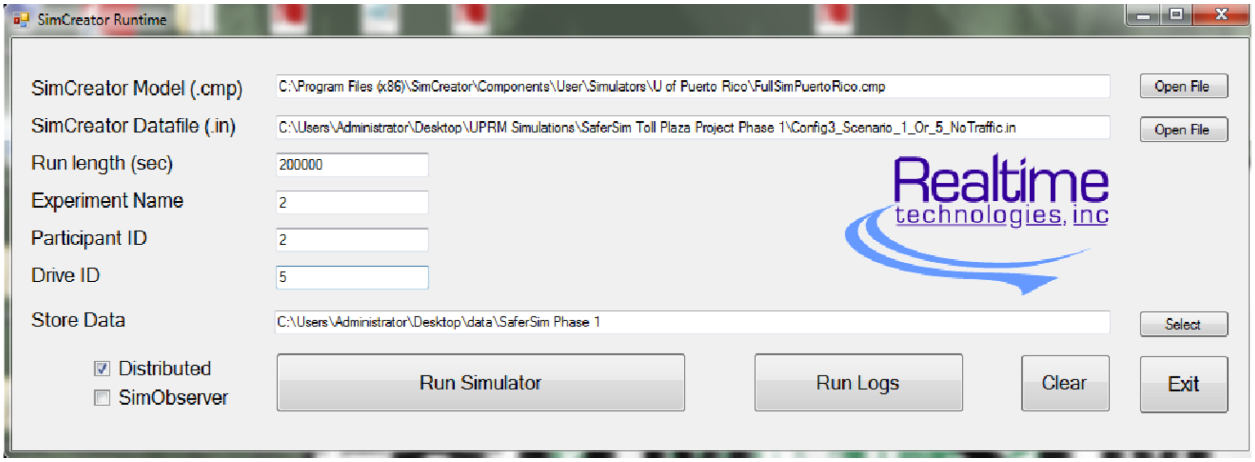


Figure 3.3 Realtime Sim Creator® Runtime Set-Up Screen

3.6 Configurations

There are two configurations; Configuration 1 represents the current roadside signage location for the toll road of Caguas Sur, Puerto Rico, and Configuration 2 represents the proposed overhead sign location for the toll road of Caguas Sur, Puerto Rico. The distributions of subjects in the configurations depends on the distribution presented in Table 3.3, which depends on gender and age.

Table 3.3 Subject Distribution by Configuration, Gender and Age

Age Group	Gender	Quantity for Configuration 1	Quantity for Configuration 2	Subjects
18-26	Female	2	2	4
	Male	2	2	4
27-55	Female	2	2	4
	Male	2	2	4
56-70	Female	2	2	4
	Male	2	2	4
Total:				24

The following table details the order in which the researcher ran the scenarios; for example: If the first subject is a 59-year-old male, the subject would be 1, Gender M, and age 59. The first scenario number would be 2, followed by scenario 3, then scenario 1, and so on from left to right until the subject driver reached the last scenario in that row (in this case, scenario 12). The researcher followed the order assigned under Scenario for each subject. If for some reason the subject could not continue the scenarios evaluated, the scenario(s) are marked in red to identify which one(s) was not completed. The information for Configuration 1 is presented in Table 3.4 and for Configuration 2 in Table 3.5.

Table 3.4 Configuration 1 Subject Drivers Sequence

Configuration 1														
Subject	Gender	Age	Scenario											
1	M	59	2	3	1	5	8	10	6	7	11	9	4	12
5	M	66	6	7	8	10	11	9	4	12	1	3	2	5
8	F	19	4	9	11	12	1	2	3	5	6	7	8	10
10	F	57	10	11	2	1	5	6	8	3	4	12	7	9
12	M	26	5	12	3	4	10	7	9	11	8	1	6	2
14	F	31	9	6	7	8	12	4	1	2	10	5	3	11
16	M	22	11	1	4	9	2	3	5	8	12	6	10	7
20	F	26	7	10	5	2	9	1	12	6	3	4	11	8
21	M	29	3	8	12	6	4	11	7	10	9	2	5	1
24	F	22	12	4	10	3	7	5	11	1	2	8	9	6
25	M	22	1	5	6	11	3	8	2	9	7	10	12	4
			8	2	9	7	6	12	10	4	5	11	1	3

Table 3.5 Configuration 2 Subject Drivers Sequence

Configuration 2														
Subject	Gender	Age	Scenario											
2	M	70	2	10	4	1	8	12	5	11	3	6	7	9
3	F	21	12	3	6	8	2	9	7	4	5	10	11	1
6	M	52	5	7	9	11	6	1	10	3	4	2	8	12
11	F	57	8	9	10	12	11	4	2	6	1	7	5	3
13	M	56	3	5	7	2	1	8	9	10	12	11	4	6
15	M	23	6	11	1	4	5	7	3	12	9	8	10	2
17	M	40	1	4	2	3	10	6	8	9	11	5	12	7
18	F	20	10	12	11	9	7	3	4	5	6	1	2	8
19	F	36	7	6	8	5	12	11	1	2	10	3	9	4
22	F	26	9	2	12	6	3	5	11	7	8	4	1	10
23	M	21	11	8	3	10	4	2	12	1	7	9	6	5
			4	1	5	7	9	10	6	8	2	12	3	11

Note: Subject that did not finish the scenarios is marked in red

3.7 Running the simulation

When the simulation was initiated, the scenarios were run in the order presented in the previous section. Each scenario took approximately five minutes to complete. To ensure the wellness of the subject, between each scenario the researcher asked the subject if he or she was fine and wished to continue on to the next scenario. While the subjects ran the scenario, the researcher took notes regarding the behavior of the driver in order to gather more information to improve future research and make a deep analysis of the subject's behavior.

While running the simulation, the subject's behaviors changed per scenario. For example, it was found that most of the subjects shifted between one hand and two hands when changing scenarios. It was also observed that most of the drivers used the lane-changing signal, something that is not usually seen on the roads. Also it was found that some of the drivers were driving slower at some points because they could read what was written on the sign.

3.8 Driving Simulator

The UPRM driving simulator system used in the experiments is a desktop simulator configured as a cockpit simulator with three primary components: the vehicle, the projection and screens, and the computer hardware and software (illustrated in Figure 3.4). The vehicle consists of a car seat placed in a wood frame with six wheels attached to make it versatile for mobile applications (see Figure 3.5). A steering wheel with turn-signal controls is installed in front of the car seat, which rests on a wooden countertop that serves as a dashboard for the simulator. The gear shifter is located on the right-hand side of the car seat, whereas the brake and accelerator pedals are fixed to the wooden floor. In terms of projection and screens, the simulator has three overhead projectors, each with their respective screen, which gives the subject a perspective visibility of 120° of the roadway. The audio from the simulation comes through a sound bar system, which is also located within the simulator's wooden frame. In terms of hardware and software, the simulator has desktop and laptop computers with Nvidia graphics and Realtime Technologies Inc. (RTI) SimCreator/SimVista simulation software.

Figure 3.4 . UPRM Driving Simulator Stationary Version

Figure 3.5 UPRM Mobile Driving Simulator Version

3.9 Scenario Development Process

For this study, toll plaza scenarios were developed because the driving simulation software provided by RTI did not have an integrated toll plaza scenario. To develop the scenarios, four commercial programs were used: AutoCAD Civil 3D, Google SketchUp, Blender 2.49b, and Internet Scene Assembler (ISA). Research was performed in two phases. The initial phase was conducted at UMass Amherst where the initial scenarios were developed, and the second phase was conducted at the University of Puerto Rico in Mayaguez and consisted of fine-tuning the scenarios and conducting the experiments in the driving simulator.

The first phase essentially consisted of three primary tasks described below. The first task consisted of designing the toll plaza structure and the toll roadway. The roadway was created by modeling a corridor in AutoCAD Civil 3D and exporting the surface of the model as a .dxf file. Pavement markings were also created in AutoCAD and exported as a .dxf file. The toll plaza structure, illustrated in Figure 3.7, was created using Google SketchUp and was then exported as a 3D model.

Figure 3.6 Caguas Sur Toll Plaza Simulated Model Illustration

In the second task, all the newly designed files were imported into Blender 2.49b. Blender was used because this software has the capability of exporting .vrml files, which is the file extension used by the simulator software employed in this experiment. In Blender, materials and textures were created so as to add color and other visual features to the roadway and the toll plaza. The created materials included the grass on the roadside, concrete for the traffic barriers, and the pavement's asphalt texture. The objects were then exported as .vrml files.

The third task consisted of importing the new .vrml files into the ISA software library. The designed objects contained within the new files were added to the objects within the simulation software library. The simulation scenarios were completed using these objects and the signs that were taken from the pre-existing files.

Figure 3.7 Configuration 1 Current Roadside Signage

Figure 3.8 Configuration 2 Proposed Overhead Signage

Figure 3.7 resembles the current signage condition, while Figure 3.8 resembles the proposed signage configuration. Both figures illustrate a perspective view of the two signage configurations that were used for the research.

3.10 Configuration Signs Description

Two signage configurations, roadside and overhead, were simulated. Configuration 1 consists of a set of 14 signs located at the freeway's roadside. Three of these signs indicate the distance with respect to the toll plaza, two indicate the location of the E-ZPass station, and the remaining nine indicate the posted speed limit for the freeway segment. In regards to driver information workload, nine of the 14 signs are located within the last ½ mile (805 meters) of the toll plaza.

Configuration 2 consists of 14 signs located both at the roadside and over the freeway. Nine out of the 14 signs are located on the side of the freeway. Out of these nine signs, three indicate the distance from the toll plaza, one indicates the location of the E-ZPass station, the next two indicate the locations of the Every Traffic Station and the Cash Lane Station, and the last three indicate the speed limit of the segment. The remaining five signs are located in overhead form. Two of these indicate the position of the E-ZPass, Every Traffic or Cash Lane Stations, and the other three indicate the position of the station and the speed limit for each lane. An additional three of the 14 signs came in the last ½ mile (805 meters) from the toll plaza. All the signs' dimensions and colors follow the requirement of the last revision of the MUTCD.

3.11 Independent Variables

Three independent variables were controlled in each configuration, specifically: the starting lane position, traffic flow condition, and destination lane at the toll plaza. Two starting lane positions are evaluated: left lane and right lane. Four different traffic flow conditions are evaluated: no traffic, only one lead vehicle in front of the test vehicle, no traffic in the left lane and traffic mix in the middle and right lanes, and traffic in all lanes. The two possible destination lanes at the toll plaza are passing through the E-Z Pass lane or passing through the cash lane.

3.12 Variables Evaluated

Three dependent variables were evaluated in the experiment, namely, Standard Deviation of Roadway Position (SDRP), average speed, and acceleration noise. SDRP is defined herein as the standard deviation of the average position of the subject drivers in the roadway for each zone. The average value of SDRP and speed were calculated for each subject in each zone of interest. The standard deviation of the acceleration, which has been used as a surrogate measure for crash frequency and a potential indicator of traffic flow quality that can be experienced by individual drivers, was calculated and denominated acceleration noise.

3.13 Locator References

Five locator references were used for the dependent variable, SDRP. The five locator references are illustrated in Figure 3.9 and described below. The first locator reference corresponds to the Toll Plaza distance located at 1.0 miles (1609 meters) from the toll plaza. For Configuration 1, the driver is informed that a toll plaza is one mile ahead. In Configuration 2, the driver is informed that the toll plaza is one mile ahead with the addition of the location of the toll stations. The second locator reference corresponds to the Toll Plaza distance sign. Configuration 1 advises the driver that there is a toll plaza in 0.5 miles (805 meters), while in Configuration 2, the driver is shown the toll station located in each lane and its corresponding speed limit. The third and fourth locator references in Configuration 1 indicate to the driver that the E-ZPass lanes are located at the left, while in these same zones in Configuration 2 the signs show the driver the toll stations located in each lane and the speed limit. The fifth locator reference is the Toll Plaza, which is the same for both configurations.

The rationale of the five zones delimited to perform the simulation was to evaluate how adequate the time allotted was for the location of each sign for the expected response of the subject drivers for a high-speed freeway segment approaching a toll plaza. For example, in the first two zones of Configuration 1, advance warning signs were located on the roadside to illustrate what to expect ahead and the corresponding distance (i.e., Toll Plaza 1 mile, Toll Plaza ½ mile). In these two zones, it was expected that the subject drivers be informed of the relative distance to the toll plaza. In zones 3 and 4, where E-ZPass signs were used to identify the electronic toll collection (ETC) lanes, it was expected that the subject drivers perform two tasks: reduce speed and change to the corresponding lane (ETC or Cash Lane). The Data Collection Area of each Locator Reference for the SDRP variable are specified in Figure 3.9

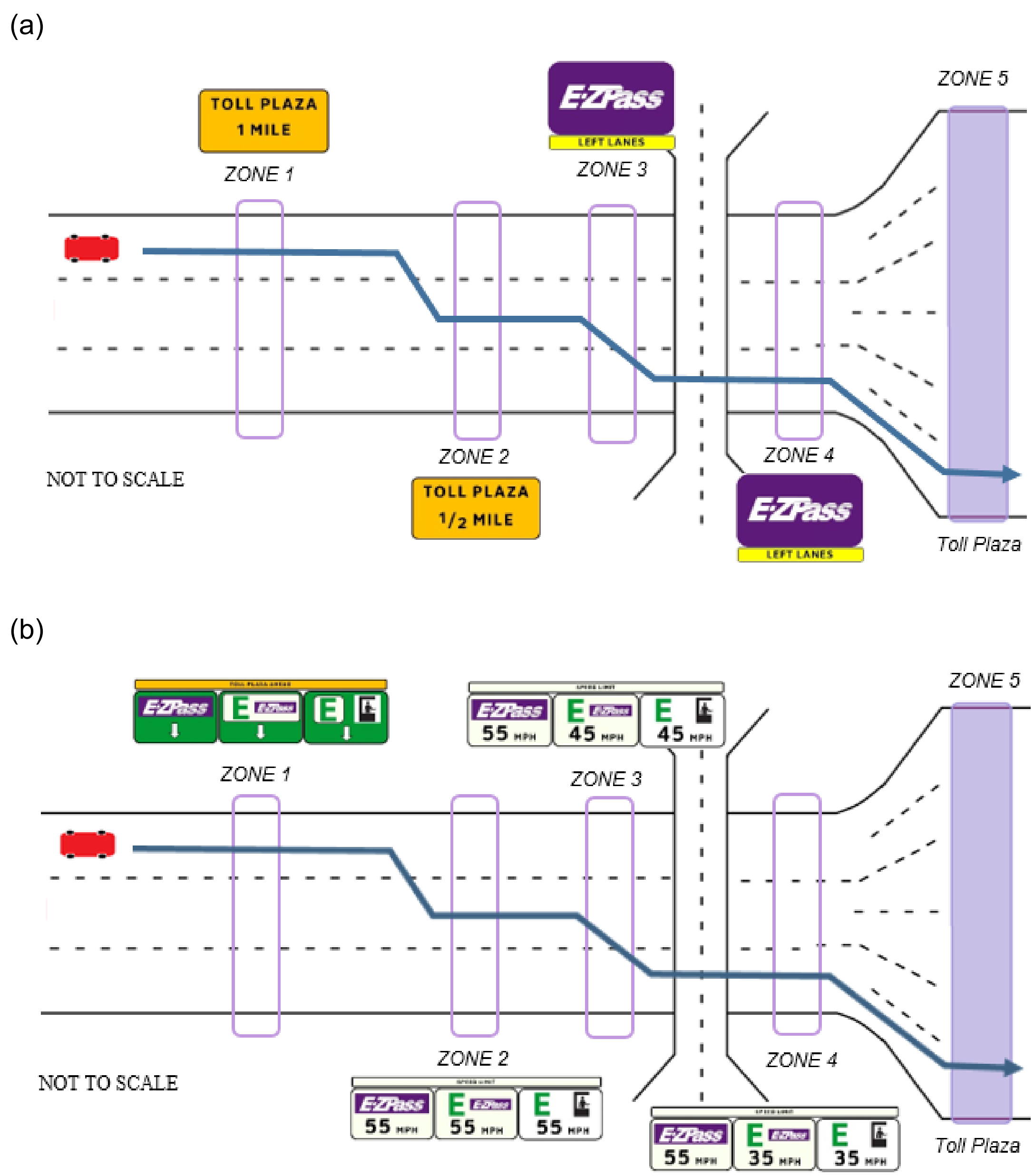


Figure 3.9 Locator References for the SDRP Variables

(a) **Configuration 1 Current Roadside Signage**

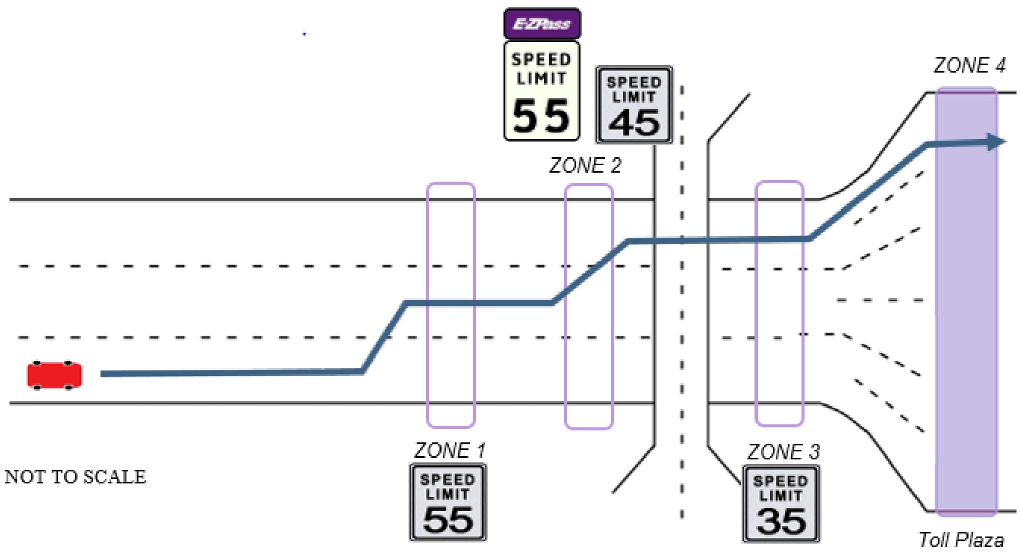
(b) **Configuration 2 Proposed Overhead Signage**

Table 3.6 Data Collection Area for SDRP Variables.

Locator Reference	Data Collection Area (meters)
Toll Plaza 1 Mile Ahead	496.8
Toll Plaza ½ Mile Ahead	334.4
E-ZPass Left Lane	280.4
E-ZPass Left Lane	198.1
Toll Plaza	246

Four locator references were used for the dependent variables average speed and acceleration noise. These locator references are illustrated in Figure 3.10 and described below. The first locator reference corresponds to the 55 mph speed limit regulatory sign. This sign is the first indication to the driver to reduce from the base speed of 65 mph to 55 mph due to the approach to the toll plaza. The second locator reference corresponds to the speed limit regulatory sign of 45 mph for the toll plaza cash lanes and the 55 mph regulatory sign for the "E-Z Pass lanes". The 45 mph regulatory sign was placed in order to indicate a decrease of speed to the vehicles traveling toward the cash lanes in the toll plaza, as opposed to those heading towards the "E-Z Pass lanes", which maintained the aforementioned speed restrictions. The third locator reference corresponds to the speed limit regulatory sign of 35 mph for vehicles traveling toward the cash lanes and 55 mph regulatory sign for vehicles traveling towards the "E-Z Pass lanes".

(a)



(b)

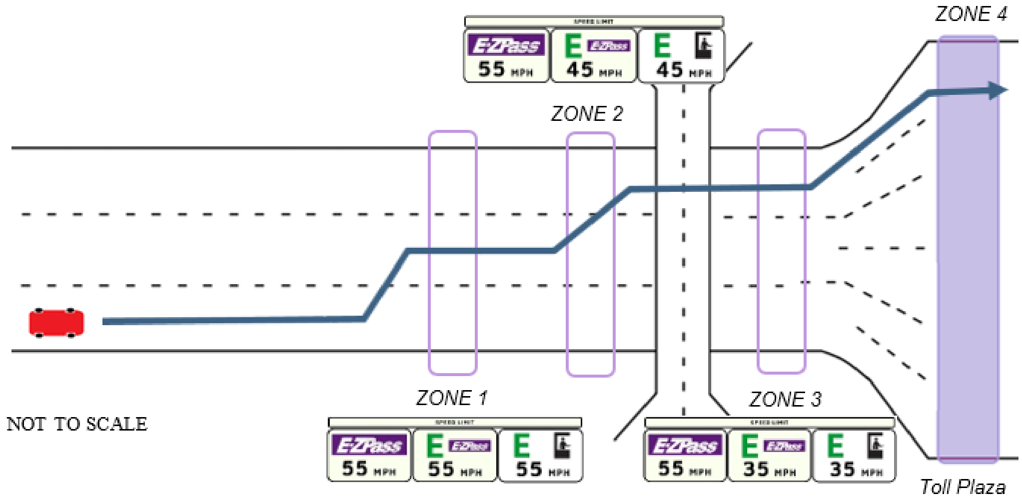


Figure 3.10 Locator References for the Average Speed and Acceleration Noise Variables

(a) **Configuration 1 Current Roadside Signage**

(b) **Configuration 2 Proposed Overhead Signage**

Table 3.7 presents the visibility distance between the test vehicle and the particular locator reference (i.e., speed limit regulatory sign or toll plaza). A decision was made to collect the speed and acceleration data starting at the visibility distance stipulated in the MUTCD and ending at the same distance passing the locator reference. This area is referred to herein as a Data Collection Area (MUTCD, 2009: Table 4D-2: Minimum sight distance for signal visibility).

Table 3.7 Data Collection Area for the Average Speed and Acceleration Noise Variables

Locator Reference	Visibility Distance (meters)	Data Collection Area (meters)
55 mph regulatory sign	190.5	380
45 mph regulatory sign	140.2	280
35 mph regulatory sign	99.1	198
Toll Plaza	190.5	380

CHAPTER 4 ANALYSIS AND RESULTS

This chapter explains the procedure used to analyze the data obtained from the UPRM driving simulator. Standard deviation of roadway position, average speed, and acceleration noise are described along with the statistical tests used for the analysis of each variable. The discussion of results explains which variables were found to be significant and how values of each variable change for both signage configurations.

4.1 Statistical Test Description

Several statistical tests were performed as part of the analysis. Initially, scenarios were compared to detect differences in the standard deviation of roadway position, average speed, and acceleration noise between configurations in each locator reference zone, as illustrated in Figure 3.9 (Locator References for the SDRP Variables) and Figure 3.10 (Locator References for Average Speed and Acceleration Noise Variables). In order to accomplish this analysis, a linear mixed model with multiple variables was used. The model takes into account locator reference, signage configuration, and randomness of the subject drivers. This method allows pairwise configuration comparison between zones. This model is used to eliminate the "Family Wise Error Rate", which is associated with the possibility of obtaining a false positive Type I error. The two-step procedure included: (a) generation of a linear mixed model for the average speed and acceleration noise, and (b) performing the ANOVA T-Test to determine if there is a significant difference in the signage configurations and locator reference in each scenario. If true, a multiple comparison by the Tukey's range test is used to determine which combination of configurations and zones differs for each specific scenario.

