Evaluation of Real-World Toll Plazas Using Driving Simulation

SAFETY RESEARCH USING SIMULATION

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Abstract

Toll plazas are becoming an essential part of the highway system, especially within the state of Florida. Many crashes reported on highways occur at toll plazas. A primary reason for vehicle collisions at these facilities is the fact that each toll plaza agency has different design, signage, and marking criteria. This, in turn, causes driver confusion and possible last minute weaving maneuvers. Even though the varying design of toll plazas is a clear highway safety factor, research in the field is very limited but expanding. This study focuses on one toll plaza, the Dean Mainline Toll Plaza, located in Orlando, Florida. The toll plaza is located directly between two roads that are in close proximity of each other. Because of this, the toll plaza is very close to the on- and off- ramps, which can be even more confusing and stressful for a driver entering or leaving the highway.

The purpose of this study was to evaluate the safety and efficiency of the Dean Mainline Toll Plaza in order to make recommendations to improve or maintain the current toll plaza design, as well as potentially contribute to a nationally set design standard for toll plazas. Seventy-two subjects were recruited and, using the National Advanced Driving Simulator (NADS) MiniSim™ Simulator, each subject was asked to drive three scenarios that were randomly selected from a pool of twenty-four scenarios. Signage and their location, pavement markings, distances between the toll plaza and ramps, and traffic conditions were changed in order to study the drivers' behavior. All of these factors were altered and observed on five of the eight possible paths that could be taken through the toll plaza. The subjects were asked to complete questionnaires before and after all of the scenarios, as well as in between each driving scenario. These questionnaires included demographic characteristics such as age, education, income, and E-PASS ownership. The data collected by the driving simulator and questionnaires were analyzed by ANOVA and multinomial logistic regression models. A positive relationship was found between non-urgent lane changing and the current real-world sign conditions prior to the toll plaza. Relationships were also found among the subjects' speed in various locations,

signage before the toll plaza, and segment length after the toll plaza. Along with specified recommendations for future research in toll plaza safety, recommendations for the Dean Mainline Toll Plaza included maintaining the current signs and pavement markings because they were found to be beneficial in drivers performing safe lane changing maneuvers.

Chapter 1: Introduction

Toll plazas are becoming an essential part of the highway system, especially within the state of Florida. In a "Toll Facility Workplace Safety Study Report to Congress", four main issues were raised, including the design of toll facilities (Rephlo et al., 2010). A primary reason for many vehicle collisions at these facilities is the fact that each toll plaza agency has different designs and even signs. This, in turn, causes driver confusion and possible last minute weaving.

Even though the varying design of toll plazas is a clear highway safety factor, research in the field has been limited but is expanding. Literature has shown that there have been proposals and recommendations, but no clear codes or guidelines that toll plaza designers can reference when designing facilities. Research on the subject of toll plaza safety has included driver surveys, microsimulation, and studying before-and-after data. With driving simulation becoming a more popular way of research, toll plaza safety can be studied more efficiently while producing clearer results.

This research was conducted using a NADS MiniSim^{TM} Driving Simulator. The purpose of this experimental design was to improve the safety and efficiency of toll plazas. A real-world toll plaza, along with real-world traffic data, was utilized in the driving simulator. The particular plaza observed was the Dean Mainline Toll Plaza located on SR-408 in Orlando, Florida. This plaza is located directly between two roads that are in close proximity of each other. Because of this, the toll plaza is very close to the on- and off- ramps which can be even more confusing and stressful for drivers entering or leaving the highway.

Multiple factors were studied within twenty-four scenarios using the MiniSim^{TM}. In order to determine whether this toll plaza is efficient and safe, the following factors were changed in order to observe the drivers' behavior: signage and their location, pavement markings, distances between the toll plaza and ramps, and traffic conditions. All of these factors were altered and observed on five of the eight possible paths that could be taken through the toll plaza.

The hypothesis was that drivers would drive in a safer manner if the signs were located at adequate locations with pavement markings and with longer distances between the toll plaza and the ramps. There were multiple reasons why safer driving behaviors could be observed under these conditions, including the fact that pavement markings and signage could help direct the driver when there is sufficient signage placed in appropriate locations without the presence of sensory overload. In addition, longer distances between the toll plaza and the on- and off-ramps would allow more time for the drivers to make decisions when switching lanes.

This study had several objectives, which included

1. Creating and analyzing replications of real-world scenarios;
2. Determining if the Dean Mainline Toll Plaza was safe in terms of signage, pavement markings, and segment lengths; and
3. Providing recommendations that would potentially contribute to national toll plaza design guidelines.

Following the brief introduction and overview in Chapter 1, Chapter 2 summarizes literature on the subjects of toll plazas and driving simulators. Chapter 3 explains the experimental design for the study, along with factors, their levels and descriptions. Chapter 4 explains the creation of the scenarios for the driving simulator, Chapter 5 discusses the subjects, Chapter 6 presents the analysis and results, and Chapter 7 concludes the report and presents suggestions and recommendations.

Chapter 2: Literature Review

2.1 Toll Plaza Safety

Limited research has been done on the subject of toll plaza safety. There are reports stating that toll plazas are one of the most common areas where crashes on highways occur, but very few of them specify which factors affect toll plaza safety. Even when toll plaza safety factors are specified, these reports (which will be explained in more detail later in this chapter) utilized crash trends or individual interviews and surveys and not crash data analyses.

Abuzwidah and Abdel-Aty (2014) found that crashes reduced significantly when toll plazas were converted from traditional mainline toll plazas to all-electronic toll plazas, with average crash reductions of 76%, 75% and 68% for total, fatal-and-injury, and property damage only (PDO) crashes, respectively. Moreover, they found that there was a slightly less significant reduction in crashes when converting the traditional mainline toll plazas to the hybrid mainline toll plazas. The majority of the crashes, including the more severe crashes, were found to occur at the diverge and merge areas before and after toll plazas. Applying a negative binomial model, Abuzwidah (2011) found that the diverge area prior to the toll plaza had an 82% higher risk of crashes than at the merge area after the toll plaza. Abuzwidah (2011) suggested two factors as to why this was true: some vehicles have an electronic toll transponder while others do not, and signage location.

Mohamed et al. (2001) found that 31.62% of crashes that occurred on the Central Florida Expressway Authority system between the years of 1994 and 1997 happened at the mainline toll plazas. In a toll plaza safety report to Congress by the Federal Highway Administration (2010), three main issues were found that could increase the probability of vehicular crashes at toll plazas. These included drivers selecting the improper lane at the plaza, making unsafe or last minute lane changes, and driver confusion. All of these issues could be due to improper signage or improper lane configurations. Generally, not only do toll facilities vary from one agency to another, but also they could vary from plaza to plaza within an agency.

This can cause major confusion and last minute lane change maneuvers. Drivers are also known to change lanes at the last minute to a lane where they see the least amount of cars in line.

In an attempt to fix the issues of improper and last minute lane changes and outlined in Chapter 4 of the Toll Facility Safety Study Report to Congress by the Federal Highway Administration (FHWA, 2010), toll authorities have implemented various changes to toll plazas. A common and standard design is to situate the dedicated electronic toll collection (ETC) lanes to the left of the toll plazas, whether they are traditional mainline toll plazas or hybrid toll plazas. However, in some cases, dedicated ETC lanes are located on both the left and the right side of the toll plaza. This is due to the toll plaza being located in close proximity to on-ramps or off-ramps and can help minimize weaving.

Another change that has been implemented in many toll plazas is the application of concrete barriers and attenuators well in advance of the plaza in order to channelize traffic. However, one disadvantage of this method is the cost of both installing and maintaining physical barriers. Instead of using physical barriers to separate traffic, the Florida Turnpike uses wide yellow sergeant-striped delineators positioned in a “bowling pin” arrangement in place of the previously used white delineators.

Signs are another effective tool toll agencies have used to minimize potential vehicle collisions. Not only has the location of signs proven to be important, but also the type of message on the signs. For example, drivers understand and react better to signs that contain the “brand,” such as E-PASS, rather than just a sign stating the ETC lane is ahead. Pavement markings, along with signage, have been applied in the design of toll facilities.

Hybrid mainline toll plazas seem to be a more favorable toll plaza design according to a study done by McDonald et al. (2001). Data on design plans were collected from various toll plaza agencies. Some agencies provided proposed toll plaza design guidelines. The data was separated into two categories: horizontal geometrics and vertical geometrics. After thorough review of the collected data, a panel of toll plaza design experts assembled for this study recommended horizontal and vertical design guidelines. In comparing design publications and the developed guidelines, it was determined that a national standardization of all-electronic toll collection on a regional level was preferred. They accepted that ticketing equipment or ACMs should continue to be used due to the belief that flexibility is important. For lane configurations, especially for traditional mainline toll plazas, a guideline that has been widely suggested and even recently researched using microsimulation (Hajiseyedjavadi et. al, 2015) includes ETC capabilities located in all lanes (see Scenario 2 in Figure 2.1). This lane configuration could be preferred due to the driver having fewer options in lane choice, which ultimately prevents last minute weaving.

Scenarios	Lane 1	Lane 2	Lane 3	Lane 4
Scenario 1 Base Case	CASH ONLY	E-ZPass ONLY NO CASH	E-ZPass ONLY NO CASH	CASH ONLY
Scenario 2	E-ZPass ONLY NO CASH	E-ZPass ONLY NO CASH	E-ZPass ONLY NO CASH	E-ZPass ONLY NO CASH
Scenario 3	E-ZPass ONLY NO CASH	CASH ONLY	E-ZPass ONLY NO CASH	CASH ONLY
Scenario 4	E-ZPass ONLY NO CASH	E-ZPass ONLY NO CASH	CASH ONLY	CASH ONLY
Scenario 5	CASH OR E-ZPass	E-ZPass ONLY NO CASH	E-ZPass ONLY NO CASH	CASH OR E-ZPass

Figure 2.1 - Various lane configurations of scenarios in a microsimulation study (Hajiseyedjavadi et al., 2015)

Toll plaza design can vary from agency to agency and even within an agency. In the past 20 years, research has been done on the development of toll plazas and various guidelines have been carried out for toll plaza design. Most of the current guidelines have come from before-and-after data or from surveys sent out to drivers, as mentioned in the beginning of this chapter. As of 2001, design guidelines for intersections and roadways were provided in manuals such as the *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD) or the Green Book, but design guidelines for toll plazas did not exist in text. However, in 2006, the U.S. Department of Transportation (USDOT) provided toll plaza design recommendations in the "State of the Practice and Recommendations on Traffic Control Strategies at Toll Plazas" (Smith et. al., 2006). Several steps were taken to complete this study:

1. Literature Review: Used literature on toll plaza design and safety to prove the validity of design elements and practices;
2. Surveys: Surveys were sent to and completed by toll agencies who were members of the International Bridge, Tunnel, and Turnpike Association (IBTTA). The survey was also announced in IBTTA newsletters. Questions were multiple choice and evaluated current practices;
3. Expert Panel Workshop: In order to represent a wide range of toll and traffic experiences from the Federal Highway Administration (FHWA), IBTTA, and Project Team members, seven experts were selected to form a panel. The panel made recommendations based on the surveys.

The survey discussions and results were divided into four technical areas: (1) "Plaza Operations/Lane Configuration", (2) "Signing, Markings and Channelization", (3) "Geometric and Safety Design", and (4) "Toll Collection Equipment Technology". Many guidelines were outlined in this report and were broken down even further into more detailed areas with several guidelines given for each of these areas. Figure 2.2 shows an example of one presented guideline. This guideline explained that toll plazas should not be within one mile of interchanges in urban sections. With this in mind, we knew that the Dean Mainline Toll Plaza was well within one mile of both interchanges near the plaza, and segment length was a good factor to test in this study.

Guideline	Plaza Locations Guideline 1
Title	Plaza and Interchange Intervals
Text	The 2001 AASHTO Policy on Geometric Design of Highways and Streets (the "Green Book") recommends separation of 1 mile (urban sections) or 2 miles (rural sections) between interchanges. It is recommended this be used as a guideline for selection of new mainline toll plaza sites: no closer than 1 mile to the nearest interchange in urban sections, or 2 miles in other sections.
Commentary	It may not be possible to meet this design guideline at bridge and tunnel crossings, but the interval spacing minimums should remain a goal.

Figure 2.2 - MUTCD guideline example: Plaza Locations Guideline 1 (USDOT)

2.2 Driving Simulator Validation

Driving simulators are becoming popular in all aspects of transportation research. They are a very cost-effective, safe, and efficient tool that researchers can use to analyze countless real-world scenarios. However, there has been much debate on whether driving simulators are valid tools, especially when it comes to actual driving behaviors.

Due to the negativity toward driving simulators, there have been studies to validate the use of simulators in research. Driving simulators have been validated for research in not only engineering, but also for research in psychology (Bedard et. al, 2010) and in medicine (Lew et. al, 2005). Various methods of validation have been used. These methods have included creating real-life scenarios in the driving simulator then comparing collected driver behavior data from the scenarios in the driving simulator to the same scenarios in real life (Bella, 2015). Many of the studies have included comparing mean speeds of the collected driving simulator data and real-life data (McAvoy et. al, 2007). Other literature has shown that mid-level driving simulators, one of which was used in the study for this report, are an acceptable method of research.

In a study done by Risto and Martens (2014), headway choice in a mid-level driving simulator was compared to a real-life environment in an instrumented vehicle. Headway choice is an important factor to keep in mind when using simulation in research. There has been much debate about how the realism of simulators is not up to par and cannot really be compared to real-life situations, especially when a driver is deciding where an object in the road is located and when it is safe for them to pass or change lanes. Hence, the objective of this research was to determine whether simulators could be compared to real-life scenarios when studying headway choice. By performing an experimental design study and analyzing the collected data using the ANOVA method, it was found that driver behavior when choosing headway was similar in both real-world driving and simulated driving.

A study at the University of Central Florida by Yan et al. (2008) was performed to validate a driving simulator as a suitable tool to analyze traffic safety. A high crash frequency signalized intersection located in Central Florida was replicated in a driving simulator. The real-life free flow speeds and crash history, obtained from the Florida Department of Transportation Crash Analysis Reporting System, were analyzed and compared to the eight scenarios that were given in the driving simulator. Four of the scenarios were designed for speed validation and the remaining four scenarios were designed for safety validation. As for the field speed measurements, free flow speeds were recorded using a radar gun at the intersection during the green phase. Four hundred and twenty observations from each direction at the intersection were recorded. The two independent variables of this study were age, divided into 5 groups, and gender. In order to divide the ages into groups, the actual driver population near this intersection was found by using the quasi-induced exposure method. It was noted that some subjects were not able to complete some scenarios in the driving simulator due to simulation sickness. This study found that a simulator could be a valid approach to further transportation research. This was concluded from the comparison of speed data from both the field and the simulator. With a significance level of 0.05, both field and simulator data followed a normal distribution and each approach through the intersection had equal means.

Chapter 3: Toll Plaza Study Experimental Design

3.1 Overview

Using a factorial design for the experiment, it was determined that seventy-two subjects were needed to complete twenty-four scenarios. Each of the seventy-two subjects completed three randomly selected scenarios and each scenario lasted about five minutes. There were five factors considered for this experiment, described in Table 3.1. IRB approval was obtained from the UCF Institutional Review Board #1 (IRB no. SBE-15-11026). The documents submitted to IRB for approval can be found in Appendix A: Protocol and Study Materials.

Table 3.1 - Descriptions and levels of the five factors

	Factor	Description	Factor Levels
X1	Path	Setting of the path	1. Mainline-Express-Mainline
			2. Mainline-Cash-Mainline
			3. Mainline-Express-Ramp
			4. Ramp-Express-Mainline
			5. Ramp-Cash-Mainline
X2	Traffic	Setting of traffic conditions	1. Peak hours/Heavy
			2. Non-peak hours/Mild
X3	Pavement Marking	Whether or not there will be pavement marking	1. Yes
			2. No
X4	Length	Segment length	1. Default (current)
			2. Added length before toll plaza
			3. Added length after toll plaza
X5	Signage	The allocation of signs	1. Default (current)
			2. Removed 3rd sign
			3. Removed 3rd sign, moved 2nd sign, and added sign on ramp

With the five factors, there were one hundred and eighty-eight possible scenarios. However, with one restriction, this could be reduced to one hundred and forty-four scenarios. The restriction was that paths 1, 2, and 3 did not need to be tested with signage scenario 3 (refer to Table 3.1 and Figure 3.1). This was because the third scenario only changed the signage on the on-ramp, which did not affect paths 1, 2, and 3. Twenty-four scenarios were randomly chosen from the one hundred and forty-four scenarios since the experiment was limited to seventy-two subjects.

3.2 Factors Description

Five of the eight possible paths were used for this design. Only four of these paths were used for the design group of eleven scenarios and the remaining path was used for the additional tests. Figure 3.1 shows the five paths that were taken. Path 1 was the most common path because the driver started on the mainline, drove through the E-PASS lanes, and continued on the mainline. This route is very common in Florida because about 80% of the driving population has an E-PASS. Path 2 started on the mainline of SR-408 westbound, went through the cash lanes, and then continued back onto the mainline. Path 3 started on the mainline, continued through the E-PASS section, and then exited off SR-408 onto Dean Road. Path 4 started on the on-ramp upstream of the toll plaza, went through the E-PASS lanes, and then continued onto the mainline. Path 5 started on the on-ramp upstream of the toll plaza, went through the cash lanes, and then continued onto the mainline.

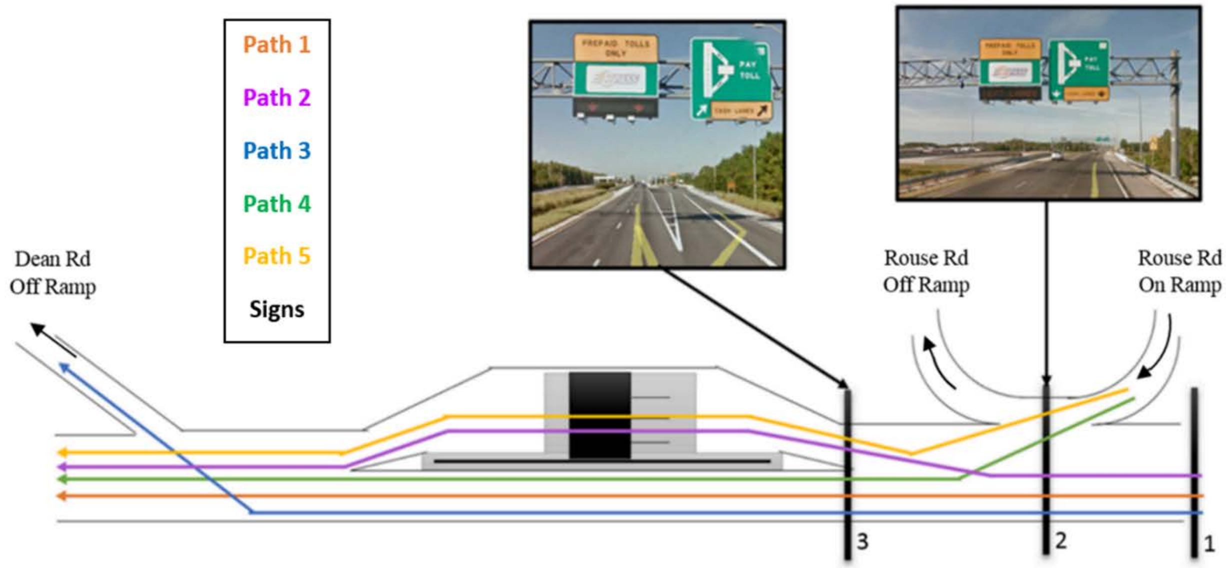


Figure 3.1 - A diagram showing the paths and signs to be used in the design

As stated previously, there were five factors of focus during this study. These factors were traffic conditions, pavement marking, length between the ramps and the toll plaza, signage, and the given paths that were previously explained. The traffic conditions varied between peak and off-peak hour. Real-world traffic data was analyzed and entered into the driving simulator to formulate realistic scenarios (explained in detail in Chapter 4). The pavement markings considered in this study are shown in Figure 3.2. Some subjects were given scenarios with markings that show where the lane splits and other subjects were given scenarios without these markings. The length factor varied among the base length, a longer distance between the toll plaza and the downstream off ramp, and a longer distance between the toll plaza and the upstream on ramp. The base length is the existing condition at the toll plaza, while a distance of 660 feet was added for each distance change.

