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Impact of Dynamic Message Signs on Driver Behavior Under Reduced Visibility Conditions

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IMPACT OF DYNAMIC MESSAGE SIGNS ON DRIVER BEHAVIOR UNDER REDUCED VISIBILITY CONDITIONS

by

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ABSTRACT

Fog along roadways is a dangerous hazard that leads to crashes resulting from limited visibility. Low visibility gives drivers less time to react to potential obstacles that can suddenly appear and require immediate action. To solve this issue, early warning systems involving Dynamic Message Signs or other types of devices are used to alert drivers of the impending visibility condition so that they are prepared. This research focuses on testing the effectiveness of one form of warning systems to investigate how it impacts driver behavior in foggy conditions.

To accomplish this objective, a simulation study is developed to test variables of interest including: Roadway Type, Fog Level, DMS Presence, Beacon Presence, Traffic Volume, and DMS Message Provided. Using a factorial design, 24 scenarios are created by randomizing the variables listed using statistical software to be tested on 72 volunteer participants. Using a NADS MiniSim Driving Simulator, the participants driving behavior is recorded including speed and breaking behavior under an initial clear condition followed by a reduced visibility fog condition.

From demographics, drivers age 35 and over consistently showed a higher likelihood of speed reduction between clear and fog conditions with overall reduction increasing with age. This is seen when looking at the mean change in speed based on driver age where young drivers (18-25 yrs) reduced speeds by 7MPH, older drivers (35-45 yrs) reduced by 12MPH, and elder drivers (65+ yrs) reduced by 17MPH. The more often a person drove and those that were educated at a graduate level also showed a higher chance of speed reductions. This demonstrates the impact of experience and exposure to driving performance under reduced visibility conditions. Those who recently drove under fog conditions or learned to drive in Florida were found to be less likely to reduce their speeds when entering the fog. This is attributed to these drivers being confident or familiar with the environment resulting in risky driving behavior.

For the scenario variables, it is determined that the type of roadway a driver travels plays a major role in how much speed reduction occurs and thus how much a driver decelerates when entering a low visibility environment. On average, drivers traversed the fog zone at 50MPH with the lowest travel speed being 30MPH. Since the speed limit on the freeway is 5MPH higher than the arterial, drivers' traveling along this road are noted to decelerate at higher rates to achieve this target speed. Additionally, DMS presence and message also provided an impact on the drivers' choice to decelerate and reduce travel speed within the fog condition. Under the most severe conditions, the probability of a driver reducing speed increases as the number of DMS present increases. Additionally, when a DMS presents a warning and specifies the action that a driver should take, in this case 'reduce speed,' greater speed reductions and decelerations are observed and are more likely to occur. Interestingly the number of DMS did not have a significant impact on driver behavior under every fog condition like the message presented did except in the most severe fog condition. Taking into account that 33% of drivers did not accurately remember the number of DMS encountered it can be concluded that the warning message itself is the most important aspect of the early warning system. This indicates that drivers accurately remember being directed to reduce speed whether they are given the advisement once or multiple times based on the number of DMS present.

Further research into how the warning message is presented or worded could provide additional insight into the impact it can have on driver behavior. Since it is observed that drivers acknowledge the 'reduce speed' advisement, it is likely that specifying a specific speed limit could also warrant driver obedience. Additional testing and observation of driver reaction to larger traffic volumes and situations within the fog would also allow for further analysis of driver behavior under reduced visibility and the impact the early warning system has on their behavior.

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NADS MiniSim	National Advanced Driving Simulator, MiniSim
DMS / VMS	Dynamic / Variable Message Sign
PDO	Property Damage Only
$\beta_{y(x)}$	Beta value of 'y' variable at 'x' variable level

CHAPTER 1: INTRODUCTION

Situations' along a roadway where visibility is obstructed is a serious issue that increases the likelihood of many different hazards to occur, including crashes, road departures, and so on. This study aims to rectify this issue by studying the impact of an early warning fog onset system on roadways I-75 and SR441 near Gainesville, Florida. These locations were chosen due to their history of severe crashes involving situations under limited visibility due to fog. The study of driving behavior for these locations is conducted via driving simulation as it is cost effective and due to the dangers of testing these situations with real world studies. These types of experiments also allows for more control of variables and constants for experimental testing and evaluation purposes.

The scenario itself features a virtual version of the roadways of interest, each containing different variables, signs, and obstacles of varying levels that can be changed and randomized for experimental design purposes. The variables of interest for this study include: Fog Intensity, Roadway Type, number of DMS Present, Beacon Presence, Message Displayed, and Traffic volume. The first four variables are necessary based on the focus of the project and the early warning system design proposed by the FDOT. The Message Displayed and Traffic Type variables were chosen based on past research and their expected impact on the driver's behavior. The message variables are tested by presenting either a cautionary (simple warning) or advisory (given instructions) message and observing how the driver responds to the given information. Traffic volume was created based on the fact that fog occurs primarily in the early mornings, typically anywhere between 2AM and 8AM based on the observed data. As such, fog could be present prior to the early morning traffic where volumes are extremely low or during the late night.

1.1 Background

Obstructed visibility crashes due to fog or rain is a common and serious problem in the State of Florida. Between the years of 2001 to 2010, over 300 fatal crashes were observed due to fog related weather conditions alone. Considering that many PDO, injury, and severe crashes also occur; Florida is actually considered among the top state in the US in fog related incidents (Abdel-Aty et al, 2012). When comparing the crash severity to the visibility condition, it is also observed that in low visibility scenarios, such as fog, crashes tend to be more severe than under normal clear conditions (Lee and Abdel-Aty, 2012). One of the biggest reasons for this stems from the fact that multi-vehicle accidents are more likely to occur under low visibility scenarios than single vehicle (Abdel-Aty et al., 2011). Due to this, there is a drastic need for countermeasures to improve driver safety and performance under reduced visibility conditions.

The current and most common solution that is being applied is the use of an early warning and detection system. This system should ideally be able to predict the onset or formation of fog and present a warning to drivers along the roadway to better prepare them for the upcoming hazard. It is noted that fog forecasting is quite difficult, even when data is collected for the region (Ray et al., 2013); this indicates that application of countermeasures are limited more towards crash prone locations with histories of fog formation. This is also noted by Ray et al. (2013), to provide the most impact towards crash reductions and thus improved safety. To accomplish this, it is proposed that the use of airport weather data, which provides hourly readings, can be applied. By using the supplied data, such as the visibility, humidity, wind speed, and so on, fog formation can be predicted and a warning can be presented to drivers either via DMS messages or other type of ITS systems.

1.2 Objectives

The primary objective of this research is to analyze driver behavior and response towards an early warning system using DMS and beacons. Specifically, it is desired to observe the following:

1. Will drivers alter their driving behavior based on the presence of a DMS and the message provided as they enter a reduced visibility environment.

2. Does the addition of beacons assist with this response or alter behavior.

3. How will drivers react or perform based on present traffic volumes and sudden fog onset.

4. How does driver speed, breaking, and other behaviors change between the clear and fog conditions.

1.3 Thesis Organization

This thesis is divided into seven chapters as seen in Figure 1. The first chapter presents an introduction to the research, including background information, objectives of the research, and the organization of the thesis.

Chapter 2 follows with a literature review covering the current research and findings related to the topic of the thesis. Specifically, it covers findings on driver behavior towards DMS and low visibility environments, as well as simulation studies. Additionally, study objectives and methodologies are also reviewed and discussed in this chapter.

Chapter 3 covers the data of interest for this study, as well as how it will be observed and collected. This data includes driver demographics and behavior, as well as environmental factors that are tested within the simulation scenario.

Chapter 4 discusses the experimental design used for the simulation testing and how it was prepared, including the list of scenarios used. This chapter also covers the population sample used, as well as how the scenarios are structured in the simulation.

Chapter 5 presents the scenario structure for the simulation testing. This includes the design as well as details on the scenarios, what they will test, and what will be analyzed.

Chapter 6 focuses on the data analysis methodology, including the statistical testing used to determine significance of the variables observed. This chapter also looks at the factorial design established in the experimental design to look at significant relationships between the observed data. Results of the indicated analysis methods are also presented within this chapter as well.

Chapter 7 contains the conclusions, research recommendations, and possible future studies that are found from the data analysis.

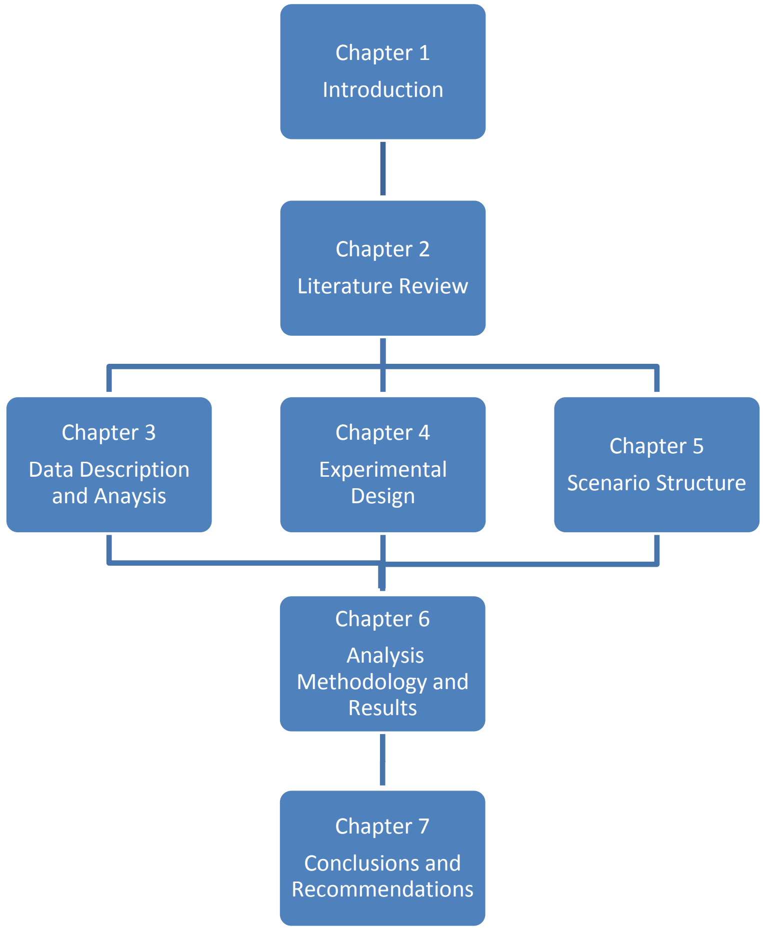

Figure 1: Thesis Organization

CHAPTER 2: LITERATURE REVIEW

2.1 Driver Behavior in Low Visibility

Low visibility situations along roadways have a considerable impact on driver behavior due to the limited view and obstruction of objects or hazards. Due to the high risk these scenarios pose, many research studies that look at driving behavior under hazardous conditions are conducted through simulation experiments.

In terms of driver speeds, many studies have looked at the impact of reduced visibility in fog on different driver characteristics. It is well researched that reduced visibility causes most drivers to be more cautious in their driving behavior due to the increased risk of a crash and reduced reaction time. To compensate for this reduced sight distance, more reaction time is desired and drivers typically reduce travel speed or headway to allow for this (Broughton et al., 2007; Ni et al., 2010; Yan et al., 2014; Koskela et al., 2012). Chakrabartya and Guptab (2013) noted that more experienced drivers of 2 years or more drove at significantly higher speeds, around 10% more, in foggy conditions than inexperienced. It is concluded in many studies that this behavior stems from experienced drivers being more confident in their abilities and have better expectations as to how they would handle potential risks (Clark et al., 2006; Curry et al., 2011; Lerner and Westat, 2011; McKnight and McKnight, 2003; Mueller et al., 2012; Pradhan et al., 2009; Vidotto et al., 2011). In terms of breaking behavior, it was found that visibility distance had an inversely proportional relationship to a drivers' breaking habit. Cullinane (2006) concluded that as visibility distance declines, drivers apply their breaks more often than simply letting the vehicle reduce speed by releasing the acceleration pedal. Additionally, when studying professional versus unprofessional drivers, it is noted that professional drivers perform more cautiously under foggy conditions while nonprofessional drivers are more likely to speed (Li et al., 2015; Yan et al, 2014; Curry et al., 2011). Gender is also found to have no significant impact on driver behavior in fog, noting that both sexes can exhibit equal aggressive or cautious behaviors under reduced visibility conditions (Harré et al., 1996; Mueller et al., 2012; Yan et al., 2014; Abou-Zeid et al. 2011). Age-related declines also impact behavior under reduced visibility; studies conclude that age can negatively impact car-following, reactions, and speeds of older drivers, leading to increased risk of crash involvement (Ni et al., 2010).

Additional findings that are common amongst different behavior studies indicated that drivers overall will not reduce speeds or demonstrate behavior change until visibility distance was severely impacted (Brooks et al., 2011; Klinjnhout, 1991; Yan et al., 2014). It is noted that speed reductions between 250m and 50m were the same overall and indicated that drivers may only decelerate up to a certain point, even as the visibility scenario worsens. This result is determined to possibly stem from the no-risk simulation environment and that drivers in simulation experiments will travel at significantly higher speeds. Due to this, mean and standard deviations of data tend to be much greater in simulation studies than the real-world (Bella, 2008; Bullough and Rea, 2000; Ekanayake et al., 2013; Tornos, 1998). Even with these unfavorable results, it is still possible to note that increased speed under foggy conditions does have potential for increased risk considering the rate that low speed crashes occur (Svenson et al., 2012; Yan et al., 2014). In terms of real-world studies, prior researches on locations have found impacts of decreased visibility on speed and headway. A project conducted by Aty et. al (2011) analyzed traffic data collected from I-4 using weather and traffic sensors found that vehicles' average speed were only reduced by approximately 2MPH, from 72MPH to 70MPH, when visibility dropped down to roughly 200m.