4.2 Standard Deviation of Roadway Position Analysis

To establish a significant difference for the SDRP variable between the two signage configurations, an F-Test was used. As illustrated in Equation 1, the F-test compared the variance of the data in each configuration between the locator references with a p-value less than 0.05. However, to eliminate the effect of the "family wise error", a Bonferroni correction was used for each scenario. The Bonferroni correction uses a p-value less than 0.0102.

$$F = \frac{S_X^2}{S_Y^2} \qquad \text{(Eq.1)}$$

where:

S_X^2 = Variance of group 1

S_Y^2 = Variance of group 2.

The variable SDRP was used in this research to study the position of the vehicle on the five locator references for comparison between Configuration 1, current roadside signage, and Configuration 2, the proposed overhead signage. In the first locator reference for the SDRP, one scenario reflects a significant difference, Scenario 3. For the second locator reference, three scenarios show a significant difference: Scenarios 3, 11 and 12. In the third locator reference, Scenarios 4, 6, 9, 11 and 12 prove to have a significant difference between configurations. These five scenarios represent 46.7% of the scenarios. In the fourth locator reference, six of the twelve scenarios (4, 5, 8, 9, 10 and 11) show a significant difference between configurations. Finally, in the fifth locator, the toll plaza, 50% of the scenarios present a significant difference (2, 7, 8, 9, 11 and 12). Table 4.1 shows the average for the SDRP variable for each locator reference for both configurations in each scenario.

Table 4.1 SDRP in the Twelve Scenarios for Both Configurations.

Scenario	First Locator Reference		Second Locator Reference		Third Locator Reference		Fourth Locator Reference		Toll Plaza	
	Configuration		Configuration		Configuration		Configuration		Configuration	
	1	2	1	2	1	2	1	2	1	2
1	95.81	95.92	95.66	96.03	95.75	96.25	95.77	95.59	86.21	89.29
2	96.44	98.15	96.43	97.71	95.87	96.63	95.76	95.43	84.36*	87.58*
3	95.35*	95.81*	95.40*	95.87*	95.40	95.57	95.37	94.61	85.45	86.28
4	95.69	96.49	95.78	96.60	95.57*	96.30*	95.40*	95.52*	84.47	88.46
5	99.66	91.36	101.31	92.74	102.39	93.33	102.69*	94.00*	117.87	106.34
6	101.16	101.91	102.11	102.58	102.4*	102.96*	103.01	103.25	117.08	116.33
7	99.51	99.67	100.76	101.16	101.01	102.27	102.33	103.21	117.20*	115.01*
8	99.19	100.59	101.92	101.55	102.37	102.39	102.61*	103.36*	117.29*	117.37*
9	97.56	98.54	97.45	96.65	97.34	95.73	96.14*	94.77*	86.19*	87.47*
10	97.95	98.11	96.94	97.15	96.79	96.21	96.69*	94.67*	87.11	86.39
11	96.60	97.02	96.60*	95.42*	96.09*	95.43*	96.02*	94.73*	85.36*	87.32*
12	95.64	96.49	95.31*	96.11*	95.40*	95.90*	95.33	94.74	84.53*	87.30*

P-Value< 0.0102 with Bonferroni correction.

4.3 Average Speed Analysis

For the average speed variable, a combination of ANOVA and the Tukey test was used to determine a significant difference between both signage configurations with a p-value less than 0.05. Four locator references were selected to compare the differences in average speed between scenarios. To identify a significant difference in a specific locator reference, the average speed variable in the proposed signage configuration, Configuration 2, should be less than the average speed in the current average speed, Configuration 1. Scenario 8 shows a significant difference in the average speed variable for the second locator reference and the Toll Plaza locator references. Table 4.2 illustrates the average speed for the locator references in both configurations for each scenario.

Table 4.2 Average Speed in the Twelve Scenarios for Both Configurations.

Scenario	First Locator Reference		Second Locator Reference		Third Locator Reference		Toll Plaza	
	Configuration		Configuration		Configuration		Configuration	
	1	2	1	2	1	2	1	2
1	62.13	59.98	54.08	55.63	52.16	51.78	51.83	47.33
2	61.05	59.84	53.15	55.50	50.92	52.43	51.57	48.98
3	61.53	58.33	56.18	53.97	54.44	51.93	52.09	50.12
4	59.30	59.00	53.77	53.63	53.44	51.74	51.10	49.28
5	63.36	59.46	54.01	52.43	45.61	40.63	21.08	18.46
6	61.17	59.52	51.30	52.01	41.73	42.69	20.03	20.50
7	56.48	57.08	51.17	49.90	45.61	40.70	18.99	19.79
8	57.46	54.71	54.10*	49.73*	47.70	43.44	22.45*	16.20*
9	60.46	61.71	55.34	54.42	52.19	51.36	49.79	49.26
10	61.66	57.52	55.38	52.82	51.64	51.56	48.04	49.35
11	61.34	57.22	54.98	52.86	53.68	52.58	51.99	52.36
12	60.47	58.69	56.75	54.36	55.16	50.95	51.72	48.83

*P-Value < 0.05

4.4 Acceleration Noise Analysis

For the acceleration noise variable, also known as the standard deviation of the acceleration, an ANOVA and Turkey test were used to determine a significant difference between the two signage configurations with a p-value less than 0.05. A T-Test equation, as illustrated in Equation 2, was used.

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{S_1^2}{N_1} + \frac{S_2^2}{N_2}}} \quad \text{(Eq. 2)}$$

where:

$\bar{x}_1$ = arithmetic mean of group 1

$\bar{x}_2$ = arithmetic mean of group 2

S_1^2 = variance of group 1

S_2^2 = variance of group 2

N_1 = sample size of group 1

N_2 = sample size of group 2.

Since the possibility of encountering a false positive value due to the multiple hypothesis tests in this research is high, a mixed linear model was used. The model compared each locator reference between both configurations and determined their corresponding p-values. The acceleration noise variable was evaluated in four different locator references in which the standard deviation of the acceleration was compared between scenarios. A significant difference in the acceleration noise variable means that the variability of the acceleration in the locator references within Configuration 2 was less than the same locator references in the scenarios of Configuration 1. Due to this variable, it was found that the Toll Plaza locator reference had a significant difference in three scenarios: Scenarios 3, 11 and 12. Table 4.3 shows the average value of the acceleration noise for the locator references of both configurations for each scenario evaluated.

Table 4.3 Average Acceleration Noise in the Twelve Scenarios for Both Configurations.

Scenario	First Locator Reference		Second Locator Reference		Third Locator Reference		Toll Plaza	
	Configuration		Configuration		Configuration		Configuration	
	1	2	1	2	1	2	1	2
1	0.6516	0.2085	0.3497	0.1841	0.4050	0.5009	0.4728	0.2694
2	0.2439	0.3107	0.7469	0.1943	0.2570	0.2969	0.6166	0.2962
3	0.3104	0.2775	0.3539	0.1598	0.3454	0.5955	0.5204*	0.1291*
4	0.2762	0.2474	0.3029	0.4277	0.4221	0.1930	0.3339	0.2355
5	0.3663	0.1719	0.6129	0.1889	0.6446	0.5047	2.1758	1.5258
6	0.4085	0.2199	0.3604	0.1389	0.4940	0.1898	1.8422	1.3895
7	0.3761	0.2579	1.0173	0.5254	0.8897	0.5207	2.0578	1.5720
8	0.3251	0.4995	0.5138	0.2358	0.5274	0.4144	1.7103	1.9817
9	0.2162	0.1676	0.3313	0.1994	0.6153	0.1501	0.3069	0.1653
10	0.2551	0.1700	0.2960	0.2398	0.1733	0.1574	0.6589*	0.1865*
11	0.6026	0.1940	0.2852	0.1541	0.4713	0.1304	0.4691*	0.1353*
12	0.2096	0.2286	0.2669	0.1844	0.2392	0.1493	0.5000	0.1390

***P-Value < 0.05**

4.5 Discussion of the Results

The SDRP proved to be the most significant difference between the variables evaluated in this research. The number of scenarios with significant differences, when comparing both signage configurations, is higher when the locator reference is nearer the toll plaza. Scenario 11 had four of the five locator references with a significant difference for the SDRP. Figure 4.1 illustrates the difference between the position of the subject drivers in Scenario 11 with traffic flow in the middle and right lanes. Lane changes occurred smoothly in Configuration 2 in comparison with Configuration 1, which did not have smooth lane changes. For example, subjects in Configuration 2 were in the desired lane, while subjects in Configuration 1 had drivers outside of the desired lane when compared in the second locator reference.

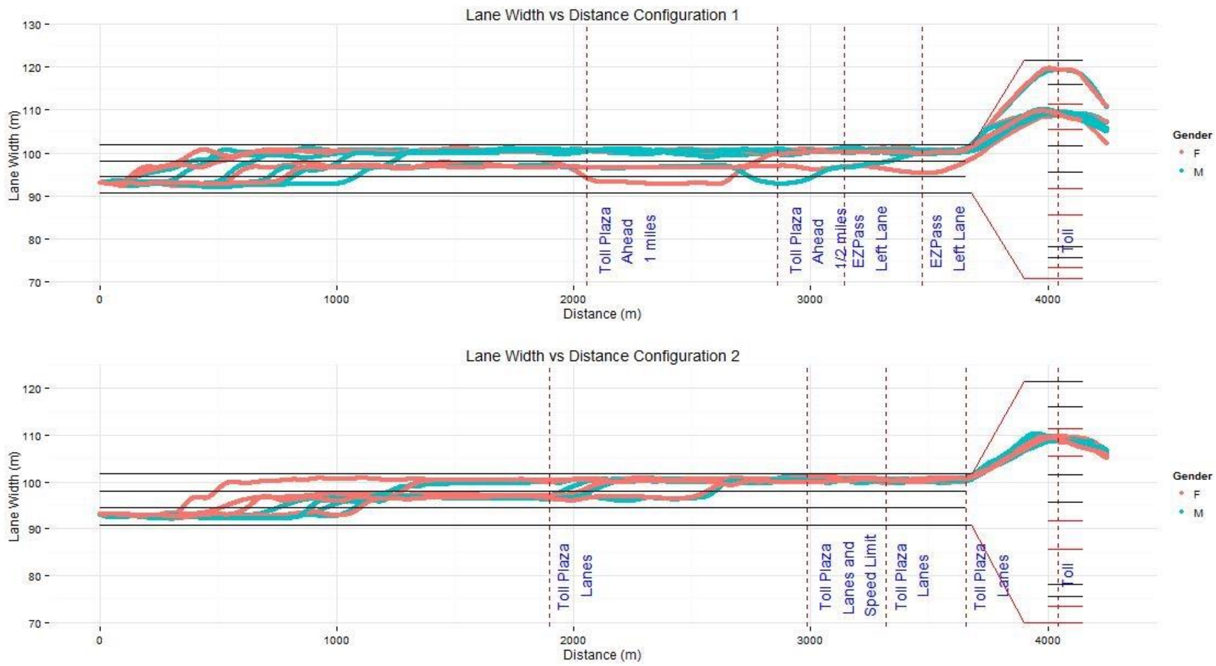


Figure 4.1 Position of the 10 Subjects vs. Distance of Scenario 11 for Both Configurations with the Delineation of the Freeway and Toll Plaza Lanes

Several scenarios demonstrate a significant difference for two or more locator references in five additional scenarios: these are Scenarios 3, 4, 8, 9 and 12. However, Scenarios 3, 4 and 12 represent a significant difference between Configuration 2 and Configuration 1 due to the fact that variability in Configuration 2 is higher than in Configuration 1. The variability obtained in these scenarios may occur because the subject started in the left lane and finished in the EZ-Pass lanes (i.e., two left stations at the Toll Plaza). In other words, the drivers did not have to change lanes to finish the simulated scenario. In Scenario 3, the subjects who drove Configuration 2 changed lanes in the first two locator references, resulting in a significant difference in these two locators in comparison with the same locator references in Configuration 1. Figure 4.2 shows the comparison between both configurations for the position of the 10 subjects in Scenario 3.

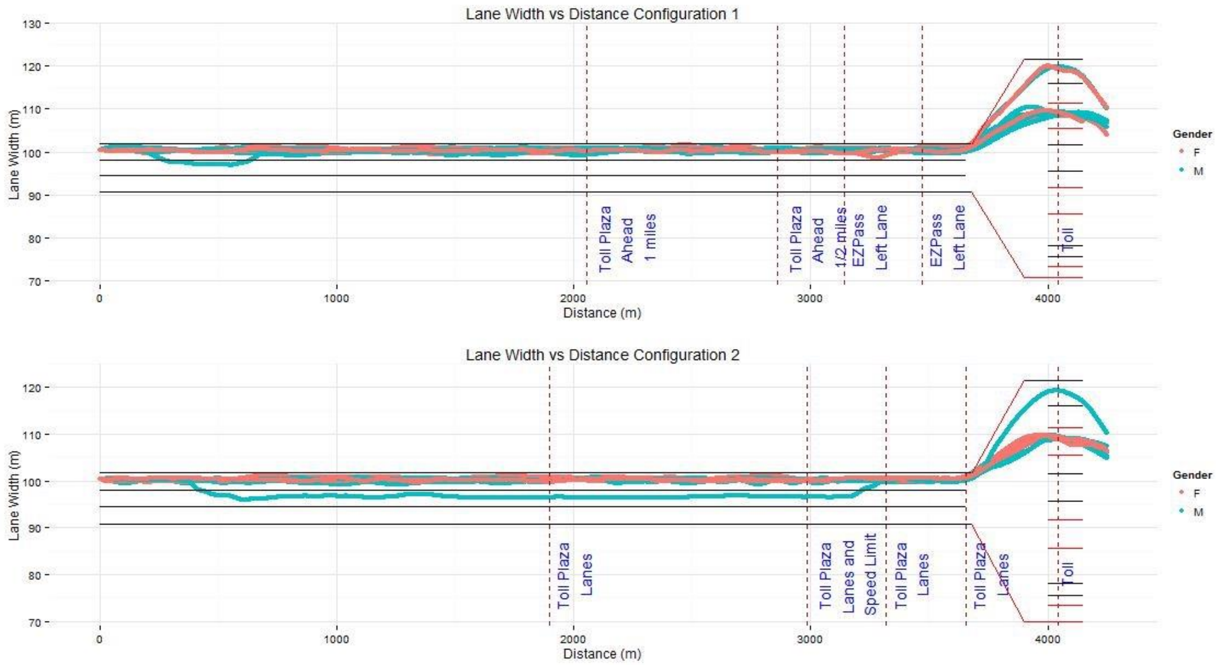


Figure 4.2 Position of the 10 Subjects vs. Distance of Scenario 3 for Both Configurations with the Delineation of the Freeway and Toll Plaza Lanes

In Scenario 4, two subject drivers in Configuration 2 changed lanes early and did not return to the left lane until the last second in comparison to Configuration 1, where all of the subject drivers were in the left lane approximately 750 meters before the toll plaza. Figure 4.3 shows the comparison between configurations for the position of the 10 subjects in Scenario 4.

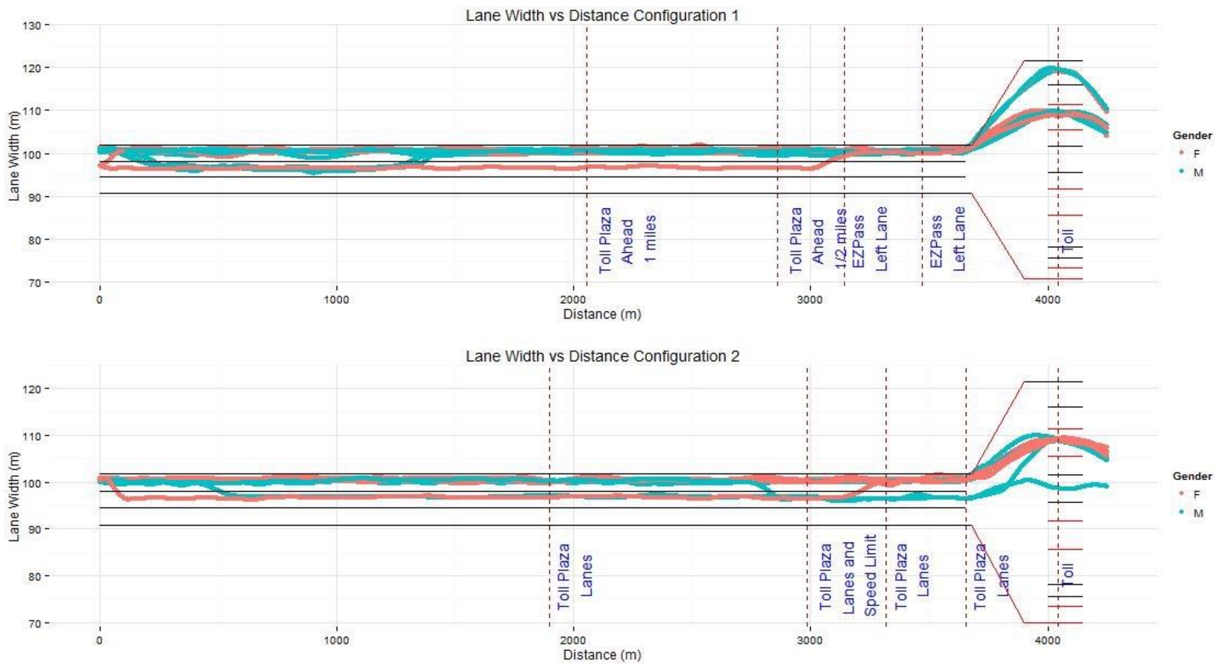


Figure 4.3 Position of the 10 Subjects vs. Distance of Scenario 4 for Both Configurations with the Delineation of the Freeway and Toll Plaza Lanes

Subjects that drove Configuration 2 in Scenario 8 changed lanes before the ones that drove Configuration 1, as is shown in Figure 4.4. For example, the second locator reference has four subjects in Configuration 1 that were out of desired lane. Two of those drivers passed through the wrong station, while in Configuration 2 only three drivers were out of the desired lane. However, the fourth locator reference and the toll plaza demonstrated a significant difference between both configurations.

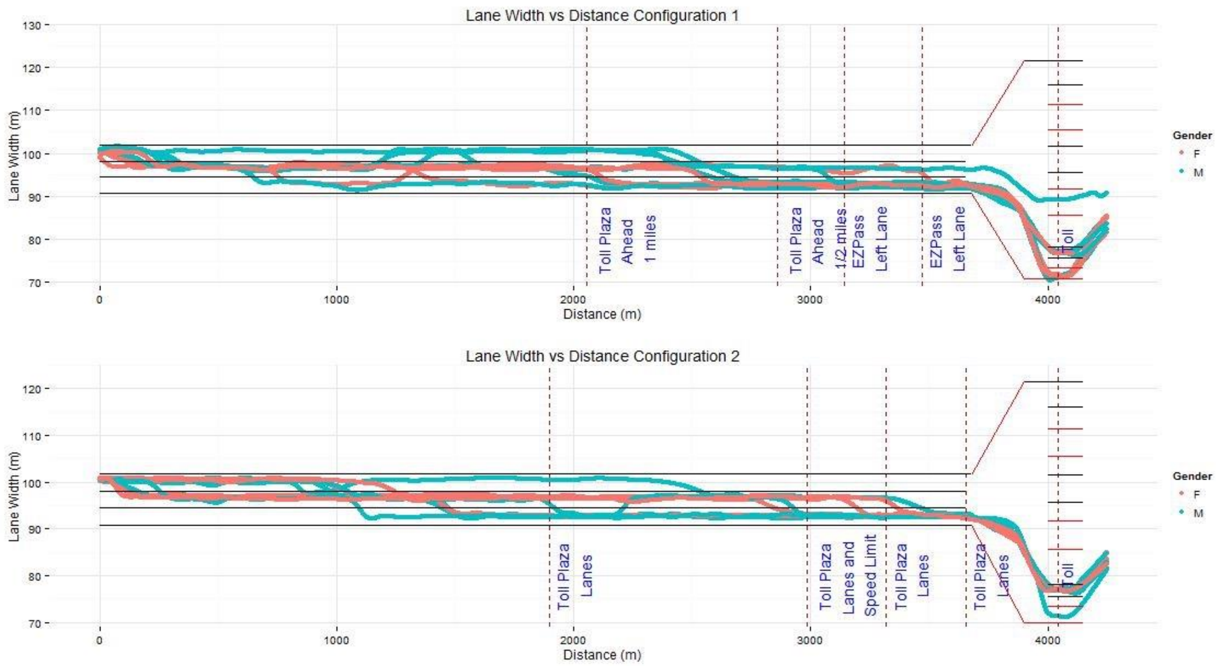


Figure 4.4 Position of the 10 Subjects vs. Distance of Scenario 8 for Both Configurations with the Delineation of the Freeway and Toll Plaza Lanes

In Scenario 9, two of the five locator references displayed significant differences between the two signage configurations. These were the fourth and Toll Plaza locator references. Two drivers in Configuration 1 did not pass through the desired lanes at the fourth locator reference, while all drivers in Configuration 2 managed to pass through the specified lane. Figure 4.5 shows the comparison between configurations for the position of the 10 subjects in Scenario 9.