Figure 3.2 - Pavement markings being studied for the toll plaza

There were three different scenarios for the signage factor. The first scenario was the existing base condition shown in Figure 3.1. Another scenario, which was called new position 2, simply removed the sign closest to the toll plaza labeled #3 in Figure 3.1.The third scenario, called new position 3, added a sign similar to Figure 3.3 to the on ramp, removed sign #3, and moved sign #2 farther upstream before the on-ramp. The sign was added to the on-ramp to keep all entering vehicles to the right and to minimize weaving as much as possible. The sign labeled #1 did not interfere with sign #2, as it was farther upstream than Figure 3.1 allows.

Figure 3.3 - DMS sign that will be used for the on-ramp to keep vehicles to the right

3.3 Experimental Design

Twenty-four scenarios were randomly chosen. The number of occurrences for each level of the five factors in the twenty-four scenarios tested is summarized in Table 3.2. Due to the restriction mentioned in section 3.1, the first three paths were each tested four times and the last two paths were each tested six times. Each level of the pavement marking factor and the traffic factor occurred twelve times. Each level of segment length occurred eight times. With the restriction, the signage factor had three levels with varying occurrences. The first two levels each occurred nine times and the third level had six occurrences. Table 3.3 shows a summary of the twenty-four scenarios tested.

Table 3.2 - Counts of each level of each factor

Level	Path	Count
1	Path1	4
2	Path2	4
3	Path3	4
4	Path4	6
5	Path5	6
Level	Pavement	Count
1	No	12
2	Yes	12
Level	Traffic	Count
1	Off-Peak	12
2	Peak	12
Level	Signage	Count
1	New Pos1	9
2	New Pos2	9
3	Base Signage	6
Level	Segment Length	Count
1	Add Down	8
2	Add Up	8
3	Base Length	8

Table 3.3 - List of the final twenty-four scenarios

Scenario	Path	Traffic	Marking	Length	Signage
1	1	Peak	No	Default	Removed 3rd Sign
2	1	Peak	No	Added Before	Removed 3rd Sign
3	1	Off-Peak	Yes	Default	Default
4	1	Off-Peak	Yes	Added After	Default
5	2	Peak	Yes	Default	Default
6	2	Peak	Yes	Added Before	Removed 3rd Sign
7	2	Off-Peak	No	Added Before	Default
8	2	Off-Peak	No	Added After	Removed 3rd Sign
9	3	Peak	No	Default	Default
10	3	Peak	No	Added After	Default
11	3	Off-Peak	Yes	Added Before	Removed 3rd Sign
12	3	Off-Peak	Yes	Added After	Removed 3rd Sign
13	4	Peak	Yes	Added Before	Added Ramp Sign
14	4	Peak	Yes	Added After	Added Ramp Sign
15	4	Peak	No	Added After	Default
16	4	Off-Peak	Yes	Default	Added Ramp Sign
17	4	Off-Peak	No	Default	Removed 3rd Sign
18	4	Off-Peak	No	Added Before	Default
19	5	Peak	Yes	Default	Removed 3rd Sign
20	5	Peak	Yes	Added After	Removed 3rd Sign
21	5	Peak	No	Added Before	Added Ramp Sign
22	5	Off-Peak	Yes	Added Before	Default
23	5	Off-Peak	No	Default	Added Ramp Sign
24	5	Off-Peak	No	Added After	Added Ramp Sign

Each of the seventy-two subjects was in three of the scenarios listed in Table 3.3. This created nine blocks of eight subjects. The scenarios were randomly selected and distributed for each subject prior to the commencement of testing. The nine blocks are shown in Table 3.4.

Table 3.4 This chart shows the nine blocks of eight groups of three scenarios. The scenarios were randomly distributed throughout the chart

Block	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13	V14	V15	V16	V17	V18	V19	V20	V21	V22	V23	V24
1	10	24	9	16	8	11	5	1	12	18	17	3	14	7	23	20	13	21	22	4	15	19	2	6
2	1	19	18	15	22	16	24	4	23	20	3	2	9	11	8	10	13	6	21	14	5	12	17	7
3	23	7	1	22	24	15	13	17	5	8	12	14	11	9	16	20	18	10	6	4	19	21	3	2
4	10	18	9	11	19	21	6	20	12	2	4	15	1	24	13	17	5	3	23	7	22	16	8	14
5	15	12	20	11	4	5	22	19	18	9	10	13	2	7	17	3	21	23	1	16	8	6	24	14
6	10	12	17	3	20	15	16	23	7	19	1	6	9	8	24	18	13	11	5	22	2	4	14	21
7	18	9	1	5	3	7	17	10	15	6	11	8	20	16	21	19	13	14	12	23	2	4	22	24
8	24	10	5	3	21	14	11	18	23	9	4	12	2	16	1	17	13	19	8	7	15	22	20	6
9	23	7	19	6	16	18	17	20	13	12	24	3	8	1	21	14	22	10	2	5	11	4	9	15

Chapter 4: Toll Plaza Development

4.1 Overview

In order to create realistic traffic volumes for the toll plaza driving simulator study, real traffic data from the Dean Mainline Toll Plaza was analyzed. This part of the report discusses the analysis and results of the peak hour traffic data from the toll plaza. Data was collected from six separate detectors located at mileposts 18.8, 19.0, 19.4, 19.7, 19.9, and 20.7 on SR-408 westbound. The detectors located at mileposts 18.8, 19.7, and 19.9 are located in the gore areas, which are the merging and diverging areas for the ramp and mainline. The locations of the detectors are shown in Figure 4.1.

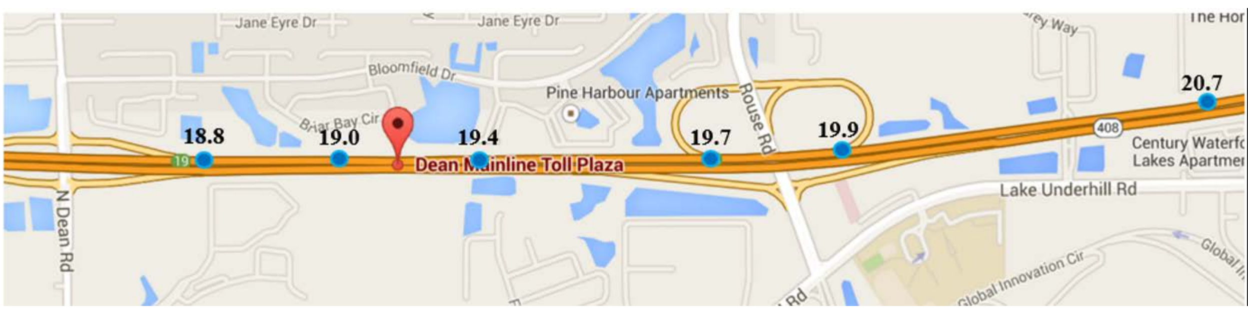


Figure 4.1 - Map of locations of detectors

4.1.1 *Peak Hour Data Analysis*

The peak hour data was collected between the hours of 7 AM and 8 AM on October 1, 8, 15, 22, and 29 of 2014. SAS software was used to calculate the mean speeds of the vehicles passing through the plaza. It was found that there were no significant differences in speeds due to the date, time, and location of the data taken. However, the speed of each lane turned out to be slightly different. The results of the speed data for the peak hour of the toll plaza are shown in Table 4.1. Lane 1 was defined as the innermost lane, while lane 3 was defined as the outer-most lane.

Table 4.1 - Peak hour speeds

Lane	Mean Speed (mph)	Standard Deviation (mph)
1	67.4	2.96
2	59.03	4.42
3	58.02	4.03
On-Ramp	45.45	2.86

As noted previously, the data had no significant differences throughout the date, time, and locations of collection. Therefore, only data collected on October 1 was analyzed for volume. For lanes 1, 2, and 3, the detector located at mile marker 20.7 was analyzed to collect each lane's volume. The detector located at mile 19.9 was analyzed for the on-ramp volume, the detector located at mile 19.7 was analyzed for the off-ramp before the toll plaza volume, and the detector located at mile 18.8 was used to analyze the volume of the traffic on the off-ramp after the toll plaza. Microsoft Excel was used to analyze the truck volume in express lanes and in cash lanes. The values are shown in Table 4.2. The volumes from Table 4.2 were used to calculate the average headways in each lane. Table 4.3 shows these values. During peak hour, 71% of the vehicles drove through the expressway, whereas 29% used the cash booths. During the peak hour, 6% of vehicles going through expressway and 6% of vehicles going through the cash booths were trucks.

Table 4.2 - Peak hour volumes

Location	Volume (vph)
Lane 1	1,162
Lane 2	1,543
Lane 3	247
Total (All Lanes)	2,952
On-Ramp	559
Off-Ramp before Toll Plaza	52
Off-Ramp after Toll Plaza	77

Table 4.3 - Peak hour average headways

Lane/Ramp	Average Headway (s)
1	3.098
2	2.333
3	14.575
On-Ramp	6.440
Off-Ramp before Toll Plaza	69.231
Off-Ramp after Toll Plaza	46.753

While inputting the traffic data into the driving simulator, it was found to be easier to add average spacing between the vehicles instead of or along with the calculated average headways. Therefore, the average spacing was calculated by using the average headways and average speeds. Table 4.4 presents the average spacing values.

Table 4.4 - Peak hour average spacing

Lane/Ramp	Average Spacing (ft)
1	307
2	203
3	1244
On-Ramp	430

4.1.2 *Off-Peak Hour Data Analysis*

Off-peak hour data was collected and analyzed in a manner similar to that of peak hour data. The off-peak data was collected from the six sensors shown in Figure 4.1 during the five weekdays from 12:30 PM to 1:30 PM. It was found that the vehicle speeds had no significant differences when the dates, time, and locations were compared. However, the speeds at different lanes were slightly different from one another. The averages on October 1 were used to determine the speeds in each lane. These off-peak speeds are summarized in Table 4.5.

Table 4.5 - Off-peak hour speeds

Lane	Mean Speed (mph)	Standard Deviation (mph)
1	69.7	2.4
2	63.5	2.3
3	60.9	4.0
On-Ramp	45.0	5.5

As with peak hour data, the volumes were calculated for the off-peak hour data. The same detectors were used to analyze their respective volume locations, shown in Table 4.6. The values for off-peak hour average headways, calculated from the volumes, are presented in Table 4.7. Table 4.8 shows the average spacing in each lane. During off-peak hours, 85% of the vehicles used the expressway, while 15% used the cash booths. Of the vehicles using the expressway and the cash booths, 15% and 14% were trucks, respectively.

Table 4.6 - Off-peak hour volumes

Location	Volume (vph)
Lane 1	769
Lane 2	807
Lane 3	120
Total (All Lanes)	1691
On-Ramp	204
Off-Ramp before Toll Plaza	24
Off-Ramp after Toll Plaza	78

Table 4.7 - Off-peak hour average headways

Lane/Ramp	Average Headway (s)
1	4.681
2	4.461
3	30
On-Ramp	17.647
Off-Ramp before Toll Plaza	150
Off-Ramp after Toll Plaza	46.154

Table 4.8 - Off-peak hour average spacing

Lane/Ramp	Average Spacing (ft)
1	480
2	417
3	2687
On-Ramp	1168

4.2 Development of Toll Plaza Scenarios

The NADS MiniSim™ was utilized in this study conducted at the University of Central Florida (UCF). Created and maintained by the University of Iowa, the simulator is a highly flexible PC-based driving simulator system designed for research, development, clinical, and training applications. It includes three different software packages: Tile Mosaic Tool (TMT), Interactive Scenario Authoring Tools (ISAT), and MiniSim™. The simulator is shown in Table 4.2.

Figure 4.2 - NADS MiniSim™ at UCF

The first software, Tile Mosaic Tool (TMT), was used to build the simulated road by assembling the road network based established road tile files (Figure 4.3). The NADS research center designed and developed the "tiles" that made up the simulated Dean Mainline Toll Plaza, which can be seen in Figure 4.3.

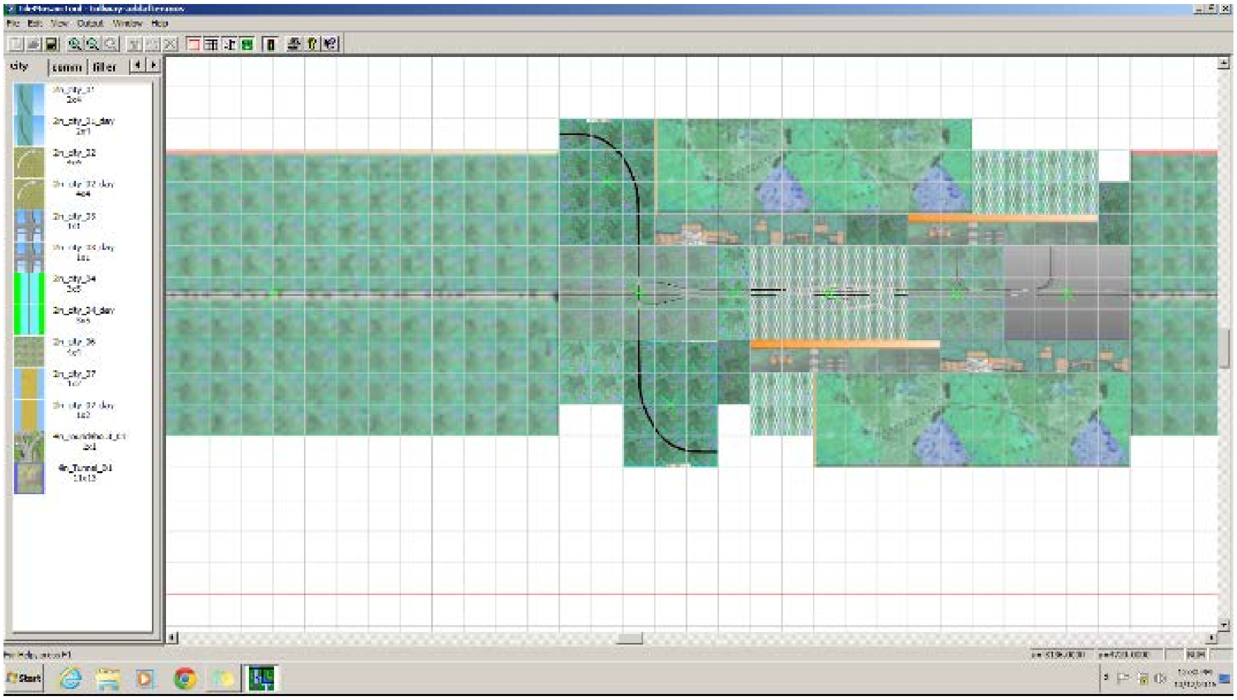


Figure 4.3 - GUI of Tile Mosaic Tool (TMT)

The second software was the Interactive Scenario Authoring Tools (ISAT) shown in Figure 4.4. This software was used to add the vehicles, or Autonomous Dynamic Objects (ADOs), and road signs. Forty ADOs were added to each scenario. Using the real-world data referenced in section 4.1, ADOs were given their respective speeds and type (car or truck). Some vehicles were also given "triggers." Triggers are applied to specific ADOs to give them specific driving instructions. For example, some ADOs were triggered to go through the cash booths, then triggered to slow down prior to arriving at the booths, and finally triggered to speed up to normal speed after the booths.

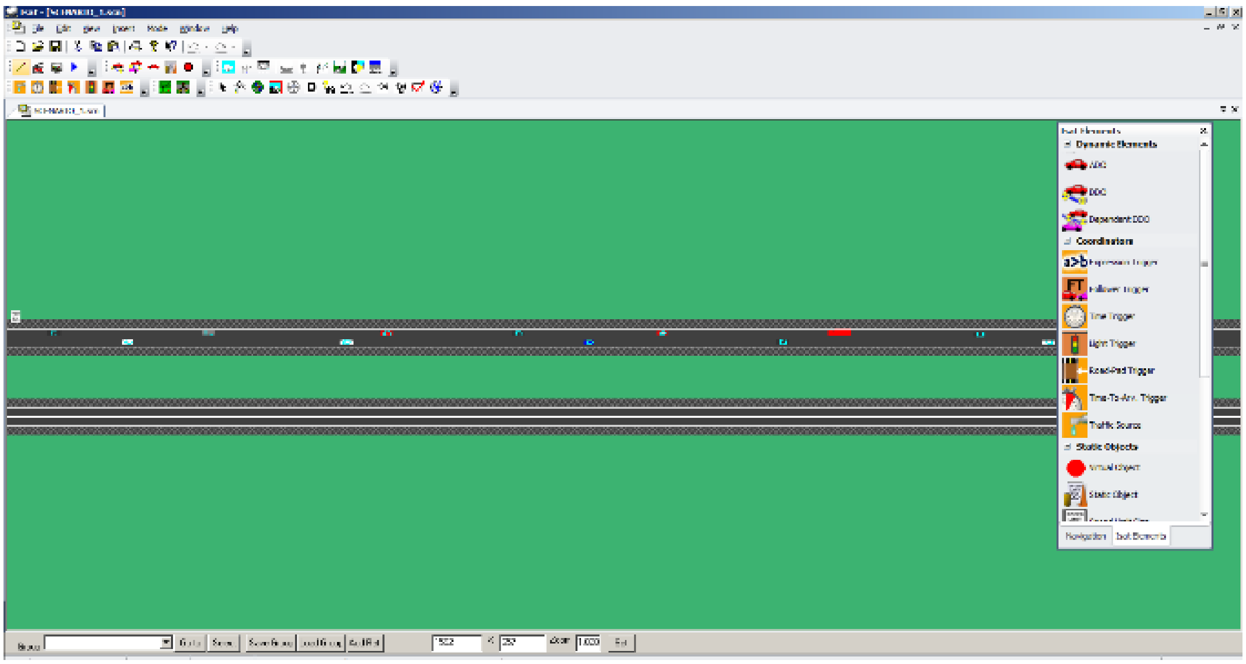


Figure 4.4 - GUI of Interactive Scenario Authoring Tools (ISAT)

Chapter 5: Toll Plaza Experiments

As previously noted, 72 subjects were needed to complete this study. They were recruited through colleagues, friends, and family. The general criteria required subjects to be in the age range of 18 to late 60s with a valid driver's license and they must not have a history of motion sickness. The latter helped ensure the safety and comfort of the subjects.

5.1 Subjects

Subjects were divided into groups depending on their age and gender. In order to be consistent with the real-world driver composition, four years (2009-2012) of no-fault driver's information from crashes was analyzed. These crashes occurred on SR-441, SR-408, and I-75. Figure 5.1 and Table 5.1 show the distribution of the drivers' age and gender. As can be seen, 40-50% of the drivers were less than 35 years old while less than 15% of drivers were 65+. The subjects' distribution should follow the distribution of the real world.