Driver recognition is another very common behavior that is observed in low visibility studies. Typically projects that focus on driver perception and visibility primarily study driver eye movements which prove beneficial in determining attentiveness and recognition (Konstantopoulos et al., 2010; Bremond et al., 2013). It is noted that the main attributes that contribute to drivers' ability to identify objects stem from the severity of visibility restriction and age. From studies on this topic, it is found that older drivers were more likely to follow lead vehicles at closer distances due to the difficulty perceiving speed change under foggy conditions (Ni et al., 2010). Additional research into this topic of headways indicated an interesting finding in car following behavior. Under reduced visibility conditions, drivers will typically demonstrate either a "lagger" or "non-lagger" behavior (Broughton et al., 2007). Broughton describes these behaviors as; drivers were found to either 'lag' by distancing themselves from other vehicles to the point where no visibility of the car was available, or 'non-lag' where drivers would keep a distance so that the car in front of them was still in visual range. Both behaviors are acknowledged to have some risk involved with them, and are attributed to defensive, low risk, and aggressive, high risk, drivers.

2.2 DMS Impact on Driver Behavior

Dynamic message signs allow for the displaying of information depending on the situation or intended use of the sign, including warnings of upcoming roadway hazards, display traffic conditions as well as alternative routes, and many more including enforcement and other important messages. With the ability to provide real-time traffic information, it becomes much easier to control traffic flow and congestion and thus improve the efficiency of the roadway network (Emmerink et al., 1996; Shang et al., 2008; Yan and Wu, 2014). To research the impact of these signs, many studies focused on simulation and real-world data to analyze the effects of the message displayed.

Studies on message comprehension found that poor use of messages, including vague messages or invalid information which can often lead to ineffective DMS/VMS application as people will simply ignore the sign due to confusion or error (Schroeder and Demetsky, 2010; Haghani et al., 2013). An individual's ability to comprehend a message can vary greatly, largely based on drivers age where older drivers require more exposure time to process the information presented (Collura, 2009). Studies also looked at other driver characteristics such as gender; however none observed significant differences in driving behavior other than age and driving experience. When considering visibility studies, comprehension can also be impacted by reduced visibility scenarios such as fog. With decreased visibility, legibility can also be impacted thus making signs much harder to read or notice thus severely reducing message exposure time to drivers. Yan and Wu (2014) observed that the overall effectiveness of different messages on a DMS is dependent on the speed of the traffic flow at the location. At higher speeds, drivers have less time to read and comprehend the message being delivered.

To counteract this, researchers have looked at different ways to present the messages via abbreviations and graphics. In terms of traffic diversion studies, it is found that emphasizing the obstacle and abbreviating longer text or using graphics led to increased diversion rates to the alternative routes given (Schroeder and Demetsky, 2010; Huang and Bai, 2014). Also, in a surprising finding, many of DMS studies focusing on diversion based on the type of message presented concluded that more people will divert, and a much higher and faster rates, when a graphic is used in place of a text message (Jeihani and Ardeshiri, 2013; Yan and Jiawei, 2014; Haghani et al., 2013; Wang et al., 2006). This is believed to be the case as many drivers, especially non-native language speaking, are able to process symbol meanings, such as arrows or works present, quicker and with more accuracy; the graphics also provide a much more eye catching message than simple text.

How the DMS message is displayed is also heavily researched, this includes the color and size of the message, what information is provided, and what instructions are given. Each of these variables of interest are found in multiple studies to have significant impact to driver recognition, behavior, and even accident rates (Haghani et al., 2013; Yan and Wu, 2014; Wang et al., 2006). Messages that provided information on alternative routes that saved drivers on travel time greatly increase divergence rates to these routes and also assisted in alleviating congestions in heavy traffic roadways. Effectiveness of these messages are observed based on the detail and how the message on the DMS/VMS sign is presented, as well as the drivers overall age, experience, and focus. Location is noted as extremely important since it is necessary to give drivers prior warning with adequate time to an obstacle so that they may prepare or be made aware of the scenario. As such, it was determined that if VMS/DMS are located too far away from the referred object or location, then drivers are less likely to follow this information (Yan and Jiawei, 2014). Additionally, it is found that drivers are also less likely to follow DMS/VMS instructions if they were unfamiliar with the message device, the information provided was too vague and not detailed, or if the message was to complex or inaccurate (Al-Deek et al., 2012; Yan and Jiawei, 2014; Jeihani and Ardeshiri, 2013; Kolisetty et al., 2006; Jamson et al., 2005).

As far as driver characteristics go in regard to DMS/VMS application and effect, driver age appeared to be the main factor that impacted performance. The consensus on this finding appears to still be in need of some focus, as some researchers have found that older drivers are more likely to follow a DMS/VMS guidance than younger drivers while other studies have found the exact opposite (Yan and Wu, 2014; Collura and Fisher, 2009). Many arguments can be made from both sides; younger drivers are less experienced, more distracted, but have better reaction time and mental processing, while older drivers are more experienced but are also possibly unfamiliar with the technology. Considering that many of these studies focus on diverting traffic due to congestion, it is likely that a person will ignore the DMS/VMS if they do not believe the information is accurate or do not understand the message being directed (Zhou and Wu, 2006; Adler, 2000; Lee and Abdel-Aty, 2008).

Additionally, the color of the message on the DMS/VMS are also found to be significant in traffic diversions, most likely due to the message being more visible or noticeable (Wang et al., 2006). Whether the message contained estimated travel times also appeared to impact the flow of traffic and decisions of the drivers as well. When no alternative route data is present, drivers are unsure if leaving their current route would prove beneficial in saving travel time and would then prefer to stay on the trip that they are more comfortable with (Collura and Fisher, 2009; Yan and Wu, 2014; Haghani et al., 2013). Ultimately, no matter the message or how it is presented, it is easily concluded that simply with the presence of a DMS/VMS, lane changing behavior is much more noticeable and frequent (Yan and Jiawei, 2014; Erke et al., 2007).

Although these findings and applications do look promising, additional research is necessary in order to better understand the most effective way to apply these signs. This however, can be very difficult especially when considering how recent the technology and usage has been. Due to this, one study suggests that future investigations on drivers responses towards the message signs when it is no longer a new technology would provide better results (Al-Deek et al., 2012). How the message on the sign is displayed also require additional extensive research; considering that many researchers found a significant impact of using a graphical message instead of just a text shows how important presentation of the message is. Testing DMS/VMS in adverse weather conditions or in different roadway geometries and segments could also provide significant findings in regards to DMS/VMS usage or placement (Haghani et al., 2013).

2.3 Additional Research Applications

Beacons are another commonly used roadway device that is primarily employed as warning devices to alert drivers and provide cautionary information to help control traffic behavior through messages. Based on their design, beacons are mainly used to draw a driver's attention to other objects such as signs; however under fog conditions the signs can become obscured thus changing how the beacon is viewed and performs.

A typical use for beacons under reduced visibility is to assist drivers in recognition of objects such as signs or warnings. A classic example can be seen from a research study which used flashing beacons on a stop sign in order to improve stopping behavior (Gates, 2004, Bullough and John, 2014). Ultimately, it was found that more vehicles came to a complete stop (approximately 29%) once the beacons were installed than prior. This shows that by drawing driver attention to this message, more were aware of the required actions that were needed.

However, in low visibility situations, a beacons ability to draw driver attention could be negatively impacted due to the reduced sight distance of the driver. If the fog is dense enough, the flashing beacon might be visible, but the message it is trying to convey will not and will be obscured to the driver. In some situations, the presence of the flashing light could create a sense of urgency or caution to the driver, but if the driver is unaware of the dangers or course of action needed, no help will be gained. To combat this problem, Fitzpatrick et al. (2011) proposed an advanced warning system, to warn drivers of an upcoming stop rather than right at the stop. It is found that when these beacons are present along with the ‘stop ahead’ warning, drivers approaching a stop sign had significantly less speed than without the device (Fitzpartrick et al., 2011, Zwahlen, 1988). This act of advanced warning indicated positive driver behavior results, the same behavior that is necessary when attempting to traverse reduced visibility situations. Interestingly, it is also noted in the study that LED brightness did not have a significant impact on sight detection; indicating drivers could identify them from any distance, regardless of how intense the flashing light is.

2.4 Simulation Validation Methods

Validation of simulation studies is necessary in order to compare the observed data to real world behavior. The most commonly used method for validation of these simulation experiments involves comparing results to real-world data either by testing the real-locations under similar conditions or looking at historical trends (Yan et al., 2014; Ekanayake et al., 2013; Blaauw, 1982; Godley et al., 2001). If a strong correlation is found between the two data sources, it is possible to conclude that the results are an accurate representation of the real-world. When considering the necessity of validation, specifically based on driver behavior, using more advanced simulators could make the correlation between the simulated and real-world stronger due to the increased realism (Allen et al., 2011; Mueller and Trick, 2012; Pradhan et al., 2009; Taylor et al., 2011; Vidotto et al. 2011).

2.5 Conclusions

Although many studies have been conducted on fog and DMS effects on driver behavior, there is a lack of research on an effective early warning system design. A large scale project with an experimental design testing a large pool of drivers provides the opportunity to also find additional information on how driver characteristics and roadway conditions can affect driver behavior under reduced visibility conditions. Finding the most effective design using simulation can also save a considerable amount of money as prior testing can determine reasonable designs without wasting costly resources. Additionally, with the considerable amount of vehicular accidents occurring along roadways due to hazardous conditions, the need for an effective system is in high demand and could save many lives.

CHAPTER 3: DATA DESCRIPTION AND PREPARATION

All data needed for this research is collected via the simulation tests as well as demographic data collected from the participants themselves. The demographic data includes: Gender, Age, Income Level, Experience, Education, etc; this data is used to compare how driver behavior varies between different types of people and also allows for studying notable trends in driving behavior changes based on the population. The main variables that are observed are more based around the drivers' behavior while under the simulated fog and DMS conditions. These observed behaviors include the drivers speed, braking, following distances, recognition of the DMS message, and so on. These variables are tested and obtained during the simulation scenarios under varying conditions. Each scenario's conditions are based on additional factors and variables that are recorded and noted for the analysis. The scenario variables, as mentioned previously, are the Roadway Type, Fog Condition, Signage Presence, Signage Text, and Setting. Additionally, since all these variables are tested on human participants, IRB approval is required in order to begin the experimental testing. IRB approval was obtained from the UCF Institutional Review Board #1 (IRB no SBE-15-11026).

With the use of human subjects, the experimental unit for this research is defined as a "Person."

The list of the observed variables follows…

1. Demographic
    a. Gender (M / F)
    b. Age
    c. Experience
    d. Driving Frequency

2. Driver Behavior
    a. Speed
    b. Breaking/Deceleration
    c. Following Distance
    d. Sign/Vehicle Recognition
3. Scenario Conditions
    a. Roadway Type (Freeway / Arterial)
    b. Fog Visibility (Light – 500ft / Medium – 300ft / Heavy – 150ft)
    c. Number of DMS Present (0 / 1 / 2)
    d. Signage Text (Null / Warning / Advised)
    e. Traffic Setting (Light / Heavy)
    f. Beacon Presence (0 / 1)

The need for the specific driver behavior and scenario condition variables is a result of the overall goal that is attempting to be accomplished in this research. Since it is desired to test how the typical person will react in a fog condition and whether DMS presence can impact these reactions, it is important to narrow down what conditions are changed and tested. In this case, fog condition, signage presence, and signage text/message are chosen. Roadway Type represents the two separate roadway scenarios that are tested, one being highway I-75 and the other being arterial SR441. Fog condition is a necessity for this experiment as fog thickness is expected to have the biggest impact on a subjects driving ability due to its impact on visibility distance. It is obvious that limitation to driver visibility plays a significant role on driver performance and habits, which itself impacts overall roadway safety. The levels of the fog indicated above for the simulation would be based on the overall visibility distance so that the data can be quantified and can be used for analysis. In this case, the most mild fog condition would have a visibility distance of roughly 500ft while the most extreme condition limits visibility to 150ft. Visibility distances greater than 500ft are not tested due to data and time limitations, and also considering that drivers will not lower their overall speed until sight distance is severely reduced based on past research.

Similar to fog conditions, dynamic message signs have a vast amount of variability in both appearance and how they can be used along the roadway. These differences include number of signs and message presented, as well as other factors including brightness, sign type, message color, and so on. Since this study focuses more on driver behavior impacts rather than how noticeable the sign is, only the first two variables were chosen for this study. By varying the number of signs, it is desired to create a greater sense of urgency and reminder when drivers proceed through the scenarios. Varying the message of the signs may also play a significant impact to this sense of urgency and driving behavior. In this case, warning and advised type messages are chosen for the scenarios. Warning messages will simply indicate the upcoming fog condition and will follow the message format of "Caution Fog Ahead." Advisement messages on the other hand will display alerts of upcoming fog, while also presenting a recommendation for driver action. For the purposes of this experiment, these messages will focus primarily on advising speed reductions, for example; "Fog Ahead, Reduce Speed." Due to the limitation of realism with simulation studies, the message designs are limited and are unable to incorporate "enforced" messages. Many different messages can be used to relay information along these lines to the driver; in order to be used however; the message must meet FDOT standards on DMS signs. In this case, since the roadway being used has a speed limit of 70MPH, only a maximum of 6 words can be used for the messages, and the exposure rate must allow one second per word in the text. Finally, the text message was decided to be amber on black in text color design as it is determined to be the most eligible and is the more common DMS color seen (Haghani et al., 2013; Wang et al., 2006). It is true that other color combinations provide better urgency and possibly better visibility under fog, but such topics are beyond the focus of the study.