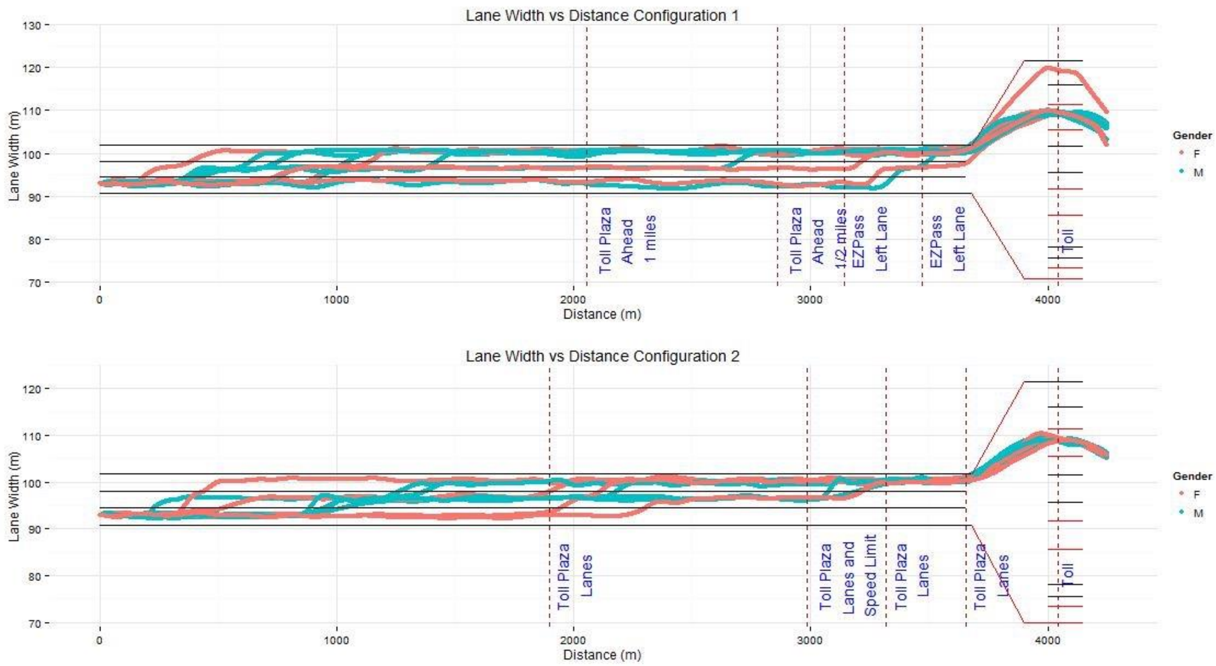


Figure 4.5 Position of the 10 Subjects vs. Distance of Scenario 9 for Both Configurations with the Delineation of the Freeway and Toll Plaza Lanes

In Scenario 12, which includes a nighttime condition, three of the five locator references concluded with significant differences between the two signage configurations in the second, third and Toll Plaza locator references. However, the differences are related to the fact that two subjects in Configuration 2 changed to the desired lane at the end, while in Configuration 1 all the subject drivers moved to the desired lane approximately 1200 meters ahead of the toll plaza. Figure 4.6 shows the comparison between configurations for the position of the 10 subjects in Scenario 12.

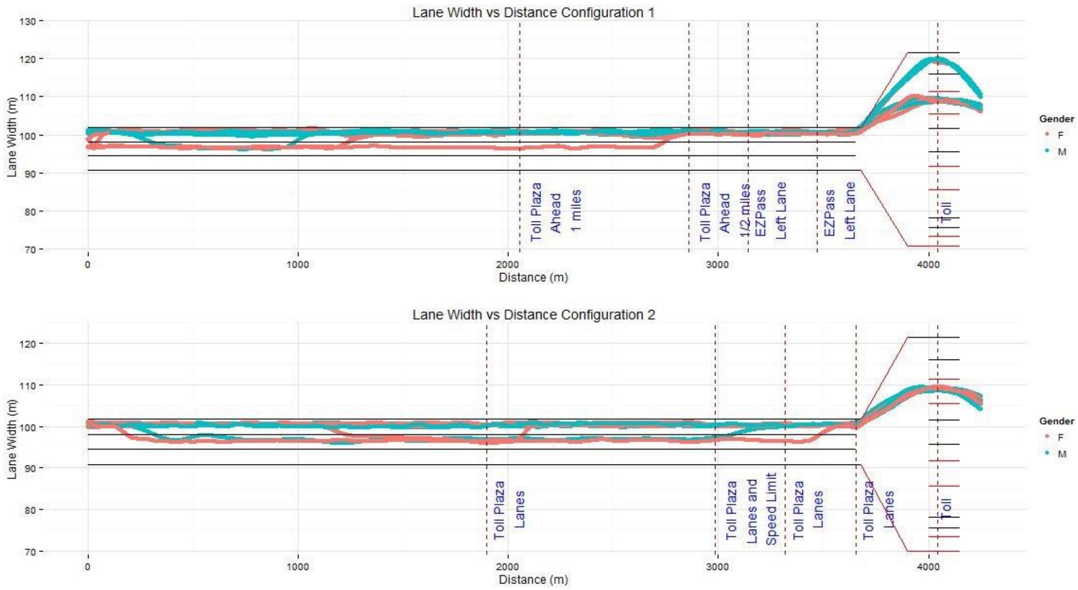


Figure 4.6 Position of the 10 Subjects vs. Distance of Scenario 12 for Both Configurations with the Delineation of the Freeway and Toll Plaza Lanes

Figure 4.7 represents Scenario 6 and shows that subject drivers changed more rapidly to their desired lane in Configuration 2, as the overhead signs provided drivers more information than the roadside signs in Configuration 1. For example, in the second locator reference, four subjects in Configuration 1 were out of their desired lane, and one of those passed through the wrong station, while in Configuration 2, at the same position, only one subject was out of the desired lane.

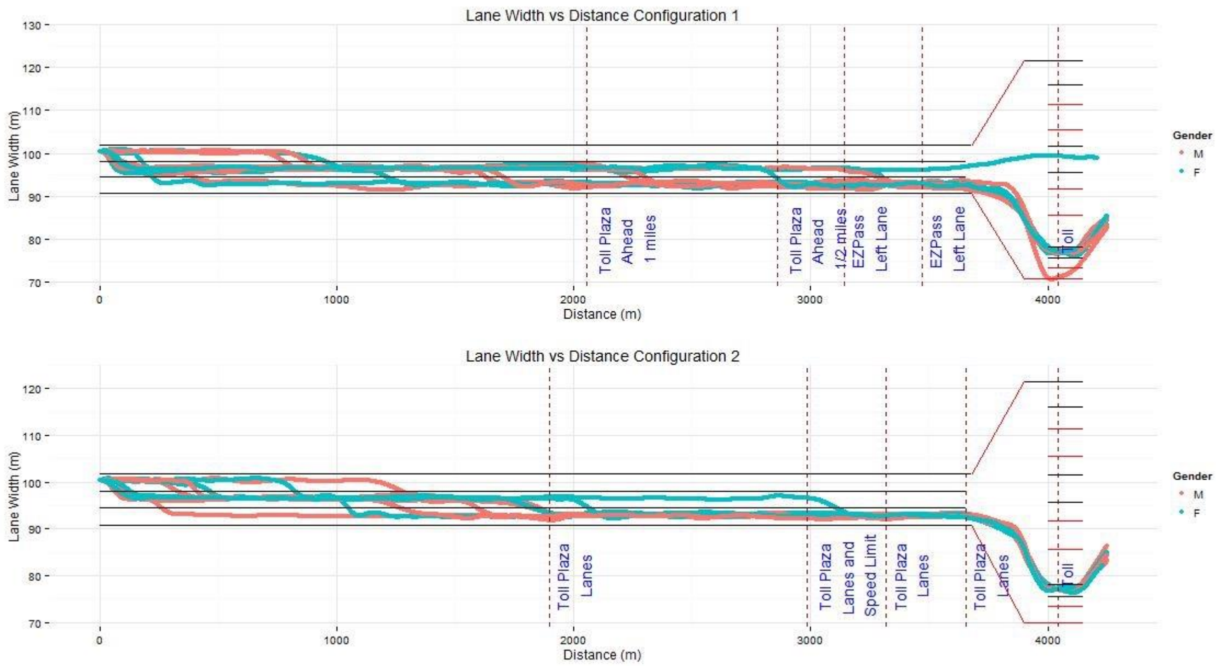


Figure 4.7 Position of the 10 Subjects vs. Distance of Scenario 6 for Both Configurations with the Delineation of the Freeway and Toll Plaza Lanes

Analyzing only the scenarios with significant differences is where improvements can be seen in the positioning of the subject drivers along the tollway scenario, with the last two locator references representing the higher percentage of difference. The fourth and Toll Plaza locator references show 14.18% and 12.81%, respectively, in the positioning of the subject driver. These two zones (i.e., locator references) are the most important because these areas are decision points where the driver has to choose which lane they would use once arriving at the toll plaza. According to the results, Configuration 2 reduces the variability in lane changes near the toll plaza, which indicates a safer roadway condition.

In terms of the average speed, only one scenario presents a significant difference between configurations: Scenario 8 in both the second and Toll Plaza locator references. For the second and Toll Plaza locator references, an 8.08% and 27.84% difference was found between Configuration 2 and Configuration 1. The reduction in the average speed variable can be associated with the fact that the subject driver is instructed to come to a complete stop at the toll plaza. Figure 4.8 illustrates the average speed of the 10 subject drivers in Scenario 8.

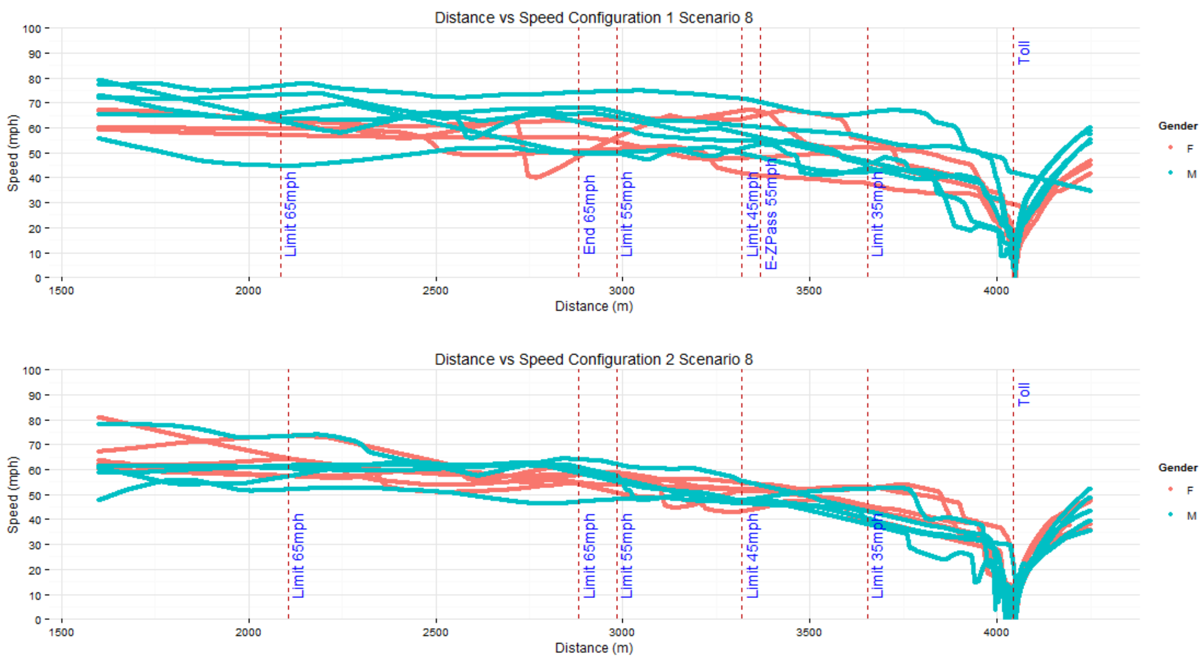


Figure 4.8 Average Speed Along the Tollway for Scenario 8

As can be seen in Figure 4.8, the variability in speed in Configuration 1 is higher than Configuration 2. Also, one of the drivers in Configuration 1 did not come to a complete stop in the toll plaza as was required in this particular scenario.

For the acceleration noise variable, the Toll Plaza locator references present three scenarios with significant differences: Scenarios 3, 10 and 11. Even though the quantity of scenarios and locator references with significant differences are low, a tendency between these drivers was found. In all three scenarios, subjects had to pass through the E-ZPass lane or the ETC lane. These three scenarios showed differences between Configuration 1 and Configuration 2 of 75.2%, 71.7% and 71.2%, respectively. The results mentioned above indicate that the behavior of drivers approaching the toll plaza with ETC improved with the incursion of the overhead signage, since less variability in acceleration and position of the driver in the corresponding lane is observed. This combination of factors allowed researchers to establish that overhead signage significantly improves road safety in toll plazas. In addition, acceleration noise has demonstrated that it can be used as a surrogate measurement of crash frequency, as established by Boonsiripant in 2009. The results of this research indicate that the proposed configuration has the potential to improve the road safety by 70% in toll plazas.

One possible explanation for the differences observed between the two configurations studied are as follows: a driver who is in a particular lane when approaching a toll plaza is more likely to observe the overhead signs on the road with large-sized letters due to catching their attention and because they are in the driver's line of vision, in contrast to having to spot a small-lettered sign at the side of the road (outside the driver's line of sight). This contributes to a greater sense of safety in making the right decision to get into the proper lane at the toll plaza. In addition, a driver approaching a toll plaza with multiple lanes is forced, by default, to make a complex decision; it is at this point that the installation of overhead signs is most effective, giving the driver the opportunity to make the right decision and give the expected response.

CHAPTER 5 CONCLUSIONS

This research project studies two different signage configurations using the UPRM driving simulator. The investigation consisted of 12 scenarios with ten subjects for each configuration. Three independent variables (traffic flow, starting lane position, and destination station at the toll plaza) were controlled. Three dependent variables were evaluated: SDRP, average speed, and acceleration noise. These variables were recorded in different locator references within 12 separate scenarios. The most significant findings are summarized below:

Signage Configuration as perceived by the subject drivers revealed that Configuration 2 is safer than Configuration 1 based on the statistical analysis used to evaluate safety.

The **SDRP,** defined as the standard deviation of the position of the vehicle in the roadway, proved to be the most significant difference between the variables evaluated in this research. Scenario 11 contained the most significant difference for SDRP variables, having significant difference in 4 out of the 5 areas studied. In addition, the third, fourth, and Toll Plaza locator references resulted in a significant difference in 41.67%, 50% and 50% of the scenarios.

The **Average Speed** proves to have a significant decrease in the subject drivers' speed in the scenarios with Configuration 2 in comparison with Configuration 1. Specifically, the average speed was found to have a significant difference in the second locator reference and the toll plaza for Scenario 8. The decreases in driver speed for the second locator reference were 8.08% and 27.84% in the toll plaza which is the fourth and final locator reference.

The **Acceleration Noise** variable, a surrogate measure for crash frequency and potential indicator of traffic flow quality that can be experienced by individual drivers, showed a significant difference in the toll plaza locator reference. Scenarios 3, 10 and 11 resulted in significant differences of 75.2%, 71.7% and 71.2%, respectively. In comparing acceleration noise between Scenarios 4 (daytime) and 12 (nighttime), it is noted that in Configuration 1 (current) this variable is 47% greater at night (0.34 m/s^2 to 0.5 m/s^2), while in Configuration 2 (dedicated signage) this variable is 42% smaller at night (0.24 m/s^2 to 0.14 m/s^2). Using the variable acceleration noise as a surrogate measure, an expected potential crash reduction between 50% and 60% can be achieved.

In summary, Signage Configuration 2 improves driver safety, as compared to Configuration 1, by improving the positioning, speed, and acceleration noise of the subject drivers as they approach a toll plaza. Overall, the proposed safety countermeasure has the potential to reduce the expected crash frequency up to 70% including both day and nighttime scenarios.

5.1 Recommendations

Several recommendations arise as a result of this research study:

In the short term, coordinate with other research centers that have driving simulators to use the Toll Plaza scenarios with subject drivers within their jurisdictions to test significant difference in the dependent variables SDRP, Average Speed and Acceleration Noise evaluated in this study.

In the medium and long term, it is recommended to evaluate operation and safety conditions on the dynamic toll lane and other tollway facilities in order to improve possible safety hazards associated with tollway systems.

5.2 Acknowledgements

The authors want to express their gratitude to the Research Innovative Transportation Administration (RITA) and its University Transportation Centers (UTC) Program for providing the funding for the UPRM SAFER-Sim research project that is reported herein. In addition, the authors acknowledge the assistance of Dr. Raúl Macchiavelli in the statistical analysis and the collaboration of Juan Rivera, Graduate Research Assistant, and Kelvin Santiago, PhD candidate, in the development of the scenarios.

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APPENDIX

A. Standard Deviation of Roadway Position for the 12 Scenarios and Two Signage Configurations Evaluated.

B. Average Speed for the 12 Scenarios and Two Signage Configurations Evaluated.

C. Forms and Questionnaires for the Caguas Sur Toll Plaza Experiments.

D. Publications and Posters Presented at Technical Forum by the UPRM SAFER-SIM Team.

   a. During this phase of the program four technical publications have been accepted in local and international conferences. All four have been peer reviewed in organizations like Road Safety and Simulation International Conference 2015, 95th Annual Meeting Transportation Research Board 2016, 19th Pan-American Conference of Traffic, Transportation Engineering and Logistics (PANAM) and Advances in Transportation Studies Journal. In addition, a technical presentation was approved in the 28th Congress of Engineering and Surveying (COINAR 2016) and a technical paper for the 14th LACCEI International Multi-Conference for Engineering, Education and Technology.

   b. A list of the publications and presentation are presented below:
      i. *Operational and Safety-Based Analysis of Toll Plaza Signage using Driving Simulation*
      ii. *Driving Simulation in the Safety and Operation Performance of the freeway toll plaza*
      iii. *Uso de Simulador de Conducción para Evaluar el Desempeño de Seguridad en Plazas de Peaje en Puerto Rico*
      iv. *Operational and Safety-Based Analysis of Toll Plaza Signage using Driving Simulation.*
      v. *Simulador de Conducción como Herramienta para Evaluar Mejoras a la Seguridad Vial y su Relación con el Desarrollo Económico*
      vi. *Manejo de "Big Data" Aplicado a Estudios de Plazas de Peaje Utilizando un Simulador de Conducción*

Standard Deviation of Roadway Position for Scenarios 1-12

Figure 0.1 Standard Deviation of Roadway Position Configuration Comparison Scenario 1

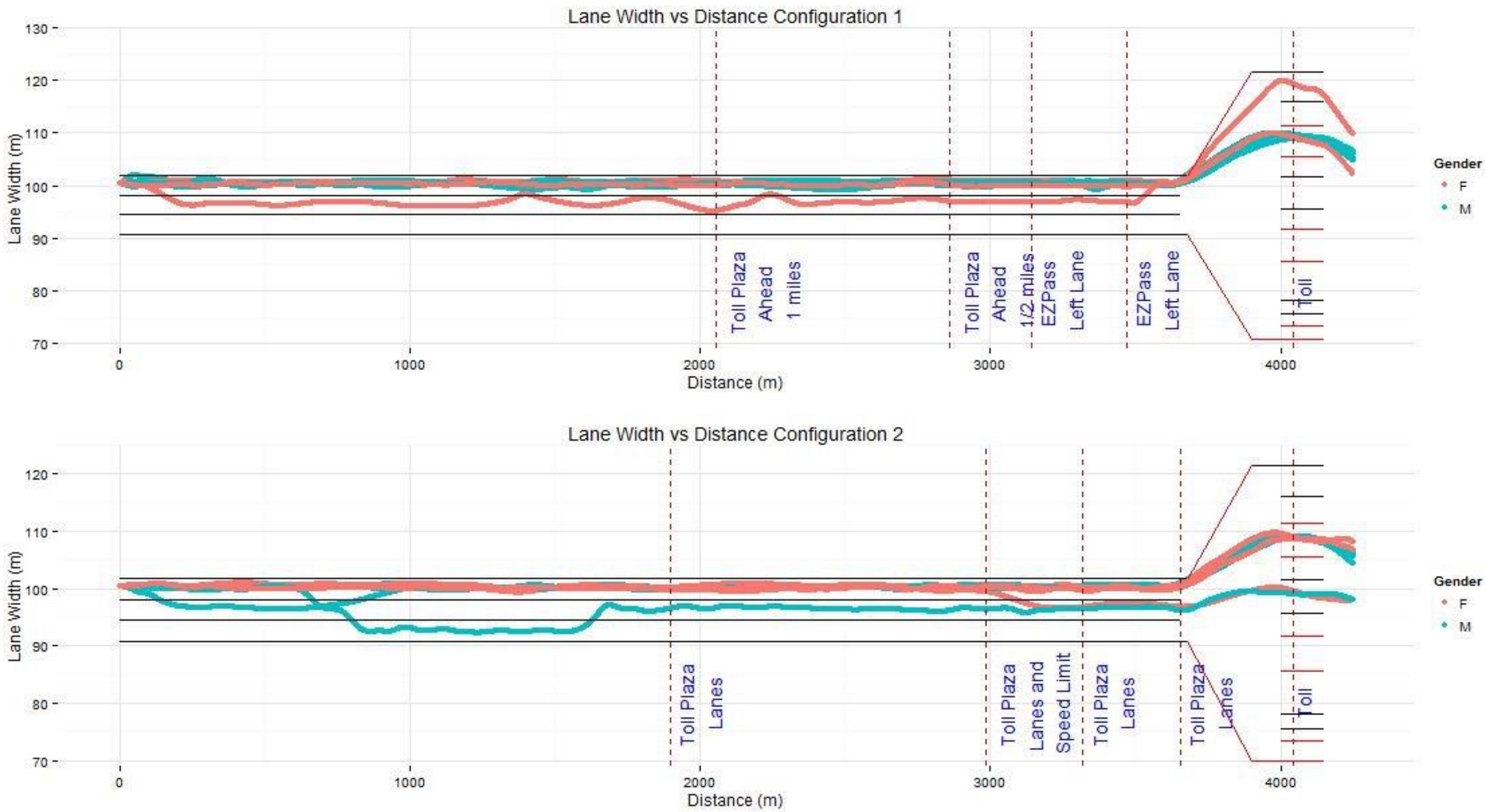


Figure 0.2 Standard Deviation of Roadway Position Configuration Comparison Scenario 2