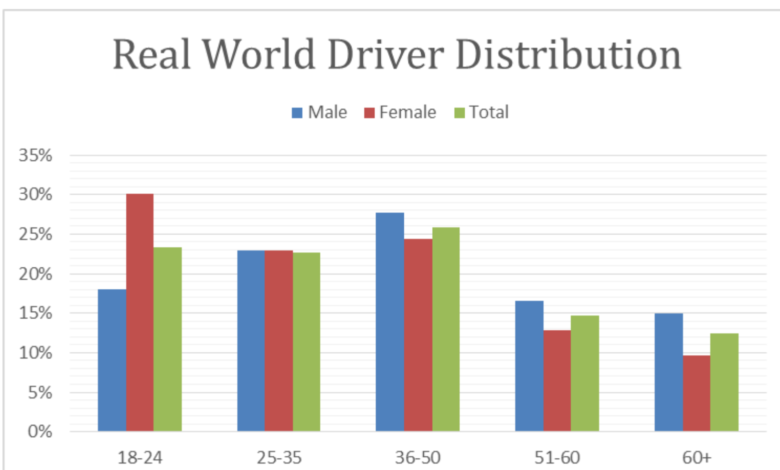


Figure 5.1 - Real-world age and gender distribution

Table 5.1 - The real-world driver distribution with desired subject distribution

REAL-WORLD DRIVER DISTRIBUTION				DESIRED SUBJECT DISTRIBUTION			
	Male	Female	Total		Male	Female	Total
18-24	18%	30%	23%	18-24	7	10	17
25-35	23%	23%	23%	25-35	9	7	16
36-50	28%	24%	26%	36-50	11	8	19
51-60	17%	13%	15%	51-60	6	4	11
60+	15%	10%	12%	60+	6	3	9
Total	100%	100%	100%	Total	39	33	72

The experiment completed on November 25, 2015. The actual distribution of subjects is shown in Table 5.2. It was possible to get a very similar gender distribution to the desired distribution. However, given the study occurred on a college campus, subjects under the age of 35 were easier to obtain than subjects above the age of 50.

Table 5.2 - Actual subject distribution

ACTUAL SUBJECT DISTRIBUTION			
	Male	Female	Total
18-24	10	13	23
25-35	13	11	24
36-50	8	6	14
51-60	2	4	6
60+	5	0	5
Total	38	34	72

A chi-squared test was performed to prove the similarity between the desired and actual subject distributions. The numbers of desired and actual subject distributions were combined and then separated by gender to obtain a comparison between actual and desired for each gender in each age group. Table 5.3 presents the crosstabulation of age group vs. actual and desired males and Table 5.4 presents the chi-square results. Figure 5.2 shows the male data in a bar chart. The null hypothesis in this chi-square test was that the number of desired males in each age group was similar to the number of actual males in each age group. With a *p*-value of 0.337, there was no statistically significant difference and the null hypothesis could be accepted.

Table 5.3 - Age group * male crosstabulation

			MALE		Total
			ACTUAL	DESIRED	
AGE GROUP	18-24	Count	10	7	17
		% within MALE	26.3%	17.5%	21.8%
	25-35	Count	13	9	22
		% within MALE	34.2%	22.5%	28.2%
	36-50	Count	8	11	19
		% within MALE	21.1%	27.5%	24.4%
	51-60	Count	2	7	9
		% within MALE	5.3%	17.5%	11.5%
	60+	Count	5	6	11
		% within MALE	13.2%	15.0%	14.1%
Total		Count	38	40	78
		% within MALE	100.0%	100.0%	100.0%

Table 5.4 - Age group * male chi-square test results

	Value	*df*	Asymp. Sig. (2-sided)
Pearson Chi-Square	4.551[a]	4	.337
Likelihood Ratio	4.721	4	.317
N of Valid Cases	78		

a. Two cells (20.0%) had expected count less than 5.

The minimum expected count was 4.38.

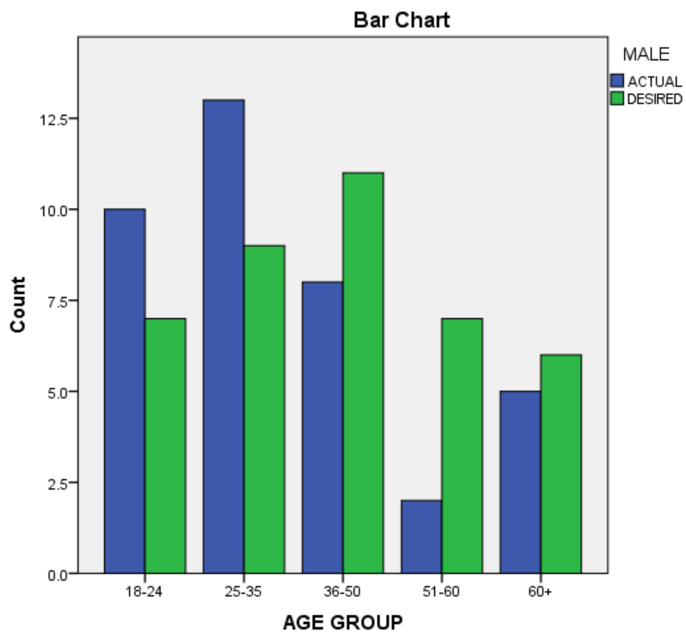


Figure 5.2 - Age group vs. male bar chart

Similarly, a chi-square test was performed for age group vs. females. Table 5.5 shows the age group vs. female crosstabulation, Table 5.6 shows the chi-square results, and Figure 5.3 presents the data in a bar chart. The null hypothesis for this chi-square test was that the number of desired females in each age group was similar to the number of actual females in each age group. With a *p*-value of 0.341, the actual and desired values were similar for females and the null hypothesis could be accepted.

Both of the previous chi-square tests proved that although the actual subject distribution was not equal in all age groups and genders, it was similar enough to follow the general distribution of real-world driver composition data in the Central Florida area.

Table 5.5 - Age group * female crosstabulation

			FEMALE		Total
			ACTUAL	DESIRED	
AGE GROUP	18-24	Count	13	10	23
		% within FEMALE	38.2%	31.3%	34.8%
	25-35	Count	11	7	18
		% within FEMALE	32.4%	21.9%	27.3%
	36-50	Count	6	8	14
		% within FEMALE	17.6%	25.0%	21.2%
	51-60	Count	4	4	8
		% within FEMALE	11.8%	12.5%	12.1%
	60+	Count	0	3	3
		% within FEMALE	0.0%	9.4%	4.5%
Total		Count	34	32	66
		% within FEMALE	100.0%	100.0%	100.0%

Table 5.6 - Age group * female chi-square test results

	Value	*df*	Asymp. Sig. (2-sided)
Pearson Chi-Square	4.509[a]	4	.341
Likelihood Ratio	5.674	4	.225
N of Valid Cases	66		

a. Four cells (40.0%) had expected count less than 5.

The minimum expected count was 1.45.

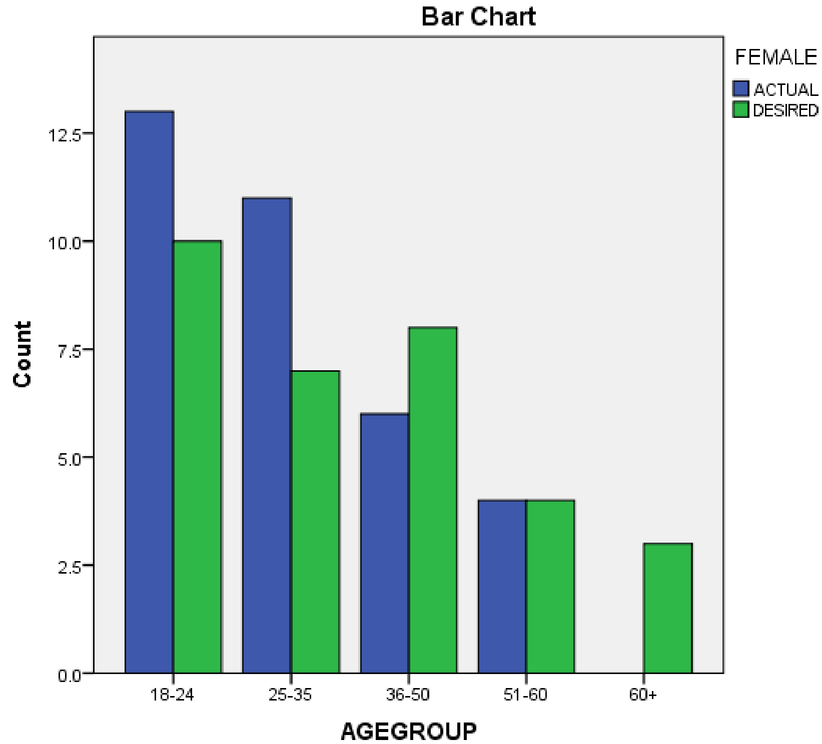


Figure 5.3 - Age group vs. female bar chart

Chapter 6: Analysis

6.1 Descriptive and Preliminary Analysis

The data analyzed for this project was collected using the NADS MiniSim™ and MATLAB. Various demographic variables were collected using questionnaires that were given to subjects before, during, and after the driving simulator scenarios. These variables included gender, age, income, education, E-PASS ownership, and others. Table 6.1 shows the crosstabulation of E-PASS ownership vs. age. These values showed that 79.2% of the subjects use an E-PASS transponder. It is necessary to note that one subject was only able to complete one out of the three scenarios due to time constraints.

Table 6.1 - E-PASS * age crosstabulation

			AGE					Total
			1	2	3	4	5	
E-PASS	1	Count	17	21	10	5	4	57
		% within SUNPASS	29.8%	36.8%	17.5%	8.8%	7.0%	100.0%
		% within AGE	73.9%	87.5%	71.4%	83.3%	80.0%	79.2%
	2	Count	6	3	4	1	1	15
		% within SUNPASS	40.0%	20.0%	26.7%	6.7%	6.7%	100.0%
		% within AGE	26.1%	12.5%	28.6%	16.7%	20.0%	20.8%
Total		Count	23	24	14	6	5	72
		% within SUNPASS	31.9%	33.3%	19.4%	8.3%	6.9%	100.0%
		% within AGE	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Figure 6.1 shows a sample speed (mph) versus “eyepoint” plot, which graphically shows where the subject was located throughout the scenario and was collected with the driving simulator and analyzed. This sample was collected from subject 33, driving scenario 20. Eyepoint location data matched the locations in ISAT. In comparing the eyepoint data to the ISAT locations where collection of data was specified, it could be determined where to analyze

the speed data (explained in section 6.4). Recall that scenario 20 was on path 5 (ramp to cash booths to mainline), during the peak hour, had a 660-foot segment added after the plaza, and the 3rd sign before the plaza was removed. Figure 6.1 illustrates where the subject slowed down to a stop to pay the cash booth and then sped up to get back on the mainline.

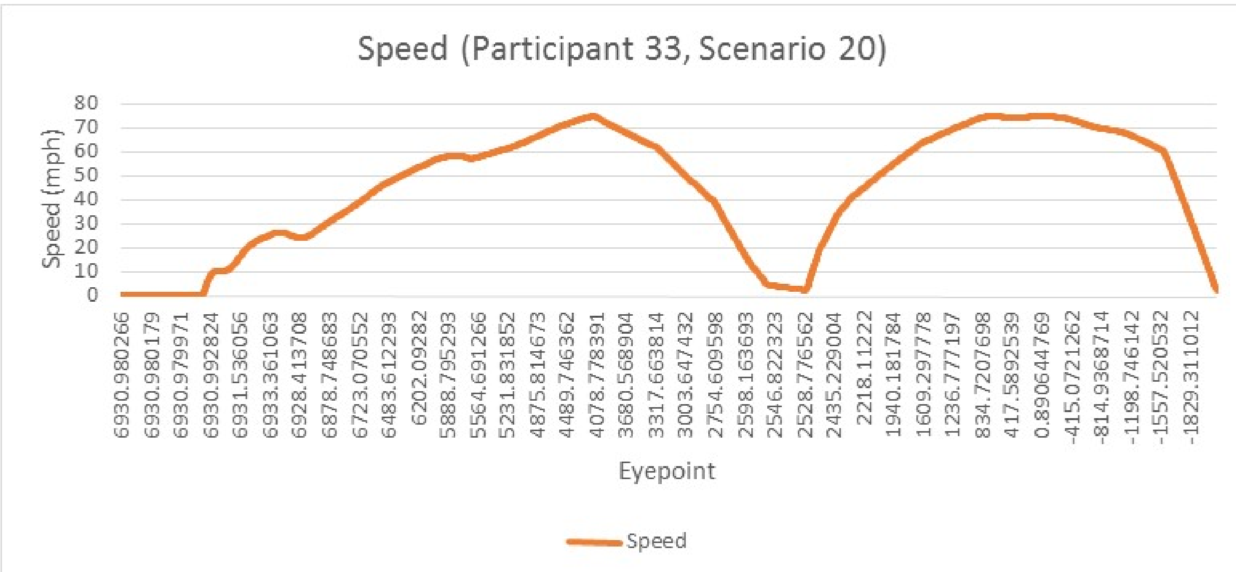


Figure 6.1 - Example of speed vs. eyepoint plot for subject 33, scenario 20

Figure 6.2 shows the lane deviation, or lane change maneuvers, verses time. In order to analyze the lane change maneuvers, the lane deviation was compared against eyepoint (to show where the subject was at a certain point on the road) and time. The lane change maneuvers were compared to time to determine whether the subject made an urgent lane change or a non-urgent lane change. All data collected by the driving simulator was recorded at sixty frames per second. With this in mind, we were able to calculate time, shown in Figure 6.2. The lane deviation variable was the actual lane position of the car. Positive depicted right and negative depicted left of the lane center. The maximum numbers for right and left of the lane center were +6 and -6, respectively. Analysis of the lane deviation in Figure 6.2 showed that there was only one lane change made in scenario 20 for this subject and it occurred after the toll plaza. This makes sense because subjects were told to continue on the mainline after the toll plaza in this scenario. In order to continue on the mainline after paying cash at the Dean Mainline Toll Plaza, drivers must merge over due to the rightmost lane becoming an exit only after the toll plaza. This driver passed the value of 6, but did not seem to change lanes. This was because the subject was in the rightmost lane and, as noted before, positive was right of the lane center. One can conclude that the subject swerved to the right and ended up slightly off road while looking in his/her blind spot before changing lanes. Many subjects commented that the steering wheel of the driving simulator was very sensitive, so swerving slightly while looking in a blind spot was not hard to do.

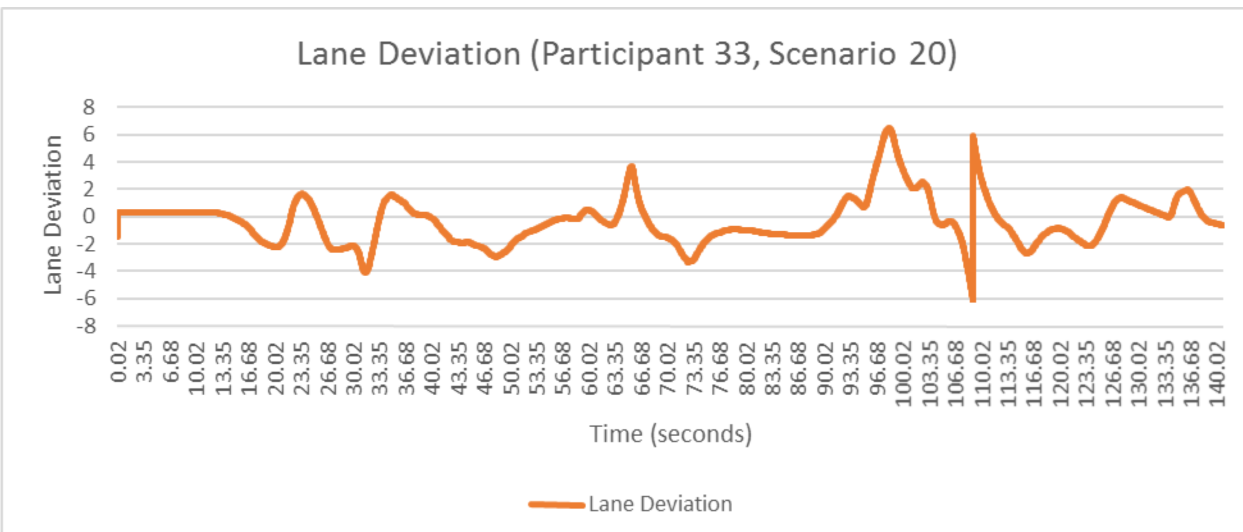


Figure 6.2 - Example of lane deviation vs. time plot subject 33, scenario 20

When analyzing the data, it was possible to tell when the driver began changing lanes and when s/he had completed changing lanes. The lane deviation variable subsequently was divided into three categories: no lane change, urgent lane change, and non-urgent lane change. Urgent lane change was defined as a lane change maneuver that occurred in less than three seconds. If this action took less than 3 seconds to complete, it was considered urgent; if this action took more than 3 seconds to complete, it was considered non-urgent. Figure 6.3 shows a zoomed in version of the only lane change in Figure 6.2. This lane change was classified as a non-urgent lane change it began around 105 seconds and ended around 115 seconds. This subject seemed to have plenty of time to change lanes, which shows that the added segment length was adequate for this subject.

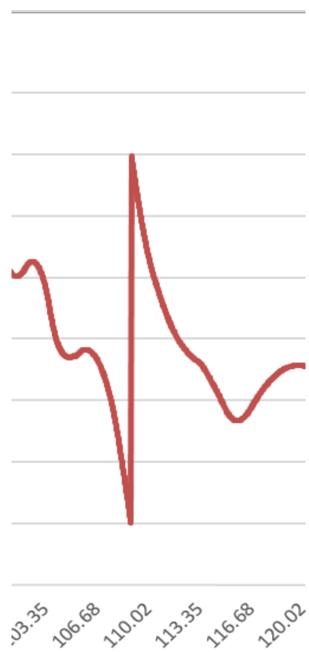


Figure 6.3 - Zoomed in version of the lane change in Figure 6.2

6.2 Lane Change before the Toll Plaza

The first dependent variable studied was lane change upstream of the toll plaza. As explained previously, this variable was divided into three classifications: 0 = no lane change, 1 = urgent lane change (<3 seconds), and 2 = non-urgent lane change (>3 seconds). A multinomial logit model with a 95% confidence interval was used to analyze this dependent variable in Biogeme. Off-peak was defined as 0 for peak and 1 for off-peak, path 1 was defined as 0 for other paths and 1 for path 1, path 4 was defined as 0 for other paths and 1 for path 4, and base sign was defined as 0 for other sign scenarios and 1 for the base signage. The results showed that five independent dummy variables were significant (see Table 6.2).