Aside from the data being collected from the simulation scenarios themselves, additional information is also collected from the participants via questions in regards to the scenarios they just ran. The types of questions asked focus primarily on the how the driver felt about the scenarios they just ran including their ability to perceive and understand the messages, vehicles, or other variables being presented to them or how they reacted to the fog condition. Collecting this information allows for further possible analysis on why the drivers performed the way they did and allows for some comparison between the simulator results and participant feedback. Following the experiment, feedback is also collected on the simulation procedure and scenarios that can be used for future research study improvements.

The scenarios themselves are tested using a NADS MiniSim driving simulator, as seen in Figure 2, which also allows for the collection of driver input and data from the study participants runs for analysis. To create these scenarios, ISAT software was used which enables the research team to add traffic, signs, and other obstacles and variables to the generated scenarios. Additionally, TILES is used to design and layout the roadway geometry for the two roadway types studied as well as additional road segments and ramps. The chosen speeds and headways for the simulated traffic for these scenarios are based on field data that is collected from traffic and weather sensors along roadways south of the study location in Polk County. By determining when fog occurs using the weather data, we are able to look at traffic behaviors during that fog duration and compare it to clear condition behaviors. The time that these readings indicate are also important as traffic headways vary greatly throughout the day as traffic volumes increase. As such, the “Traffic Setting” variable is used to reflect these variations in observed traffic throughout the day.

Figure 2: NADS MiniSim Driving Simulator

CHAPTER 4: EXPERIMENTAL DESIGN

4.1 Overview

The design for the scenarios breaks them down into specific variables of multiple levels related to the simulation scenario environment. These variables and levels are as follows:

- Roadway Type: (Freeway / Arterial)
- Fog Visibility: (Light – 500ft / Moderate – 300ft / Heavy – 150ft)
- Number of DMS: (0 / 1 / 2)
- Signage Text: (Null / Warning / Advised)
- Beacon Presence (0 / 1)
- Traffic Setting (Light / Heavy)

Considering that no sign text can be displayed on a sign that is not present, and every combination of variables is used, 108 scenarios can be generated to run on the freeway and another 108 on the arterial. This number of scenarios can then be further reduced when assumptions are made such that any signs beyond a single one within a light fog condition would prove insignificant in effect to the more severe conditions. It can also be assumed that beacons are not necessary for light fog conditions and can be ignored in the study. Removing theses conditions further reduces the number of possible scenarios for both road types allowing more focus to test the remaining scenarios to a further extent. Attempting to use this many scenarios in testing would require a considerable amount of participants to run, especially when accounting the fact that these scenarios must be tested for both freeways and arterials as well as different traffic settings. To avoid this issue, multiple scenarios are run by each participant using experimental block design. It is also considered that each participant will have the same driving habits based on the fog and sign conditions rather than the road itself.

As previously discussed, the ‘Fog Visibility’ variable deals with how thick the fog in the simulation appears to be and the levels will be based off overall sight distance in feet to determine a measureable intensity. The ‘Number of DMS’ variable indicates how many DMS signs are present, and the signage text tells what type of message is displayed on them. The ‘Traffic Setting’ variable is used in order to test light and heavy traffic scenarios that are likely to occur during the timeframe fog forms. Since fog typically occurs in the very late to early morning hours due to the rapid cooling and heating of the air, it was important to reflect the traffic volumes of these times for further analysis and validation. In this case, the setting used will reflect an early morning scenario that occurs between 6:00AM and 8:30AM, as fog is more likely to be present during this time of day with traffic available, and is consistent with the data collected. The light traffic setting uses data observed between 6:00AM and 7:00AM which has average headways of 20 seconds, while the heavy setting occurs between 7:30AM and 8:30AM with headways of 10 seconds. Based on past research and the traffic data collected, it is also known that traffic speeds will vary depending on the severity of the fog in the scenario. To reflect this, the simulated traffic will have its speed adjusted as it enters the fog region from the initial clear segment. These changes are summarized in Table 1 below. It is important to note that fog data is limited for visibility distances below 500ft soassumptions and estimations are necessary for fog-speed relationships at the 300ft and 150ft level.

Table 1: Fog-Speed Relationships

I-75 (Speed Limit = 70MPH)				
Visibility (ft)	Clear	500	300	150
Speed (MPH)	72	70.6	68	65
Std (MPH)	6.5	3.4	6.8	7
SR441 (Speed Limit = 65MPH)				
Visibility (ft)	Clear	500	300	150
Speed (MPH)	67	65	63	60
Std (MPH)	6.2	6.5	6.5	6.8

The scenarios generated with the restrictions, seen in Table 2, follows:

Restrictions:

1. If Light Fog and 2 Signs present then scenario is not needed.
2. If No Signs present then No Message can be displayed.
3. If 1 or 2 Signs are present then No Message (Null) can be displayed.
4. If Light Fog then no Beacon needed.

Table 2: Full Scenario List with Marked Restrictions

Run	Fog	#DMS	Message	Setting	Beacon
1	Light	0	Null	Heavy	0
2	Moderate	0	Null	Heavy	0
3	Heavy	0	Null	Heavy	0
4	Light	1	Advised	Heavy	0
5	Moderate	1	Advised	Heavy	0
6	Heavy	1	Advised	Heavy	0
7	Light	2	Advised	Heavy	0
8	Moderate	2	Advised	Heavy	0
9	Heavy	2	Advised	Heavy	0
10	Light	0	Null	Heavy	0
11	Moderate	0	Null	Heavy	0
12	Heavy	0	Null	Heavy	0
13	Light	1	Mandatory	Heavy	0
14	Moderate	1	Mandatory	Heavy	0
15	Heavy	1	Mandatory	Heavy	0
16	Light	2	Mandatory	Heavy	0

Run	Fog	#DMS	Message	Setting	Beacon
17	Moderate	2	Mandatory	Heavy	0
18	Heavy	2	Mandatory	Heavy	0
19	Light	0	Null	Light	0
20	Moderate	0	Null	Light	0
21	Heavy	0	Null	Light	0
22	Light	1	Advised	Light	0
23	Moderate	1	Advised	Light	0
24	Heavy	1	Advised	Light	0
25	Light	2	Advised	Light	0
26	Moderate	2	Advised	Light	0
27	Heavy	2	Advised	Light	0
28	Light	0	Null	Light	0
29	Moderate	0	Null	Light	0
30	Heavy	0	Null	Light	0
31	Light	1	Mandatory	Light	0
32	Moderate	1	Mandatory	Light	0
33	Heavy	1	Mandatory	Light	0
34	Light	2	Mandatory	Light	0
35	Moderate	2	Mandatory	Light	0
36	Heavy	2	Mandatory	Light	0
37	Light	0	Null	Heavy	1
38	Moderate	0	Null	Heavy	1
39	Heavy	0	Null	Heavy	1
40	Light	1	Advised	Heavy	1
41	Moderate	1	Advised	Heavy	1
42	Heavy	1	Advised	Heavy	1
43	Light	2	Advised	Heavy	1
44	Moderate	2	Advised	Heavy	1
45	Heavy	2	Advised	Heavy	1
46	Light	0	Null	Heavy	1
47	Moderate	0	Null	Heavy	1
48	Heavy	0	Null	Heavy	1
49	Light	1	Mandatory	Heavy	1
50	Moderate	1	Mandatory	Heavy	1
51	Heavy	1	Mandatory	Heavy	1
52	Light	2	Mandatory	Heavy	1
53	Moderate	2	Mandatory	Heavy	1
54	Heavy	2	Mandatory	Heavy	1

Run	Fog	#DMS	Message	Setting	Beacon
55	Light	0	Null	Light	1
56	Moderate	0	Null	Light	1
57	Heavy	0	Null	Light	1
58	Light	1	Advised	Light	1
59	Moderate	1	Advised	Light	1
60	Heavy	1	Advised	Light	1
61	Light	2	Advised	Light	1
62	Moderate	2	Advised	Light	1
63	Heavy	2	Advised	Light	1
64	Light	0	Null	Light	1
65	Moderate	0	Null	Light	1
66	Heavy	0	Null	Light	1
67	Light	1	Mandatory	Light	1
68	Moderate	1	Mandatory	Light	1
69	Heavy	1	Mandatory	Light	1
70	Light	2	Mandatory	Light	1
71	Moderate	2	Mandatory	Light	1
72	Heavy	2	Mandatory	Light	1

This scenario set up is useful in developing scenarios specific to testing a certain variable under any of the possible conditions. A good example of this includes scenarios that have no signs present but have different fog densities. This develops scenarios that are focused primarily on how the fog impacts the driver. Similarly, the light fog condition is expected to not have much of an impact on the driving behavior due to visibility distance, so some scenarios most likely will not see a majority of driving behavior being affected ideally by the message the sign presents.

Based on how the scenarios are currently established, the actual design that is used for this experiment represents a simple factorial design. Due to the amount of scenarios present and the limitation of the number of participants, these scenarios will need to be reduced further in order to generate an acceptable balanced design. To accomplish this, 12 scenarios were generated via randomized variables through statistical software. These 12 scenarios create the Block design that is used throughout the experiment. Since each participant is expected to complete 3 scenarios, each block will test 4 different participants. By repeating each block 9 times with different randomized orders and for each roadway type, we end up with a total of 72 participants running a total of 216 scenarios.

Table 3: Scenario Variable Levels

	Attribute	Description	Attribute Levels
x1	Roadway Type	Roadway types for simulation	1. Freeway
			2. Arterial
x2	Fog/Visibility	Fog intensity based on visibility	1. Low, 500ft
			2. Moderate, 300 ft
			3. High, 150 ft
x3	No. of DMS	Number of DMS used for warning	1. 0 sign
			2. 1 sign
			3. 2 signs
x4	Content of DMS	Message displayed on DMS	1. Null
			2. Warning
			3. Advised
x5	Traffic Setting	Traffic conditions	1. High Volume
			2. Low Volume
x6	Flashing beacons	Presence of flashing beacons along road	1. No
			2. Yes

With these variable levels seen in Table 3, it is possible to randomly generate 12 scenarios separately for each roadway type and then randomly choose from the pool of 24 scenarios to generate the testing blocks.

From Table 4, the scenarios that are tested are shown. These 24 scenarios are used in the block design to determine how the scenarios will be tested. Tables 5-10 list how many times the specific variable levels are tested within these scenarios.

Table 4: Chosen Test Scenarios

Scenarios	Road Type	Fog	#DMS	Message	Setting	Beacon
1	1	1	1	1	2	1
2	1	1	2	2	2	1
3	1	2	1	1	2	1
4	1	2	2	2	1	2
5	1	2	2	3	1	1
6	1	2	2	3	2	2
7	1	2	3	2	1	1
8	1	3	1	1	2	1
9	1	3	2	3	2	2
10	1	3	3	2	1	2
11	1	3	3	3	1	1
12	1	3	3	3	1	2
13	2	1	1	1	1	1
14	2	1	2	3	1	1
15	2	2	1	1	1	2
16	2	2	2	3	1	1
17	2	2	3	2	2	1
18	2	2	3	2	2	2
19	2	2	3	3	2	2
20	2	3	1	1	1	2
21	2	3	2	2	1	1
22	2	3	2	2	2	1
23	2	3	2	2	2	2
24	2	3	3	3	2	1

Table 5: Road Type Variable Count

Level	Road Type	Count
1	Freeway	12
2	Arterial	12

Table 6: Number of DMS Variable Count

Level	Number DMS	Count
1	0	6
2	1	10
3	2	8

Table 7: Traffic Setting Variable Count

Level	Traffic Setting	Count
1	Heavy	12
2	Light	12

Table 8: Fog Level Variable Count

Level	Fog	Count
1	500ft	4
2	300ft	10
3	150ft	10

Table 9: DMS Message Variable Count

Level	Message	Count
1	Null	6
2	Warning	9
3	Advised	9

Table 10: Beacon Presence Variable Count

Level	Beacon	Count
1	No	14
2	Yes	10

Table 11: Scenario Block Testing Order

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

As can be seen from the resulting scenario testing order in Table 11, each block contains 9 blocks of multiple 3 scenarios to test, which indicate the scenarios each participant will be running. Each block also contains exactly one occurrence of each scenario with no duplicates tested within the individual block; meaning only one scenario 1, 2, 3, etc occurs within each block.

As previously mentioned, the experimental design of the simulation experiment will follow a factorial design in order to effectively analyze the results from this experiment. Overall, we are looking for driver behavior trends based on severity of fog and the whether the DMS presence affects or significantly impacts these trends. This involves comparing how drivers act with no DMS presence and vise versa for each fog condition. We expect to see variability in driver speed and vehicle headway as the fog condition worsens, however the impact of the DMS sign on the drivers reaction to the fog is not very well known. Ideally, as the fog condition becomes more severe, driving speed is expected to be reduced due to the reduced visibility. These reactions are hopefully going to be much more apparent under DMS conditions as the driver will have forewarning of the upcoming conditions. Depending on these findings, the demographic variables can be referenced to see if any trends can be noticed between the collected data and the results.

The final part of the experimental analysis involves the validation of the simulation and resulting data. This can be done in many different ways, but in the case of this experiment data is collected from the real world roadways (I-75 and SR441) discussed previously. Through comparing the data between the simulator and sensors, it is expected to see similarities and common trends of the data. Since the real world scenario does not have any DMS present, the two sources will be compared with the base, zero signage, condition. The results of this comparison is discussed in section 6.

To observe a participants reaction in the scenarios, driver actions involving sudden percent change in acceleration or deceleration rates, braking, and vehicle headways will play a vital role in this analysis. These variables are modeled independently during analysis and will be focused on the locations where Dynamic Message Signs are present and where the clear condition begins to transition into foggy conditions. By doing this, it is possible to develop cases of drivers responding to these given variables from a constant base condition that can be compared with the scenario of interest.