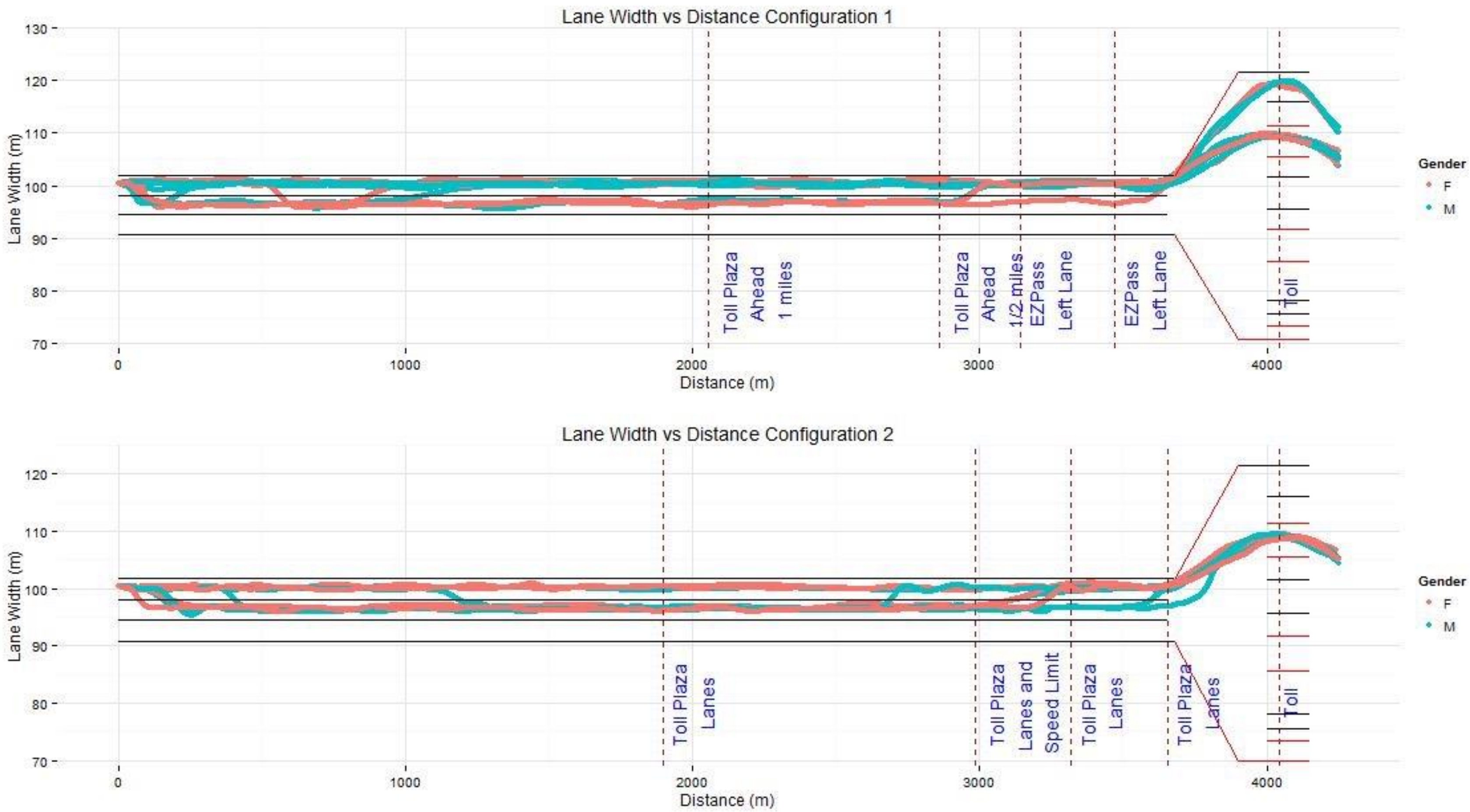
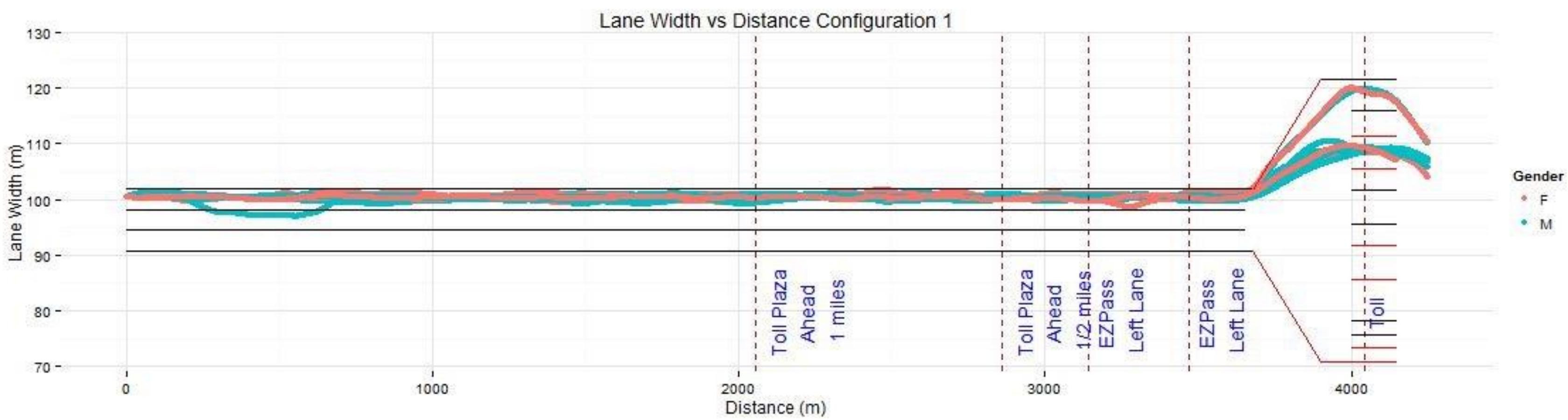


Figure 0.3 Standard Deviation of Roadway Position Configuration Comparison Scenario 3



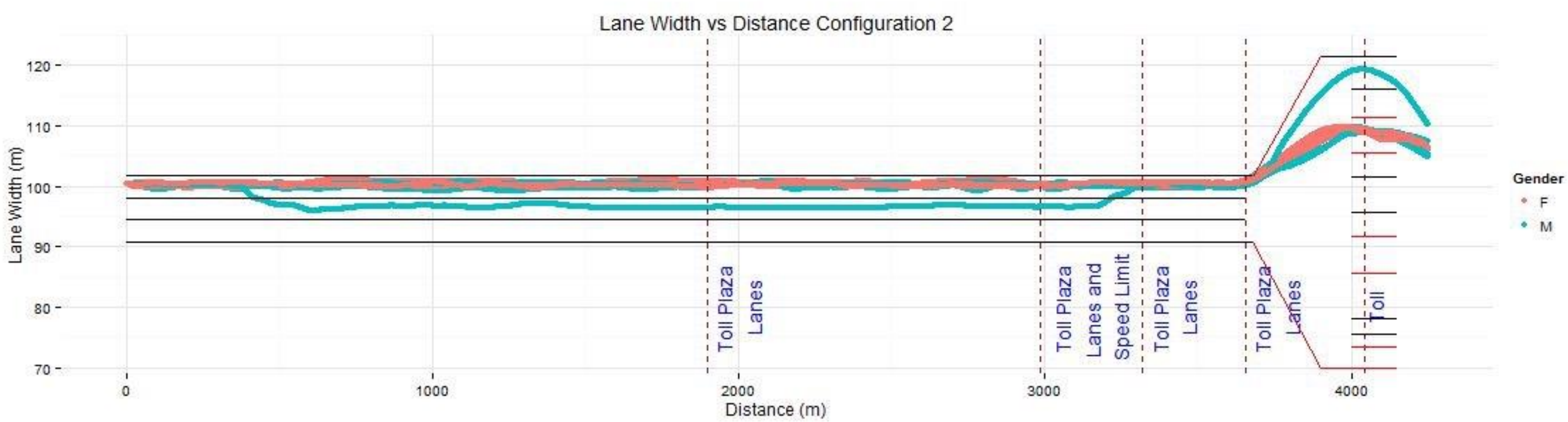


Figure 0.4 Standard Deviation of Roadway Position Configuration Comparison Scenario 4

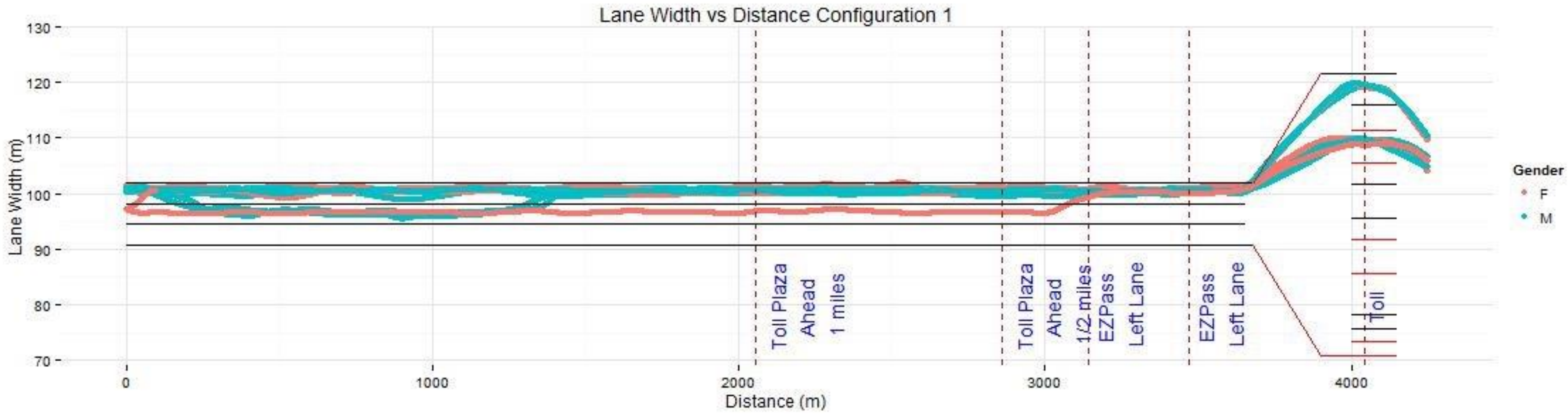


Figure 0.5 Standard Deviation of Roadway Position Configuration Comparison Scenario 5

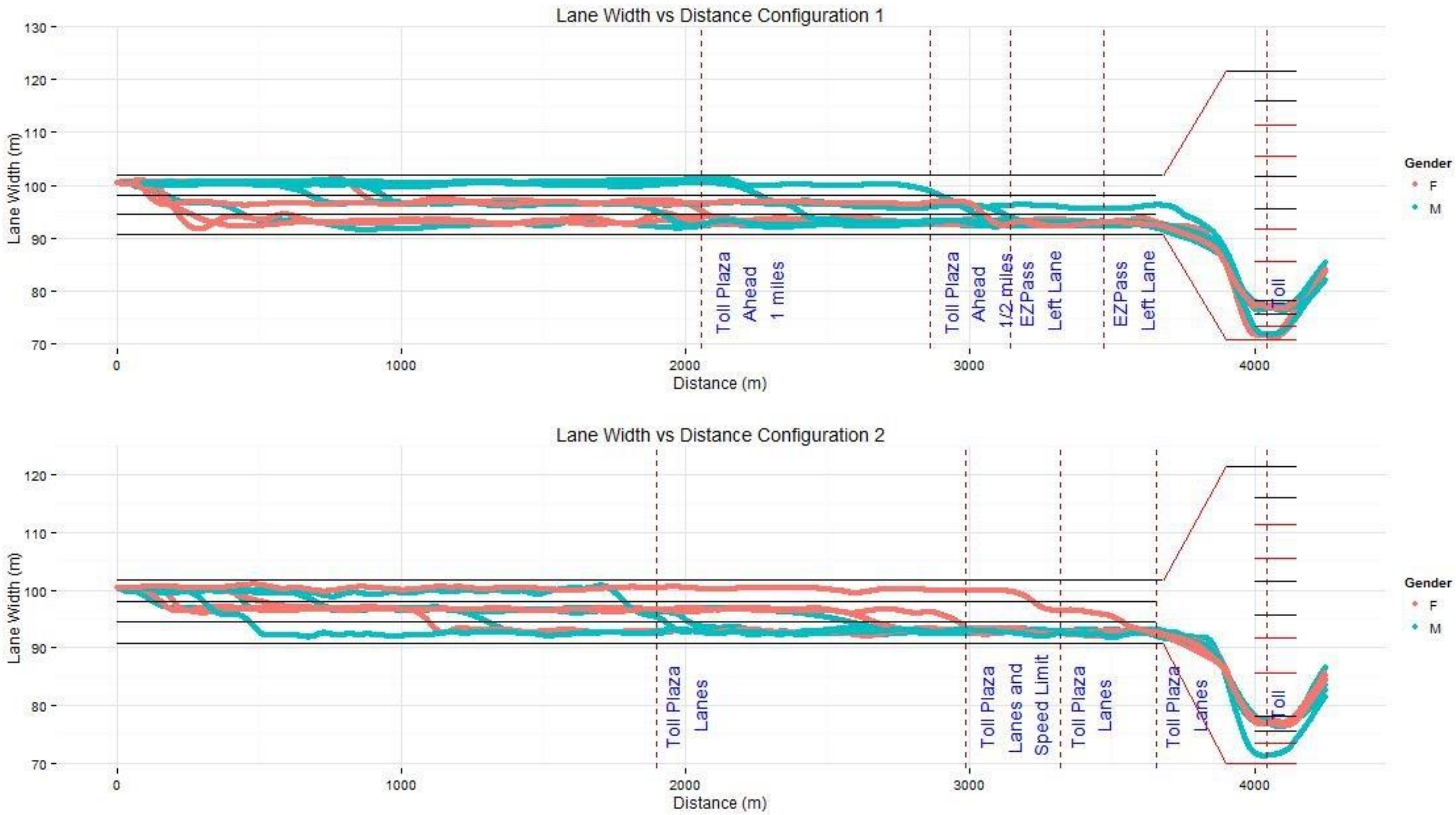


Figure 0.6 Standard Deviation of Roadway Position Configuration Comparison Scenario 6

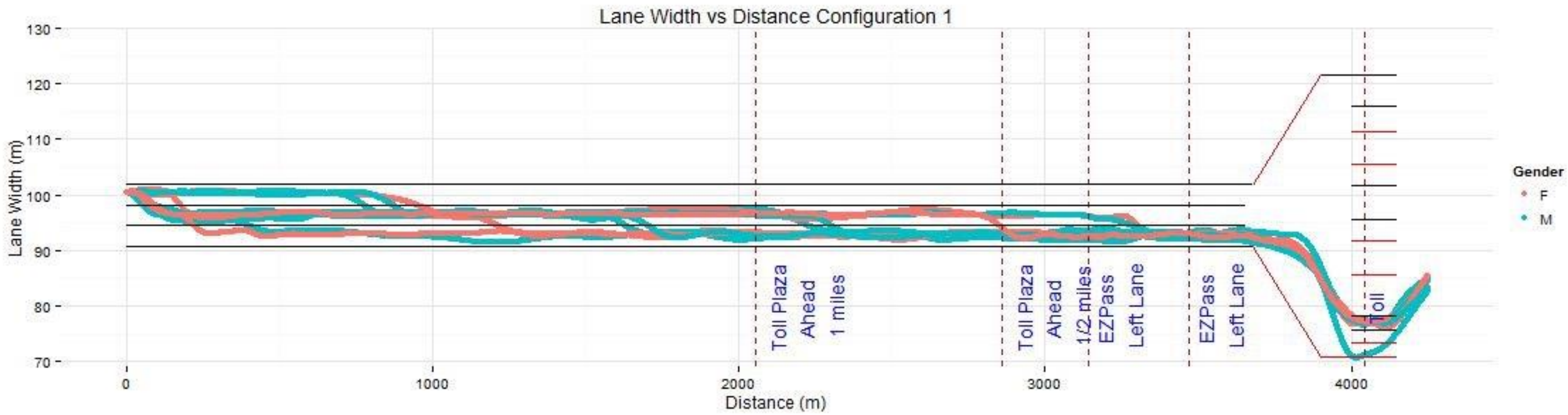


Figure 0.7 Standard Deviation of Roadway Position Configuration Comparison Scenario 7

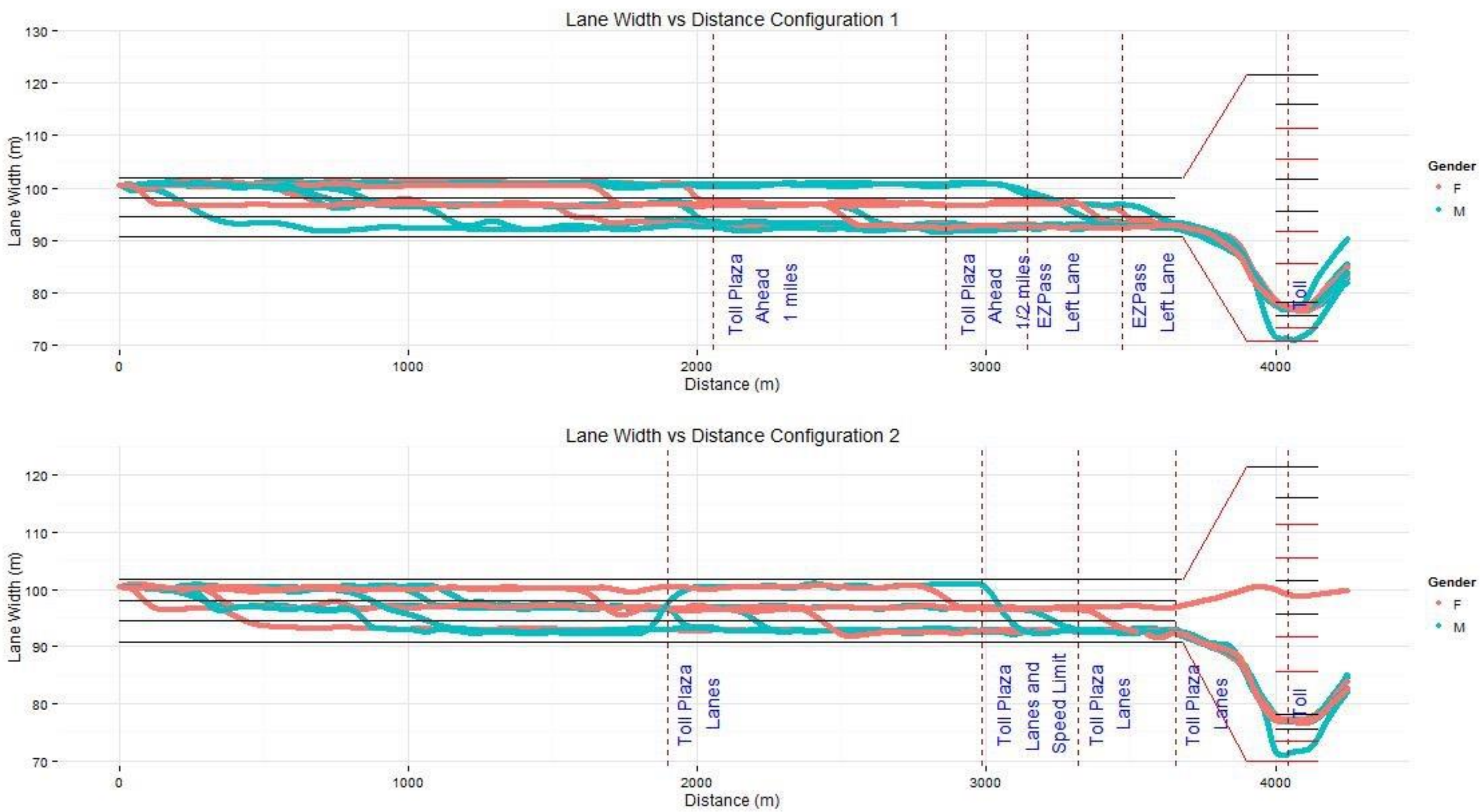


Figure 0.8 Standard Deviation of Roadway Position Configuration Comparison Scenario 8

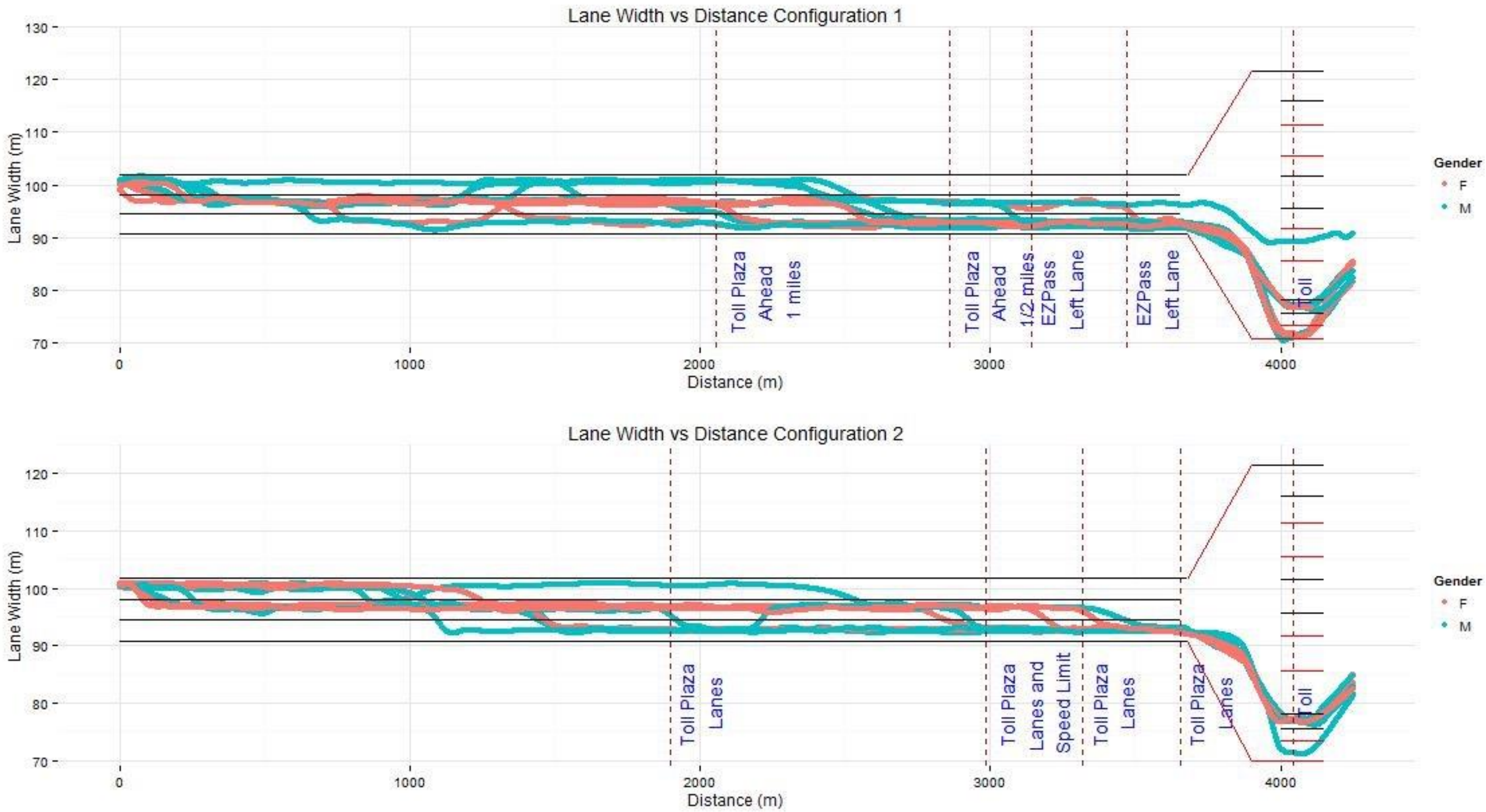


Figure 0.9 Standard Deviation of Roadway Position Configuration Comparison Scenario 9