Table 6.2 - The final multinomial logit model for lane change before the toll plaza

Explanatory Variables	URGENT			NON-URGENT			NO CHANGE		
	Parameter	*t*	*p*-value	Parameter	*t*	*p*-value	Parameter	*t*	*p*-value
Constant	-0.829	-3.39	0.00	0.111	0.42	0.67	--Fixed--		
Off Peak				0.576	1.95	0.05	--Fixed--		
Path1				-1.42	-3.18	0.00	--Fixed--		
Path4	2.70	3.38	0.00	2.38	3.15	0.00	--Fixed--		
Base Sign				0.713	2.26	0.02	--Fixed--		
Number of Cases	214								
Log Likelihood at Convergence	-187.980								
Log Likelihood for Constants-Only Model	-235.103								
Rho^2	0.200								
Adjusted Rho^2	0.171								

Subjects on path 1 had a lower probability of changing lanes non-urgently with a *t* statistic of -3.18 and a parameter of -1.42. Path 1, in which subjects began on the mainline, were given an E-PASS, and continued on the mainline after the toll plaza, was the simplest path. These results made sense because the “no change” utility was fixed, so subjects had a lower probability of changing lanes non-urgently on path 1, but also had a higher probability of not changing lanes at all.

Path 4 started the subject on the on-ramp with an E-PASS and continued on the mainline after the toll plaza. This variable had a positive effect on both urgent and non-urgent lane change. However, since the parameter and *t* statistic were higher for the urgent utility, subjects on path 4 had a slightly higher probability of changing lanes urgently. This variable was further examined to determine if the DMS sign on the on-ramp had any effect on lane changing behavior (see section 6.4 for more detail). The “base” sign variable had a slightly positive effect on the non-urgent lane changing utility. This showed that subjects had a higher probability of changing lanes non-urgently with the current Dean Mainline Toll Plaza signs.

6.3 Lane Change after the Toll Plaza

The second dependent variable studied was lane change after the toll plaza. This variable was also divided into three classifications: 0 = no lane change, 1 = urgent lane change (<3 seconds), and 2 = non-urgent lane change (>3 seconds). A multinomial logit model with a 95% confidence interval was used to analyze this dependent variable in Biogeme. Table 6.3 shows the final multinomial logit model for lane change after the toll plaza.

Table 6.3 - The final multinomial logit model for lane change after the toll plaza

Explanatory Variables	URGENT			NON-URGENT			NO CHANGE		
	Parameter	*t*	*p*-value	Parameter	*t*	*p*-value	Parameter	*t*	*p*-value
Constant	-1.43	-4.66	0.00	1.59	6.23	0.00	--Fixed--		
Path1	-	-	-	-2.29	4.99	0.00	--Fixed--		
Path2	2.51	4.99	0.00	-	-	-	--Fixed--		
Path4	-	-	-	-1.98	-5.17	0.00	--Fixed--		
Path5	1.47	2.81	0.00	-	-	-	--Fixed--		
Number of Cases	214								
Log Likelihood at Convergence	-183.958								
Log Likelihood for constants-only model	-235.103								
Rho^2	0.218								
Adjusted Rho^2	0.192								

The only variables, which were all dummy variables, found to be significant for lane change after the toll plaza included the paths the subjects were told to take. Each dummy variable was defined as 0 for other paths and 1 for the respective path of that dummy variable. For example, path1 was defined as 0 for other paths and 1 for path 1. The parameters and *t* statistics of path 2 and path 5 showed that drivers on these paths had a higher probability of changing lanes urgently than on other paths, with path 2 having the highest probability. These findings were very interesting in that these two paths were the paths that go through the cash booths, as explained in Chapter 5.

6.4 Speed Analysis using ANOVA

The last dependent variables analyzed involved the subjects' speeds at various locations. Figure 6.4 shows the locations at which these speeds were collected and the number that corresponds to the locations. These locations were selected to later compare the collected speeds to the real-world speed data from Chapter 4. Table 6.4 shows the descriptive statistics of the speeds at each location in miles per hour (mph). SAS and JMP Pro were used to analyze the speed data.

Figure 6.4 - Locations of speed data collected from the driving simulator

Table 6.4 - Descriptive speed statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Speed1	214	25.8	79.4	51.833	9.4874
Speed2	214	33.4	83.2	58.707	9.0338
Speed3	214	27.8	82.3	59.551	8.9680
Speed4	214	25.6	91.0	61.424	10.3495
Speed5	214	19.7	87.6	61.681	11.3417
Valid *N* (listwise)	214				

Table 6.5 - One-way ANOVA results between peak and off-peak speeds at each location

		Sum of Squares	*df*	Mean Square	*F*	*p*-value
Speed1	Between Groups	56.132	1	56.132	.623	.431
	Within Groups	19115.979	212	90.170		
	Total	19172.111	213			
Speed2	Between Groups	2538.173	1	2538.173	36.248	.000
	Within Groups	14844.655	212	70.022		
	Total	17382.828	213			
Speed3	Between Groups	1265.010	1	1265.010	16.903	.000
	Within Groups	15865.625	212	74.838		
	Total	17130.635	213			
Speed4	Between Groups	116.654	1	116.654	1.090	.298
	Within Groups	22698.099	212	107.067		
	Total	22814.754	213			
Speed5	Between Groups	.535	1	.535	.004	.949
	Within Groups	27398.356	212	129.238		
	Total	27398.891	213			

One-way ANOVA tests were performed for the speeds at each of the five locations to determine if there were any differences in speeds at locations between the peak and off-peak hours. The results for each of these tests are found in Table 6.5. Two locations, location 2 and location 3 (both before the toll plaza) had statistically significant differences in their off-peak and peak speeds. With this in mind, off-peak and peak speeds at locations 1,4, and 5 were analyzed together, while the off-peak and peak speeds at locations 2 and 3 were analyzed separately.

Next, the mean speeds at each location were analyzed using one-way ANOVA by first dividing the speeds into peak and off-peak traffic. Table 6.6 and Table 6.7 show the results of the one-way ANOVA and multiple comparisons for each speed location during off-peak traffic. Figure 6.5 presents the mean speeds during off-peak traffic at each location in a graphical presentation. Table 6.8 and Table 6.9 show the results of the one-way ANOVA and multiple comparisons for each speed location during peak traffic. Figure 6.6 presents the mean speeds during peak traffic at each location in a graphical presentation.

Table 6.6 - One-way ANOVA results for speeds at each location during off-peak hours

ANOVA[a]

Speed

	Sum of Squares	*df*	Mean Square	*F*	*p*-value
Between Groups	9749.180	4	2437.295	25.688	.000
Within Groups	50286.217	530	94.880		
Total	60035.397	534			

a. TRAFFIC = 1.0

Table 6.7 - Multiple comparisons results of one-way ANOVA for speeds at each location during off-peak hours

Multiple Comparisons[a]

Dependent Variable: Speed
Tukey HSD

(I) LOCATION	(J) LOCATION	Mean Difference (I-J)	Std. Error	*p*-value	95% Confidence Interval Lower Bound	Upper Bound
1	2	-10.8308*	1.3317	.000	-14.476	-7.186
	3	-10.6617*	1.3317	.000	-14.307	-7.017
	4	-10.8421*	1.3317	.000	-14.487	-7.197
	5	-10.3103*	1.3317	.000	-13.955	-6.665
2	1	10.8308*	1.3317	.000	7.186	14.476
	3	.1692	1.3317	1.000	-3.476	3.814
	4	-.0112	1.3317	1.000	-3.656	3.634
	5	.5206	1.3317	.995	-3.125	4.166
3	1	10.6617*	1.3317	.000	7.017	14.307
	2	-.1692	1.3317	1.000	-3.814	3.476
	4	-.1804	1.3317	1.000	-3.826	3.465
	5	.3514	1.3317	.999	-3.294	3.997
4	1	10.8421*	1.3317	.000	7.197	14.487
	2	.0112	1.3317	1.000	-3.634	3.656
	3	.1804	1.3317	1.000	-3.465	3.826
	5	.5318	1.3317	.995	-3.113	4.177
5	1	10.3103*	1.3317	.000	6.665	13.955
	2	-.5206	1.3317	.995	-4.166	3.125
	3	-.3514	1.3317	.999	-3.997	3.294
	4	-.5318	1.3317	.995	-4.177	3.113

*. The mean difference was significant at the 0.05 level.
a. TRAFFIC = 1.0

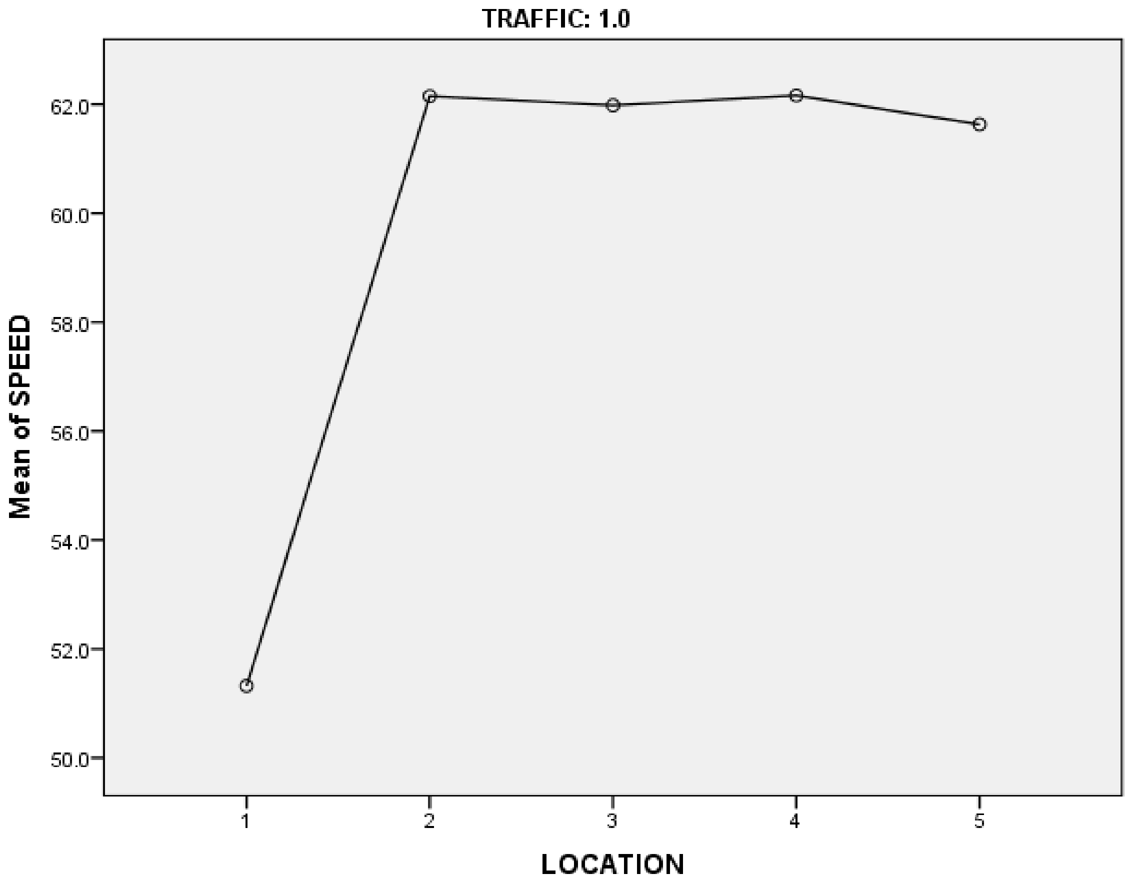


Figure 6.5 - Mean speeds at each location during off-peak hours

The results presented in Table 6.6 and Table 6.7 show that there were no statistically significant differences for speeds between each location, with the exception of location 1. Speeds at location 1 were statistically significant when compared to the other locations as can be seen clearly in Figure 6.5. The null hypotheses here were that the speeds at location 1 were significantly different from the speeds at locations 2, 3, 4, and 5 during off-peak traffic. With *p*-values of 0.000 for each location, the null hypothesis for each location could be accepted and it was concluded that speeds at location 1 had a statistically significant difference from speeds at location 2, location 3, location 4, and location 5 during off-peak traffic.

Table 6.8 - One-way ANOVA results for speeds at each location during peak hours

ANOVA[a]

Speed

	Sum of Squares	*df*	Mean Square	*F*	*p*-value
Between Groups	6392.942	4	1598.236	17.065	.000
Within Groups	49636.499	530	93.654		
Total	56029.441	534			

a. TRAFFIC = 2.0

Table 6.9 - Multiple comparisons results of one-way ANOVA for speeds at each location during peak hours

Multiple Comparisons[a]

Dependent Variable: Speed
Tukey HSD

(I) LOCATION	(J) LOCATION	Mean Difference (I-J)	Std. Error	*p*-value	95% Confidence Interval Lower Bound	Upper Bound
1	2	-2.9187	1.3231	.179	-6.540	.703
	3	-4.7748*	1.3231	.003	-8.396	-1.153
	4	-8.3411*	1.3231	.000	-11.963	-4.720
	5	-9.3860*	1.3231	.000	-13.008	-5.764
2	1	2.9187	1.3231	.179	-.703	6.540
	3	-1.8561	1.3231	.626	-5.478	1.765
	4	-5.4224*	1.3231	.000	-9.044	-1.801
	5	-6.4673*	1.3231	.000	-10.089	-2.846
3	1	4.7748*	1.3231	.003	1.153	8.396
	2	1.8561	1.3231	.626	-1.765	5.478
	4	-3.5664	1.3231	.056	-7.188	.055
	5	-4.6112*	1.3231	.005	-8.233	-.990
4	1	8.3411*	1.3231	.000	4.720	11.963
	2	5.4224*	1.3231	.000	1.801	9.044
	3	3.5664	1.3231	.056	-.055	7.188
	5	-1.0449	1.3231	.934	-4.666	2.577
5	1	9.3860*	1.3231	.000	5.764	13.008
	2	6.4673*	1.3231	.000	2.846	10.089
	3	4.6112*	1.3231	.005	.990	8.233
	4	1.0449	1.3231	.934	-2.577	4.666

*. The mean difference was significant at the 0.05 level.
a. TRAFFIC = 2.0

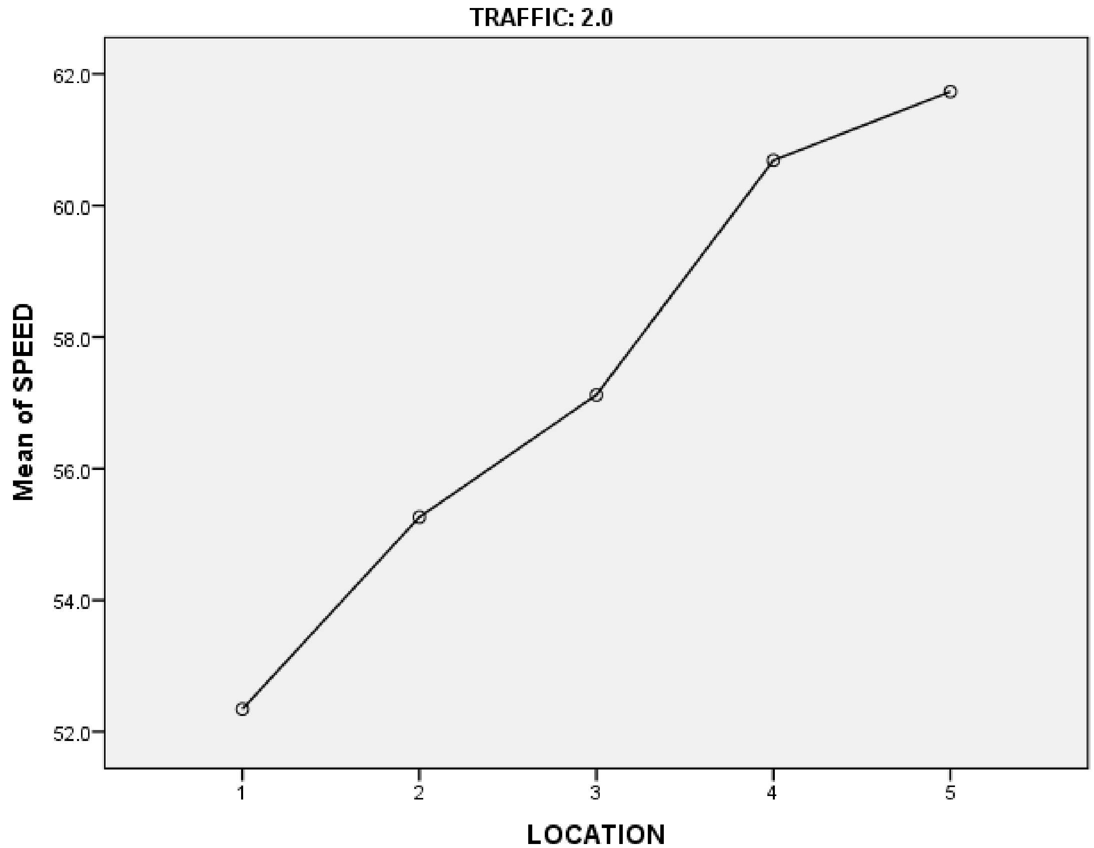


Figure 6.6 - Mean speeds at each location during peak hours

As presented in Table 6.8 and Table 6.9, statistically significant differences were found during the peak hours between (1) speed at location1 and speed at location 3, (2) speed at location 1 and speed at location 4, (3) speed at location 1 and speed at location 5, (4) speed at location 2 and speed at location 4, (5) speed at location 2 and speed at location 5, and (6) speed at location 3 and speed at location 5. These differences can be seen graphically in Figure 6.6.

6.4.1 *Speed at Location 1 (Speed1)*

Speeds at location 1 were analyzed using two-way ANOVA for all of the experimental design variables. Path and signage were the only variables found to be significant. These results are shown in Table 6.10. The first null hypothesis was that path had no effect on speed at location 1, the second null hypothesis was that sign had no effect on speed at location 1, and the third null hypothesis was that the two variables were independent and had no effect on each other. Recall that the first signage scenario removed the third sign, moved the second sign from just past the on-ramp to a location before the on-ramp, and added a DMS sign that read “ALL ON RAMP VEHICLES KEEP RIGHT.” The second signage scenario simply removed the third sign directly before the diverge gore area of the toll plaza, and the third signage scenario was the existing “base” case signage currently in use at the Dean Mainline Toll Plaza.