4.2 Population and Sample

The population that are observed in this experiment consists of both male and female participants with ages ranging from 18 to late 60's who have their drivers' licenses and live in the State of Florida. In order for this experimental design to be performed properly approximately 72 participants are needed where each will be expected to run 3 random scenarios involving different visibility, DMS, or other roadway conditions. Also, since this research experiment tests two different scenario environments (freeways and arterial roads), both are equally represented in terms of the number of scenarios tested. In terms of gender, though not a variable that is ultimately focused on, there is an attempt to get as close to a fair balance between genders as possible. Similarly with age, it is expected that a majority of the participants will be ages 20-30's, so extra effort must be put into finding older participants through recruitment. To combat this issue, older friends, family, and working faculty and staff are recruited to participate in the study.

The decided age and gender distribution used for this study is based on observed crashes along SR 408, I75, and SR441. These results can be seen in table 12, and although it does not completely represent the participant sample, it is still used as an estimate in selecting which participant groups are tested. Overall, approximately half of the participants tested are in the 20's and 30's age group representing the majority of our testing sample. Likewise, older participants in their 60's will be the smallest sample tested making up about 10 percent of the population sample.

Table 12: Population Age and Gender Distributions

Real World			
Age Group	**Male**	**Female**	**Total**
18-24	7	10	17
25-35	9	7	16
36-50	11	8	19
51-60	6	4	11
60+	6	3	9
Total	39	33	72
Simulation			
Age Group	**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

Comparing the simulation and real world distributions in Table 12 via chi square analysis it is noted that comparisons between the male and female groups are not identical but are fairly similar. Significance for males is shown to be 0.337 and for females 0.341 which is fairly low and indicates that the two samples are not strongly correlated. However, when comparing the total ages of the two distributions, a stronger correlation is achieved. By comparing the correlation between the categorized age groups of the real world and simulation totals, a significance of 0.138 is achieved via a Pearson's R test. Although again, the distribution is not exactly the same, it is similar enough to use for testing of the driver ages and genders.

CHAPTER 5: SCENARIO STRUCTURE

Each scenario begins with the driver entering or traveling along the respective roadway under clear conditions and DMS presence if applicable to the scenario. Drivers will travel along this segment of the roadway with a posted speed limit of 70MPH for I-75 and 65MPH for SR441for until they reach the fog study region. By having the drivers travel along this clear road segment prior to the introduction of the test variables, we can allow the driver to get up to speed and develop a base condition of driving behavior that can be used for comparison and analysis of the impact of the variables. Once drivers pass the clear segment of the roadway, they will enter the variable testing zone of the roadway segment. Within this segment of road, the participants may encounter DMS or beacons if present in the scenario; the driver will encounter them within this area in the form of an overhanging gantry and static sign, respectively. After traveling along this segment, the driver will then gradually enter the variable fog zone with overall sight distance based on the scenario. As the driver approaches the zone, the fog will increase in thickness until the desired condition is met. The driver will continue along this roadway for another 2.5 miles until they exit the fog zone which indicates the end of the scenario. Assuming the driver keeps roughly to the speed limit, the entire scenario should take approximately 7 to 8 minutes.

Prior to this testing procedure, drivers are familiarized with the simulators' controls and operation. Participants are instructed on how to activate the vehicle as well as use the turn signals, pedals, and camera controls. Following this, participants are given a simple test course on the simulator which consists of a looping road path with present traffic. This scenario allows the participants to practice operating the vehicle as well as get adjusted to the sensitivity of the steering, acceleration, and breaking controls. Once the participant indicates that they feel comfortable with the handling of the vehicle, the actual test scenarios are conducted.

Aside from the presence of DMS signs, other obstacles such as traffic are also included in the simulation scenarios based on data collected from similar real-world locations. The traffic volumes used will present an uninterrupted flow with average expected traffic that would normally occur during the specific times of day when fog is expected to occur; in this case, the scenario is based on an early morning fog situation as it is the most common situation with high traffic volumes while fog is present. The behavior of the traffic is also based on the data presented and discussed in Chapter 4, including the speed and headway. Trucks are also represented in the scenarios based on observed truck percentages during the time of day studied. In this case, about 10% of the total simulated traffic are large trucks. These vehicles will be useful in creating a reference and environment that feels more realistic than an empty roadway, ideally dissuading participants from speeding through the scenarios and adding a sense of urgency. Being that these volumes occur at the indicated specific time of day, the lighting and environment of each scenario are set to best reflect these conditions and settings. Beacon presences are also a possible condition that participants may encounter as well. In scenarios with beacons present, they will be activated along the roadway and are attached to a standard “Fog Warning” or “Caution” signs. A visual representation of the described scenarios can be seen below in Figures 3, 4 and 5, as well as examples of the fog levels, DMS, Messages, and Beacons in Figures 6 to 10.

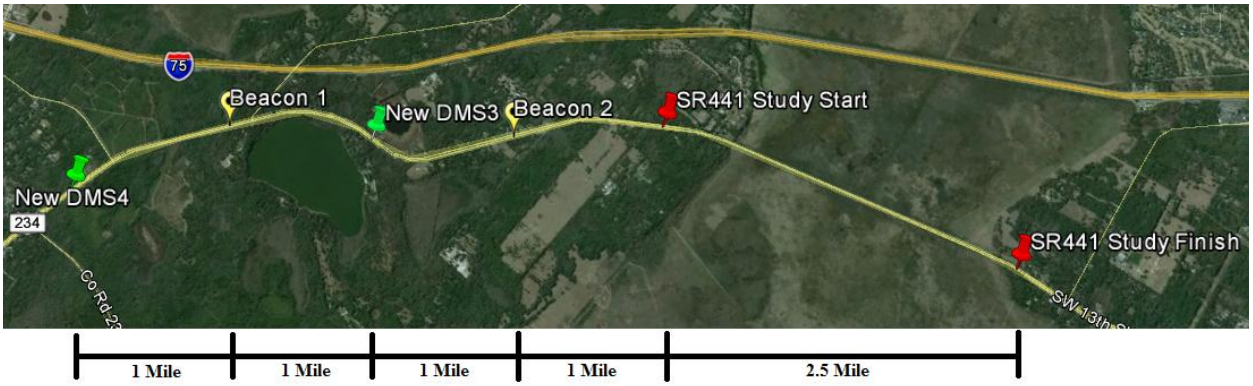

Figure 3: Simulation Scenario Plan for SR441

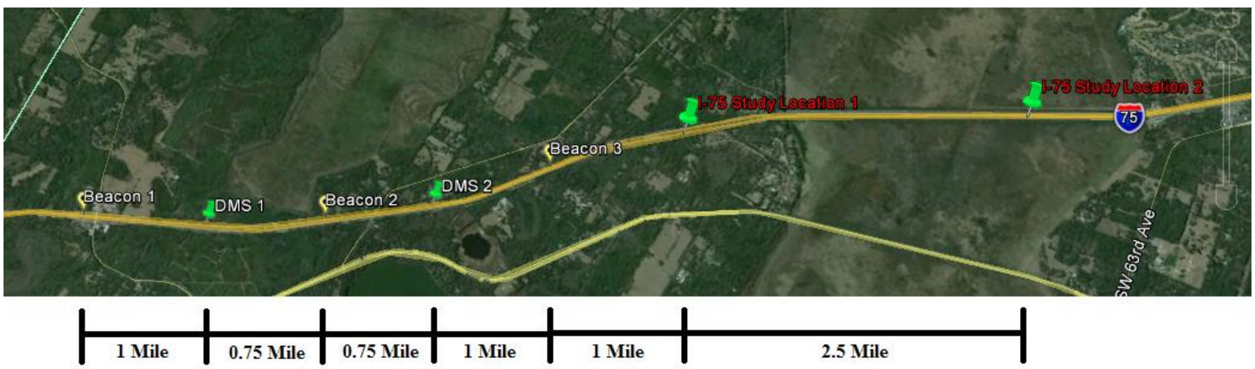

Figure 4: Simulation Scenario Plan for I-75

Figure 5: ISAT Model with Marked Fog Zone for I-75

Figure 6: DMS Model with Caution Message

Figure 7: DMS Model with Advised Message

Figure 8: Beacon Model Example

Figure 9: Light Fog Level Example

Figure 10: Heavy Fog Level Example

CHAPTER 6: ANALYSIS METHODOLOGY AND RESULTS

For the analysis of the simulation results and validation, ANOVA and logistic models appear to be the most common option based on the literature review of simulation studies. From these studies, varying ANOVA models (MANOVA, Repeated Measures, etc.) are used to compare results based on a response variable of interest. An example of this includes observing headways or speeds based on gender or age of the driver studied. Likewise, these models can also be used to compare observations from the simulation and real-world environment to see if similar trends appear for validation purposes. Binary Logistic and Logistic Regression models are used to fulfill these same purposes, i.e by finding significance in an observed variable or condition towards the resulting driver behavior. Additionally, Ordinal Logit and Multinomial Logit models are used to further analyze speed change behavior and validate results found from other models.

Driver speeds are collected from the simulation results to analyze changes between the clear and fog condition based on the presence of the experimental variables. To read the data, which is stored in a DAT file format from the simulator, Matlab is used to read the data files and export them to excel for use in SAS and SPSS analysis. Distances and fog level are also obtained from the DAT file in order to identify changes in speeds around DMS, beacon, and fog transition areas as well. Car following and lane change behavior are observed from the recorded video footage from the participants tests. These are simply recorded to indicate if the action or behavior is present and under what condition the driver performed the action. Driver reaction to the fog onset is observed by studying their deceleration behavior within the fog transition zone which provides additional insight to how the scenario variables impact driver reaction to fog.

6.1 Variable Overview

Before the analysis of the participants' reaction to the reduced visibility from fog is observed, frequencies and descriptive are accounted for to better understand the representation of the population. The results of the driver demographic variables can be seen below in the following figures and tables. Table 13 shows the distribution and corresponding variable level of how long the sample population possessed a driver's license.

Table 13: License Length Variable Distribution

Driver License Length		
Level	**Corresponding Variable**	**Percent**
1	Less than 5 years	20.1
2	5 to 10 years	36.4
3	11 to 15 years	15.3
4	16 to 20 years	7.2
5	21+ years	21.1

Based on the distribution, it is seen that a majority of the population for this sample had a license within the 5 to 10 year range, making up about 36% of the sample. The next highest groups were those who possessed a license for less than 5 years and 21 or more years, each level containing approximately 20% of the participant sample. With these results in mind, it can be seen that the sample contains a reasonable representation of both experienced and inexperienced drivers.

Driver age is also accounted for during the study in order to meet the population sample criteria discussed previously in table 12. The distribution and corresponding levels can be seen in Table 14.

Table 14: Driver Age Variable Distribution

Driver Age		
Level	**Corresponding Variable**	**Percent**
1	18 to 24	31.6
2	25 to 35	32.1
3	36 to 50	18.2
4	51 to 60	12.4
5	60+	5.7

This frequency of ages is reasonable and meets the requirement based on the distribution of crashes by age group described in section 4. Younger drivers, typically being the most risky, are more likely to demonstrate unsafe responses to the visibility reduction compared to older participants who are more experienced and cautious in their driver behavior.

Table 15: Drive Often Variable Distribution

Trip Frequency		
Level	**Corresponding Variable**	**Percent**
0	Never	1.4
1	1 to 5 trips per week	11.5
2	1 to 2 trips per day	43.1
3	3 to 5 trips per day	31.6
4	5+ trips per day	12.4

The results of the distribution in Table 15 demonstrate an expected distribution of driving habits. The typical person will drive 1-2 trips a day, primarily due to work or school travel. Following this are those who travel 3-5 trips for those who must make the previously mentioned trips as well as additional trips for shopping, eating, or personal reasons. It is also good to note that only 2 participants never drove due to not having a personal vehicle at the time and relied on public transportation. Additionally, those who drove 1-5 trips per week indicate participants who did not drive on a daily basis.

Since the simulation test is conducted on the UCF campus, noting a drivers' education was necessary in order to view how much of the sample is college educated. The distribution of education levels are shown on Table 16.

Table 16: Driver Education Variable Distribution

Education		
Level	**Corresponding Variable**	**Percent**
1	Some High School	0
2	High School	2.9
3	Some College	33
4	Bachelors'' Degree	30.6
5	Graduate School	33.5

From Table 16, those who have some or only a high school education are underrepresented in this model as these participants are rare and difficult to recruit for the study. However, the other three education levels are evenly distributed allowing for a reasonable observation of those with varying college educations.

Table 17: Driver Income Variable Distribution

Income		
Level	**Corresponding Variable**	**Percent**
1	0 to 10,000	18.7
2	10,000 to 25,000	18.2
3	25,000 to 40,000	12.9
4	40,000 to 55,000	15.8
5	55,000 to 70,000	11
6	70,000+	23.4

Table 17 shows a fairly even distribution in the sample for income is obtained which allows for a reasonable analysis of driver behavior under reduced visibility to income level.

Aside from the demographic information, participants are also asked if they were involved in a vehicular incident within the last 3 years resulting in the distribution Table 18.

Table 18: Had Accident in Last 3 Years Variable Distribution

Involved in Vehicular Accident		
Level	**Corresponding Variable**	**Percent**
1	Yes	16.7
2	No	83.3

From the distribution, it is seen that only about 18% of the sample represents drivers who were recently involved in an accident. Analyzing only the participants involved in crashes could show interesting results, however the sample size is fairly low, possibly resulting in an unreasonable model.

Driver gender is noted during the study for analysis purposes as well as ensuring a reasonable population sample is used to represent the real world.

Table 19: Driver Gender Variable Distribution

Gender		
Level	**Corresponding Variable**	**Percent**
1	Male	52.2
2	Female	47.8

As seen in Table 19, the distribution between the genders is evenly represented, demonstrating a good representation of the driver crash data from FDOT described in chapter 4.

Table 20 shows whether a participant learned to drive in the State of Florida or not.

Table 20: Learned to Drive in Other State Variable Distribution

Learned to drive in another State		
Level	**Corresponding Variable**	**Percent**
1	Yes	37.3
2	No	62.7

Finally, the type of vehicle the participant drove is recorded with the results shown in Table 21.