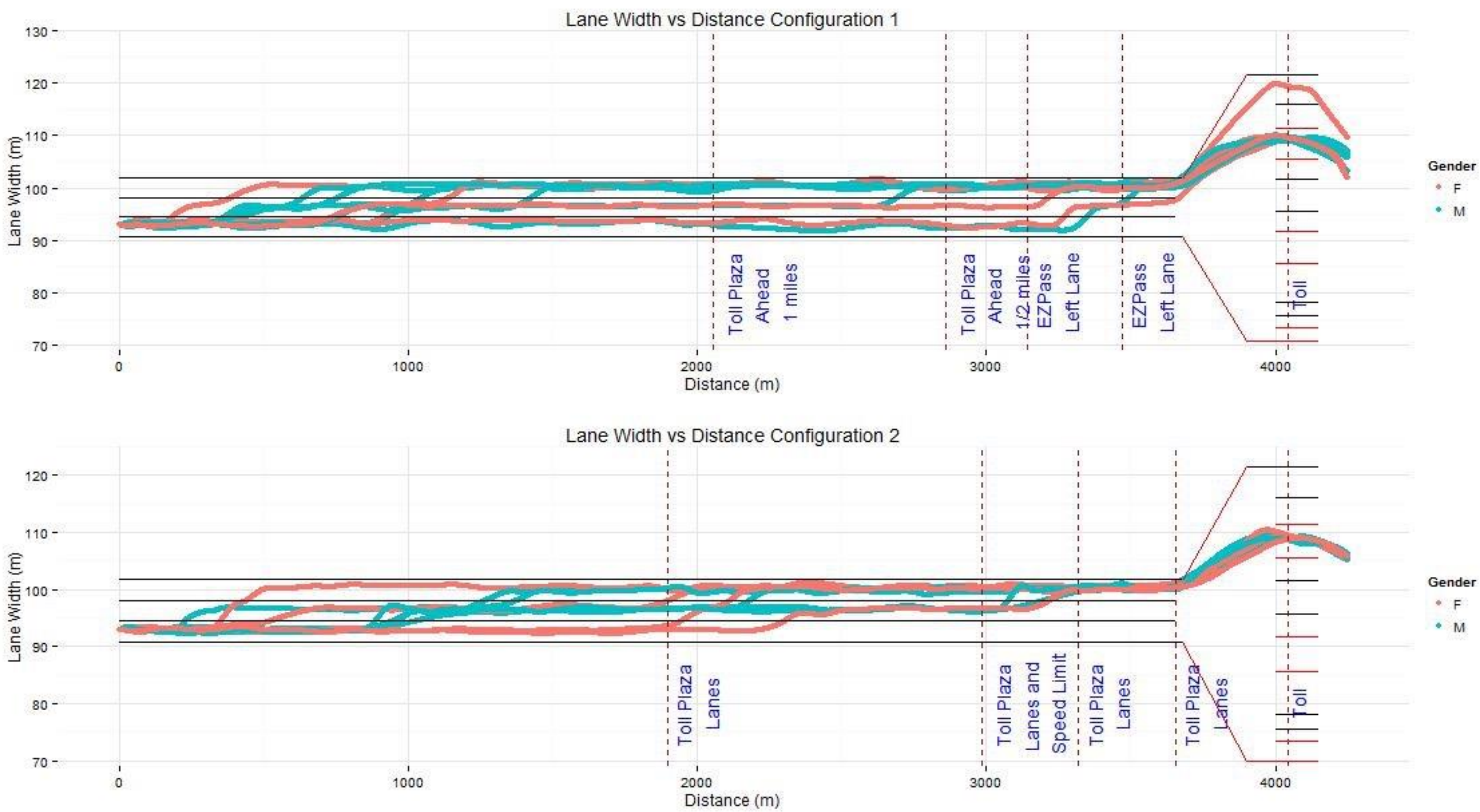


Figure 0.10 Standard Deviation of Roadway Position Configuration Comparison Scenario 10

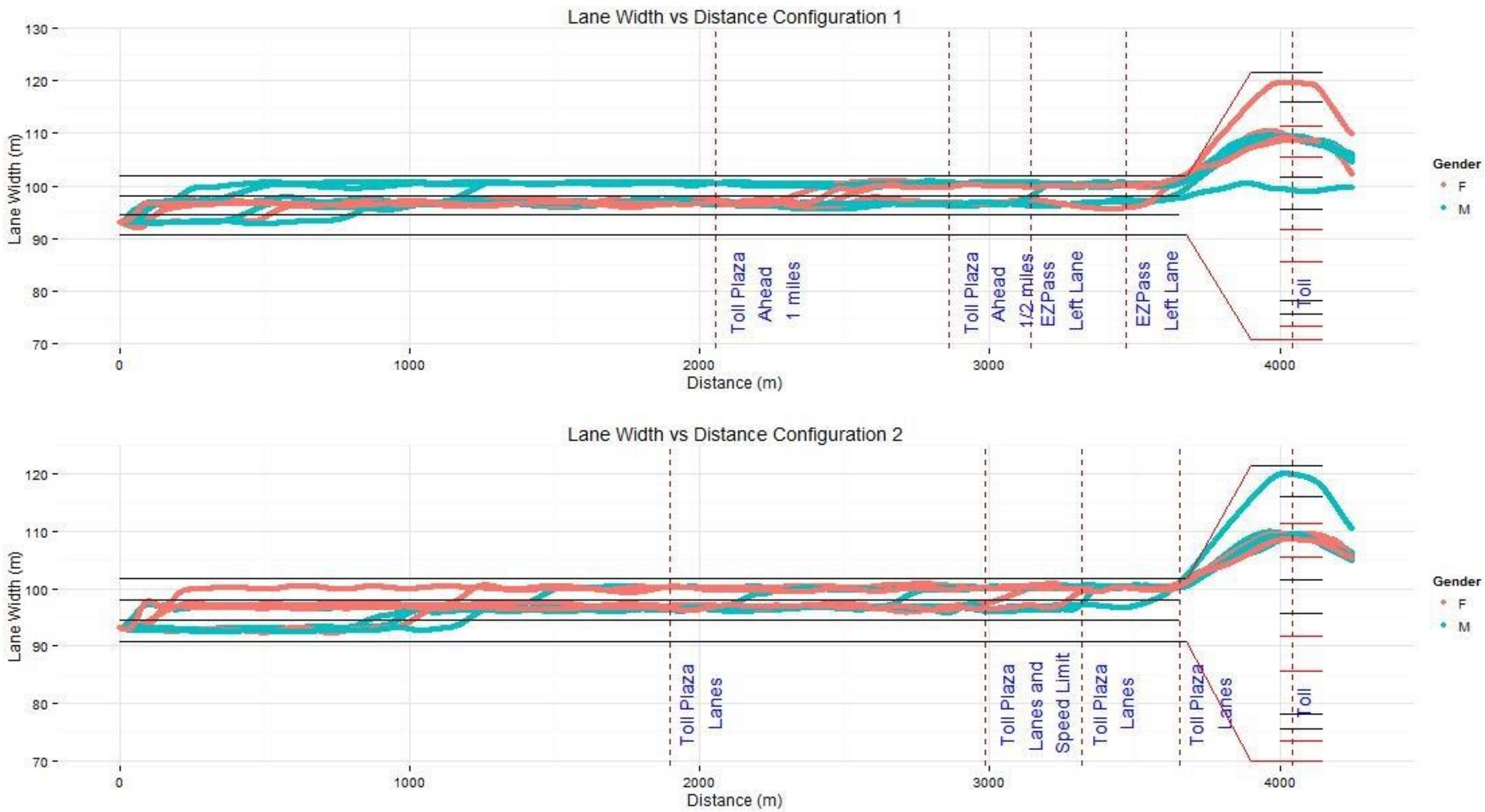


Figure 0.11 Standard Deviation of Roadway Position Configuration Comparison Scenario 11

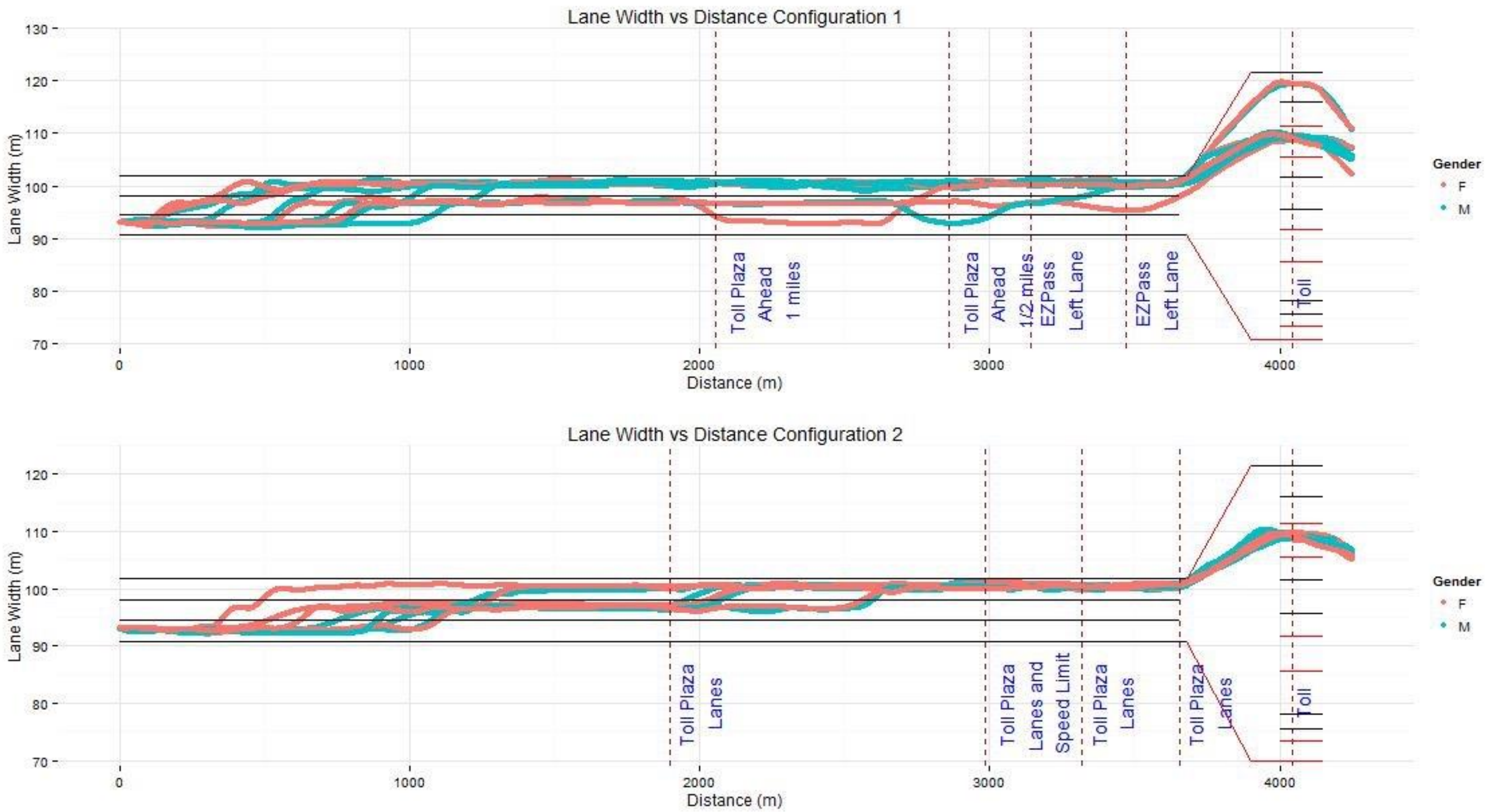
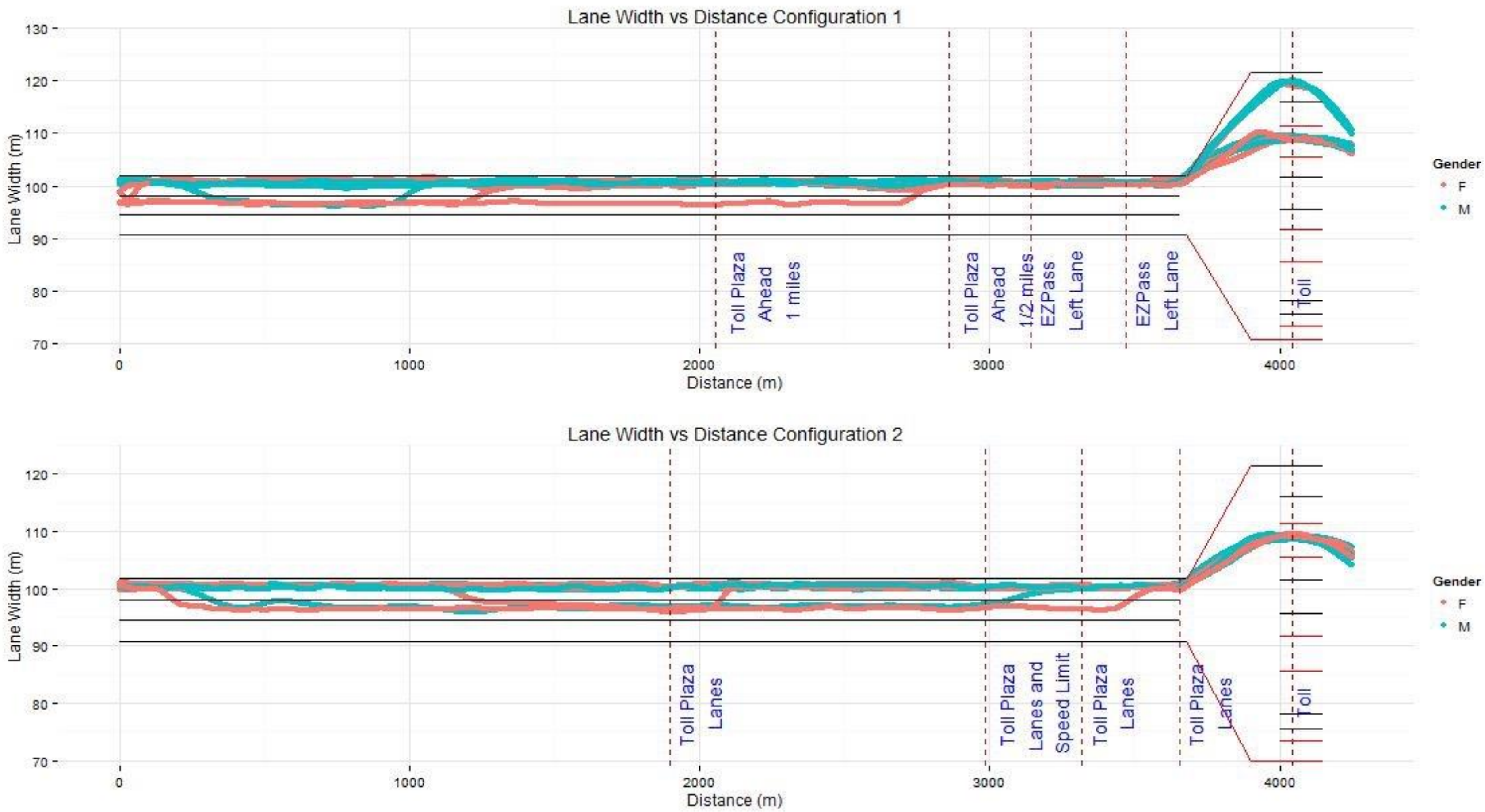
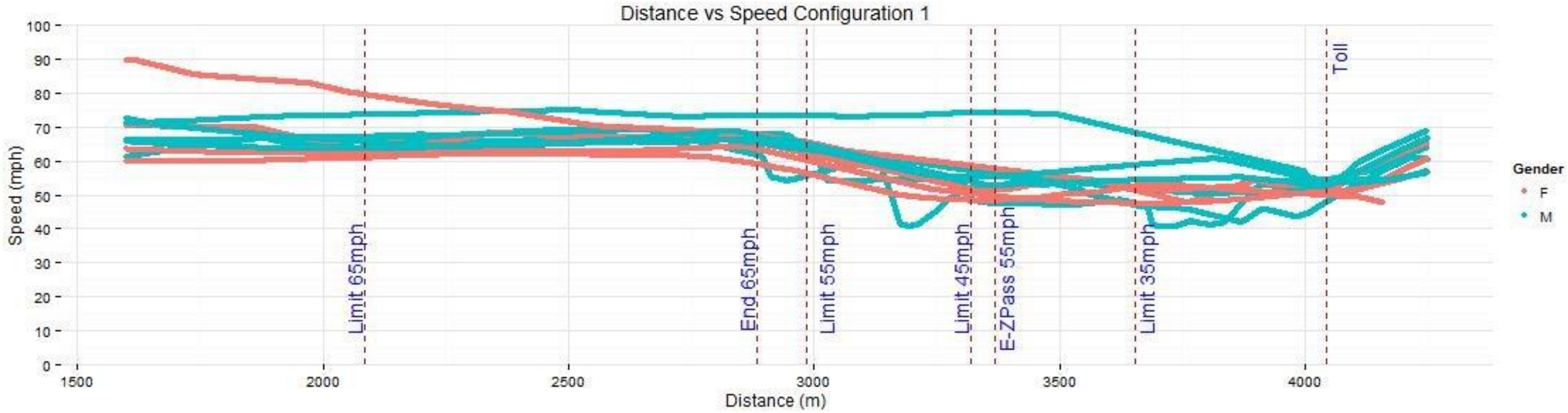


Figure 0.12 Standard Deviation of Roadway Position Configuration Comparison Scenario 12



Average Speed for Scenarios 1-12

Figure 0.1 Average Speed Diagram for Scenario 1


Distance vs Speed Configuration 1
Speed (mph)
Distance (m)
Limit 65mph
End 65mph
Limit 55mph
Limit 45mph
E-ZPass 55mph
Limit 35mph
Toll
Gender
F
M

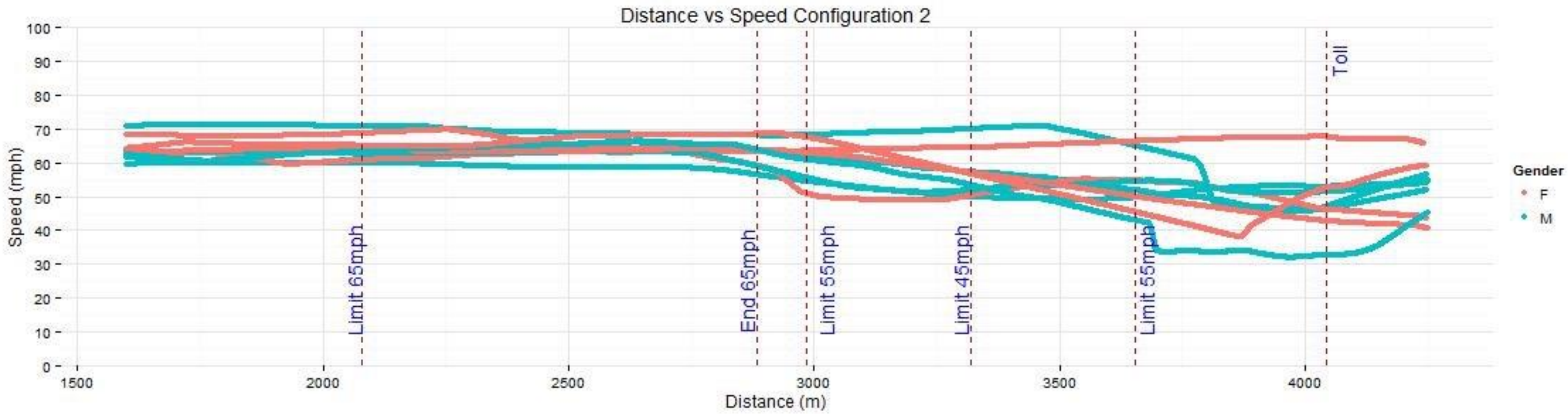

Distance vs Speed Configuration 2
Speed (mph)
Distance (m)
Limit 65mph
End 65mph
Limit 55mph
Limit 45mph
Limit 55mph
Toll
Gender
F
M