Table 6.10 - Two-way ANOVA results of path and signage at speed1

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	4896.10832	445.10076	6.30	<.0001
Error	202	14276.00270	70.67328		
Corrected Total	213	19172.11103			

R-Square	Coeff Var	Root MSE	SPEED1 Mean
0.255377	16.21899	8.406740	51.83271

Source	DF	Anova SS	Mean Square	F Value	Pr > F
PATH	4	4418.532218	1104.633054	15.63	<.0001
SIGNAGE	2	1529.679653	764.839827	10.82	<.0001
PATH*SIGNAGE	5	0.000000	0.000000	0.00	1.0000

With a confidence interval of 95%, the *F* values of path and signage separately were each greater than 3.68, which meant they were significant. However, although the variables path and signage were significant by themselves, their interaction was not significant. Therefore, the first two null hypotheses were rejected and the third null hypothesis was accepted. In other words, both path and sign variables had a significant effect on speed at location 1 and were independent from each other. Figure 6.7 shows the boxplot for path and Figure 6.8 shows the boxplot for signage.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	4418.53222	1104.63305	15.65	<.0001
Error	209	14753.57881	70.59129		
Corrected Total	213	19172.11103			

R-Square	Coeff Var	Root MSE	SPEED1 Mean
0.230467	16.20958	8.401862	51.83271

Source	DF	Type I SS	Mean Square	F Value	Pr > F
PATH	4	4418.532218	1104.633054	15.65	<.0001

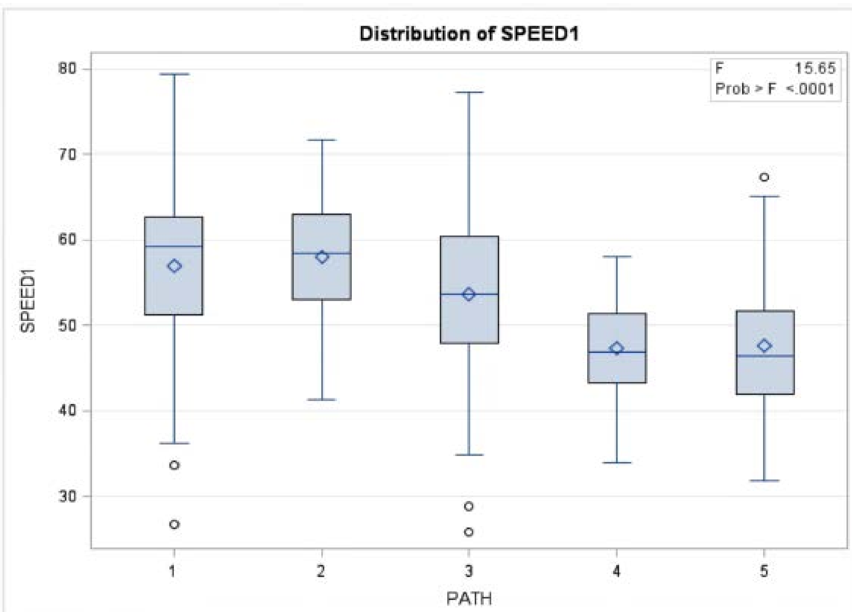


Figure 6.7 - Path boxplot for speed at location 1

Looking at the boxplot for the paths that the subjects took in Figure 6.7, the average speed was lowest on path 4 and highest on path 2. The speeds at location 1 for paths 4 and 5 were lowest because both of these paths began on the ramp. It seems that at location 1, subjects had not yet accelerated to their normal highway speeds. As seen in Figure 6.8, the boxplot for signage showed that the average speed at location 1 was lowest for signage 2 with a value of 47.5 mph. Speeds for signage 1 and signage 3 were similar with mean speeds of 52.2 mph and 54.4 mph, respectively.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	1529.67965	764.83983	9.15	0.0002
Error	211	17642.43138	83.61342		
Corrected Total	213	19172.11103			

R-Square	Coeff Var	Root MSE	SPEED1 Mean
0.079787	17.64144	9.144037	51.83271

Source	DF	Type I SS	Mean Square	F Value	Pr > F
SIGNAGE	2	1529.679653	764.839827	9.15	0.0002

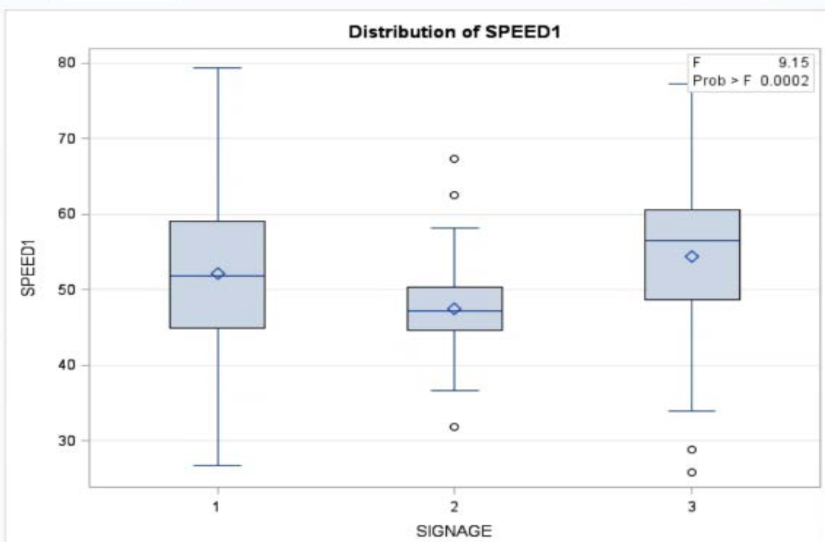


Figure 6.8 - Signage boxplot for speed at location 1

6.4.2 *Speed at Location 2 (Speed2)*

As noted previously, the differences in off-peak and peak speeds at location 2 were found to be statistically significant and, therefore, needed to be analyzed separately at this location. Multiple one-way ANOVA tests were performed and, for the peak hours, a significant difference in speeds was found at location 2. Table 6.11 presents the descriptives for speeds for each signage scenario during the peak hour and Table 6.12 shows the one-way ANOVA results. The null hypothesis was that at location 2, peak hour speeds were significantly different between the signage scenarios. With a *p*-value of 0.010, the null hypothesis was accepted. Figure 6.9 presents the means in a graphical representation and shows that mean speeds were similar for signage scenarios 1 and 2 but they were 5 mph lower than the speeds for signage scenario 3.

Table 6.11 - Descriptives of the signage variable for speeds at location 2 during peak hours

Descriptives[a]

Speed2

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
1.0	36	53.136	8.4435	1.4072	50.279	55.993	38.9	79.5
2.0	27	53.441	6.9889	1.3450	50.676	56.205	43.1	68.6
3.0	44	58.123	8.0913	1.2198	55.663	60.583	33.4	78.5
Total	107	55.264	8.2374	.7963	53.685	56.842	33.4	79.5

a. TRAFFIC = 2.0

Table 6.12 - One-way ANOVA results of signage for speeds at location 2 during peak hours

ANOVA[a]

Speed2

	Sum of Squares	*df*	Mean Square	*F*	*p*-value
Between Groups	612.342	2	306.171	4.839	.010
Within Groups	6580.346	104	63.273		
Total	7192.688	106			

a. TRAFFIC = 2.0

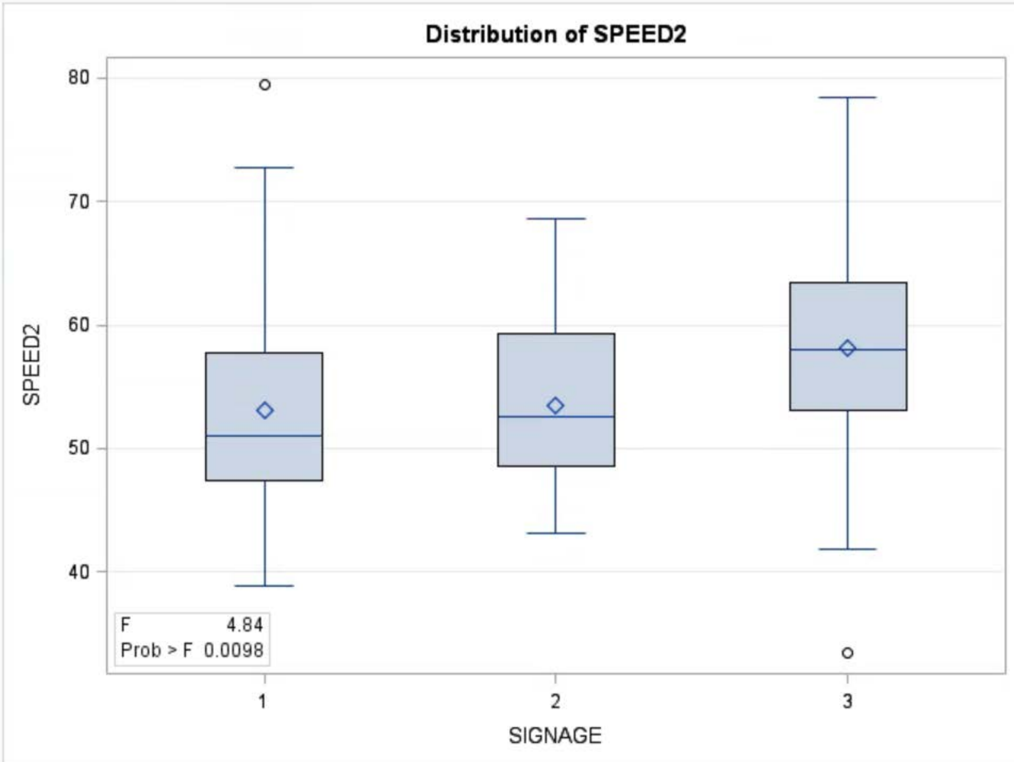


Figure 6.9 - Signage boxplot for mean speeds at location 2 during peak hours

Recall the differences in the three signage scenarios. The results indicated that the base signage case had the highest average speed during peak hours at location 2 compared to the other signage cases. However, this speed of 58 mph was closest to the speed limit of 65 mph. This potentially meant that the base signage case had a low impact of effecting normal speed compared to the other two signage cases.

6.4.3 *Speed at Location 3 (Speed3)*

As noted previously, the differences in off-peak and peak speeds at location 3 were found to be statistically significant and, therefore, needed to be analyzed separately at this location. Only one factor was found to be statistically significant – path during off-peak. Table 6.13 shows the descriptives of the path factor for the speeds at location 3 during off-peak hours and Table 6.14 shows the one-way ANOVA results. The null hypothesis was that the speeds during off-peak hours at location 3 were significantly different between each of the path scenarios. With a *p*-value of 0.004, the null hypothesis could be accepted.

Table 6.13 Descriptives of the path variable for speeds at location 3 during off-peak hours

Descriptives[a]

Speed3

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
1.0	18	66.328	8.2285	1.9395	62.236	70.420	51.2	82.3
2.0	18	64.389	9.7247	2.2921	59.553	69.225	50.0	80.9
3.0	18	64.256	5.4223	1.2781	61.559	66.952	55.9	74.1
4.0	27	60.115	6.5325	1.2572	57.531	62.699	48.4	72.4
5.0	26	57.673	9.8378	1.9293	53.700	61.647	31.8	81.1
Total	107	61.982	8.6339	.8347	60.327	63.637	31.8	82.3

a. TRAFFIC = 1.0

Table 6.14 - One-way ANOVA results of path for speeds at location 3 during off-peak hours

ANOVA[a]

Speed3

	Sum of Squares	*df*	Mean Square	*F*	*p*-value
Between Groups	1114.133	4	278.533	4.186	.004
Within Groups	6787.604	102	66.545		
Total	7901.736	106			

a. TRAFFIC = 1.0

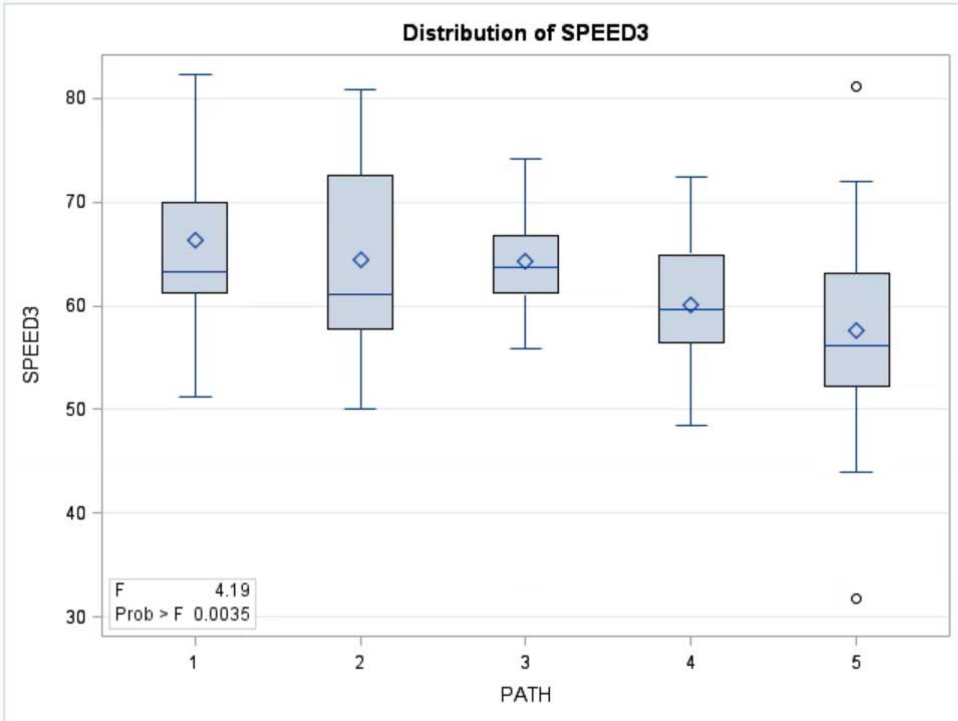


Figure 6.10 – Path boxplot for mean speeds at location 3 during off-peak hours

Recall each potential path: (1) mainline – EPASS – mainline, (2) mainline – cash – mainline, (3) mainline – EPASS – off-ramp, (4) on-ramp – EPASS – mainline, and (5) on-ramp – cash – mainline. Figure 6.10 presents the average speeds for each path during off-peak. The average speed for path 1 was the highest at about 66 mph while the speed for path 5 was lowest at about 58 mph. The low speeds for path 4 and path 5 may be due to subjects merging over or trying to decide whether to stay in their lane because these paths began on the on-ramp which continued into the rightmost lane that went through the cash booths.

6.4.4 *Speed at Location 4 (Speed4)*

Only two variables were found to be significant for speed at location 4. These were path and length. Even though they were both slightly significant with *F* values greater than 3.68, their interaction was not found to be statistically significant. The results of the final two-way ANOVA are in Table 6.15. Boxplots of the significant variables are presented in Figure 6.11 and Figure

6.12. Recall that length scenario 1 added 660 feet to the segment after the toll plaza, length scenario 2 added 660 feet to the segment before the toll plaza, and length scenario 3 was the base length. In other words, length scenario 2 and length scenario 3 have the same length after the toll plaza, and location 4 was directly after the toll plaza at the beginning of the merge area. From the boxplot, scenario 3 had the highest average speed, yet scenario 2 had the lowest average speed. Even though the two-way ANOVA model showed there was no real significance in the interaction between path and length, this might have to do with the path the subject took. JMP Pro was used to obtain a more detailed boxplot and average values, as shown in Figure 6.13.

Table 6.15 - Two-way ANOVA results of path and length variables for speed at location 4

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	14	3993.36149	285.24011	3.02	0.0003
Error	199	18821.39216	94.57986		
Corrected Total	213	22814.75364			

R-Square	Coeff Var	Root MSE	SPEED4 Mean
0.175034	15.83285	9.725218	61.42430

Source	DF	Anova SS	Mean Square	F Value	Pr > F
PATH	4	2293.372066	573.343017	6.06	0.0001
LENGTH	2	842.442181	421.221090	4.45	0.0128
PATH*LENGTH	8	857.547241	107.193405	1.13	0.3424

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	2293.37207	573.34302	5.84	0.0002
Error	209	20521.38158	98.18843		
Corrected Total	213	22814.75364			

R-Square	Coeff Var	Root MSE	SPEED4 Mean
0.100521	16.13206	9.909007	61.42430

Source	DF	Type I SS	Mean Square	F Value	Pr > F
PATH	4	2293.372066	573.343017	5.84	0.0002

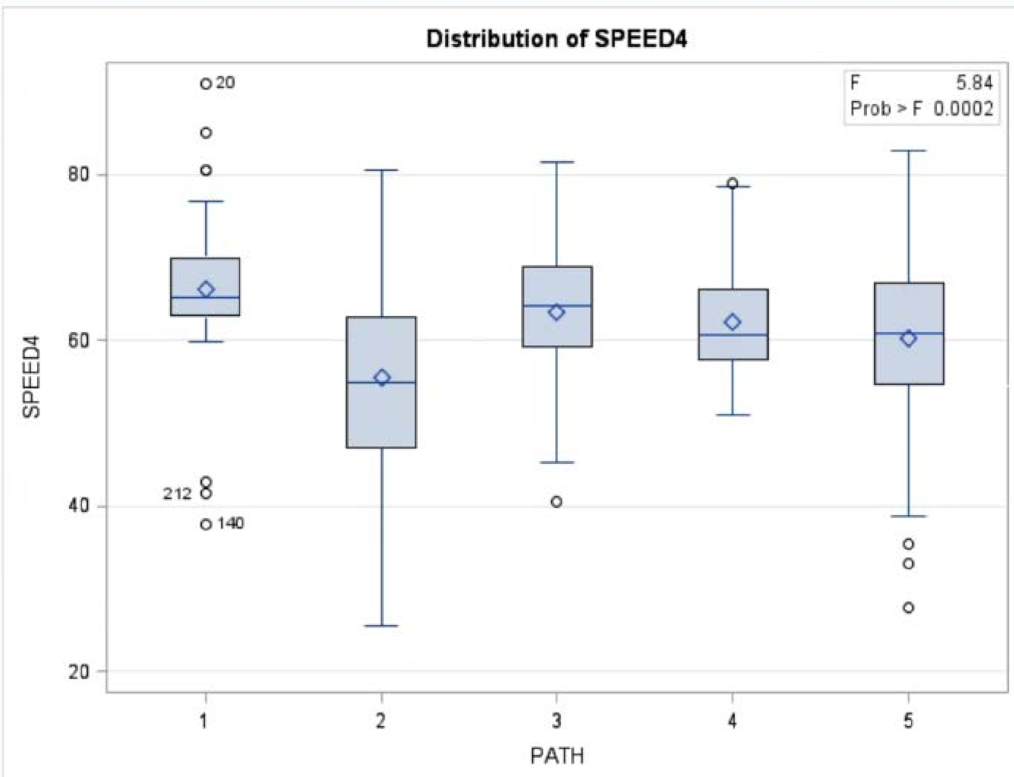


Figure 6.11 – Path boxplot for speed at location 4

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	842.44218	421.22109	4.04	0.0189
Error	211	21972.31146	104.13418		
Corrected Total	213	22814.75364			

R-Square	Coeff Var	Root MSE	SPEED4 Mean
0.036925	16.61332	10.20462	61.42430

Source	DF	Type I SS	Mean Square	F Value	Pr > F
LENGTH	2	842.4421806	421.2210903	4.04	0.0189