Table 21: Vehicle Type Variable Distribution

Type of Vehicle Driven		
Level	**Corresponding Variable**	**Percent**
0	No Vehicle	1.4
1	Sedan	67
2	Truck/Van	13.9
3	Motorcycle/Moped	0
4	Professional Vehicle	0
5	Other	17.7

From the results we see that a majority of the participants drove with a sedan while none used a motorcycle or professional vehicle. Additionally, whether the participant is a professional driver or not is also recorded. Those who were professional drivers were not common within the study, which is also reflected in the vehicle type variable, and do not provide a reasonable representation of the population sample for analysis.

Aside from driver demographic data, multiple scenario variables are also present which are implemented via experimental design to create the scenarios used for testing. Distributions of these variables and the level descriptions are listed below, starting with road type in Table 22.

Table 22: Road Type Variable Distribution

Road Type		
Level	**Corresponding Variable**	**Percent**
1	Freeway	49.8
2	Arterial	50.2

From the distribution of roadway types, it is noted that each road has equal representation in the simulation testing process. This allows for comparison between the two types, primarily on the impact of number of lanes and speed limit.

Table 23: Fog Level Variable Distribution

Fog Level		
Level	**Corresponding Variable**	**Percent**
1	500ft Visibility Distance	17.2
2	300ft Visibility Distance	41.1
3	150ft Visibility Distance	41.6

The distribution of fog levels, seen in Table 23, is established so that the more severe fog cases are present as it is expected that 500ft visibility distance will not result in many significant behavioral changes. The more severe levels, 300ft and 150ft are evenly represented in order to compare significant impacts between the two.

Ideally, the two most important variables of interest for this study focus on the number of DMS present and the message that they display. Due to this, a somewhat even distribution is desired in order to view the extent that each variable level and combination impacts the driver responses to the fog hazard. The distributions and variables levels are shown Tables 24 and 25.

Table 24: Number of DMS Variable Distribution

Number of DMS		
Level	**Corresponding Variable**	**Percent**
1	No DMS Present	25.8
2	1 DMS Present	41.6
3	2 DMS Present	32.5

Table 25: Message Type Variable Distribution

Message Type		
Level	**Corresponding Variable**	**Percent**
1	No Message (No DMS)	25.8
2	Warning (Fog Alert)	36.8
3	Advised (Reduce Speed)	37.3

From these distributions, it is important to note that a message of variable level 1 corresponds to no DMS present. With this in mind, it is shown that No DMS and No Message are equally represented, as well as the remaining two message types. However, there are more scenarios tested involving just one DMS present rather than two. This still allows for comparison between no DMS present versus not.

The last two scenario variables tested include traffic volume and beacon presence whose distributions can be seen in Table 26 and 27. The traffic volume is not expected to impact driver speed changes, but instead can be used to test car following and headway behavior for future studies. Beacon presence on the other hand is tested to see if it has an impact on driver behavior both alone and in combination with DMS present.

Table 26: Traffic Volume Variable Distribution

Traffic Volume		
Level	**Corresponding Variable**	**Percent**
1	Low Volume	49.3
2	High Volume	50.7

Table 27: Beacon Presence Variable Level

Beacon Presence		
Level	**Corresponding Variable**	**Percent**
1	No Beacon Present	62.2
2	Beacon Present	37.8

Since a majority of both the demographic and scenario variables are observed as categorical values, some must be broken into individual dummy variables for analysis. Examples of such variables include age, income, fog, and so on. Each level of these variables will have its own variable created where if the indicated level is met for the value, then the variable will be '1' otherwise it will contain the value of '0.'

The continuous speed and speed ratio for the analysis is calculated using the indicated equations and results in the descriptive data seen in Tables 28 and 29.

$$Speed\ Change = (Avg\ Speed\ Clear) - (Avg\ Speed\ Fog)$$

$$Speed\ Change\ Ratio = \frac{Speed\ Change}{Average\ Speed\ Clear}$$

Table 28: Average Change in Speed Discriptives for Freeway

Descriptive Statistics for Freeway Road					
Variable	**N**	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
Avg. Speed Clear	105	64.45	99.73	73.63	5.23
Avg. Speed Fog	105	31.27	104.94	60.39	12.69
Speed Change	105	-5.21	41.12	13.24	10.16
Speed Ratio	105	-0.0522	0.568	0.183	0.143

Table 29: Average Change in Speed Discriptives for Arterial

Descriptive Statistics for Arterial Road					
Variable	**N**	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
Avg. Speed Clear	107	56.34	90.2	68.48	5.38
Avg. Speed Fog	107	29.63	97.16	59.72	11.71
Speed Change	107	-15.11	35.89	8.75	9.33
Speed Ratio	107	-0.194	0.548	0.131	0.141

The zones used to obtain these given values for the clear and fog speeds, as well as the zone used to study driver deceleration is shown in Figure 11. The distance of the clear study zone is approximately 5 miles while the fog study zone is about 2.5 miles in length. As for the deceleration zone, instead of being based on distance a 60 second time interval is used observing their initial and final speed over the given timeframe.

It is also important to note that less scenario observations are noted instead of the expected 216 from the experimental design. Some observations are dropped due to some participants being too motion sick to complete their last scenario. This reduction however is very minor and will not have a severe impact on the analysis results.

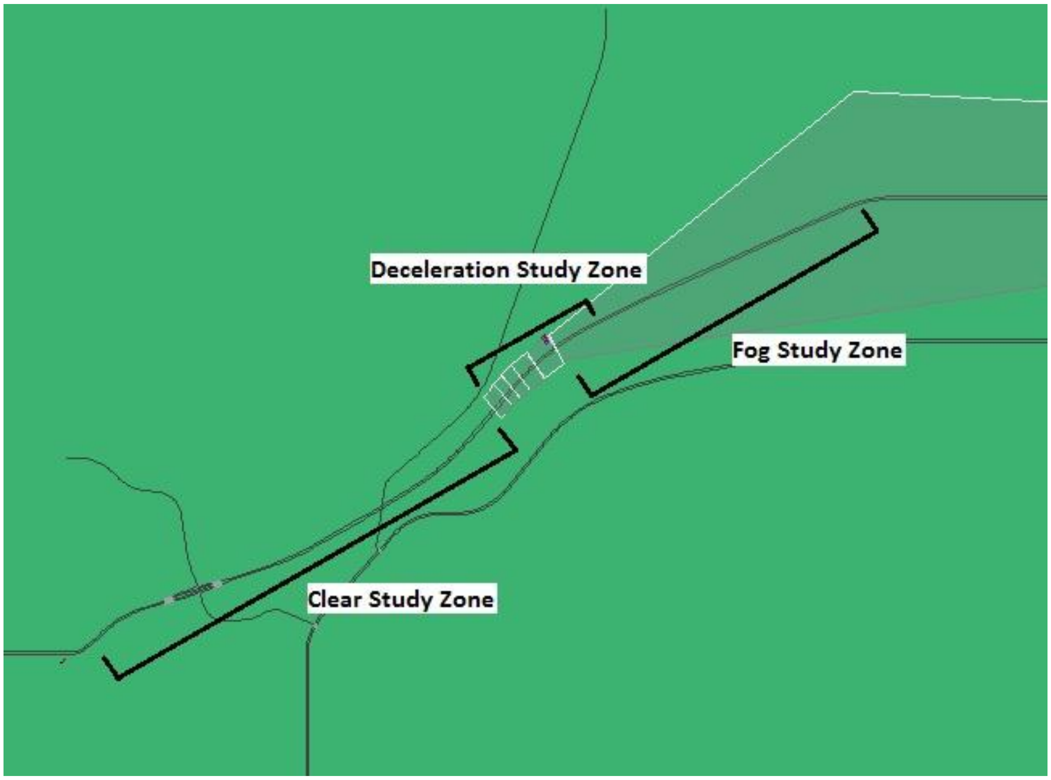

Figure 11: Simulation Study Zones

When comparing the simulated average speeds in Tables 28 and 29 with the real world average speeds in Table 1 of chapter 4, similar results are seen. Based on the clear speeds alone, drivers treated the simulation environment as if it were a real scenario, allowing for a valid analysis of the data for comparison of real world application. Additional analysis can be conducted using results from the study performed by Abdel-Aty et al. (2014) using speed data collected from I-4 which has a similar roadway structure to I-75. A summary of the traffic speeds observed are seen in Table 30.

Table 30: I-4 Traffic Speed Data

Variable	N	Minimum	Maximum	Mean	Std. Deviation
Speed Clear	300	65.5	78.57	73.38	2.24
Speed Fog	300	60.96	84.15	70.61	3.42

Computing an unpaired t-test between the clear conditions of the samples of the simulation results in Table 28 and the collected real world results in Table 30, it can be determined if the two samples present similar or different driver behaviors. From a 95% confidence test, a P value of 0.5023 is obtained indicating that there is no significant difference between the two samples. Additionally, since fog speed data is available for the 500ft visibility distance, comparison between the fog speeds of I-4 in Table 30 and the resulting simulation speeds of I-75 under 500ft visibility can also be performed for validation. Given that the sample size, mean speed, and speed standard deviation are 18, 70.62MPH, and 6.92MPH respectively, a 95% confidence t-test results in a P-value of 0.9822 which again shows no significant difference between the simulated and real world data. These results confirm that participants of the driving simulation experiment performed the same as drivers observed in the real world environment and therefore the simulation data is applicable to expected real world results.

The dependent variable of interest for the study focuses on the change in speed between the initial clear segment of the roadway and the final foggy segment. Average speeds from both parts are recorded and used to determine this change in speed resulting in the data seen above. Since two roadway types with different speed limits are observed in this study, the change in speed needs to be further worked to allow easy comparison between these two roads. This is necessary as the mean speed change is significantly less on the arterial road than the freeway. Since the arterial has a lower speed limit, drivers will not reduce their speed as much since they will meet their target speed reduction quicker due to the lower initial speed. To accomplish this, the speed change ratio is used when comparing the entire sample with both roadway types while the actual speed change is used when looking at individual road tests.

An example of one participant's results is shown below in Figure 12. The scenario shown involves a heavy fog condition along a freeway with two DMS and beacons present. Initially it is seen that drivers drastically increase speeds in order to quickly achieve a comfortable travel speed, typically at the roadways speed limit or slightly above. As the participant travels through the study zone, their speeds remain fairly consistent with some variations due to the sensitivity of the simulation controls. Once the fog transition zone is encountered, subjects show an exponential decrease in speeds due to the sudden onset of fog and will continue to reduce speeds until the target fog level is met. Within the target fog condition, similarly to the clear zone, subject's speeds are fairly consistent. Under heavy fog conditions, the typical subject reduced their speeds to 50MPH, as demonstrated by this participant, along both I-75 and SR441.

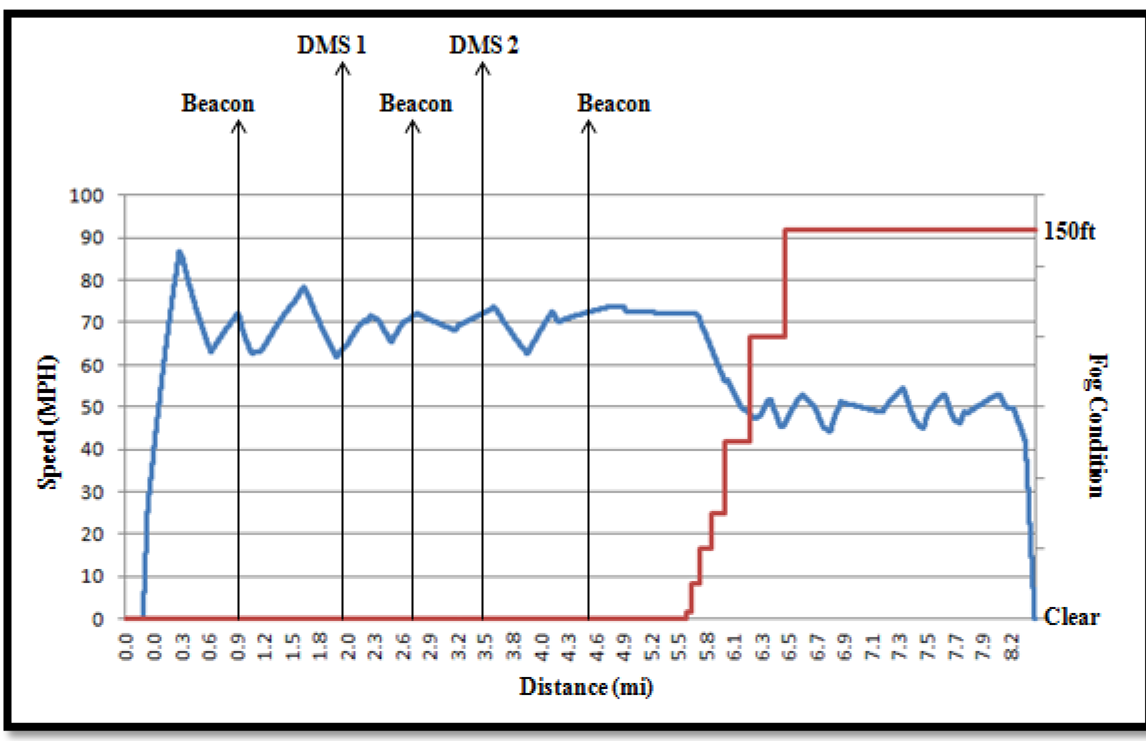

Figure 12: Driver Scenario Example

6.2 Continuous Speed Regression Analysis

Using the ratio of change in average speed between the two segments as the dependent variable, a regression analysis is performed to look at how the different levels of the variables impact the drivers' choice to reduce their speed when entering the fog condition. To allow for easier analysis, variables from the driver demographics and variables from the scenarios are analyzed separately. The insignificant variables are also removed until a best fit model is achieved.