Figure 0.2 Average Speed Diagram for Scenario 2

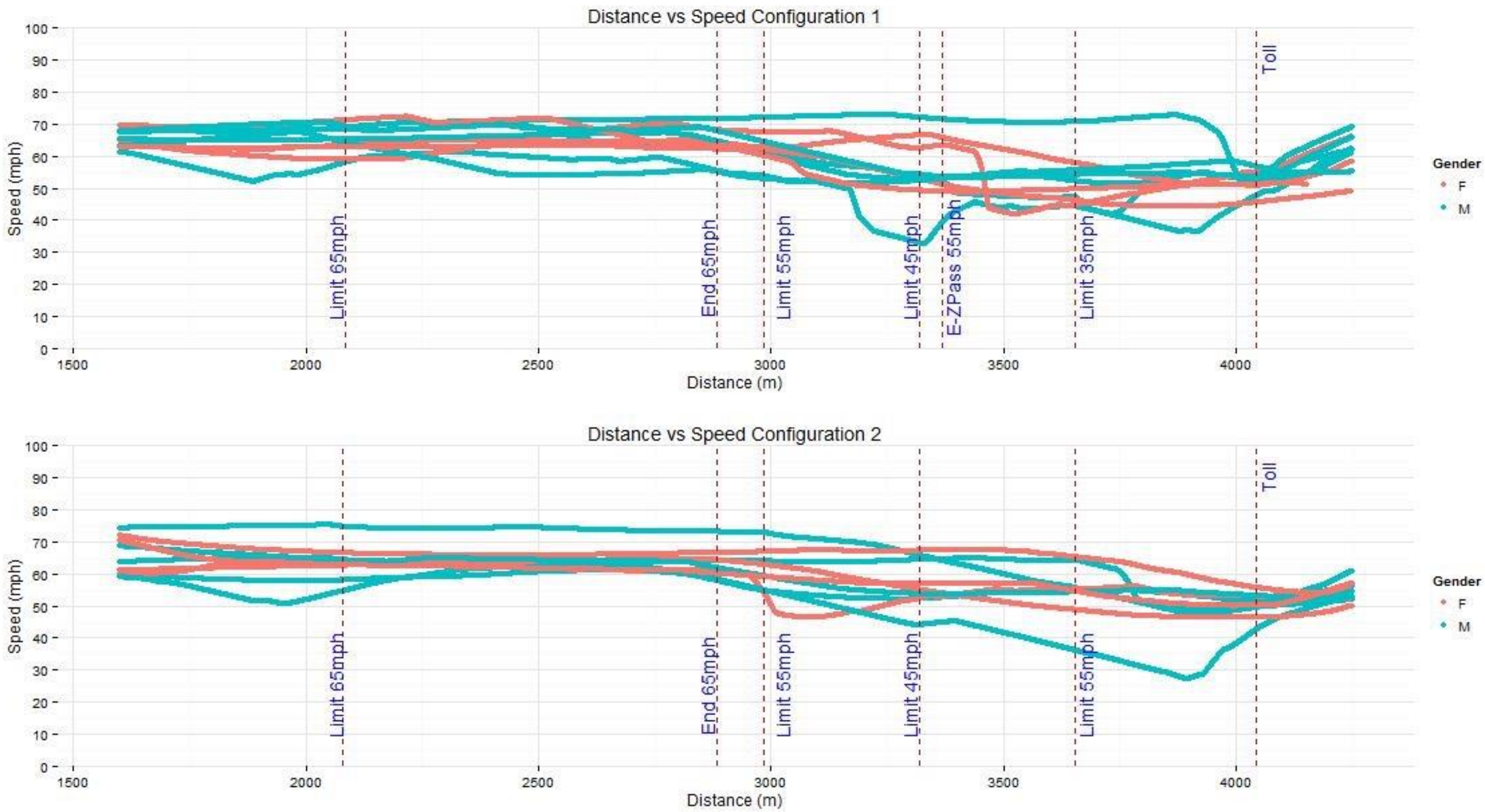


Figure 0.3 Average Speed Diagram for Scenario 3

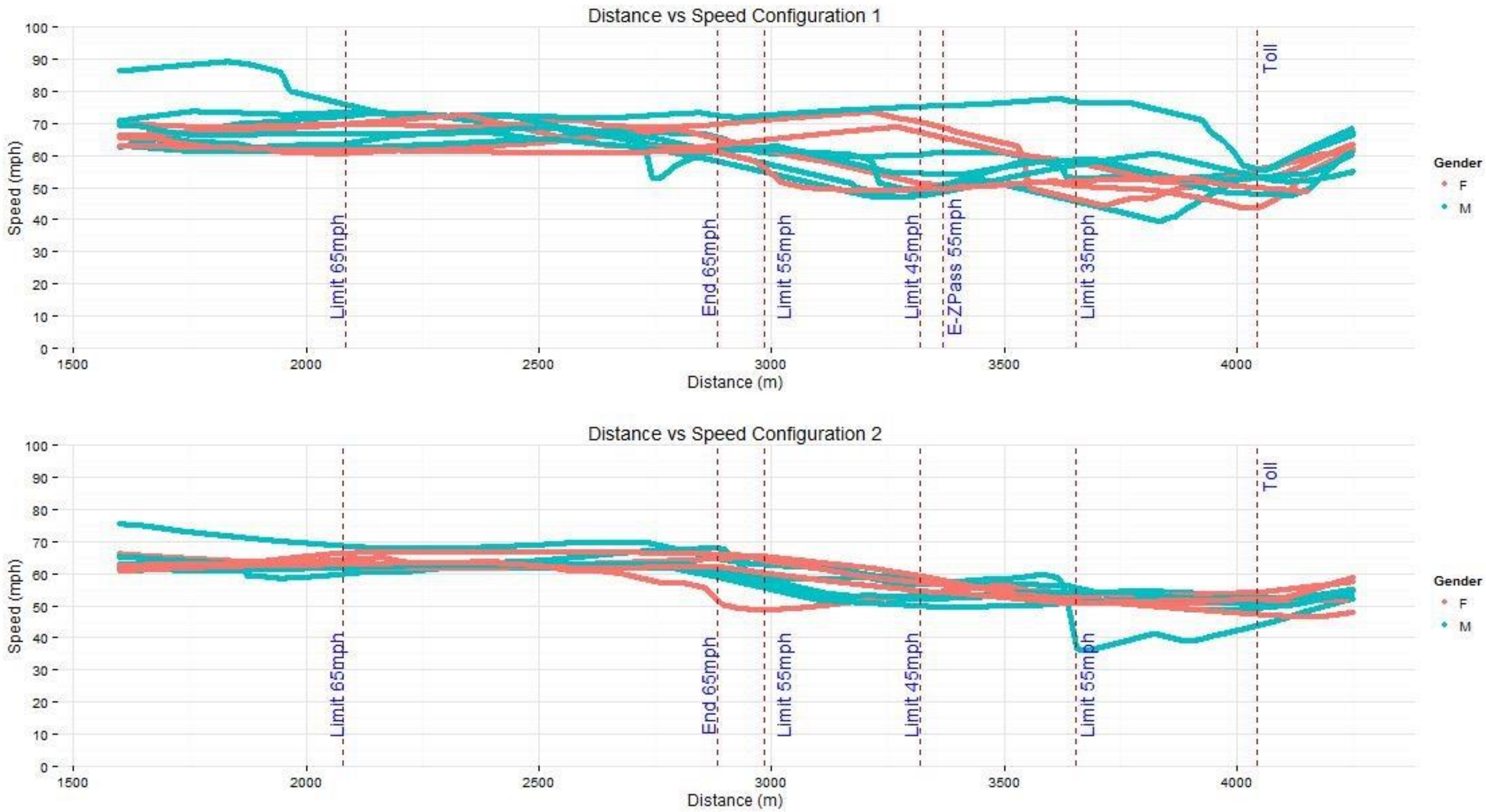


Figure 0.4 Average Speed Diagram for Scenario 4

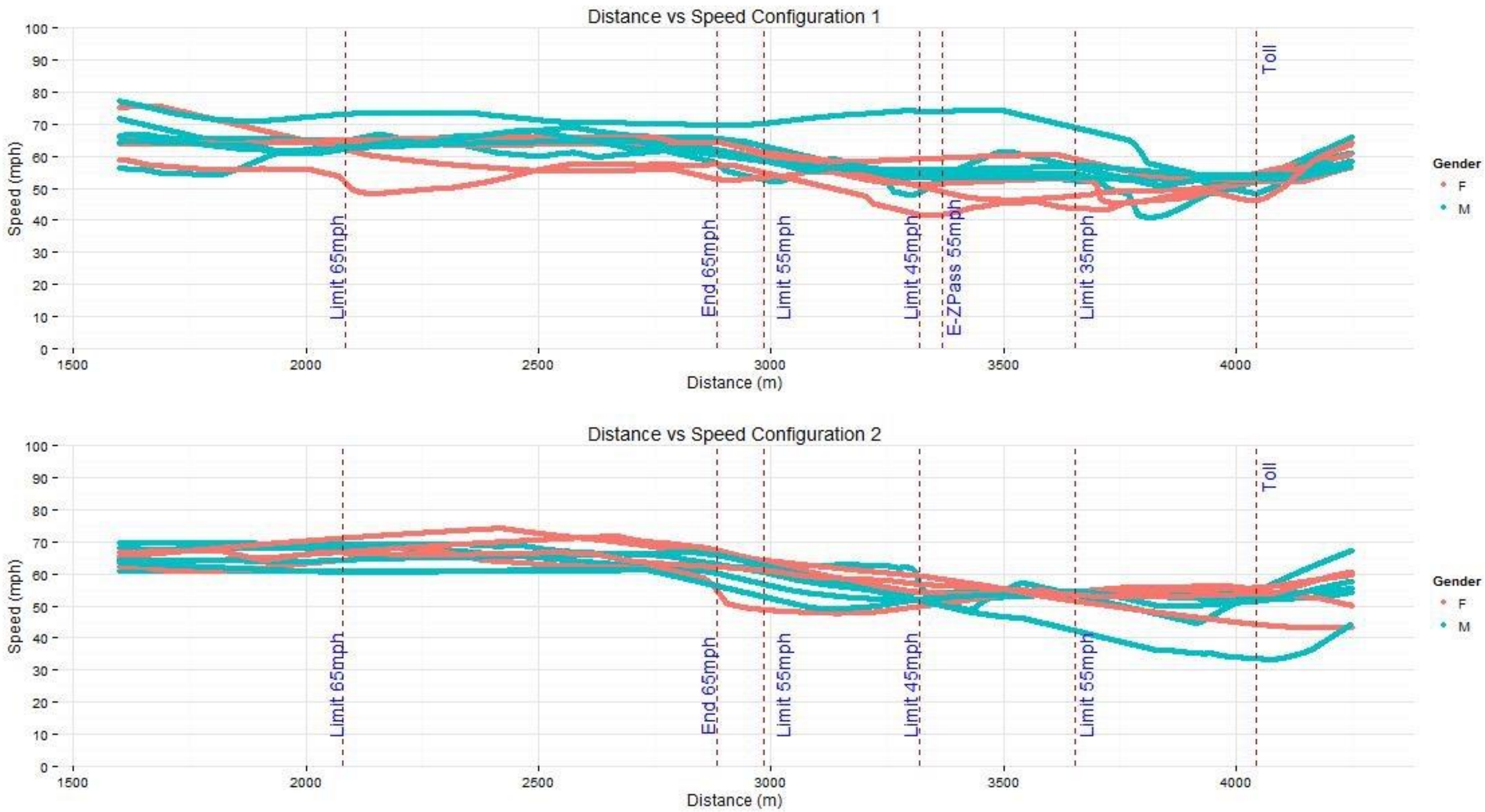


Figure 0.5 Average Speed Diagram for Scenario 5

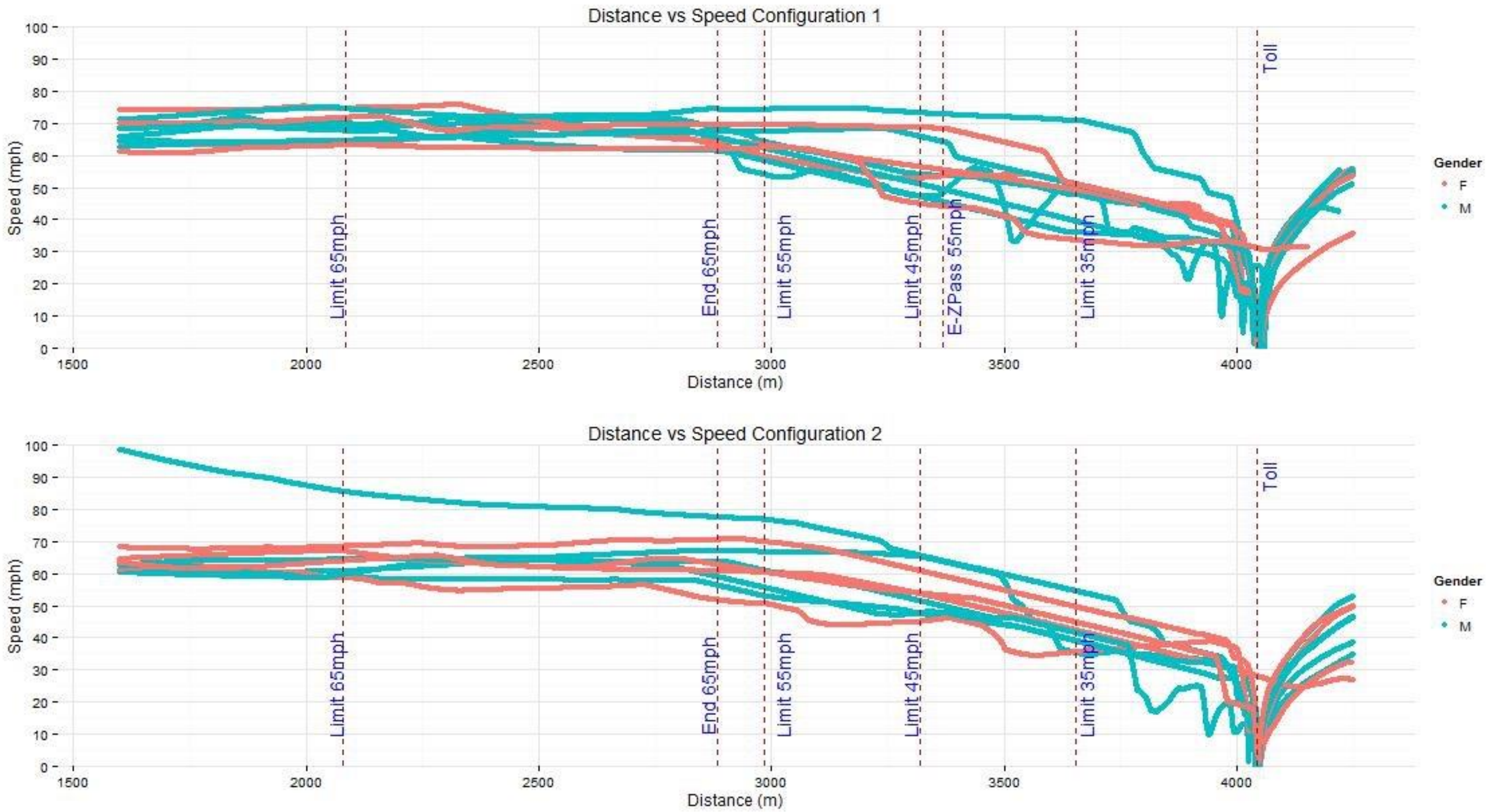


Figure 0.6 Average Speed Diagram for Scenario 6

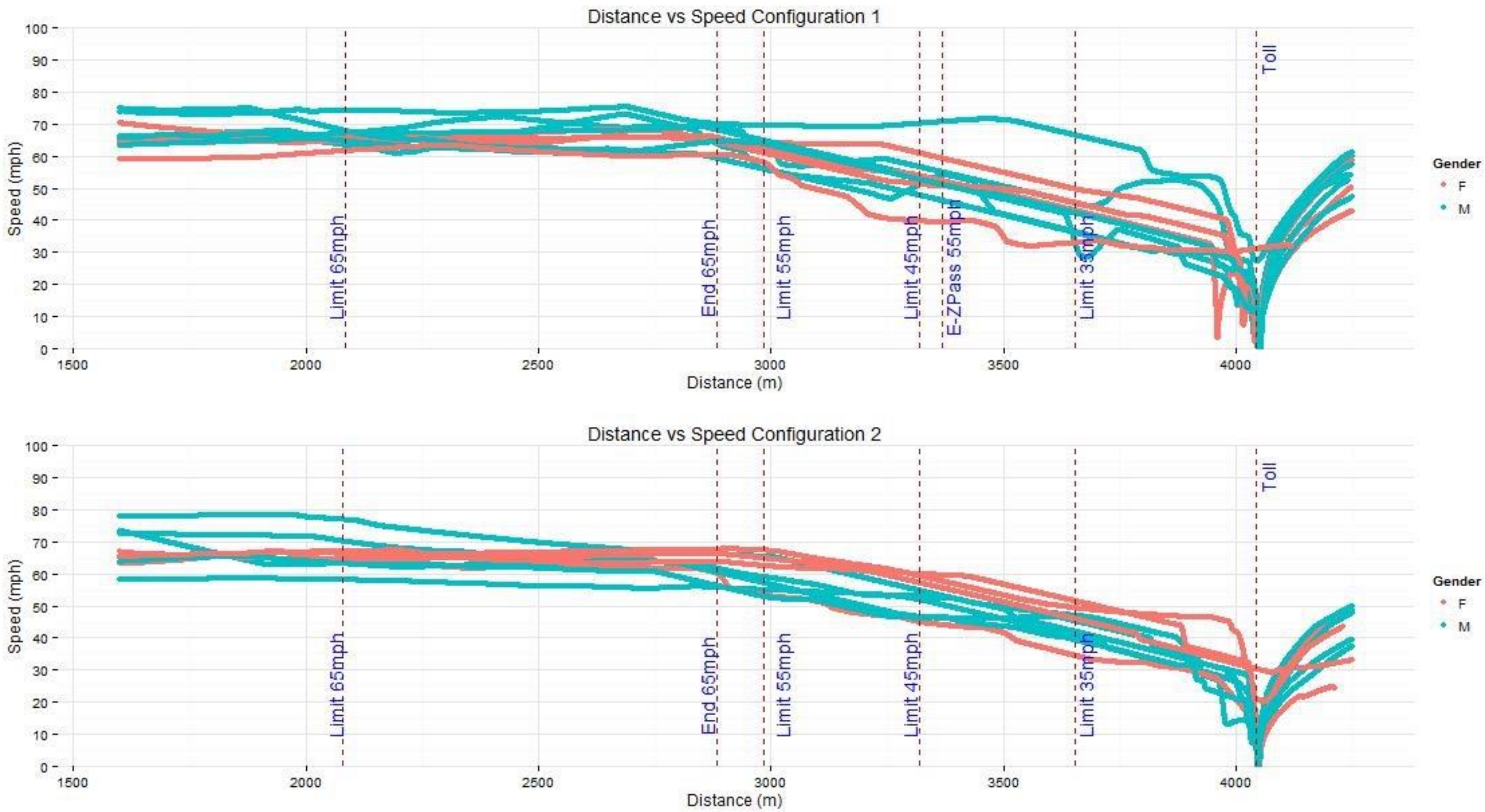


Figure 0.7 Average Speed Diagram for Scenario 7

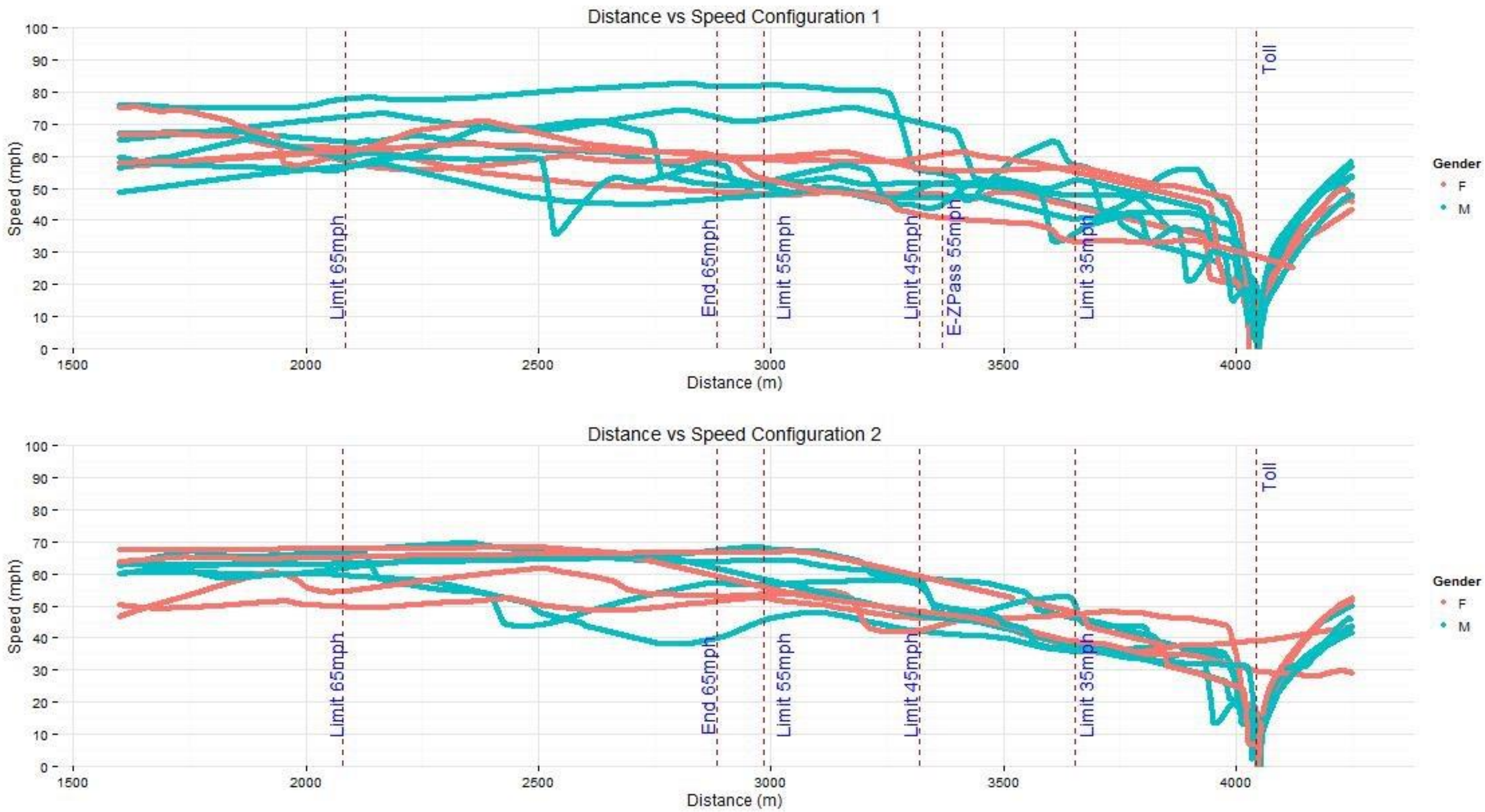


Figure 0.8 Average Speed Diagram for Scenario 8

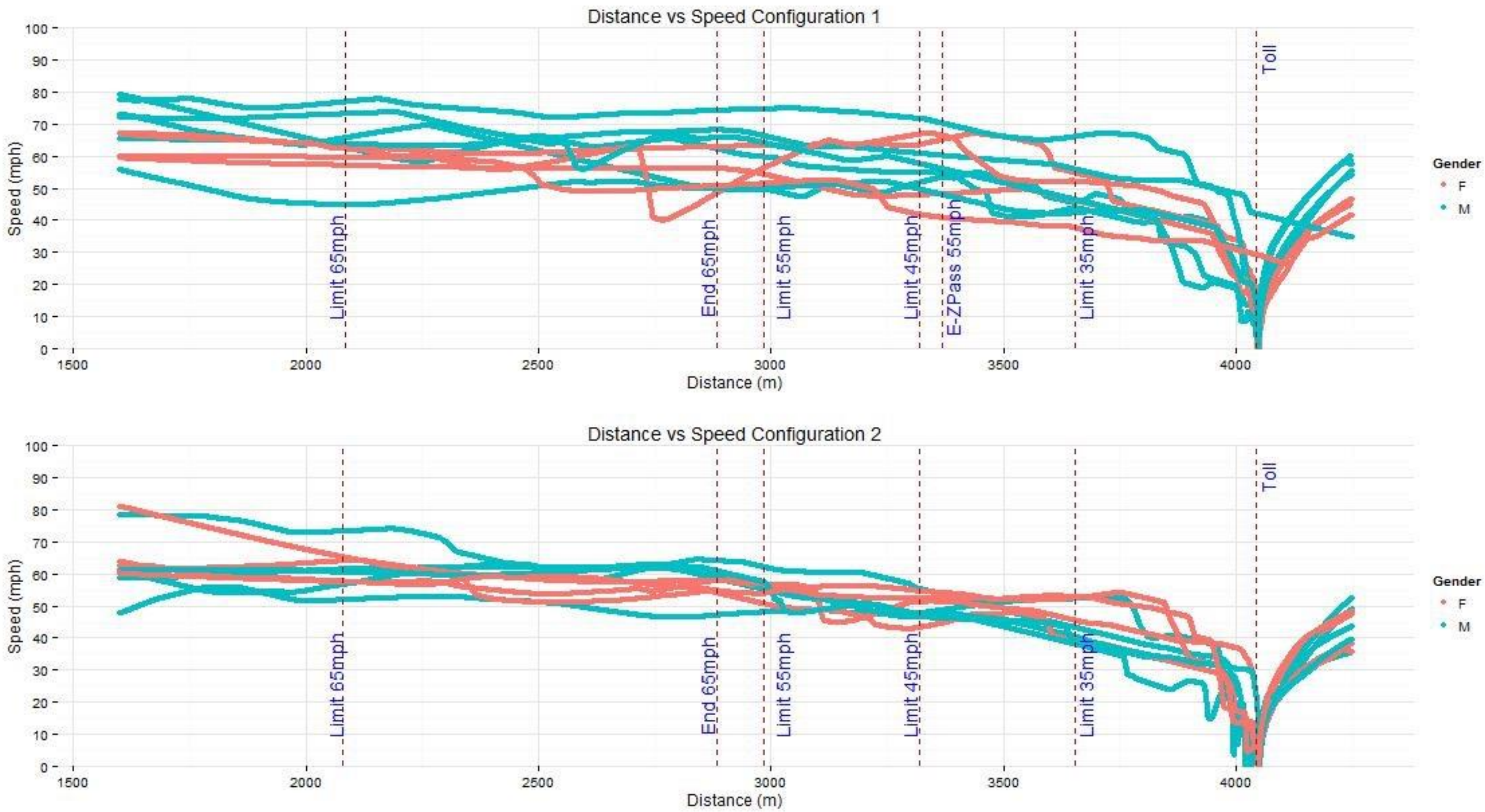


Figure 0.9 Average Speed Diagram for Scenario 9

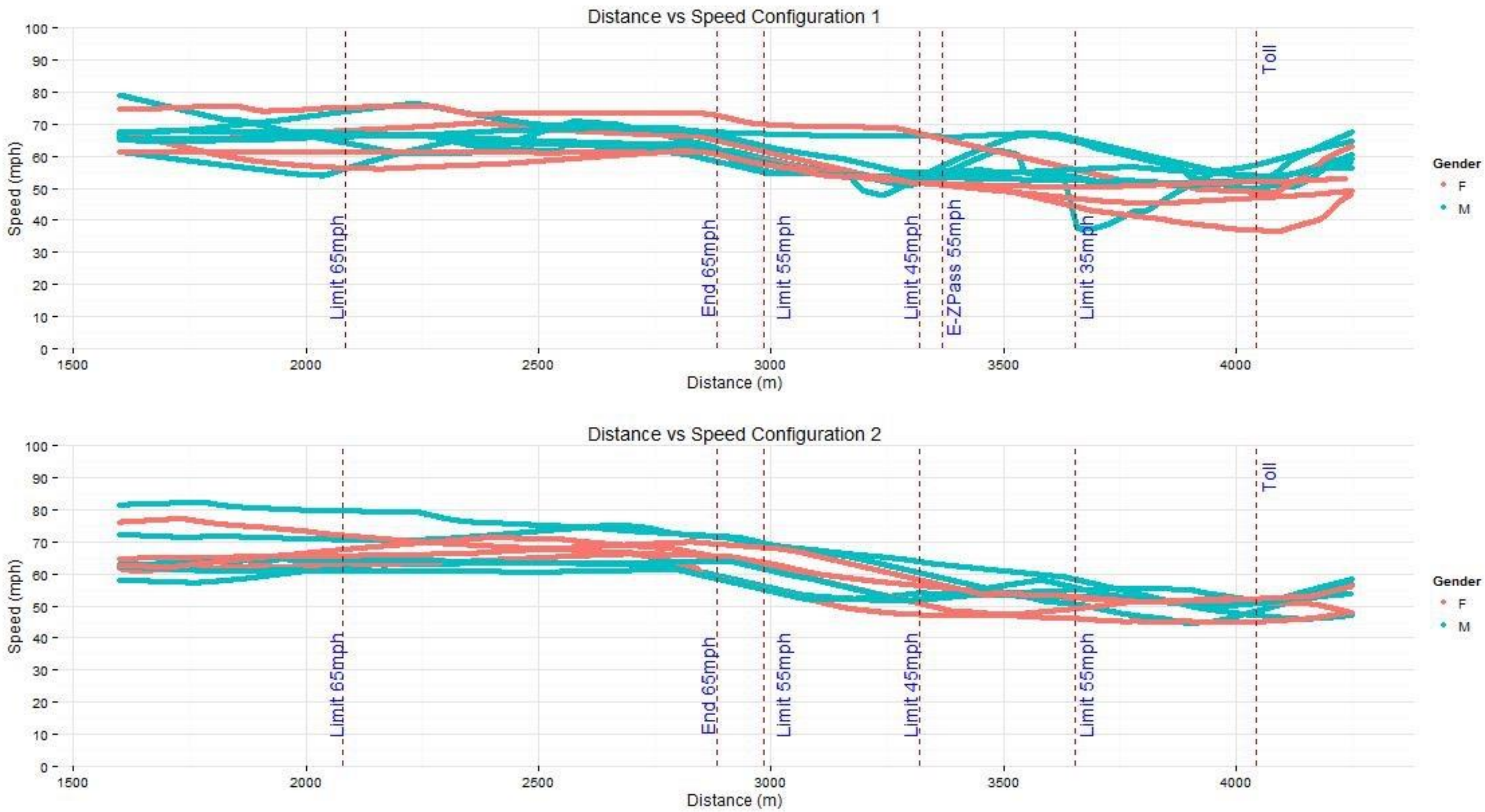


Figure 0.10 Average Speed Diagram for Scenario 10

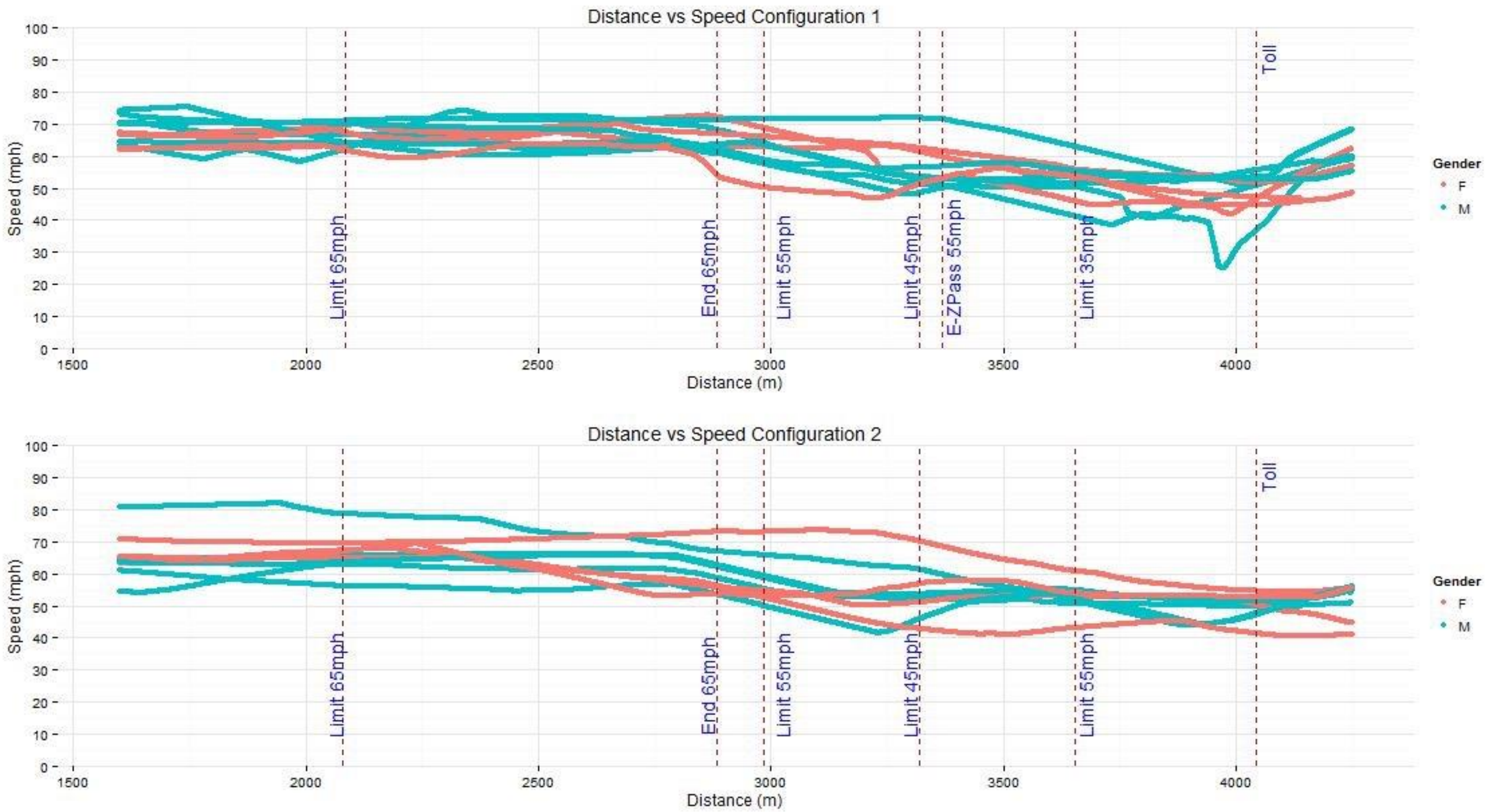


Figure 0.11 Average Speed Diagram for Scenario 11

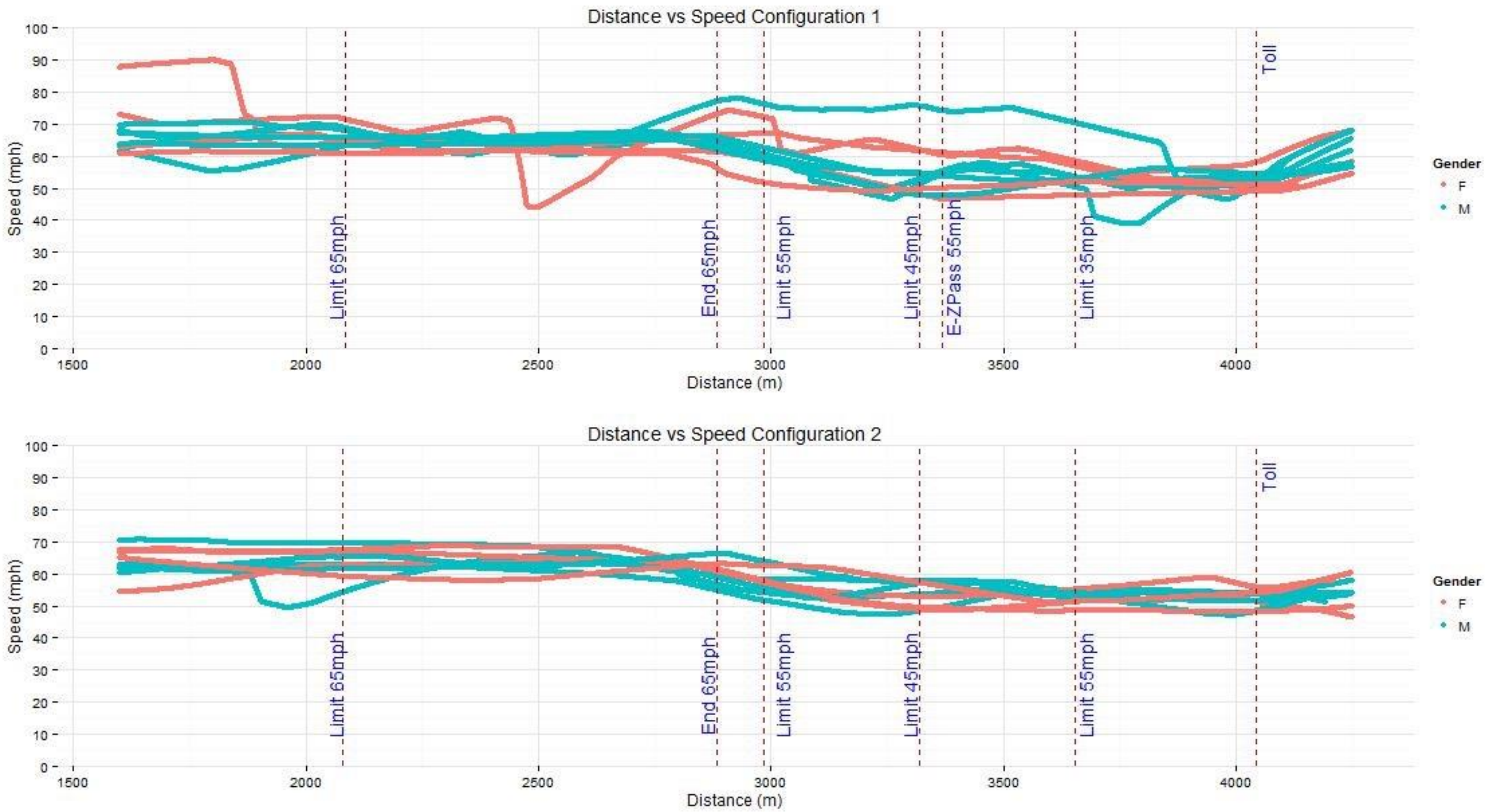
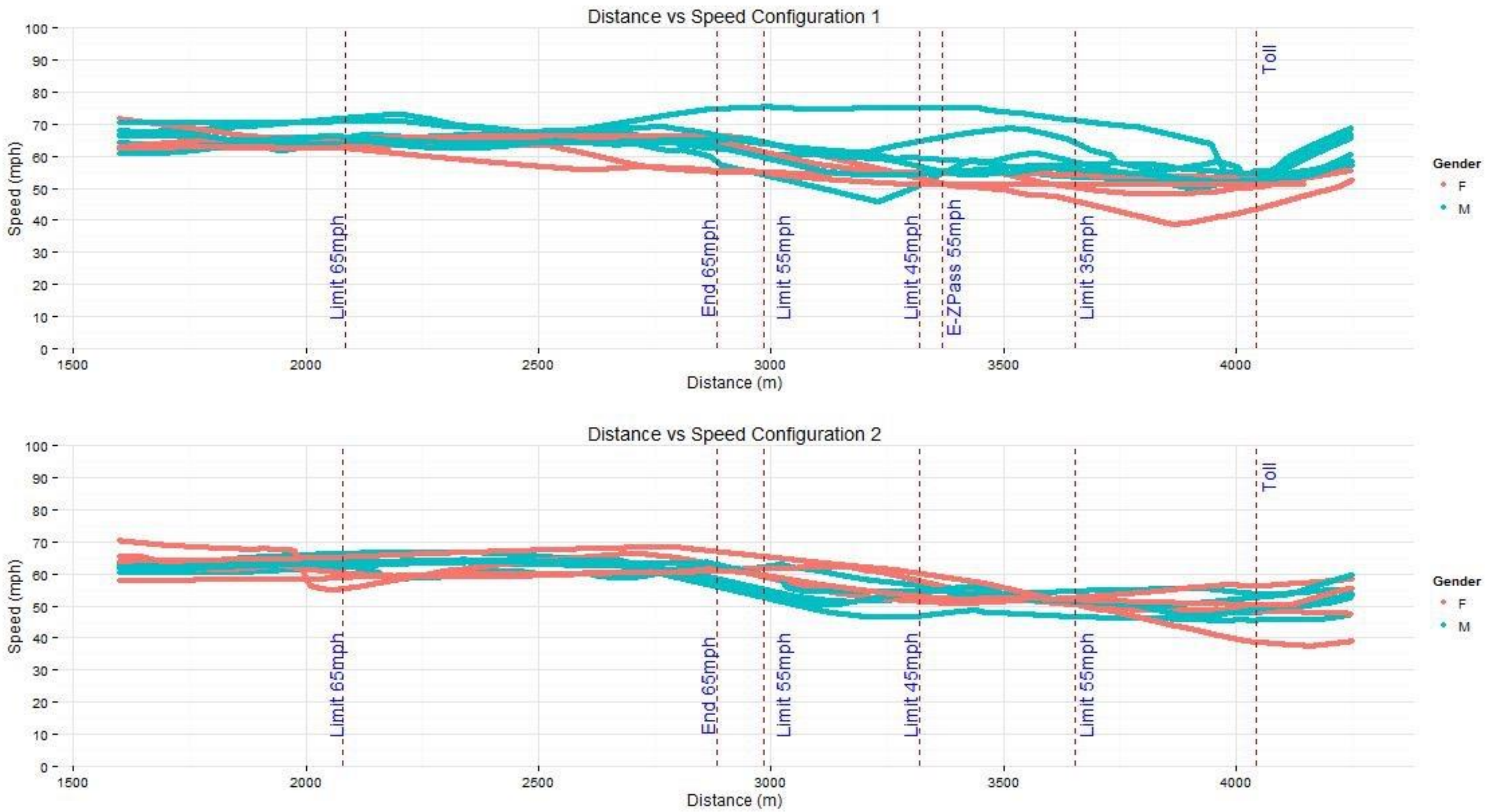


Figure 0.12 Average Speed Diagram for Scenario 12



Forms and Questionnaires for the Caguas Sur Toll Plaza Experiments.

ESTUDIO DE SIMULACION DE PLAZA DE PEAJE

FORMULARIO DE CONSENTIMIENTO INFORMADO

Investigador Principal: Juan Manuel Rivera Meléndez

Patrocinador: UTC SaferSim (Safety Research Using Simulation)

Título de Proyecto: Operational and Safety-Based Analyses of Varied Toll Lane Configurations

1. ¿QUÉ ES ESTE FORMULARIO?

Esto es un Formulario de Consentimiento Informado. Le proveerá información acerca de este estudio para que usted pueda tomar una decisión informada sobre su participación. Usted debe tener 18 años de edad o más para dar *consentimiento* informado.

2. ¿QUIÉN ES ELEGIBLE PARA PARTICIPAR?

Individuos que se encuentran entre las edades de 18 y 70 años y han tenido una licencia de conducir por al menos 18 meses. Conductores que han experimentado cinetosis (mareo por movimiento), ya sea en su propio vehículo como pasajero o conductor, o en otros modos de transporte, no deberían participar.

3. ¿QUIÉN PATROCINA ESTE ESTUDIO?

Este estudio es patrocinado por el UTC SaferSim.

4. ¿CUÁL ES EL PROPÓSITO DE ESTE ESTUDIO?

El propósito de este estudio es evaluar el comportamiento del conductor bajo varias condiciones de tráfico en configuraciones específicas de una plaza de peaje.

5. ¿DÓNDE ESTE ESTUDIO TOMARÁ LUGAR Y CUÁNTO DURARÁ?

Esta sesión de estudio se llevará a cabo en el Laboratorio de Ingeniería de Transportación de la Universidad de Puerto Rico en Mayagüez, localizado en el Edificio de Ingeniería Civil y Agrimensura, salón 102-F.

El estudio durara aproximadamente 60-100 minutos por participante e incluirá cuestionarios y uso del simulador.

6. ¿QUÉ SE ME PEDIRÁ HACER?

i) Se le pedirá que llene un breve cuestionario antes del experimento.

ii) El investigador le enseñará cómo manejar el simulador y le proveerá instrucciones generales para los escenarios de simulación. Durante la simulación, usted deberá operar los controles del simulador del vehículo de la misma manera que usted manejaría los de cualquier otro vehículo, y manejar por el mundo simulado como corresponde. Usted debe de seguir los límites de velocidad y las reglas estándares de la carretera y tener un cuidado razonable cuando utilice los frenos.

iii) Usted se sentará en el simulador, y se le dará una simulación de práctica para familiarizarse con el simulador de conducción. Una vez usted se sienta cómodo con el simulador, usted manejará a través de un trayecto que tomará cerca de 2 a 3 minutos para cada escenario virtual en que conducirá. Si en algún momento del trayecto siente molestia o cinetosis/mareo, informe al investigador de inmediato para que se detenga la simulación. No habrá ningún tipo de penalidad, o efecto adverso al estudio porque su participación no pueda ser completada.