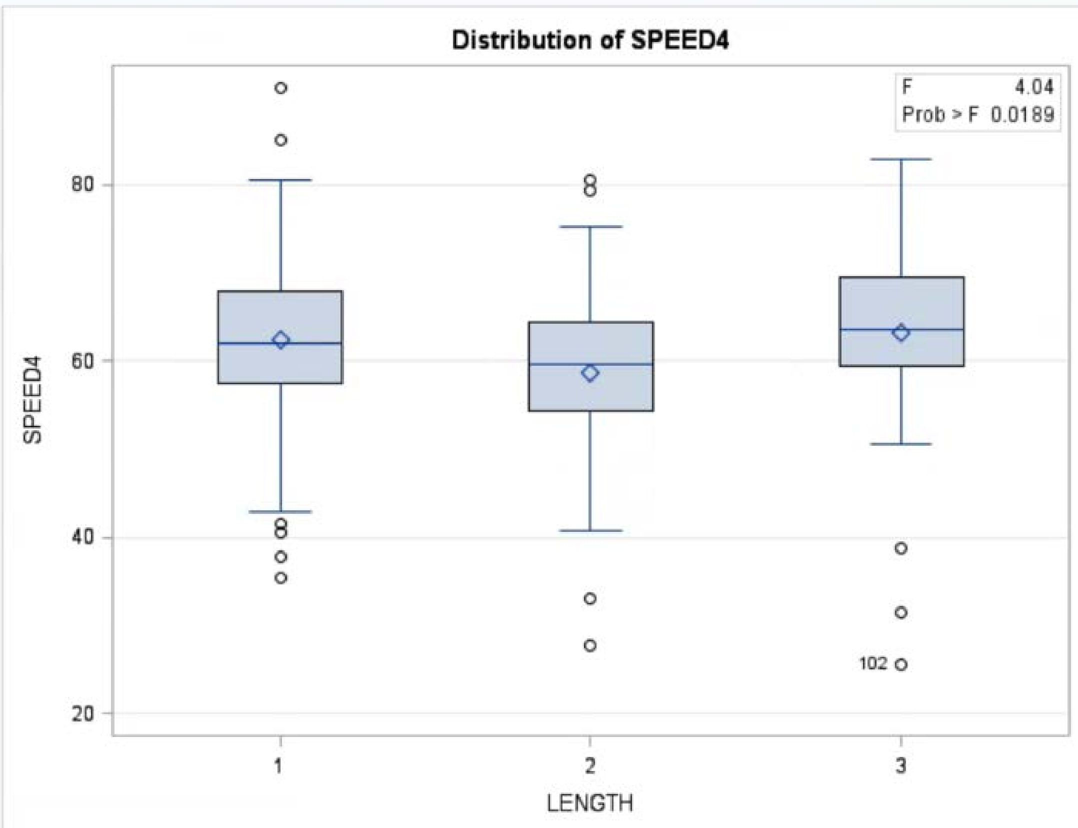
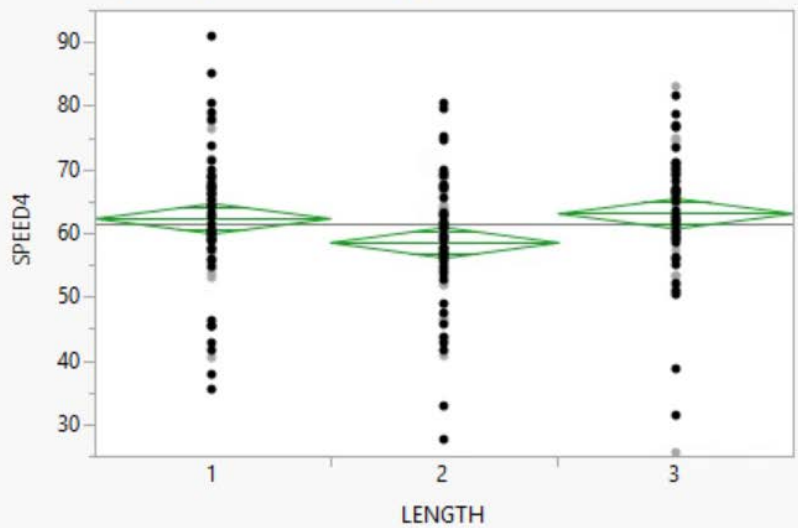


Figure 6.12 – Length boxplot for speed at location 4

Oneway Analysis of SPEED4 By LENGTH



Missing Rows 8

Oneway Anova

Summary of Fit

Rsquare	0.036925
Adj Rsquare	0.027797
Root Mean Square Error	10.20462
Mean of Response	61.4243
Observations (or Sum Wgts)	214

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
LENGTH	2	842.442	421.221	4.0450	0.0189*
Error	211	21972.311	104.134		
C. Total	213	22814.754			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	72	62.4000	1.2026	60.029	64.771
2	70	58.6157	1.2197	56.211	61.020
3	72	63.1792	1.2026	60.808	65.550

Std Error uses a pooled estimate of error variance

Figure 6.13 - One-way ANOVA results of length for speed at location 4 analyzed in JMP Pro

6.4.5 *Speed at Location 5 (Speed5)*

The segment length was found to be statistically significant for speed at location 5. However, at this location, the average speed was found to be much lower when 660 feet was added to the segment after the toll plaza. To be more specific, subjects with the added length after the toll plaza had an average speed of 58.4 mph, while subjects with the current base length had an average speed of 65.34 mph. Comparing these two values, a possible explanation was that drivers tend to drive at lower speeds when they feel they are not in a hurry to change lanes (added length to segment after), and drivers tend to speed up when they feel they do not have enough time to change lanes (current base length). Figure 6.14 shows the results of length for speed at location 5, and Figure 6.15 shows a more detailed version of this variable.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	1747.02840	873.51420	7.19	0.0010
Error	211	25651.86305	121.57281		
Corrected Total	213	27398.89145			

R-Square	Coeff Var	Root MSE	SPEED5 Mean
0.063763	17.87590	11.02601	61.68084

Source	DF	Type I SS	Mean Square	F Value	Pr > F
LENGTH	2	1747.028397	873.514199	7.19	0.0010

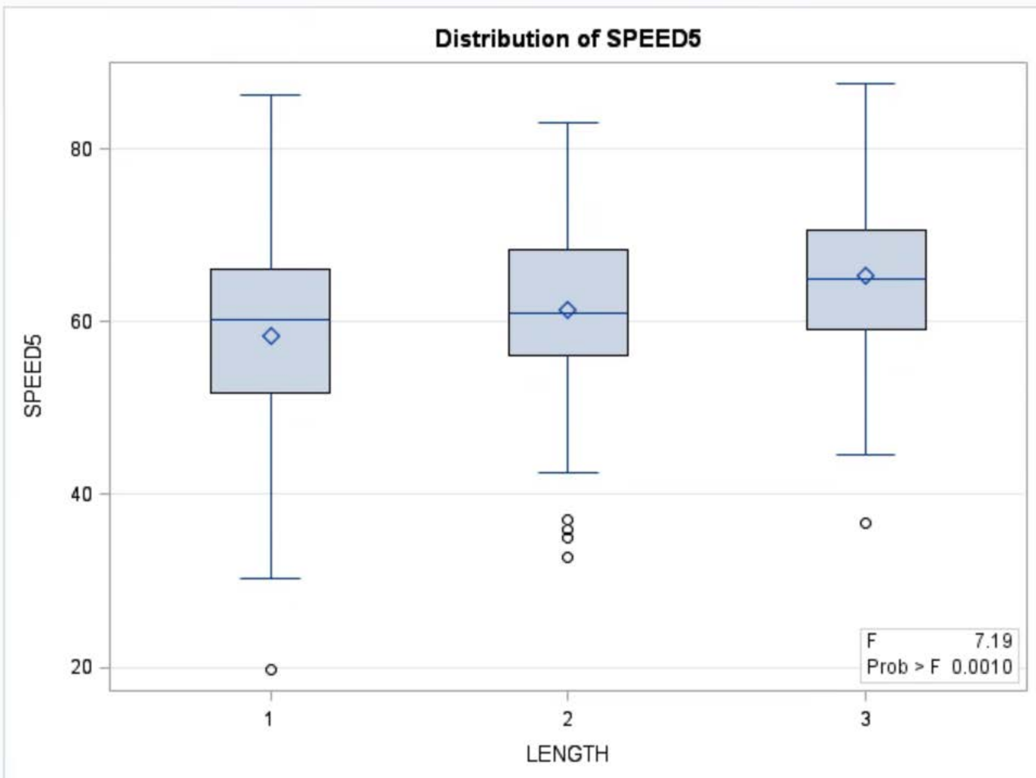
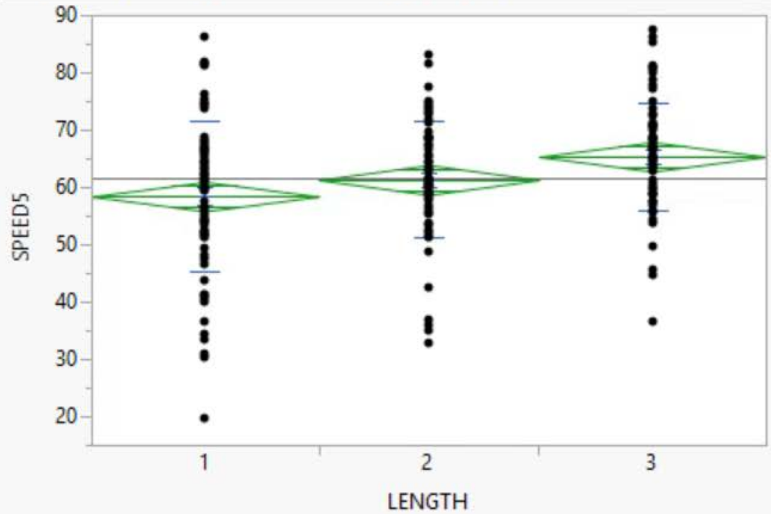


Figure 6.14 – Length boxplot for speed at location 5

Oneway Analysis of SPEED5 By LENGTH



Missing Rows 8

Oneway Anova

Summary of Fit

Rsquare	0.063763
Adj Rsquare	0.054888
Root Mean Square Error	11.02601
Mean of Response	61.68084
Observations (or Sum Wgts)	214

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
LENGTH	2	1747.028	873.514	7.1851	0.0010*
Error	211	25651.863	121.573		
C. Total	213	27398.891			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	72	58.4028	1.2994	55.841	60.964
2	70	61.2914	1.3179	58.694	63.889
3	72	65.3375	1.2994	62.776	67.899

Std Error uses a pooled estimate of error variance

Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
1	72	58.4028	13.0513	1.5381	55.336	61.470
2	70	61.2914	10.1849	1.2173	58.863	63.720
3	72	65.3375	9.4946	1.1189	63.106	67.569

Figure 6.15 - One-way ANOVA results of length for speed at location 5 analyzed in JMP Pro

6.5 Speed Comparison: Real World vs. Simulator

In order to validate the driving simulator scenarios used for this study, the real-world speeds analyzed in Chapter 4 were compared to the speeds collected from the driving simulator. Both the real-world speed data and the driving simulator speed data were first separated into peak and off-peak, then separated even further into the locations at which they were collected. However, in order to maintain similarity, we needed to use simulated scenarios that were analogous to the toll plaza where the real-world speed data was recorded. As can be seen in the Five Year Work Plan prepared for the Central Florida Expressway Authority by Atkins North America, Inc. (2014), the pavement markings were not added to SR-408 until after 2014. Given this, only scenario 9 could be used to compare the peak speed data. Unfortunately, this study did not have a completely default toll plaza layout with off-peak traffic. In addition, scenario 9 only had nine runs.

As explained previously, the simulator speed data was collected at locations that corresponded to where the real-world speed data was collected. Therefore, location 1 corresponded to mile marker (MM) 19.9, location 2 corresponded to MM 19.7, location 3 corresponded to MM 19.4, location 4 corresponded to MM 19, and location 5 corresponded to MM 18.8. The following section presents the results of the analysis for both peak speed comparisons using the *t*-test. Real-world data from October 1 was used once again.

6.5.1 *Peak Real World vs. Simulator*

As previously explained, the peak speeds for both the real world and the driving simulator were tested for similarity using the *t*-test. The data from the driving simulator included 9 runs of scenario 9, and the data from the real world included over 150 speeds collected at each location. The results for each location are presented in Tables 6.16, 6.17, 6.18, 6.19, and 6.20. To interpret these results, the *p*-value under Levene's test for equality of variances was first observed. If the value was less than 0.05, then the bottom *t*-test *p*-value was used; if not, then the top *t*-test *p*-value was used. For example, for location 1, $p = 0.386$ so the top *p*-value of

0.404 was used. With a confidence interval of 95% and an alpha 0.05, there was no statistically significant difference between the real-world and the simulated speed data for location 1. Overall, no statistically significant differences between the real-world peak speed data and the simulated peak speed data for locations 1, 3, and 5 were found at a 95% confidence interval. Furthermore, there were no statistically significant mean speed differences for location 2 at a 98% confidence interval and for location 4 at a 90% confidence interval. Using this, we could validate the driving simulator for this study.

Table 6.16 - T-test results comparing real-world peak speed data to simulator peak speed data at location 1

Independent Samples Test

		Levene's Test for Equality of Variances		*t*-test for Equality of Means						
		F	*p*-value	*t*	*df*	*p*-value (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference: Lower	Upper
PEAK1	Equal variances assumed	.754	.386	.836	190	.404	2.7490	3.2876	-3.7359	9.2339
	Equal variances not assumed			.780	8.690	.456	2.7490	3.5231	-5.2645	10.7625

Table 6.17 - T-test results for comparing real-world peak speed data to simulator peak speed data at location 2

Independent Samples Test

		Levene's Test for Equality of Variances		*t*-test for Equality of Means						
									98% Confidence Interval of the Difference	
		F	*p*-value	*t*	*df*	*p*-value (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
PEAK2	Equal variances assumed	1.885	.171	2.320	224	.021	8.8891	3.8309	-.0871	17.8653
	Equal variances not assumed			3.863	10.164	.003	8.8891	2.3013	2.5476	15.2306

Table 6.18 - T-test results for comparing real-world peak speed data to simulator peak speed data at location 3

Independent Samples Test

		Levene's Test for Equality of Variances		*t*-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	p-value	*t*	*df*	p-value (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
PEAK3	Equal variances assumed	11.384	.001	3.792	219	.000	6.8428	1.8045	3.2864	10.3992
	Equal variances not assumed			1.841	8.136	.102	6.8428	3.7173	-1.7045	15.3900

Table 6.19 - T-test results for comparing real-world peak speed data to simulator peak speed data at location 4

Independent Samples Test

		Levene's Test for Equality of Variances		*t*-test for Equality of Means						
									90% Confidence Interval of the Difference	
		F	*p*-value	*t*	*df*	*p*-value (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
PEAK4	Equal variances assumed	.508	.477	-2.732	190	.007	-7.1796	2.6284	-11.5241	-2.8351
	Equal variances not assumed			-2.301	8.549	.048	-7.1796	3.1199	-12.9334	-1.4258

Table 6.20 - T-test results for comparing real-world peak speed data to simulator peak speed data at location 5

Independent Samples Test

		Levene's Test for Equality of Variances		*t*-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	*p*-value	*t*	*df*	*p*-value (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
PEAK5	Equal variances assumed	7.136	.008	-2.881	173	.004	-7.0163	2.4350	-11.8224	-2.2102
	Equal variances not assumed			-1.653	8.248	.136	-7.0163	4.2439	-16.7519	2.7192

Chapter 7: Conclusions

This study focused on studying the Dean Mainline Toll Plaza located in Orlando, Florida. Experimental design scenarios were created in a NADS MiniSim^{TM} driving simulator. The objective of this study was to determine what factors affect safety at toll plazas, namely hybrid toll plazas, and to potentially contribute to national toll plaza design guidelines.

The data for this study was collected through the simulator, organized in MATLAB and Excel, and analyzed using Biogeme, SAS, SPSS, and JMP Pro. Seven dependent variables were analyzed. These included lane change before the toll plaza, lane change after the toll plaza, and speed at five separate locations. Lane change was divided into three categories: 0 = no lane change, 1 = urgent lane change, and 2 = non-urgent lane change. The results and findings are summarized below.

7.1 Lane Change before the Toll Plaza

Using a multinomial logit model, two of the five paths were found to be statistically significant with a 95% confidence interval. Off-peak and base signage were also found to be statistically significant. The results showed that the current signage at the Dean Mainline Toll Plaza had a positive effect on non-urgent lane changing. In other words, drivers had a higher probability of changing lanes non-urgently with the current signage compared to the alternative sign scenarios. The same was found to be true for off-peak traffic.

7.2 Lane Change after the Toll Plaza

A multinomial logit model with a 95% confidence interval was also used to analyze the lane changing behavior after the toll plaza. However, there were no significant findings aside from the paths that the subjects drove.

7.3 Speed at Location 1 (Speed1)

Speed data was analyzed through two-way ANOVA models using SAS. At location 1, the path and sign variables were found to be statistically significant and independent from each other. Using a boxplot, it was found that subjects who were on path 2 had the highest average speed while those on path 4 had the lowest average speed. For the sign variable, the boxplot showed that while sign scenarios 1 and 3 had similar average speeds, sign scenario 2 had the lowest average speed with a value of 47.5 mph. Only the third sign before the toll plaza was removed in scenario 2. This low speed may be due to subjects slowing down to look for signs and direction as to where to go.

7.4 Speed at Location 2 (Speed2)

Multiple one-way ANOVA tests were performed and it was found that the average speeds for this location during peak hour were statistically significantly different. The average speeds for signage scenarios 1 and 2 were found to be about 5 mph lower than the average speed for signage scenario 3, which was the base sign scenario. The average speed during peak hour for the base sign scenario was about 58 mph. Since this speed was closer to the speed limit of 65 mph than the speeds for sign scenarios 1 and 2 were, we could suggest that the base sign scenario was adequate for safe driving maneuvers at location 2.

7.5 Speed at Location 3 (Speed3)

Only the path variable was found to have statistically significant differences in speeds at location 3 during off-peak traffic. The boxplot of this variable showed that paths 4 and 5 have the lowest average speed. The reason for the speeds being so low for path 4 and path 5 might be due to subjects merging over or trying to decide whether to stay in their lane because these paths began on the on-ramp which continued into the rightmost lane that went through the cash booths.

7.6 Speed at Location 4 (Speed4)

The path and length variables were found to be independently statistically significant at location 4, which was directly at the beginning of the merge area after the toll plaza. The average speed for length 3, which was the base case, had the highest value, and speed for length 2, which only added a segment length before the toll plaza, had the lowest value. Before any conclusions could be made about the segment length after the toll plaza, speed at location 5 was analyzed.

7.7 Speed at Location 5 (Speed5)

As expected, the length variable was found to be statistically significant. The one-way ANOVA for this variable showed that the average speed, with a segment length added after the toll plaza, was 58.4 mph. The average speeds for adding a segment length before the toll plaza case and the base length case were 61.3 mph and 65.3 mph, respectively. The speeds for length 2 and length 3 went up and the speed for length 1 went down from location 4 to location 5. With these results, we could suggest that the shorter segment length after the toll plaza caused drivers to speed up in order to change lanes. However, with longer segment lengths, drivers had more time to change lanes and did not feel as rushed to do so.

7.8 Recommendations

The main objectives of this study were to analyze the safety of the Dean Mainline Toll Plaza and potentially contribute recommendations to the developments of national toll plaza design guidelines. Summarized below (and presented in Figure 7.1) is the ideal hybrid toll plaza design based on this report. We found that it is best not to locate a toll plaza within close proximity to an interchange or interchanges, it is acceptable for signs to be located above the diverge gore area before the toll plaza, and toll plazas should maintain “cookie cutter” designs throughout an entire region if possible.

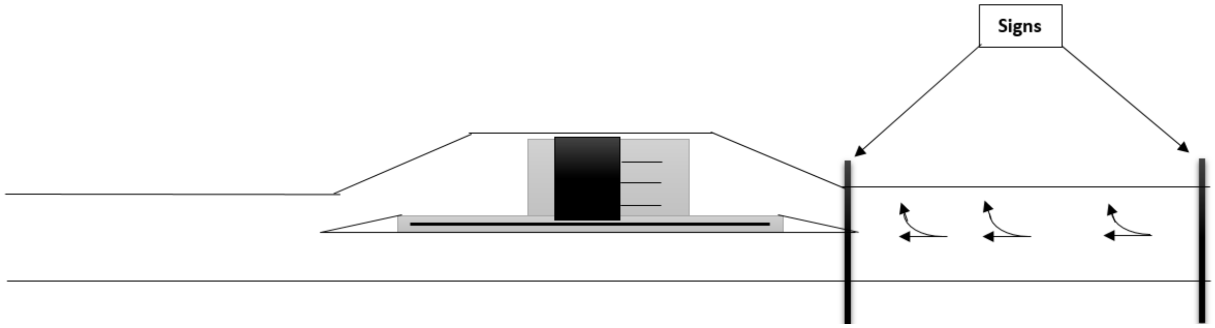


Figure 7.1 - Sketch of ideal hybrid toll plaza layout

For future research, there are several suggestions to take into consideration:

1. Many of the subjects were very familiar with this toll plaza, especially because all of the Central Florida Expressway Authority toll plazas are very similar. To overcome this familiarity when using the driving simulator, it is suggested that the same study be done in another area (i.e., a different state or country).
2. Each subject drove three scenarios and the scenarios were similar, so most subjects became very familiar with the toll plaza and did not pay attention to the signs. Testing one or two scenarios per subject is advised.
3. Change the content of the DMS that was added on the on-ramp because most subjects did not pay attention to it once they entered the highway. “E-Pass and cash keep right for booths” or something similar is suggested.
4. The segment length after the toll plaza was found to sway drivers to make unsafe maneuvers. However, more analysis should be done in order to conclude whether this segment length is sufficient.