Initially, a regression model is generated without considering dummy variables in order to determine which variables were more likely to be significant and worth further study

Table 31: Initial Driver Demographic Variable Regression

Variable	Beta Value	Std. Err	t-stat	Sig.
Constant	10.542	11.901	0.886	0.377
License Length	-0.053	0.927	-0.057	0.955
Not Recently in Fog	-4.543	1.719	-2.643	0.009
Familiar with DMS	-5.849	4.323	-1.353	0.178
Age	2.859	1.231	2.323	0.021
Learned in other State	-2.918	1.611	-1.812	0.072
Often Drive	1.276	0.76	1.679	0.095
Education	1.668	0.855	1.95	0.053
Income	-0.432	0.492	-0.877	0.382
Accident in last 3 years	-1.877	4.688	-0.4	0.689
Crash Type	-1.079	2.067	-0.522	0.602
Vehicle Type	-0.949	0.454	-2.092	0.038
Professional Driver	3.269	3.146	1.039	0.03
Gender	0.967	1.619	0.598	0.551

From Table 31, it can be seen that gender, crash history, and license length have no impact on speed change allowing their removal for further analysis.

Table 32: Initial Scenario Variable Regression

Variable	Beta Value	Std. Err	t-stat	Sig.
Constant	-1.641	3.366	-0.488	0.626
Road Type	-4.336	1.094	-3.965	0
Fog Level	8.006	0.796	10.059	0
Number of DMS	-1.095	1.015	-1.078	0.282
Message Type	1.633	0.962	1.698	0.091
Traffic Level	0.353	1.093	0.323	0.747
Beacon Presence	-0.383	1.155	-0.332	0.74

Likewise, for the scenario variables seen in Table 32, the traffic volume level and beacon presence is not expected to impact speed behavior and can be ignored for further regression analysis. For this additional regression analysis, the significant variables that have multiple levels are broken into separate dummy variables which allows for additional insight on the impact of the variables. The result of this final regression analysis is seen in Table 33, with an adjusted Rho value of 0.255.

Table 33: Final Driver Demographic Variable Regression

Variable	Beta Value	Std. Error	t-stat	Sig.
Constant	0.21	0.044	4.835	0
Not Recently in Fog	-0.093	0.023	-3.959	0
Learned in Florida	-0.024	0.021	-1.145	0.254
Drives Sedan	0.04	0.02	1.983	0.049
Age1	-	-	-	-
Age2	0.022	0.024	0.904	0.367
Age3	0.054	0.028	1.939	0.054
Age4	0.117	0.032	3.705	0
Age5	0.151	0.046	3.289	0.001
Edu1	n/a	n/a	n/a	n/a
Edu2	-0.059	0.057	-1.033	0.303
Edu3	-	-	-	-
Edu4	0.009	0.023	0.408	0.684
Edu5	0.062	0.024	2.617	0.01
Drive Often0	0.24	0.081	2.985	0.003
Drive Often1	-0.032	0.032	-0.979	0.329
Drive Often2	-0.043	0.021	-2.035	0.043
Drive Often3	-	-	-	-
Drive Often4	0.042	0.031	1.347	0.179

From the regression model of the driver demographic variables, it is seen that age, education, how often a person drives, the vehicle type, where the person learned to drive, and if the person did not recently drive in fog impacts speed change behavior. Focusing on age and education, we see that as both increase, the driver is expected to reduce their speed by greater amounts. These results stem from the fact that older drivers are much more experienced and therefore cautious when traveling through hazardous situations. Likewise, those who are more educated tend to be older and again more cautious of hazards as well as more aware of the possible dangers that could occur. It can also be noted that drivers are expected to reduce their speed when entering fog if they normally drive a sedan, indicating that those who drive larger vehicles such as trucks or vans are more likely to drive at faster speeds under reduced visibility.

This is possibly due to the feeling that the larger vehicle provides the drive with more protection or a higher eye level to see traffic ahead of them. These drivers could also be more used to this behavior under normal clear conditions and therefore are so used to it that they do the same under reduced visibility.

Looking at variables that decrease the probability that a driver will reduce their speed under severe fog conditions we see that those who learned to drive in Florida and drivers who have not recently driven in fog impact this behavior. Those who indicate these variables are most likely more confident in their driving behavior due to familiarity within the location and unfamiliarity driving under reduced visibility condtions. How often a person drives also has this effect if they drive 1-2 times a day. However, this effect is opposite for those who do not drive regularly or drive many times throughout the day.

Table 34: Final Scenario Variable Regression

Variable	Beta Value	Std. Error	t-stat	Sig.
Constant	0.024	0.029	0.843	0.4
Fog1	-	-	-	-
Fog2	0.055	0.023	2.407	0.017
Fog3	0.206	0.023	8.996	0
Advised Message	0.039	0.018	2.162	0.032
Arterial Road	-0.05	0.016	-3.209	0.002
DMS Present	-0.044	0.033	-1.352	0.178

From the scenario variable results based on the speed ratio dependent variable in Table 34 (R=0.388), it is seen that there are also aspects of the roadway and early warning system that also influence a drivers speed changing behavior when entering fog. With the based fog variable being a visibility level of 500ft it can be seen that as the fog becomes thicker, drivers are more likely to reduce their speed. This is expected as drivers will wish to increase their available time to react to objects that may suddenly appear within the fog. It’s also interesting to note that impact that each fog level has, where a visibility distance of 300ft has a slight speed impact and a visibility distance of 150ft has a much more considerable change. This demonstrates an exponential relationship between visibility distance and speed reduction where drivers will not greatly reduce their speeds until visibility is extremely limited.

Other scenario variables that have an impact on driver speed reductions include the message provided by the DMS and the roadway type. From the regression model it can be concluded that advised messages where drivers are told to reduce their speeds are more likely to cause drivers to do so rather than a simple warning message that provides no instruction. Based on this result, it can be hypothesized that indicating a specific speed to reduce to could provide an even greater result in drivers reducing their speeds when entering fog. For roadway type, an interesting result was found where drivers on arterial roadways were less likely to reduce their speeds compared to those who drove on freeways. This is most likely due to freeways feeling more busy and dangerous making drivers perform more cautiously compared to a fairly rural arterial road. This indicates that further emphasis on speed reduction is needed for arterial roadways in order to make drivers comply and travel safely through the fog.

Table 35: Combined Variable Regression

Variable	Beta Value	Std. Error	t-stat	Sig.
Constant	0.138	0.041	3.351	0.001
Not Recently in Fog	-0.082	0.019	-4.294	0
Learned in Florida	-0.028	0.017	-1.631	0.105
Drives Sedan	0.022	0.016	1.353	0.178
Age1	-	-	-	-
Age2	0.006	0.02	0.331	0.741
Age3	0.042	0.022	1.878	0.062
Age4	0.057	0.026	2.185	0.03
Age5	0.124	0.037	3.348	0.001
Edu1	n/a	n/a	n/a	n/a
Edu2	0.0004	0.046	-0.001	0.999
Edu3	-	-	-	-
Edu4	0.012	0.019	0.648	0.518
Edu5	0.059	0.019	3.095	0.002
Drive Often0	0.191	0.065	2.933	0.004
Drive Often1	-0.002	0.025	-0.091	0.927
Drive Often2	-	-	-	-
Drive Often3	0.02	0.017	1.214	0.226
Drive Often4	0.045	0.024	1.899	0.059
Arterial Road	-0.04	0.014	-2.834	0.005
Advised Message	0.018	0.009	1.957	0.052
Fog1	-0.054	0.02	-2.639	0.009
Fog2	-	-	-	-
Fog3	0.125	0.016	8.009	0

Combining the regression models for both demographic and scenario variables, as seen in Table 35, a stronger model is generated and provides a much better estimation of the variable impacts (R=0.522). Through the use of these estimates, a utility equation is used to determine the probability that a driver will reduce their speed when entering a fog situation.

$$U_s = Constant + B_{edu(x)} * x_1 + B_{age(x)} * x_2 + B_{oft(x)} * x_3 + B_{sedan} * x_4 + B_{Fog\,Year} * x_5 + B_{advised} * x_6 + B_{arterial} * x_7 + B_{Learn\,Florida} * x_8$$

Table 36: Combined Significant Variable Regression

Variable	Beta Value	Std. Error	t-stat	Sig.
Constant	0.22	0.043	5.09	0
Not Recently in Fog	-0.085	0.018	-4.783	0
Learned in Florida	-0.038	0.016	-2.382	0.018
Age3	0.039	0.019	2.057	0.041
Age4	0.057	0.022	2.559	0.011
Age5	0.104	0.033	3.174	0.002
Edu5	0.058	0.015	3.804	0
Drive Often0	0.16	0.061	2.632	0.009
Arterial Road	-0.044	0.014	-3.152	0.002
Advised Message	0.019	0.009	2.152	0.033
Fog1	-0.055	0.02	-2.75	0.007
Fog2	-	-	-	-
Fog3	0.128	0.015	8.269	0
N Observations	211			
R Square	0.548			
Adj. R Square	0.523			

Removing the insignificant variables from Table 35, the impact of each significant variable is seen in Table 36. From these results, the same conclusions can be drawn from the previous tables. Drivers who learned to drive in Florida or have not recently driven in fog are shown to be less likely to reduce their speeds by high amounts. This again, stems from the fact that these types of drivers are more confident or experienced driving in this environment. From the age variable, it is noted that drivers aged 36 and up are likely to significantly reduce their speeds under low visibility conditions. Additionally, it can be seen that as the age group increases, this speed reduction coefficient become greater, with the oldest age group being almost double than the second oldest group. This indicates that as a person ages, they become more cautious with their driving habits due to experience. Highly educated drivers (with graduate level education) are also noted to have significant speed reductions when entering fog conditions.

How often a person drives has an interesting result from the regression analysis. Those who rarely drive are noted to significantly reduce their speed by a great amount, and actually have the biggest impact of all the significant variables. This shows that those who are not comfortable with driving are extremely cautious in their driving behavior and greatly reduce their speed when encountering a visibility reduction. Of the groupings for how often an individual drives, this one is the only one found to be significant indicating that those who drive one to two times a day or more have similar driving behaviors.

Aside from these findings, arterial roads are again found to have significantly lower speed reductions compared to freeways. As previously stated, this result most likely stems from the speed limit difference between the two road types and that the drivers reduce their speeds to a specific speed limit rather than by a consistent amount overall. Additionally, advised messages result in significant speed reductions compared to just a simple warning message due to drivers being instructed to reduce speed. Finally, as expected, as fog level increases and visibility distance decreases there is a noted significant increase in speed reductions due to drivers compensating for the reduced available reaction time.

A final regression analysis is performed on the speed ratio, however this time using a different method of calculation.

$$Speed\ Change\ Ratio = \frac{Speed\ Change}{Speed\ Limit}$$

Table 37: Regression Analysis of Speed Ratio Using Speed Limit

Variable	Beta Value	Std. Error	t-stat	Sig.
Constant	0.431	0.044	9.845	0
Not Recently in Fog	-0.091	0.018	-5.087	0
Learned in Florida	-0.033	0.017	-1.974	0.05
Age3	0.038	0.019	1.973	0.05
Age4	0.046	0.023	2.041	0.043
Age5	0.106	0.034	3.132	0.002
Edu5	0.053	0.015	3.433	0.001
Rarely Drive	0.159	0.062	2.571	0.011
Drive 5+ Trips Daily	0.037	0.022	1.663	0.098
Arterial Road	-0.046	0.014	-3.265	0.001
Advised Message	0.03	0.014	2.076	0.039
Fog1	-0.195	0.021	-9.508	0
Fog2	-0.134	0.016	-8.58	0
Fog3	-	-	-	-
N Observations	211			
R Square	0.557			
Adj. R Square	0.53			

From the results in Table 37, it is seen that similar results to the regression shown in Table 36 occur. The only difference is seen based on how often a participant drove, where those who frequently traveled daily had a slightly higher likelihood of reducing speed. However this value is only significant with 90% confidence, it is still an expected result as those who constantly drive have more exposure to the roadway and the hazards that come with it. Additionally, when comparing the R square values of the two models in Tables 36 and 37, it is seen that the new model using the road speed limit has a slightly stronger representation of the data. However, since the models still show very similar results, it is concluded that these variables indeed have an impact on driver speed changes.

6.3 Categorized Speed Ordinal Logit Analysis

An Ordinal Logit is performed on the data using 5 categorical levels for the change in average speed between the clear and fog condition. This model allows for the observation of the likelihood that a variable will influence the probability that a driver will reduce their speed when driving under reduced visibility. The categories for speed change were separated into ranges of 4MPH, with the first being speeds equal to or less than 4MPH and the last being speeds greater than 16MPH. The distribution and descriptions of the levels of speed change are shown in Figure 13 and Table 38.