7. ¿EXISTE ALGÚN RIESGO O BENEFICIO ASOCIADO CON LA PARTICIPACION?

En términos de la operación del simulador de conducción, existe un leve riesgo de cinetosis (mareos). Un pequeño porciento de los participantes que manejan el simulador podrían experimentar sensación de nauseas o nausea actual. El experimento ha sido trabajado para minimizar el riesgo. Se recomienda que <u>si usted ha experimentado cinetosis (mareos) anteriormente mientras viaja o maneja un vehículo real, usted no debería participar en este experimento.</u>

Si durante el trayecto de la simulación, usted siente molestia o nauseas, debería de informar al investigador inmediatamente para que la simulación pueda ser detenida. La interrupción de la simulación debería de reducir la molestia rápidamente. Si usted no se siente mejor tan pronto la simulación es interrumpida, los investigadores pueden gestionar para que alguien los guie a su hogar o a buscar atención medica si es necesario.

Beneficios de participar en este estudio incluyen aprender potencialmente como ser un conductor más precavido/seguro y a familiarizarse con los cambios de configuración de plazas de peaje.

8. ¿QUIÉN VERÁ LOS RESULTADOS Y/O MI DESEMPEÑO EN ESTE ESTUDIO?

Los resultados de esta investigación serán publicados en revistas de investigación científica y serán presentados en conferencias y simposios de entidades científicas profesionales. Los resultados de esta investigación también serán publicados en la tesis de maestría del investigador Juan Manuel Rivera. Los resultados podrían ser utilizados por los investigadores aprobados para propósitos internos. Ningún participante será identificable en los reportes o publicaciones ya que ni el nombre ni las iniciales de ningún participante serán utilizados. Para mantener confidencialidad de los archivos, los investigadores utilizarán códigos para identificar a cada sujeto, en vez de nombres, para toda la data colectada mediante cuestionarios y la data colectada durante su utilización del simulador. La data será asegurada en el Laboratorio de Ingeniería de Transportación de la Universidad de Puerto Rico en Mayagüez y solo será accesible por el investigador principal, y cualquier otro investigador aprobado para el estudio.

Es posible que su archivo de investigación, incluyendo información sensitiva y/o información de identificación, pueda ser inspeccionado y/o copiado por agencias federales o de gobierno estatal, en el curso del desempeño de sus funciones. Si su archivo es inspeccionado por alguna de estas agencias, su confidencialidad será mantenida en la medida permitida por la ley.

9. ¿RECIBIRÉ ALGUN TIPO DE COMPENSACION MONETARIA POR PARTICIPAR DE ESTE ESTUDIO?

No. Su participación en este estudio es completamente voluntaria.

10. ¿QUÉ PASA SI TENGO UNA PREGUNTA?

Si tiene alguna pregunta sobre el experimento o cualquier otro asunto relativo a su participación en este experimento, o si sufre de alguna lesión relacionada a la investigación como resultado del estudio, puede llamar al investigador, Profesor Didier Valdés, al (787) 832-4040 ext. 2179 o didier.valdes@upr.edumailto:mknodler@ecs.umass.edu. Si, durante el estudio o después de, usted desea discutir su participación o preocupaciones en cuanto al mismo con una persona que no participe directamente en la investigación puede comunicarse con el Comité para la Protección de los Seres Humanos en la Investigación del Recinto Universitario de Mayagüez al (787) 832-4040 ext. 6277 ó 6347 o cpshi@uprm.edu**.** Una copia de este formulario de consentimiento será proveída a usted para que la guarde en sus archivos.

11. ¿QUÉ PASA SI ME NIEGO A PROVEER MI CONSENTIMIENTO?