. From this study, apart from the segment length after the toll plaza, the Dean Mainline Toll Plaza showed to have a safe design layout. Similar to the current MUTCD toll plaza guidelines, the segment length, specifically after the toll plaza, should be longer than it currently is. Even though it is difficult to implement this change at the Dean Mainline Toll Plaza, it is necessary to consider this factor when designing new hybrid toll plazas.

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Appendix A: Protocol and Study Materials

Evaluating Toll Plazas and Visibility Conditions Using Driving Simulation

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1. PROTOCOL TITLE

Evaluating Toll Plazas and Visibility Conditions Using Driving Simulation

2. PRINCIPAL INVESTIGATOR

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3. OBJECTIVE

There are two main objectives for this driving simulator experiment. The first is to determine driver behavior in varying fog conditions and whether the presence of a Dynamic Message Sign (DMS) plays a significant impact on driving. The second is to study driver behavior while driving through a hybrid toll plaza. To do this, subjects will run through different scenarios on a NADS MiniSim driving simulator provided for the research. Variables of interest for the experiment will also be collected from the subjects, which will be observed with the results of the simulations to see if there is any correlation with these variables and the results from the scenarios. These variables will be collected confidentially and include the subject's age, gender, driving experience and frequency, highest education level, accomplished income level, or zip code, and whether they have been in an accident in the last 3 years. Questions will also be given to the subjects in written form before, during, and after the experiment in order to collect additional information that may provide an impact in the results. Feedback will also be collected from the subjects at the end of the simulation which will be used to make improvements to future simulation research projects.

Source: Mini Sim Driving Simulator (http://sonify.psych.gatech.edu/research/driving/index.html)

(4)

Questions asked prior to the simulation testing involve determining the subjects driving history and experience, as well as familiarity in fog conditions and toll plazas, as well as variable collection. These questions also allow us to get a better understanding of individuals driving habits and whether they will experience any sort of motion sickness during the testing. Between each simulation scenario, subjects will be asked addition questions in regards to the scenario they just ran. These questions include how the subject performed in the given scenario, what they observed, how they reacted, and how they felt about the situation. The subjects will also be asked how they are feeling and whether they need a few minutes to rest between these scenarios as well. Finally, at the end of the entire simulation test, subjects will again be asked if they are feeling well enough to leave and feedback will be collected from the subject on what they thought of the simulation experiment. By using this feedback, we have the opportunity to improve future simulation studies. (Samples of these questions that will be asked can be found on the attached questionnaire.)

Once the simulations have been completed and the required data has been collected, we will then analyze the results to see how people react in fog and dynamic message sign conditions, as well as toll plazas. From our research, we hope to find ways to improve the safety of our roadways by determining potential benefits from the tested environments.

4. BACKGROUND

Studying driving behavior in a real world scenario can be extremely challenging and dangerous, especially when these situations involve adverse conditions, such as fog. Due to unpredictability, it is hard to create fixed or constant environmental factors along the physical roadways. Interference from other drivers can also complicate data and also pose potential safety hazards when trying to conduct studies with volunteers. Simulations allow us to test specific scenarios under user specific conditions, allowing for more control over the environment and consistency between each subjects tests. Using simulation software also allows a cheaper alternative to testing driving behaviors compared to bigger more advanced systems such as Virginia Tech's "Smart Road." Although the simulation scenario is not as realistic as a 'real world' setting, we can validate the data in many different ways, one of which, stated by Dr. Kathy Broughton, Dr. Fred Switzer, and Dr. Dan Scott in their "Car Following Decisions" paper, would be to simply compare it to results from 'real world' studies and see if the trends are comparable (1-2). This is an absolute possibility for this research, as a sensor will be placed at the location the fog scenarios are based off of. Ultimately it was determined from the investigation that driving simulation studies were much safer and more economic than a real world setting.

Currently, there have been many research and study topics involving the analysis of driver behavior in fog conditions using driving simulation. However, many focus on simply how varying fog levels compare to collision, driving behavior, or sight distance. For this study, we will be focusing on whether the presence of a Dynamic Message Sign (DMS) effects an individual's driving behavior in fog conditions, and in what way it impacts this behavior. Validation in this regard will be fairly simple as well thanks in part to the previous fog simulation studies. Again, many of these past studies have focused on purely driving behavior, and many of which drew similar conclusions and results based on their studies. It was found that there is much consistency in driving behavior (acceleration or deceleration in fog, braking, speed, ect.) in fog conditions (3), meaning that it could be possible to validate the results based on other simulation findings if the data is consistent.

Aside from fog, dynamic message signs will play a very important role in this research as it is our overall goal to determine their impacts in driving behavior, especially when considering them for early detection warning devices. Dynamic message signs (DMS), as they sound, are signs capable of displaying different data such as warnings, directions, speed limits, and much more. In today's technology advanced age, DMS messages are becoming more and more used due to their convenience and ability to relay messages rapidly and readily. Due to this, more studies have been created to examine their potential in transportation engineering and safety. For one, it has been well researched that DMS brightness and color pattern plays an influential role in driver response to them, as well as the presence of beacons. Although this topic does not directly impact this simulations specific focus, these findings do provide significant information that could be used or considered when creating the DMS messages in the simulation software.

Very little research has been done to evaluate the safety and behavior of drivers traveling through toll plazas. This is especially true for the new tolling systems. However, toll roads have become very popular and along with this popularity research has started growing on the subject in order to make toll plazas safer. According to the literature, there are three most common toll collection systems (6). These systems are the Traditional Mainline Toll Plaza (TMTP), the Hybrid Mainline Toll Plaza (HMTP), and the All-Electronic Toll Collection (AETC). The Hybrid Mainline Toll Plaza will be the only type of toll system that will be focused on in this experiment. The HMTP is a mixture of both the Traditional Mainline Toll Plaza and All-Electronic Toll Collection. This system contains either the express Open Road Tolling (ORT) lanes on the mainline and the traditional toll collection to either side or traditional toll collection on the mainline and the separate ORT lanes on the sides. The ORT lanes and traditional toll collection are separated by barriers so that the driver must decide which lane he or she will use well before the toll collection occurs. Signs must be adequate enough to ensure that the driver can decide where to go in a safe and timely manner.

It has been found by the U.S. National Traffic Safety Board (NTSB) that toll plazas are the most dangerous locations on highways as of April 2006 (5). Using a simulator will benefit in researching these areas to allow us to examine driver behavior and to determine where exactly the problems are in toll plazas. In his "Traffic Safety Evaluation and Modeling of Toll Collection Systems", Dr. Muamer Abuzwidah compared multiple scenarios of toll plazas including a comparison between diverge-and-merge areas. Sixty hybrid mainline toll plazas were used to compare the areas. He noted that "since the lengths are different between the (diverge-and-merge) areas, the frequency of crashes were controlled by the segments' lengths." It was found that more crashes occurred within the diverge area than within the merge area (6). This is understandable and will be further analyzed in our research so that we can determine what can be done to lessen the chance of crashes.

A big problem that will need to be dealt with is the fact that the diverge area of the Dean toll plaza, which our simulator is based on, is very close to the on ramp that is located upstream of the plaza. Therefore, not only is the driver concentrating on merging onto the highway, but also on diverging into the hybrid toll plaza. Even though there is a lane in the toll plaza which is designated solely to E-Pass users, many E-Pass users who come from the on ramp on the right of the highway change lanes across the highway to the left side in order to use the ORT lanes. We can assume that this could mainly be due to poor signage. This research will expand further upon the problems caused within the diverge-and-merge areas of toll plazas.

5. SETTING OF RESEARCH

The simulation study will be conducted at the University of Central Florida, in one of our available offices in Engineering building II. The office itself is large enough to accommodate the testing equipment and personnel, and is easily accessible by the research assistants. Since the research location is conducted within the UCF engineering building, many accommodations and equipment are readily available in case of any issue. Restrooms and water fountains are accessible to subjects and personnel, and first-aid kits, fire extinguishers, and so on are also ready to use.

6. RESOURCES AVAILABLE TO CONDUCT HUMAN RESEARCH

Since we plan on recruiting many of the subjects for this study through friends, family, and the University itself, many recruitment options are available to us. Friends, family, and even possibly campus faculty can be easily contacted and requested for participation either in person or by other means of communication. However, recruiting students for the study will require a bit more work to accomplish. The current plan is to advertise the study by word of mouth in classrooms, clubs, and around campus to recruit potential volunteers for the short study.

Overall, the simulation study should only take around one hour to complete, making time commitment not a huge problem. This hour block includes pre-simulation procedures, such as going over the disclaimer and allowing the subject time to practice to become more acquainted with the simulator. Three questionnaires will be given to the subjects throughout the study. One before driving the simulator, one after each scenario, and one after the study. Following these preliminary procedures, each subject will then run through 8 scenarios chosen at random from a pool of created scenarios. The scenarios chosen will vary between the toll plaza and fog related scenarios. Assuming each scenario lasts 3-5 minutes, there should be plenty of time to familiarize the subject, run the tests, and even allow some time in between tests for the subject to rest if he or she needs it.

A majority of the research group involved in the research have a few years of transportation safety research experience, a few already obtained PhD's in the field. We are also working with other universities in the country. These include the University of Massachusetts, University of Iowa, the University of Puerto Rico, and the University of Wisconsin who have current experience in simulation research. The other universities will have no access to the data that we will collect. The only collaboration we will have and have had with these universities is guidance with simulation research, since they have more experience in the field. Furthermore, we will only share our results and findings with them in order to expand this research further. They are not involved in the data or experiments.

As previously stated, the simulation will be conducted in a private office inside Engineering Building II on UCF campus. Access to the room is approved, and only a select few research staff have access to the room and simulator. Amenities, such as water fountains and restrooms are readily available, as well as seating if someone needed to rest. While the simulation is being conducted, subjects will be with at least one staff member at all times to monitor them and walk them through the procedure.

7. STUDY DESIGN

7a) Recruitment

For this experiment, a maximum of 72 subjects will be needed to run the simulation and be tested. The subjects will ideally range from ages 18 to late 60's, and each will be a Florida resident. Since most of the variables of interest in this study are based on the subjects' demographics, a nice even distribution will need to be met to assure unbiased results. To meet this, we will recruit a variety of subjects with varying age, gender, education, ethnicities, and backgrounds. Subjects will run the simulations through voluntary means, and will be recruited through UCF clubs and classes, friends or relatives, and possibly other local students who are interested in the research. No matter how they are recruited, each subject is expected to run through the scenarios presented in the MiniSim as if they were, or as close as possible to, driving in a real life scenario.

Subjects will be recruited during the months of May, June, and possibly July. The family and friends of the researchers be recruited by word of mouth or by e-mail. Likewise, faculty and staff will also be recruited by word of mouth or by e-mail. A description will be given to explain the basis of the research and will be sent out through these e-mails.

Identifying potential subjects will not be a difficult task for this research because the only requirements are as follows: The subject must be in the age range of 18 to late 60's, must have a driver's license, and must not have a history of motion sickness. Being in a college environment, it should be possible to find many potential subjects. As stated previously, 72 subjects will be needed to complete this research study.

7b) Compensation

Since this experiment will only last one hour and it is being ran strictly through voluntary subjects, no compensation is planned on being offered.

7c) Inclusion and Exclusion Criteria

In order to be eligible for this research experiment, subjects must fit within a predefined demographic determined by the research group. The demographic of interest includes both male and female Florida residents ages 18 to late 60's. The subjects must have a valid driver's license and have no history of extreme motion sickness or other medical conditions that can be caused by disorientation such as seizures or strokes. Subjects must also be physically capable of concentrating at a computer screen for at least one hour without having any complications.

Each person who partakes in the simulation testing will have general information about themselves questioned and or recorded. These include age, gender, ethnicity, driving experience and history, approximate income, and a few other general variables that could prove to be significant in the final analysis. Assuming the subject meets the required criteria and performs the simulation, additional variables and information will be gathered from the subject including data from their scenario performance and info on the driver's reaction based on their answers to the post simulation questions. The data that we are most interested in for this experiment is primarily the driving behavior, including speed, acceleration or deceleration rates, brake usage, lane changing, and vehicle distancing just to name a few. With the addition of the questionnaire we can also gain information in regards to how the subject reacted to the given scenarios. Information such as; were the sign(s) encountered easy to read or understand, how confusing the scenario was, or even how they reacted to a specific event can provide valuable research information in terms of driver reactions.

Again, 72 subjects are expected to be needed for the study; the results from each subject are expected to be used. The only situation where data results will be ignored or not used is if a situation occurs that results in an early withdraw of the subject or an error occurred during the simulation. Since the experiment requires the subjects to have a drivers license and must be at least 18 years or older, no children or teenagers will be considered for this research.

7d) Study Endpoints

N/A

7e) Study Timelines

The duration of the participation of a subject will be approximately one hour. This includes the explanation of what will be needed of them during the study, the scenarios the subject will be tested on, and breaks in between scenarios, as needed. It is estimated that testing will take 3 to 4 months. The primary analyses should be completed by August 2015.

7f) Procedure

The overall procedure for running the simulation should not take more than one hour for each subject, and each run will aim to be as consistent as possible. Before the simulation is started, each subject will be given a consent form that goes over what is expected of them and any possible health advisories. This consent form must be read by any subject before any testing can begin so each subject knows what to expect. Once this is done, the subject will be given preliminary questions in written form, including questions on the variables of interest (age, gender, ect.), and then will be given a test simulation to get them more acquainted and comfortable with the hardware. This portion of the procedure should take approximately 10 minutes where ideally the subject gets 5 minutes of test driving in the simulator.

Following this initial practice, the subject will be given short rest if needed and then the actual study scenarios will be provided. Prior to starting the group of scenarios, the subject will be reminded of what their task is in the simulation; and following the scenarios, each subject will be questioned in regards to the scenarios they just ran. Between each scenario group, the subject will also be given the option to take a rest if they are feeling motion sick or ill, and if they are unable to continue the test will be concluded.

Since this simulation study is looking at both Visibility DMS and Toll plaza conditions, the scenarios that the subjects will run involve completely different conditions. To keep things more in order and consistent, the groups of scenarios will each be based on one study. For the first group, both a freeway and arterial road will be generated and along them will contain a random fog and sign condition. In order to create a valid experiment, a pool of many different scenarios with varying conditions will be created, but only a few will be used randomly on each subject. The same applies for the toll plaza as multiple conditions could be present and needs to be tested.

The simulated toll plaza has been designed to represent the Dean Road toll plaza in Orlando, Florida. There are many conditions that will be tested for the toll plaza scenario as stated previously. One group of conditions includes using signs that the driver looks at to help them decided which lane they should be in as well as the location of these signs. The Dean Road toll plaza is located close to on and off ramps. Therefore, another group of conditions is the different lengths between the ramps and the plaza. These conditions can help determine what will make the road more efficient and safe when drivers diverge and merge to and from toll plazas. Ideally five random scenarios will be chosen for both the fog and toll plaza simulations, each taking around 2 to 4 minutes.

These scenarios will also include other computer controlled vehicles that could encourage the subject to change lanes or provide roadway obstacles that the subject must watch out for. Additional signage will also be included apart from the dynamic message signs, such as speed limit signs and exit signs. The DMS themselves will have varying messages depending on the scenario; these include a “recommended speed” message, a “slow down or reduce speed” message, or even a “fog warning” message. After all this simulation data is collected, analysis will begin to determine correlation between driving conditions and subject data.

There are four recording devices that are used by this simulator. One device is pointed directly at the subject’s feet and will record only their feet. One is directed towards their face and another towards their hands. The last recording device will be located behind the subject, recording the monitors and where they direct the simulated vehicle. It is necessary to note that the researchers will be the only people that will access these videos and they will be deleted immediately after the necessary data is collected. The videos will be stored in a locked, safe place. The data collected from these videos include, but are not limited to, eye movements, gas and brake pedal usage, and head movements. There is very minimal risk when using the MiniSim. The only risk the subjects have in using the simulator is motion sickness. In this case, the subject would be provided water and a cool place to sit. The motion sickness will be monitored by the research assistants who will watch for signs of uneasiness. There will be questionnaires for each subject before and after the scenarios. Attached is a copy of each questionnaire used.

Data collected during the experiment range from how the subject uses there pedals to how often they switch lanes to swerving. Data will also be collected using the questionnaires. This data includes age, gender, years of driving experience, years of driving experience in Florida, how often a person uses toll roads or roads susceptible to fog, occupation, range of income, highest level of education, how realistic the person thought the scenarios were, etc.

For the visibility related scenarios, the subject will drive through freeways and arterial lanes with varying fog and DMS conditions. These scenarios will be based in Paynes Prairie, Gainesville; a location that has seen severe crashes in the past due to visibility issues. By basing our study on this location, we gain the added benefit of using data collected from the actual site to compare and validate the simulator results. As previously stated, multiple scenarios will be made for different situations including fog density, DMS presence and number, and DMS message presented. Normally each scenario will begin under clear or slight fog conditions and as the driver proceeds down the courses, the set conditions will begin to change. From this pool of scenarios, roughly 3 or 4 will be randomly selected for each subject to run.

The toll plaza simulation will be based on the toll plaza at Dean Road in Orlando, Florida. It is very closely located in between on- and off- ramps from both Dean Road. The on-ramp from Dean Road westbound is extremely close to the toll plaza and gives a driver very little time to decide which lane they would like to use. Because of this, there will be multiple scenarios of how different distances between the on-ramp and the toll plaza affect the behavior of a driver. There will also be different signs located at different locations and distances from the toll plaza. In the simulation, the driver will be told in what form he or she will be paying with for the toll so that they can decide which lane to choose. More scenarios will include whether the subject will start on the on-ramp and go through the plaza with cash or E-Pass and then continue on the mainline. Others will be starting on the mainline, going through the plaza, and then exiting on the off-ramp after the plaza. Other drivers will start on the mainline and continue through on the mainline.

7g) Data Specimen Management

N/A

7h) Provisions To Monitor

N/A

7i) Withdrawal

If subjects show continuous or extreme signs of motion sickness, he or she will be withdrawn from the simulation test. Once withdrawn, the subject will be given a place to rest and water until they feel well enough to leave.

In a situation where a subject was withdrawn from a test, the data collected will most likely be invalidated and will not be used. However, if the subject completes a specific scenario prior to the issues causing the withdrawal to occur, then the data for those scenarios might still be usable.

8. RISKS

The main risk that is encountered while driving in the simulation is motion sickness, or any other form of motion related ailments. If a subject begins to feel any uneasiness or needs a break, they will be free to do so. Once out of the simulator, the sickness should subside momentarily. At the end of the test, subject will also be questioned to give them time to relax and will be offered a place to rest if they need some time before they leave. Also, were any serious problem occur, a researcher will be with the subject at all times so subjects should never be along for long periods of time.