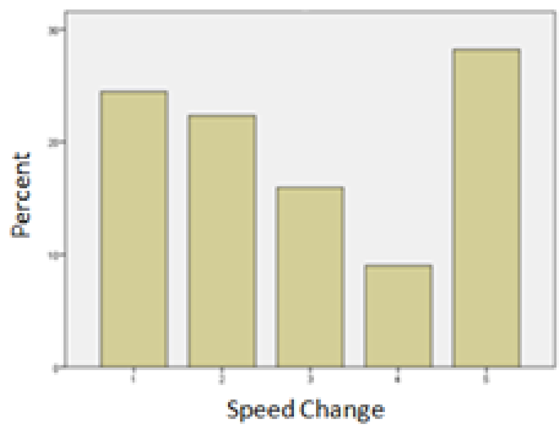

Figure 13: Categorized Speed Change for Ordinal Logit

Table 38: Ordinal Logit Speed Categorization Levels

Speed Change	
Level	**Corresponding Variable**
1	$S \leq 4$
2	$4 < S \leq 8$
3	$8 < S \leq 12$
4	$12 < S \leq 16$
5	$16 < S$

Using this distribution of speeds for the Ordinal Model, the independent variables from the simulation experiment dataset are added individually for analysis. By doing this, insignificant variables can be eliminated from each increment of the model, while the significant findings are kept. In the case of this model, we are testing and hypothesizing that the variables will influence the drivers' decision to change their speed between the clear and fog condition. The results of the final model are seen in Table 39 with the tau distribution visually represented in Figure 14 for a 90% confidence interval:

Table 39: Ordinal Logit Results

Variable	Parameter	t stat	P value
Fog	1.93	8.64	0
License Length	0.177	1.72	0.09
Learn Other	-0.74	-2.46	0.01
Often	0.315	2.04	0.04
Road Type	-1.24	-4.45	0
Vehicle Type	-0.172	-1.93	0.05
Tau1	0.532	0.55	0.58
Tau2	1.94	1.98	0.05
Tau3	3	3.01	0
Tau4	3.71	3.69	0
N Observation	212		
Rho Square	0.224		
Adj Rho Square	0.195		

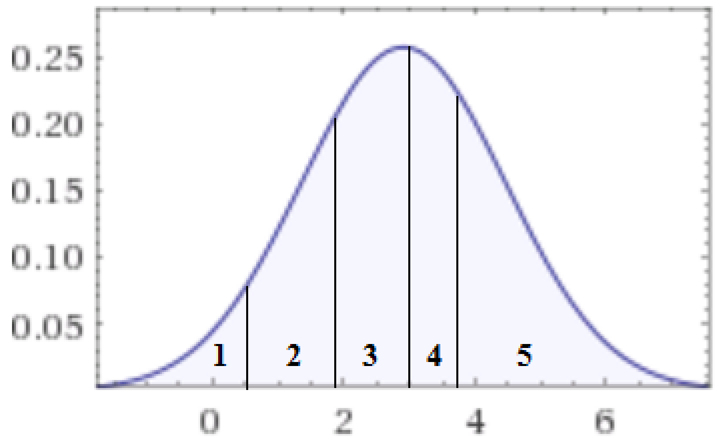

Figure 14: Ordinal Logit Tau Distribution

From these results, many conclusions can be drawn about how the variables impact the likelihood of a driver reducing their speed within the fog condition. For fog itself, it can be seen that there is an overwhelmingly positive effect from the parameter. This indicates that the thickness of the fog has a huge influence on a drivers' reduction in speed making them very likely to reduce their speed as visibility decreases. This makes sense as drivers' need to adapt to their obscured vision and slow down to allow for more time to react to possible hazards that may occur within the fog hazard. How often a person drives has similar results, although not as extreme, as fog where the more often a person drives the higher the chance they will reduce their speed within fog. This is primarily due to the fact that those who drive more are possibly more experienced and have more exposure to driving on roadways creating a more cautious behavior. The length a driver has his license has a similar effect where the longer an individual held a drivers license the more likely they are to reduce their speed in fog. However, this factor only appears as driver age is not present. This indicates a correlation between driver age and the length they own a license which is expected. Performing a Chi square analysis between the two variables confirms this as a strong significance is noted; the distribution of license length by age group for this analysis can be seen below in Figure 15.

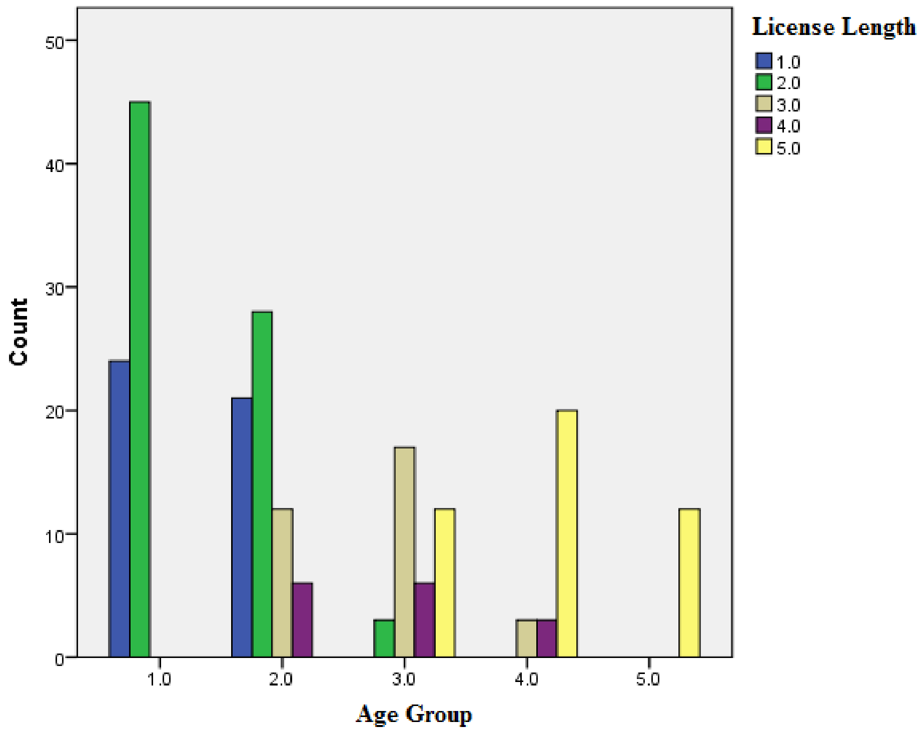

Figure 15: Length of License by Age Distribution

Additionally, there are two variables within the model that decrease the probability of a person reducing their speed within the fog hazard. Based on the 'learn other' variable (0=yes, 1=no), it can be concluded that people who learned to drive in Florida were less likely to reduce their speed compared to those who learned elsewhere. This can be best explained by the fact that drivers from Florida might be more comfortable and confident driving in a familiar environment. It is also possible that those who learned to drive in Florida are not well experienced with severe fog conditions as those who come from locations where it is more prevalent or have more roadway obstacles such as inclines due to mountain ranges. Road Type (0=Freeway, 1=Arterial) also had a negative impact, indicating that those who drove on the arterial roadway were less likely to reduce their speed compared to those who drove the freeway. This is best explained by the speed limit difference between the road types. Since the arterial has a lower speed limit and is less busy than the freeway, drivers feel that they do not need to reduce their speed as much. This also indicates that drivers reduce their speed to a specific point rather than a certain amount. They vehicle type result also indicates a decrease in likelihood to reduce speed if a person does not drive a sedan and instead travels using trucks, vans, or SUVs.

From this model, it can also be good to note the relationship between the change in speed and the fog condition. From Figure 16, it can be seen that those who reduced their speeds greater than 16MPH, typically only did so under the 150ft visibility condition. This shows that drivers typically will not reduce their speeds until visibility is extremely limited. Given that the other visibility levels were 500ft and 300ft, it can also be concluded that the typical driver is not reducing their speed enough to compensate for the visibility reduction. This puts the driver at a high risk of getting into an accident and possible injury.

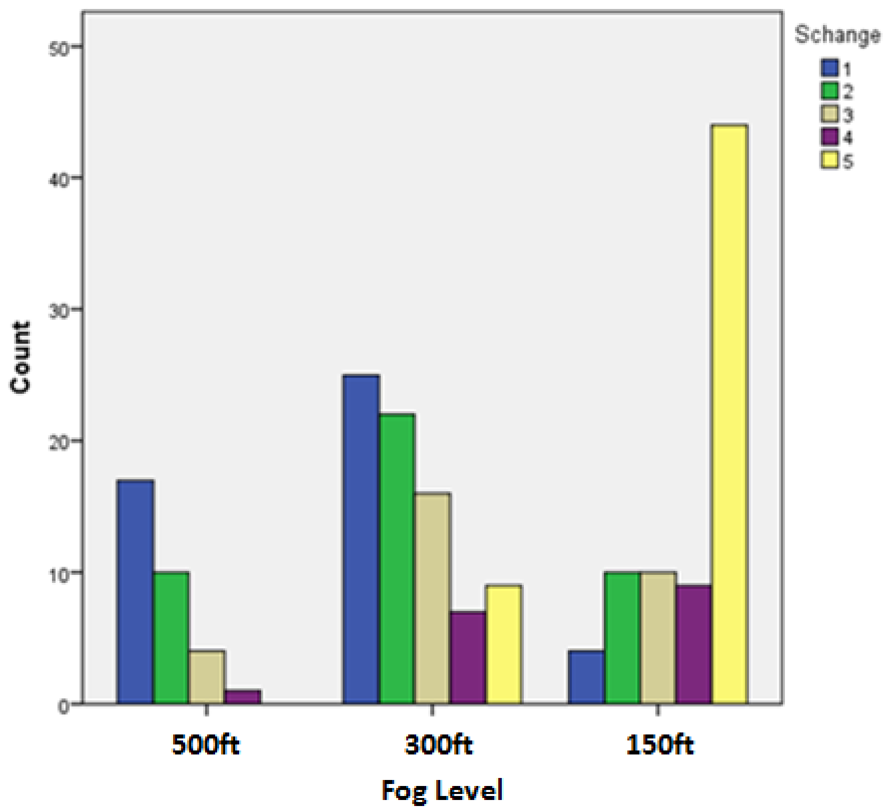

Figure 16: Speed Change Distribution by Fog Level

6.4 Categorized Speed Multinomial Analysis

In order to confirm and strengthen the results of the Ordinal logit model, a Multinomial model was also performed using 3 levels instead of 5 which can be seen in Figure 17 and Table 40. Doing this allowed for a more even distribution of the change in speed for each category and assisted in simplifying the model for easier analysis.

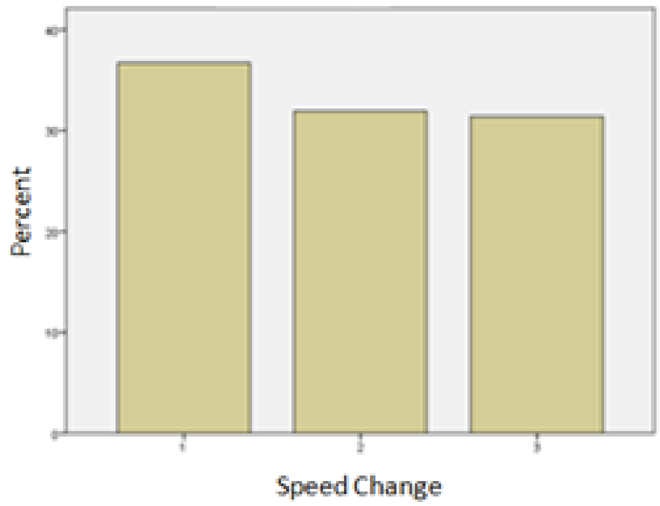

Figure 17: Categorized Speed Change for Multinomial

Table 40: Multinomial Speed Categorization Levels

Speed Change	
Level	**Corresponding Variable**
1	S < 6
2	6 ≤ S < 14
3	14 ≤ S

Using this distribution, variables were again added to the Multinomial model where only the significant variables were kept for further model iterations. The results of the final model obtained are seen in Table 41 at a 95% confidence interval.

Table 41: Multinomial Results

Variables	Less Than 6		6 To 14		14 Plus	
	Parameter	t stat	Parameter	t stat	Parameter	t stat
Constant	0	fixed	-0.576	-0.8	-9.78	-5.56
Fog	-	-	1.07	3.81	3.43	7.08
Road Type	-	-	-1.08	-2.93	-1.96	-3.91
Age	-	-	insig	insig	0.36	2.03
Education	-	-	insig	insig	0.464	1.86
Often	-	-	insig	insig	0.628	2.72
Observations	212					
Rho Square	0.284					
Adj Rho Square	0.245					

From these results, it can be seen that fog, road type, and how often a person drivers has similar results to that in the Ordinal Logit model. However, additional results can be seen in terms of driver's age, education, and the constant variable. For age, it can be concluded that older drivers have a higher preference to greatly reducing their speed between the clear and fog condition. This can be attributed to the fact the older drivers are more experienced and possibly even more cautious of their surroundings. Drivers with more education also tend to reduce their speed in greater amounts under severe fog which again stems from the idea that those with higher education are more cautious of the environment. The constant variable is negative for speed reductions, indicating that drivers prefer to not reduce their speed; however when considering that fog is always present within the scenarios, combining these parameters show that drivers prefer to do a mild change in speed and do not prefer to greatly reduce their speed.

6.5 Additional Analysis by Fog Level

Since the level of fog in the scenarios is found to consistently have the greatest impact on a participants speed changing behavior, additional findings are possible by comparing the change in speed and observed variables based on the fog visibility level. Running Chi Square tests for each individual fog level results in the following significant pairings:

Table 42: Chi-Square Significant Results by Fog Level

Visibility Distance	Chi Square Results		
	Variable	Value	Significance
500ft	Message	11.427	0.076
300ft	Road Type	10.579	0.032
	Traffic Level	8.99	0.061
150ft	Road Type	11.493	0.022
	Message	16.288	0.038
	Number DMS	15.671	0.047

Based on the results in Table 42, it is seen that the road type and the DMS message still has an impact on this behavior, however another interaction also appears and adds value to the results. The previous models that analyzed the data showed no significance in the number of DMS present along the roadway other than an individual's ability to recount the amount that they encountered. However, at the most severe fog level it is seen that the number of DMS do in fact influence a drivers speed change behavior.

Table 43: Regression Results for Speed Change at Fog Level of 3

Variable	Beta Value	Std. Error	t-stat	Sig.
Constant	38.04	4.407	8.632	0
Not Recently in Fog	-5.681	2.273	-2.5	0.014
Learned in Florida	-8.807	1.78	-4.949	0
Arterial Road	-5.345	1.942	-2.752	0.007
No DMS	-	-	-	-
1 DMS	3.162	2.423	1.305	0.196
2 DMS	4.812	2.43	1.98	0.051
N Observations	86			
R Square	0.363			
Adj. R Square	0.324			

From the results seen in Table 43, DMS presence does influence a driver's behavior and makes them more likely to reduce their speed going into a fog hazard when compared to situations where none are present. Although this appears to be a very mild effect compared to the other variables present, reworking of the message to indicate a specific speed change may help increase this impact even further. Additionally, when the DMS are applied to a real-world roadway, drivers will probably be more likely to pay attention and heed the DMS warning as there is more risk involved in those situations than in simulation.