Su participación es voluntaria, por lo tanto, usted puede negarse a participar o puede retirar su consentimiento y dejar de participar en el estudio en cualquier momento y sin penalidad alguna.

12. ¿QUÉ SI ME LESIONO?

Como usted es parte de la comunidad del Recinto Universitario de Mayagüez (ya sea empleado o estudiante) el seguro médico del Recinto le cubre en caso de tener algún riesgo o incomodidad.

13. DECLARACIÓN DE CONSENTIMIENTO VOLUNTARIO DEL SUJETO

Al firmar abajo, yo, el participante, confirmo que el investigador me ha explicado el propósito de la investigación, los procedimientos del estudio a los que voy a someterme y los beneficios, así como los posibles riesgos que puedo experimentar. También se han discutido alternativas a mi participación en el estudio. He leído y entiendo este formulario de consentimiento.

____ ______________

Nombre en letra de molde del participante Fecha

____

Firma del participante

14. DECLARACIÓN DEL EXPERIMENTADOR

Al firmar abajo, yo, el investigador, indico que el participante ha leído este Formulario de Consentimiento Informado y yo le he explicado a él/ella el propósito de la investigación, los procedimientos del estudio a los que él/ella va a someterse y los beneficios, así como los posibles riesgos que él/ ella puede experimentar en este estudio, y que él/ella ha firmado este formulario de consentimiento informado.

____ _______________

Firma de la persona que obtiene el consentimiento informado Fecha

Fecha: ______________

Número de participante: ______________
(Para uso exclusivo del investigador)

LABORATORIO DE SIMULACIÓN DE TRANSPORTACIÓN
CUESTIONARIO ANTES DEL ESTUDIO

Esto es un cuestionario estrictamente confidencial. Solamente un número de participante dado por el investigador se usara para identificar la información en este cuestionario. Ninguna información que usted provea aquí será utilizada para llegar a la identidad del participante (usted). **Usted puede decidir no contestar alguna pregunta que no se sienta cómodo/a contestando.**

Sección 1: Demografía

Sexo: ☐ Masculino ☐ Femenino ☐ Otro

Fecha de Nacimiento: **Mes** ____ **/ Día**____ **/ Año** _______ **Edad:** ______

Raza / Etnicidad: ☐ Negro / Afro-Americano ☐ Asiático
(Marque todas las que apliquen) ☐ Blanco / Caucásico ☐ Hindú
(Pregunta hecha para propósitos de reporte) ☐ Hispano / Latinoamericano ☐ Otro

¿Usted ha participado en un estudio en este laboratorio en el pasado? ☐ Sí ☐ No

Sección 2: Historial de Manejo

¿Aproximadamente que edad tenía cuando obtuvo su licencia de conducir? _____ **Años** _____ **Meses**

¿Aproximadamente cuantas millas manejó la semana pasada?
☐ Menos de 50 ☐ Menos de 100 ☐ 100 a 200 ☐ 200 a 300 ☐ 300 a 500 ☐ Más de 500

¿Usted usualmente utiliza espejuelos o lentes de contactos cuando maneja? ☐ No
☐ Sí, espejuelos
☐ Sí, lentes de contacto

Mencione su país de procedencia: ___________________________
¿Aprendió a manejar en ese país? ☐ Sí ☐ No
Si su respuesta es no, indique en cual país fue el que aprendió a manejar: _______________________
¿En qué país usted ha manejado por la mayor parte de su vida? __________________________

¿Usted experimenta síntomas de mareo cuando maneja o cuando va de pasajero en un vehículo?
☐ Sí ☐ No
(Si su respuesta a esta pregunta es Sí, por favor hágaselo saber de inmediato al investigador)

¿Usted tiene alguna otra restricción en su licencia de conducir? ☐ Sí ☐ No

Si su respuesta es sí, por favor descríbala: ____

¿Hay algún otro factor relacionado a su historial de manejo o su salud, incluyendo algún medicamento, que puede causar que usted maneje mucho mejor o peor que otros conductores?
☐ Sí ☐ No

Si su respuesta es sí, por favor descríbala: ____

Comentarios del Participante:

Selecciona la opción que mejor describa su experiencia, siendo 5 excelente y 0 deficiente.

	5	4	3	2	1	0
Sensación de que el Vehículo Fuese Real						
Aceleración						
Frenos						
Sonido						
Imagen						

Comentarios adicionales:

___

___

___

Publications and Posters Presented at Technical Forum by the UPRM SAFER-SIM Team

Operational and Safety-Based Analysis of Toll Plaza Signage using Driving Simulation

Enid M. Colón Torres[1]; Ricardo E. García Rosario[1]; Julio C. Valdés Valderrama[1]
Didier Valdés, PhD[1]; Benjamín Colucci, PhD[1]; Donald Fisher, PhD[2]
[1]University of Puerto Rico at Mayagüez, [2]University of Massachusetts, Amherst

Introduction

- Driver confusion when approaching toll plazas associated with signage location and proximity can create hazardous safety conditions, particularly for high speed freeways.
- This study presents the first prototype of a virtual simulation environment for a toll plaza. It was used in assessing the effectiveness of electronic toll collection lane types and how signage affects driver behavior and safety in toll plazas.
- The study consisted of two phases:
  - The initial phase conducted at UMass Amherst where the scenario was developed.
  - The second where the experiment was conducted using the driving simulator located at the University of Puerto Rico in Mayagüez.
- The variables taken into consideration were average speed and acceleration noise. The standard deviation of acceleration (acceleration noise) was used as a surrogate measure for crash frequency.

Objectives

- Evaluate whether implementing overhead signs better informs subject drivers and prevents drastic speed changes when approaching the toll plaza.
- Evaluate whether there is a difference in the subject drivers' behavior with respect to different sign configurations with different traffic flow conditions.
- Compare subject drivers' behavior for the different sign configurations during the day and night.

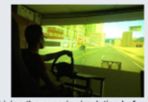
Experiment

- Subject-gender distribution 45% females and 55% males:
  - 18 to 25 years old: 40%
  - 26 to 55 years old: 35%
  - 56 to 70 years old: 25%
- Four decision areas (Areas 1- 4), two configurations and twelve scenarios were evaluated.
- Three different factors were simulated in each configuration, (traffic flow condition, destination lane at the toll plaza and starting lane position).

Equipment

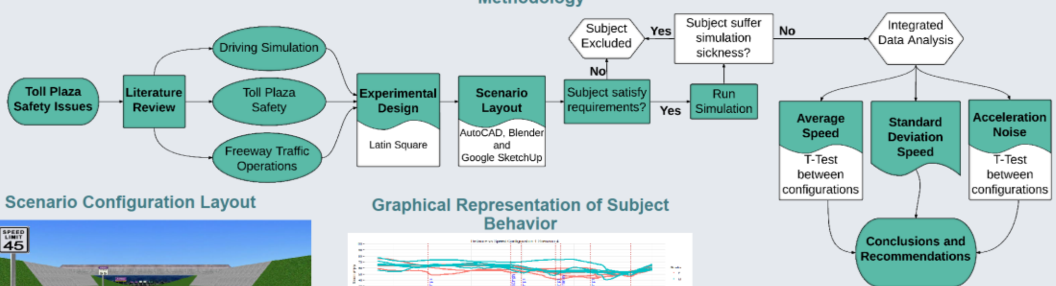
- Desktop simulator configured as a cockpit simulator
- Portable and permanent simulator vehicle
- Scenario projectors and screens
- Operator station and the host computer hardware and software

UPRM Transportation and Simulation (Laboratory Setup)

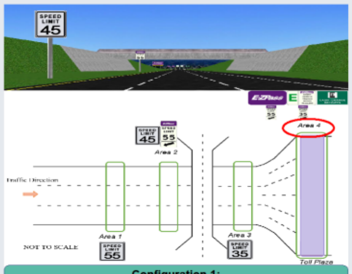


Subject driving the generic simulation before running the experiment scenarios

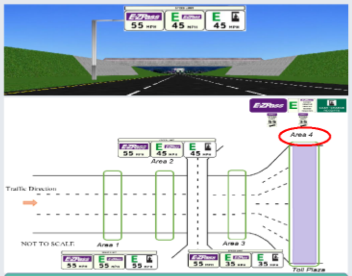
Methodology



Scenario Configuration Layout



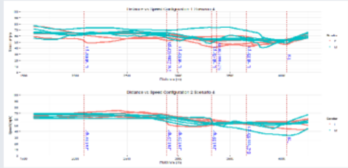
Configuration 1:
Signs located on the freeway's roadside



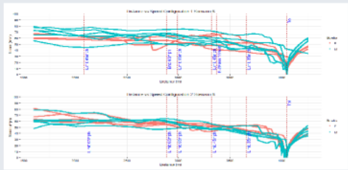
Configuration 2:
Overhead signs

Caguas Sur Toll Plaza

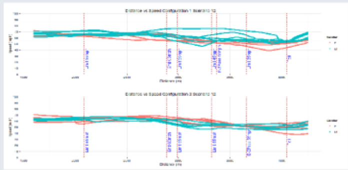
Graphical Representation of Subject Behavior



Scenario 4 Configurations 1 & 2, respectively



Scenario 8 Configurations 1 & 2, respectively



Scenario 12 Configuration 1 & 2, respectively

Scenarios Description

Scenario	Description
1	No Traffic, Start Left Lane, pass through E-Z Pass Lane
2	Lead Vehicle Only, Start Left Lane, pass through E-Z Pass Lane
3	No driver Ahead- Traffic Middle and Right Lane, Start Left Lane, pass through E-Z Pass Lane
4	Traffic for All Lanes, Start Left Lane, pass through E-Z Pass Lane
5	No Traffic, Start Left Lane, pass through Cash Lane
6	Lead Vehicle Only, Start Left Lane, pass through Cash Lane
7	No driver Ahead- Traffic for Middle and Right Lanes, Start Left Lane, pass through Cash Lane
8	Traffic for All Lanes, Start Left Lane, pass through Cash Lane
9	No Traffic, Start Right Lane, pass through E-Z Pass Lane
10	Lead Vehicle Only, Start Right Lane, pass through E-Z Pass Lane
11	No driver Ahead - Traffic for Middle and Right Lanes, Start Right Lane, pass through E-Z Pass Lane
12	Traffic for All Lanes, Start Left Lane, Night, pass through E-Z Pass Lane

Table 1

Area 4	Average Speed		Acceleration Noise	
Scenario	Configuration		Configuration	
	1	2	1	2
4	51.49	49.43	0.15	0.13
8	*24.39	*16.75	1.70	1.83
12	52.25	49.65	0.24	0.08

*** T test P-value <0.05**

Table 2

Acceleration Noise Comparison			
Scenario	Acceleration Noise (m/s^2)		Difference between configuration 1 & 2 (%)
	Configuration 1	Configuration 2	
4	0.69	0.54	24
8	0.99	1.01	2
12	0.67	0.54	21

Relevant Findings

- In Scenarios 4, 8, and 12 the average speed is lower for configuration 2 than for configuration 1.
- In Scenario 8, Area 4, the comparison between configurations is significant.
- Incorporating a dedicated signage for nighttime driving improves driver behavior.
- Using the variable acceleration noise as a surrogate measure, an expected potential crash reduction of more than 60% can be achieved.

Conclusions

- Signage modifications for Configuration 2 will lead to improvements in driver behavior.
- When vehicle flow increases, the acceleration noise also increases, except in Configuration 2, where the acceleration noise decreases in all traffic flows.
- The proposed safety countermeasure has the potential to reduce the expected crash frequency up to 60%, including both day and nighttime scenarios.

Acknowledgments

The authors thank the Research Innovative Transportation Administration (RITA) for funding this project and the UPRM's Chancellor's Office for providing matching funds for the purchase of the equipment used to support the portable and permanent driving simulation laboratory.


Outreach Activities to Create Safety Awareness Using UPRM Driving Simulator
Didier Valdés, PhD and Benjamín Colucci, PhD; Co-PI's
Johnathan Ruiz González, BSCE; Enid M. Colon Torres and Ricardo E. García Rosario; Research Assistants
University of Puerto Rico at Mayagüez
SAFETY RESEARCH USING SIMULATION
UNIVERSITY TRANSPORTATION CENTER
2015 Mega-Friday Civil
The UPRM Driving Simulator was center stage at the Convention Center of Puerto Rico during this event.
Participants learned the benefits of performing research and how the driving simulator operates, giving them a hands-on experience.
It helped professional civil engineers and students in the island become more aware of the research.
Ideas concerning the potential applications of the driving simulator were exchanged with top management officials from the island's main agencies (ATI, DTPW, PRTHA)
IMPACT: Approximately 1000 students, teachers, and Civil engineering professionals from the private and public sectors were exposed to the toll plaza driving simulation scenarios.
Introduction
Seven activities were performed in 2015 to promote highway safety awareness to elementary and high school students, teachers, leaders and civil engineering professionals from the public and private sectors.
The general topics of this outreach were: road safety, driving simulations, data gathering and analysis, and an explanation of the UPRM research project.
The activity consisted of an initial overview of the driving simulation component and a hands-on experience, followed up by a presentation of driving simulator outputs and a exchange of ideas.
Research was funded by the Research and Innovative Technology Administration (RITA).
2015 Summer Transportation Institute (STI)
The STI is a summer camp sponsored by the Federal Highway Administration (FHWA) and the Puerto Rico Transportation Administration (PRTA) to motivate tenth grade students to pursuit a career associate with transportation.
The purpose of the students' project was to compare the behavior of a drunk driver and a regular driver using the UPRM driving simulator by creating simulated scenarios which took place in an urban area with signalized and non-signalized intersections to test the drivers.
Drunk driver behavior was simulated with "Drunk Busters" goggles that visually impaired participants with a BAC of 0.16.
IMPACT: Over 100 students, leaders, teachers and parents were presented with the final project.
MVC2015
Summer Transportation Institute
UPRM Driving Simulation Outreach
Pre-Engineering Camp
Civil Engineering Freshman and Transfer Student Orientation
PAEC Summer Camp
2015 Pre-Engineering Camp
Junior and senior students from all around Puerto Rico were exposed to the UPRM Driving Simulator to promote highway safety.
Using the Toll Plaza Scenario, the UPRM SAFER-SIM Team explained the on-going research and the importance of highway safety.
Exchanged ideas of the driving simulation experience in order to enhance the models' safety and operational characteristics.
IMPACT: Approximate 85 students learned the benefits.
2015 Community Support and Engagement Program Summer Camp
The UPRM SAFER-SIM Team created safety awareness in the next generations of drivers, starting with a representative group of 7-year-olds.
IMPACT: Over 30 students and teachers for the program learned the benefits of the driving simulator.
2015 Civil Engineering Freshman and Transfer Student Orientation
Orientate the freshman students of the Department of Civil Engineering and Surveying about new technology and the importance of research to improve transportation systems using the UPRM Transportation and Driving Simulation Laboratory.
Exposed second year transfer engineering students to the UPRM driving simulator scenarios to create safety awareness and to motive the to pursue career in transportation.
The activity served to motivate future civil engineers to study transportation engineering.
The event stand out the importance of research, specially in transportation.
IMPACT: Approximately 200 students were orientated.
Benefits/Impact
For the fist time elementary and high school students, leaders, teacher and civil engineering professionals were exposed to UPRM driving simulator system to promote highway safety.
Exchanging ideas with the participants to calibrate the UPRM Driving Simulator model and develop new scenarios.
The UPRM SAFER-SIM Team has impact over 2,000 students and engineering professionals .

Driving Simulation in the Safety and Operation Performance of the Freeway Toll Plaza

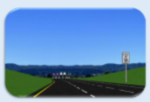
Didier Valdés[1], PhD; Benjamín Colucci[1], PhD; Donald Fisher[2], PhD;
Johnathan Ruiz González[1]; Enid M. Colon Torres[1]; Ricardo E. García Rosario[1]; Research Assistance
[1] University of Puerto Rico at Mayagüez; [2] University of Massachusetts Amherst

ABSTRACT

- Toll plaza designs have implemented electronic toll collection and other technologies to improve toll systems, however, with these improvements an increase in crashes has resulted.
- Two different signage configurations that indicate the corresponding speed limits and toll station for each lane in the area prior to the toll plaza were compared. Configuration 1 corresponds to the current signage condition in Puerto Rico, with signs located at the highway roadside while Configuration 2 presents a proposed overhead signage.
- A representative group of 20 subjects drivers were selected to test the effectiveness of the two signage configurations on the approach zone of the toll plaza.
- The Standard Deviation of Roadway Position (SDRP), speed and acceleration noise in five different zones were evaluated.
- The drivers behavior using Configuration 2 appears to be safer than Configuration 1 and drivers using Configuration 2 changed lanes more smoothly and reduced their vehicle's speed more when approaching the toll plaza.

INTRODUCTION

- Driving simulation have been used to evaluate driving behaviors and other human factors related issues, making it an effective tool for transportation and other engineering disciplines as well as professionals in the fields of psychology, medicine and computer science.
- There is a lack of simulator studies of toll plazas with multiple lanes, leaving a gap for driving simulation researchers to study the driver behaviors in the approach zone leading to toll plazas.
- To study pertinent aspects of driver behavior in toll plazas with electronic toll collection, a cockpit driving simulator housed at the University of Puerto Rico at Mayagüez was used.
- Five references zones (Zone 1-5), two signage configurations and twelve driving scenarios were evaluated.
- Three factors were simulated in each signage configuration, (starting lane position, traffic flow condition, destination lane at the toll plaza).



Configuration 1: Current Roadside Signage

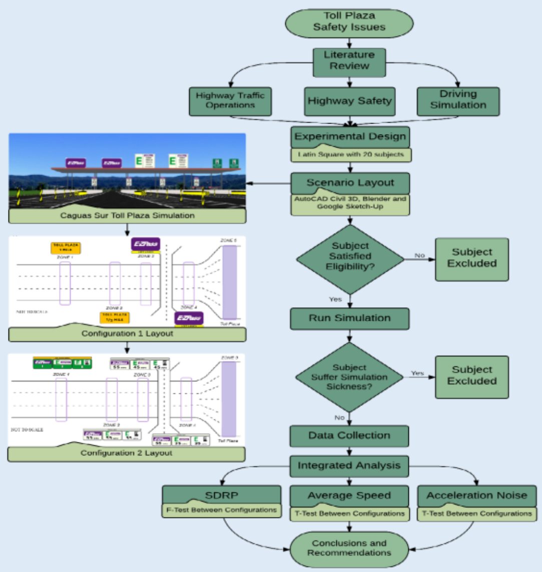
Configuration 2: Proposed Overhead Signage

DRIVING SCENARIOS DESCRIPTION SIMULATED

Scenario	Traffic[a]				Start Lane		Toll Lane		Environment	
	1	2	3	4	Left	Right	E-ZPass	Cash	Day	Night
1	✓				✓		✓		✓	
2		✓			✓		✓		✓	
3			✓		✓		✓		✓	
4				✓	✓		✓		✓	
5	✓				✓			✓	✓	
6		✓			✓			✓	✓	
7			✓		✓			✓	✓	
8				✓	✓			✓	✓	
9	✓					✓	✓		✓	
10		✓				✓	✓		✓	
11			✓			✓	✓		✓	
12				✓	✓		✓			✓

[a] 1-No Traffic; 2-Lead Vehicle Only; 3-No driver Ahead-Traffic in Middle and right lanes; 4-Traffic in all lanes.

RESEARCH METHODOLOGY

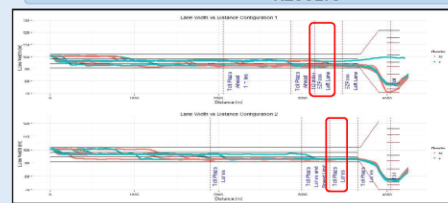


UPRM Driving Simulator Human Factor Lab

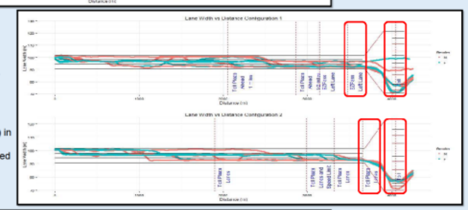
HYPOTHESIS

Driving subjects on signage Configuration 2 (i. e. Overhead Signage) would have better performance (i.e. vehicle speed, acceleration noise and SDRP will be smaller) than those presented with Configuration 1(i. e. Roadside Signage).

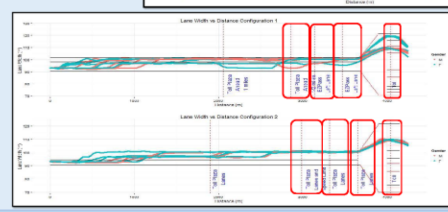
RESULTS



Scenario 6: A significant difference between configurations in Zone 3 was detected, the variability of the subject is greater in configuration one then in configuration 2.



Scenario 8: A significant difference between configurations in Zones 4 and 5 was detected, It could be notice that in Configuration 2 the subjects follow the same trajectory (i.e. same lane) in contrast with those in Configuration 1 that passed through different lanes.



Scenario 11: A significant difference between Configurations in Zones 2, 3, 4 and 5 was detected. The difference is notable in Configuration 2 that lane changes are smooth and the subject drivers change lanes gradually (i.e. didn't wait until last minute to change to the designated lane.

CONCLUSIONS

- It can be inferred in Configuration 2 (overhead signage) that the action of subject drivers of releasing the acceleration pedal is favorable in providing a gradual deceleration toward the toll plaza. This is reflected in the significance level associated with average speed reduction in Configuration 2 as compared to Configuration 1.
- Statistically significance differences show Configuration 2 is safer than Configuration 1 for both SDRP and speed.
- For Zones 3, 4, and the toll plaza in signage Configuration 2 the decrease in the SDRP is significant in 41.66%, 50% and 50%, respectively in comparison to Configuration 1.
- For Zones 2, 3 and Toll Plaza in signage Configuration 2 8.33% of the scenarios reflected a significant decrease in the driver's speed as compared to Configuration 1. In Zone 4, 33.33% of the scenarios reflect significant decreases in the driver's speed in Configuration 2, prior to arriving at the toll plaza in comparison to Configuration 1.
- In the acceleration noise the scenarios reflected a significant difference in Zones 3, 4 and Toll Plaza. The acceleration noise was reduced in 8.33% of scenarios tested for Zone 3 and 16.66% of the scenarios tested in Zones 4 and 5.
- The perception and reaction time of the subjects drivers in Configuration 2 has improved in comparison to Configuration 1 due to the overhead sign, creating less variability in subject speed and movement from their starting lane to their destination.

ACKNOWLEDGEMENTS

- The authors want to express their gratitude to the University Transportation Centers (UTC) Program for providing the funding to the SAFER-SIM UTC that supported the research project that is reported in this paper.
- The authors acknowledge the assistance of Dr. Raúl Macchiavelli in the statistical analysis, Juan Rivera and Kelvin Santiago in the development of the scenarios, and Angélica Valdés, Julio Valdés and Yanira Rivera for their assistance in the technical editing of the final publication.