9. POTENTIAL BENEFITS

Overall there is no real direct benefit towards subjects in this study other than compensation or learning something about the transportation engineering field and simulation research. The subject will also be contributing to research for safer and more efficient roadways.

10. PROVISIONS TO PROTECT PRIVACY OF SUBJECT

The simulation tests will be conducted behind closed doors with only the research assistants and subject present. The data collected from the subject will be completely confidential, where no information collected from the subject will be related to a name or identity. If subjects are not comfortable answering a question, such as income or crash history, a value range will be provided to choose from or the subject has the right to not answer. The data collected will be strictly used for academic purposes and will only be accessible to those involved in the research group.

11. PROVISIONS TO MAINTAIN CONFIDENTIALITY

In order to maintain confidentiality of the data, as well as the subjects, all data collected will be kept secure where only research staff will be able to access and look at it. Subject names will also not be used, recorded, or related to the data collected from the subjects in order to assist in creating anonymous data. The data is also going to be restricted to limited use, not only by who can access it but also where it can be accessed. The data will be stored for at least five years after the research study has been completed, per UCF IRB Policies and Procedures.

12. MEDICAL CARE AND COMPENSATION FOR INJURY

N/A

13. COSTS TO SUBJECTS

Subjects may incur a cost for parking, if this occurs, they will be reimbursed.

14. CONSENT PROCESS

All consent will be taken care of at the very start of the study, prior to any simulation testing on the subject. Each subject will be given an informed consent form that they are to go over before any testing can begin. While the subject does this, the available staff at the time will go over the form with them, ideally in the first 10 minutes, covering the most important parts of the document and check with the subject to ensure that they understand what is being discussed. This means that before any testing has begun, the subject will have been given a verbal form of consent for both what is expected of the simulation as well as understanding. The potential subjects will be asked if they have had a seizure or if they have a history of seizures. They will be excluded from partaking in the study if they answer “yes” to this question. Also, since the subject if free to withdraw from the simulation at any time, a person’s willingness to continue shows adequate ongoing consent.

Since all the subjects expected to take part in this experiment are Florida residents, we can assume that practically all of the subjects will have English as a primary language or at least have a firm grasp the language. This will be the only language spoken during the study and we will not be able to recruit subjects that do not know English.

15. CONSENT DOCUMENTATION

A written consent form will be provided prior to any testing, and will be gone over by the tester to ensure the subject understands everything. Before the simulation is started, each subject will be given a consent form that goes over what is expected of them and any possible health advisories. This consent form must be read by any subject before any testing can begin so each subject knows what to expect. The assistant conducting the research will also be available to answer any questions the subject may have and go over the consent form with them. Once this is done, the subject will be given preliminary questions, including questions on the variables of interest (age, gender, etc.).

16. VULNERABLE POPULATIONS

N/A

17. DRUGS AND DEVICES

N/A

18. MULTI-SITE HUMAN RESEARCH

N/A

19. SHARING RESULTS WITH SUBJECTS

N/A

SUMMARY

Through observation of the results of these simulation scenarios, we hope to use the findings to determine more efficient ways to use dynamic message signs for adverse weather conditions, as well as improve efficiencies at toll plazas. The work done and data collected also provides a base for other research projects and studies to read the data or do further testing on the results. As far as fog research, these studies can include closer analysis on the type of DMS used, additional signal data such as beacons, and even possibly more focus on the DMS message presented. These toll plaza studies will comprise of determining how to make the signs more understandable for drivers and where to place them in order to help them drive through toll plazas safely. Again, one of the biggest issues with simulation studies is validation of the simulation environment to accurately reflect real world data. Luckily, this will not be too big of an issue due to having access to traffic data collected from the sites of interest.

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3. Xuedong Yan, Xiaomeng Li, Yang Liu, Jia Zhao. (2014). *Effects of foggy conditions on drivers' speed control behaviors at different risk levels.* Beijing Jiaotong University, Beijing 100044, China.
4. Georgia Institute of Technology – School of Psychology. (2009). *Sonification Lab Driving Research*. 'Mini Sim Driving Simulator.' *(http://sonify.psych.gatech.edu/research/driving/index.html).*
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Evaluating Toll Plazas and Visibility Conditions Using Driving Simulation

Informed Consent

Principal Investigator:	Mohamed Abdel-Aty, PhD. P.E.
Co-Investigator(s):	Kali Carroll Ryan Selby
Sub-Investigator(s):	Qi Shi, PhD Muamer Abuzwidah, PhD Qing Cai, PhD Candidate Yina Wu, PhD Candidate
Sponsor:	Florida Department of Transportation National Center for Transportation Systems Productivity and Management UTC SAFER-SIM UTC
Investigational Site(s):	University of Central Florida, Department of Civil, Environmental, and Construction Engineering

Introduction: Researchers at the University of Central Florida (UCF) study many topics. To do this we need the help of people who agree to take part in a research study. You are being invited to take part in a research study which will include about 60 people from around the Orlando area as well as faculty, staff, and students at UCF. You have been asked to take part in this research study because you are within the age range of 18-65 and have driver's license. You must be 18 years of age or older to be included in the research study.

The people conducting this research are Kali Carroll and Ryan Selby of UCF department of Civl, Environmental, and Construction Engineering. Qi Shi, Muamer Abuzwidah, Yina Wu, and Qing Cai will also be helping with this research. The researchers are collaborating with Dr. Michael Knodler and Dr. Donald Fisher the from the University of Massachussetts Amherst, as well as graduate students from the University of Puerto Rico in Mayaguez. Because the researchers are graduate students, they are being guided by Mohamed Abdel-Aty, PhD P.E., a UCF faculty advisor in the department of Civil, Environmental, and Construction Engineering.

What you should know about a research study:

- Someone will explain this research study to you.
- A research study is something you volunteer for.
- Whether or not you take part is up to you.
- You should take part in this study only because you want to.
- You can choose not to take part in the research study.
- You can agree to take part now and later change your mind.
- Whatever you decide it will not be held against you.
- Feel free to ask all the questions you want before you decide.

Purpose of the research study: The purpose of this study is to Evaluate driver behavior (1) in varying fog visibility conditions along a roadway with or without dynamic message sign presence and (2) in a hybrid toll plaza under different operating conditions.

What you will be asked to do in the study: The laboratory assistant, with whom you will interact, will give you a questionnaire to fill out before and after the experiment has been completed. This questionnaire will be kept confidential. You do not have to answer every question or complete every task. You will not lose any benefits if you skip questions or tasks. The laboratory assistant will then have you sit in the driver's seat of the simulator, which contains a steering wheel, gas and brake pedals, buttons that will be explained, three monitors that display the simulation world you will drive in, and another small monitor that displays the car's dashboard information. Before starting the actual testing scenarios, the laboratory assistant will execute a practice simulation, which involves a simple roadway and intersection. This practice scenario can be used to better acquaint you with the displays and how the vehicle operates.

Once you feel comfortable enough with the simulator, you will have a short break if needed and then continue on to the experiment. The experiment will consist of six different and random scenarios that will last about 5-7 minutes each. You will also have a 5 minute break in between each scenario if needed. The entire session should last a maximum of 70 minutes.

Location: As noted previously, the study will be done using a driving simulator. The simulator will be located on the main campus of the University of Central Florida. It is in the Engineering 2 building, room 325A.

Time required: We expect that you will be in this research study for, at the very most, 70 minutes.

Audio or video taping: You will only be video taped during this study. If you do not want to be video taped, you will still be able to be in the study. Discuss this with the researcher or a research team member. If you are video taped, the tape will be kept completely confidential in a locked, safe place. The tape will be erased or destroyed immediately after we process the data. There are four recording devices that are used by this simulator. One device is pointed directly at your feet and will record only your feet. One is directed towards your face and another towards your hands. The last recording device will be located behind you, recording the monitors and where you direct the simulated vehicle. It is necessary to note that the videos will be kept confidential and only the researchers will be the only people that will access these videos. The data collected from these videos include, but are not limited to, eye movements, gas and brake pedal usage, and head movements.

Funding for this study: This research study is being paid for by the Florida Department of Transportation, National Center for Transportation Systems Productivity and Management UTC, and SAFER-SIM UTC.

Risks: Side effects of VE (virtual environment) use may include stomach discomfort, headaches, sleepiness, dizziness and decreased balance. However, these risks are no greater than the sickness risks you may be exposed to if youwere to visit an amusement park such as Disney Quest (Disney Quest is a VE based theme park), Disney World or Universal Studios parks and ride attractions such as roller coasters. You will be given 5-minute breaks during the exercise, if necessary, to lessen the chance that you will feel sick. If you experience any of the symptoms mentioned, please tell the researcher and remain seated until the symptoms disappear. Water will also be provided to you if needed. Please let the researcher know if you have had a seizure or have a history of seizures.

Benefits: The benefits of this experiment will include contributing to the safety of future roadway designs and help researchers better understand driving habits in various driving conditions. There is no actual compensation or other payment to you for taking part in this study.

Confidentiality: All personal data collected from this experiment, both documented and filmed, will be kept strictly confidential and will only be assessable to personel directly involved in the research. Absolute confidentiality cannot be guaranteed, however data collected will be made as anonymous as possible and will only be used for research purposes. Aside from the research team, IRB will also have access to any recorded information as well for review purposes.

Study contact for questions about the study or to report a problem: If you have questions, concerns, or complaints, or think the research has hurt you, talk to Kali Carroll, Graduate Student, Transportation Engineering Program, College of Civil, Environmental, and Construction Engineering, by email at kcarroll@knights.ucf.edu or Ryan Selby, Graduate Student, Transportation Engineering Program, College of Civil, Environmental, and Construction Engineering, by email at ryans1298@knights.ucf.edu or Dr. Mohamed Abdel-Aty, Faculty Supervisor, Department of Civil, Environemental, and Construction Engineering at by email at m.aty@ucf.edu.

IRB contact about your rights in the study or to report a complaint: Research at the University of Central Florida involving human subjects is carried out under the oversight of the Institutional Review Board (UCF IRB). This research has been reviewed and approved by the IRB. For information about the rights of people who take part in research, please contact: Institutional Review Board, University of Central Florida, Office of Research & Commercialization, 12201 Research Parkway, Suite 501, Orlando, FL 32826-3246 or by telephone at (407) 823-2901. You may also talk to them for any of the following:

- Your questions, concerns, or complaints are not being answered by the research team.
- You cannot reach the research team.
- You want to talk to someone besides the research team.
- You want to get information or provide input about this research.

SIMULATOR QUESTIONNAIRE

Before scenarios

1. Do you have a history of severe motion sickness or seizures?
   a. Yes
   b. No

2. How long have you had a Florida driver's license?
   a. Less than 5 years
   b. 5-10
   c.11-15
   d.16-20
   e.21+

3. How often do you use toll plazas?
   a. One to two times per year
   b. One to two times per month
   c. One to two times per week
   d. One to two times per day
   e. Three or more times per day

4. What type of toll plaza are you most familiar with?
   a. Traditional Mainline Toll Plaza
   b. All-Electronic Toll Collection System
   c. Hybrid Mainline Toll plaza

5. Do you own a SunPass?
   a. Yes
   b. No

6. Have you driven in any fog conditions in the past year?
   a. Yes
   b. No

7. Are you familiar with dynamic message signs?
   a. Yes
   b. No

8. How old are you?
   a. 18-24
   b. 25-35
   c. 36-50
   d. 51-60
   e. 60+

9. Did you learn how to drive in another state?
   a. Yes
   b. No

   If yes, please explain:

10. How often do you typically drive?
    a. 1-5 trips per week
    b. 1-2 trips per day
    c. 3-5 trips per day
    d. 5+ trips per day

    If never, please explain:

11. What is your highest level of education?
    a. Some high school
    b. High school
    c. Some College
    d. Bachelor’s Degree
    e. Grad. School

12. What is your range of income?
    a. 0 – 10,000
    b. 10,000 – 25,000
    c. 25,000 – 40,000
    d. 40,000 – 55,000
    e. 55,000 – 70,000
    f. 70,000+

13. Have you been in any vehicular accidents in the last 3 years?
    a. Yes
    b. No

    If so, what was the crash type (e.g. sideswipe, rear-end, head-on, etc.)? How many cars were involved? Where did the crash occur (e.g. intersection, highway, toll plaza, etc.)?

14. What vehicle do you normally drive?
    a. Sedan
    b. Pickup Truck or Van
    c. Motorcycle or Moped
    d. Professional Vehicle (Large Truck or Taxi)
    e. Other

15. Are you a professional driver / Does your job involve driving?
    a. Yes

b. No

SIMULATOR QUESTIONNAIRE

Between scenarios

1. Do you feel sick or nauseous and need a rest?
   a. Yes
   b. No

2. Were you able to understand the signs?
   a. Yes
   b. No

   Please, explain:

3. Did you have trouble navigating/understanding the course?
   a. Yes
   b. No

   Please, explain:

<u>FOG SCENARIOS</u>

1. How did you react to the change in visibility?

2. How much more difficult would you say it was driving in the fog compared to the clear condition? How difficult was it to see other vehicles or signs?
   a. Extremely Difficult
   b. Very Difficult
   c. Somewhat Difficult
   d. No Difference

3. Did the DMS sign make driving in the fog condition easier or less stressful or was it a distraction or unhelpful?
    a. Helpful
    b. Unhelpful

4. Was the DMS sign easy to read and understand?
    a. Yes
    b. No

5. How did you feel while driving in the fog condition?
    a. Very Nervous
    b. Slightly Nervous
    c. Indifferent
    d. Slightly Confident
    e. Very Confident

6. How many DMS did you notice during your drive?
    a. 0
    b. 1
    c. 2
    d. 3

7. (If applicable) Did the beacons better prepare you for the fog condition?
    a. Yes
    b. No

TOLL PLAZA SCENARIOS

1. Did you have more trouble diverging into the separate toll plaza lanes and merging back on after the toll plaza?
    a. Yes
    b. No

Please, explain:

2. Do you think the signs were placed in proper locations and contained helpful information?
    a. Yes
    b. No

Please, explain:

3. Do you think you had a sufficient amount of time to decide which lane to get in and stay in to go through the appropriate toll collection area?
    a. Yes
    b. No

Please, explain:

SIMULATOR QUESTIONNAIRE

Between scenarios

4. Do you feel sick or nauseous and need a rest?
   c. Yes
   d. No

5. Were you able to understand the signs?
   c. Yes
   d. No

   Please, explain:

6. Did you have trouble navigating/understanding the course?
   c. Yes
   d. No

   Please, explain:

   FOG SCENARIOS

8. How did you react to the change in visibility?

9. How much more difficult would you say it was driving in the fog compared to the clear condition? How difficult was it to see other vehicles or signs?
   a. Extremely Difficult
   b. Very Difficult
   c. Somewhat Difficult
   d. No Difference

10. Did the DMS sign make driving in the fog condition easier or less stressful or was it a distraction or unhelpful?
    a. Helpful
    b. Unhelpful

11. Was the DMS sign easy to read and understand?
    a. Yes
    b. No

12. How did you feel while driving in the fog condition?
    a. Very Nervous
    b. Slightly Nervous
    c. Indifferent
    d. Slightly Confident
    e. Very Confident

13. How many DMS did you notice during your drive?
    a. 0
    b. 1
    c. 2
    d. 3

14. (If applicable) Did the beacons better prepare you for the fog condition?
    a. Yes
    b. No

<u>TOLL PLAZA SCENARIOS</u>

4. Did you have more trouble diverging into the separate toll plaza lanes and merging back on after the toll plaza?
    a. Yes
    b. No

Please, explain:

5. Do you think the signs were placed in proper locations and contained helpful information?
    a. Yes
    b. No

Please, explain:

6. Do you think you had a sufficient amount of time to decide which lane to get in and stay in to go through the appropriate toll collection area?
    a. Yes
    b. No

Please, explain:

SIMULATOR QUESTIONNAIRE

Between scenarios

7. Do you feel sick or nauseous and need a rest?
    e. Yes
    f. No

8. Were you able to understand the signs?

e. Yes
f. No

Please, explain:

9. Did you have trouble navigating/understanding the course?
    e. Yes
    f. No

    Please, explain:

<u>FOG SCENARIOS</u>

15. How did you react to the change in visibility?

16. How much more difficult would you say it was driving in the fog compared to the clear condition? How difficult was it to see other vehicles or signs?
    a. Extremely Difficult
    b. Very Difficult
    c. Somewhat Difficult
    d. No Difference

17. Did the DMS sign make driving in the fog condition easier or less stressful or was it a distraction or unhelpful?
    a. Helpful
    b. Unhelpful

18. Was the DMS sign easy to read and understand?

a. Yes
b. No

19. How did you feel while driving in the fog condition?
    a. Very Nervous
    b. Slightly Nervous
    c. Indifferent
    d. Slightly Confident
    e. Very Confident

20. How many DMS did you notice during your drive?
    a. 0
    b. 1
    c. 2
    d. 3

21. (If applicable) Did the beacons better prepare you for the fog condition?
    a. Yes
    b. No

<u>TOLL PLAZA SCENARIOS</u>

7. Did you have more trouble diverging into the separate toll plaza lanes and merging back on after the toll plaza?
    a. Yes
    b. No

Please, explain:

8. Do you think the signs were placed in proper locations and contained helpful information?
    a. Yes
    b. No

Please, explain:

9. Do you think you had a sufficient amount of time to decide which lane to get in and stay in to go through the appropriate toll collection area?
    a. Yes
    b. No

Please, explain:

SIMULATOR QUESTIONNAIRE

After scenarios

1. How do you feel? Are you capable of leaving or need some time to rest?

2. Do you have any suggestions or feedback on how to improve the simulation or have any complaints in regards to the scenarios you ran?

3. Do you think the scenarios were logical and true to a real life situation?

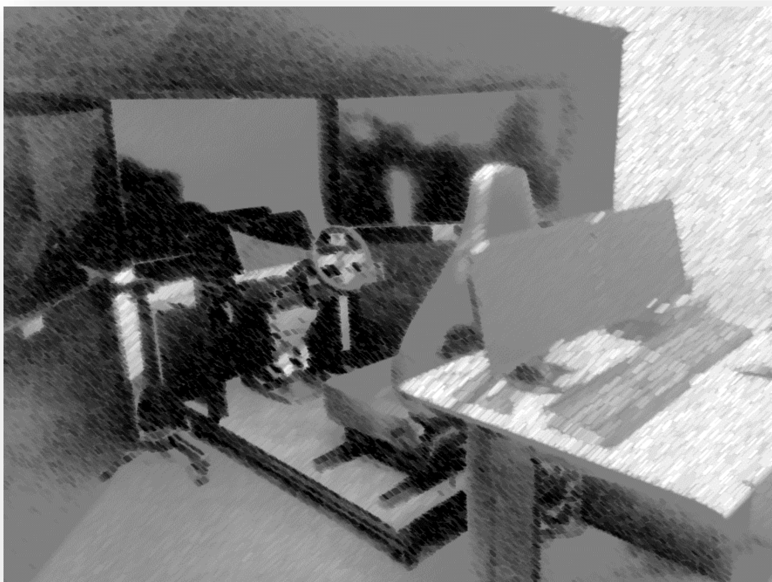
4. What did you like and dislike about the simulation?

5. What did you think was the most beneficial towards your ability to navigate the courses?

Bored and would like to drive in a virtual universe?

Would you like to be a part of making the roads safer?

You may be qualified to help in a transportation research study!



Requirements: You must have a driver's license. You cannot be prone to extreme motion sickness. Must be between the ages of 18 and 70.

Only takes **1 hour** of your time!

Please contact the research assistants below for more information.

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