Further analysis within this level of fog using the ratio speed change shows additional findings that provide insight into the variables' impact on driving behavior seen in Table 44 with an R^2 value of 0.255.

Table 44: Regression Results for Speed Ratio at Fog Level of 3

Variable	Beta Value	Std. Error	t-stat	Sig.
Constant	0.353	0.123	2.864	0.005
Not Recently in Fog	-0.114	0.035	-3.239	0.002
Learned in Florida	-0.147	0.027	-5.484	0
Professional Driver	0.113	0.064	1.764	0.082
Often0	0.215	0.091	2.368	0.02
Advised Message	0.069	0.029	2.392	0.019
DMS Present	0.09	0.035	2.574	0.012

From the final results in Table 44, similar findings are seen that are similar to the results in Table 36 where every fog level is considered for analysis. Those who did not recently drive in fog or learned to drive in Florida are both less likely to reduce their speeds by high amounts under low visibility conditions, even in the most severe condition. Participants who did not drive often or at all are noted to be very likely to greatly reduce their speeds, as are those who are professional drivers. Interestingly, being a professional driver did not appear as significant when all fog levels are considered which indicates that these drivers only reduce their speeds by a considerable amount when visibility is extremely limited. This possibly stems from their experience driving due to the exposure from their profession. Advised messages are again shown to influence drivers to reduce speeds under reduced visibilities when present. Considering that the fog is very severe in this analysis, the message has a greater impact on driver speed reductions than in the general model.

The only aspect of this model that is different from the one in Table 41 is that DMS presence is shown to cause significant speed changes between the clear and fog condition. Although this could be due to the message provided by the DMS being significant, it is interesting that the DMS only impacts speed changes at the most severe fog condition. Further analysis of the number of DMS and the impact they provide can be seen in Table 45.

Table 45: Speed Ratio Regression at Fog Level 3 with Number of DMS

Variable	Beta Value	Std. Error	t-stat	Sig.
Constant	0.355	0.044	7.989	0
Not Recently in Fog	-0.085	0.022	-3.799	0
Learned in Florida	-0.081	0.019	-4.288	0
Often0	0.197	0.08	2.477	0.014
Advised Message	0.041	0.021	1.959	0.051
One DMS Present	0.051	0.025	2.021	0.045
Two DMS Present	0.083	0.026	3.144	0.002
N Observations	86			
R Square	0.235			
Adj. R Square	0.21			

Based on the regression results for the number of DMS, it is seen that two DMS versus one being present results in slightly higher speed reduction. This is most likely attributed to the fact that drivers encounter and are more exposed to the message that they provide. When entering a light fog condition, drivers are most likely not influenced by the number of DMS due to feeling like there is not much risk as compared to driving under the severe visibility condition. Additionally, when comparing the R Square values between Tables 45 and 43, it can be concluded that when the message type is included the regression model has a significantly better fit and representation of the data. This further indicates that the message of the DMS is much more important than the number of DMS present.

6.6 DMS Remember Chi-Square Analysis

During the simulation experiment, drivers are asked how many DMS they encountered in each of their scenarios. This will be used to test whether the drivers remembered or noticed the signs during their drive. It can also be used to look at the effectiveness of the DMS countermeasure and also draw conclusions about effective uses for the device. The results from this question are shown in Figure 18 with variable levels listed in Table 46. Significant variables resulting from the Chi-square tests are also listed in Table 47 with the proportion of each variable shown in Table 48, 49, and 50.

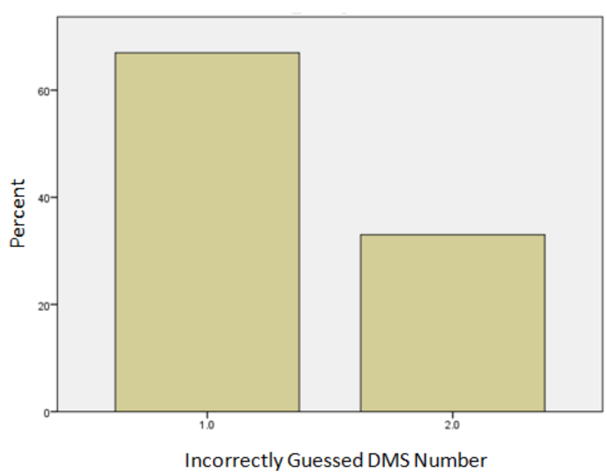

Figure 18: Distribution of Drivers Who Correctly Remember DMS

Table 46: Remember DMS Variable Level

Remember DMS	
Level	**Corresponding Variable**
1	Yes
2	No

Table 47: Chi-Square Significant Variables for DMS Correct

Chi Square of DMS Correct by Variable		
Variable	**Value**	**Significance**
Beacon Presence	2.831	0.092
Learn Other State	10.43	0.001
Income	12.961	0.024

Table 48: Proportion DMS Correct for Beacon Presence

Results		**Beacon Present**	
		No	Yes
Remember DMS	Yes	94	48
	No	38	32
% Correct		**71.21**	**60**

Table 49: Proportion DMS Correct for Learned Other

Results		**Learned Other**	
		Yes	No
Remember DMS	Yes	61	68
	No	14	45
% Correct		**81.33**	**60.18**

Table 50: Proportion DMS Correct for Number of DMS

Results		**Number of DMS**		
		0	1	2
Remember DMS	Yes	32	61	36
	No	16	18	25
% Correct		**66.67**	**77.22**	**59.02**

Surprisingly about 33% of the drivers did not correctly remember the correct number of DMS in their scenario. When comparing this result to the number of DMS it can be seen that the greatest number of incorrect responses occurred when 2 DMS were present. Since in these scenarios the first DMS encountered is far away from the hazard, many drivers seemed to forget about it or possibly ignore it altogether. This indicates that the distance a DMS from the indicated hazard is extremely important for the effectiveness of the device. No DMS present also showed a high incorrect response, demonstrating again that many drivers will not pay close attention to warnings encountered along roadways which leads to uncertainty when attempting to recall the information. Interestingly, people who learned to drive in Florida were also less likely to correctly remember the DMS as well possibly due to overconfidence by driving in a familiar environment.

6.7 Deceleration Behavior by ANOVA Analysis

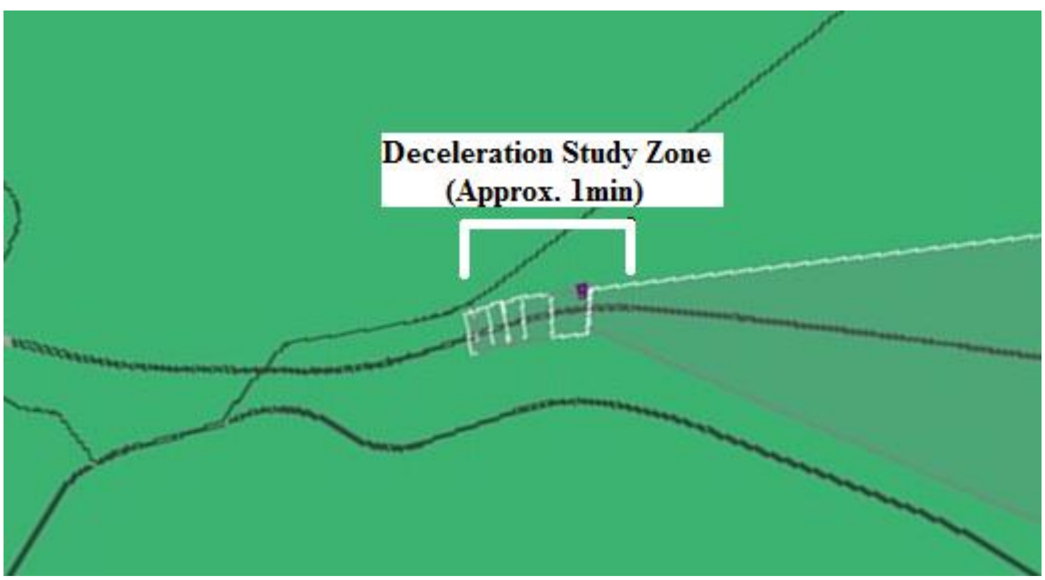

Figure 19: Deceleration Study Zone

Driver deceleration rate is calculated by using the difference between the initial speed of the participant within the fog transition zone and their speed at the beginning of the fog zone followed by dividing the time it takes them to traverse the distance as seen in Figure 19. The typical time it takes for the participants to pass this study segment is approximately 60 seconds and the rate is calculated as miles per hour per second. To allow for complete analysis, ANOVA models are used on deceleration as a continuous variable rather than categorical. The significant variables resulting from this analysis are listed in Tables 51 to 58 with descriptive statistics of the deceleration rates shown in Table 51

Table 51: Deceleration Variable Descriptive Statistics

Deceleration (mi/hr/sec)			
Mean	**Std. Dev.**	**Min**	**Max**
0.2017	0.1814	-0.38	0.69

Table 52: ANOVA Results of Deceleration by Road Type

ANOVA (Deceleration by Road Type)				
Var Level	**Mean**	**Std. Dev.**	**F factor**	**Sig.**
Freeway	0.2268	0.1836	3.973	0.048
Arterial	0.177	0.177		

Table 52 shows that road type impacts deceleration rates where those who travel on freeways typically have higher deceleration rates compared to arterial. This is consistent with the results found for speed change and stem from the fact that freeways have higher speed limits and require a larger speed change within a short period of time to achieve a comfortable travel speed within the reduced visibility condition.

Table 53: ANOVA Results of Deceleration by Fog Level

ANOVA (Deceleration by Fog Level)				
Var Level	**Mean**	**Std. Dev.**	**F factor**	**Sig.**
500ft	0.06	0.1458	45.347	0
300ft	0.1464	0.1494		
150ft	0.3144	0.1566		

Table 53 shows a strong significance in deceleration rates based on the fog level present. This is also expected based on the speed study as drivers will reduce speeds by greater amounts as visibility drops. With the larger speed changes, a greater declaration rate is required. However, these results also demonstrate that drivers have a much stronger reaction to using their breaks when visibility begins to decrease at an extreme rate.

Table 54: ANOVA Results of Deceleration by Number of DMS

ANOVA (Deceleration by Number DMS)				
Var Level	**Mean**	**Std. Dev.**	**F factor**	**Sig.**
0	0.1398	0.1818	5.329	0.006
1	0.2064	0.1644		
2	0.2448	0.1908		

Table 54 shows another strong significant impact on deceleration rates this time based on the number of DMS present. When comparing these mean deceleration values to those of the descriptive stat in Table 50, interesting conclusion can be made. When no DMS is present the deceleration rate is considerably lower than the sample average, 1 DMS results in an average deceleration rate, and 2 DMS present shows a greater deceleration behavior. This is interesting as the speed change study shows that the number of DMS present above 1 had no additional benefit. However, based on the findings for deceleration, it is seen that an additional DMS has a significant impact on a drivers deceleration rate, possibly due to exposure to the warning message of the DMS or a sense of urgency due to the sudden visibility drop from the transition zone.

Table 55: ANOVA Results of Deceleration by Message Type

ANOVA (Deceleration by Message Type)				
Var Level	**Mean**	**Std. Dev.**	**F factor**	**Sig.**
Warning	0.2148	0.1638	0.367	0.546
Advised	0.2316	0.1896		

Unlike the speed change results, Table 55 shows that the message type has no impact on drive deceleration. Since the transition zone creates a sudden visibility change, the driver does not have the attention to remember what type of message they are given. However, based on the results in Table 54, it is known that the drivers at least remember they encountered some form of fog warning from the DMS encountered on their trip. Since the speed study did show the DMS message as significant for a fog level of 3, further analysis for this fog level, seen in Table 56, shows significant results.

Table 56: ANOVA Results of Declaration by Message Type and Fog = 3

ANOVA (Deceleration by Message Type, Fog=3)				
Var Level	**Mean**	**Std. Dev.**	**F factor**	**Sig. (STD)**
Warning	0.3132	0.126	.	0.024
Advised	0.3492	0.1704		

From Table 56, the result of the message is found to be significant at a fog level of 150ft and is consistent with the findings of the speed study. When drivers are advised to reduce speed rather than just given a simple warning they reduce their speeds by greater amounts which results in greater deceleration rates to achieve these lower speeds.

Table 57: ANOVA Results of Declaration by Traffic Level

ANOVA (Deceleration by Traffic Level)				
Var Level	**Mean**	**Std. Dev.**	**F factor**	**Sig.**
Light	0.198	0.186	0.074	0.786
Heavy	0.2052	0.1776		

Table 57 shows that the level of traffic along the roadways does not significantly impact driver deceleration rates. This is expected as the traffic between the two variable types did not provide much obstruction to the driver and were expected to not have an impact on driver behavior.

Table 58: ANOVA Results of Deceleration by Beacon Presence

ANOVA (Deceleration by Beacon Present)				
Var Level	**Mean**	**Std. Dev.**	**F factor**	**Sig.**
Yes	0.2034	0.1902	0.031	0.861
No	0.1986	0.1668		

Finally, Table 58 shows beacon presence also has no impact on driver deceleration rates and is consistent with the results of the speed change study. This further shows that DMS are much more effective at influencing a driver to reduce their speeds during fog hazards. Even when analyzing the impact of beacon presence when no DMS are present shows no significance in deceleration rates as seen in Table 59.

Table 59: ANOVA Results by Beacon Presence with No DMS

ANOVA (Deceleration by Beacon Present)				
Var Level	**Mean**	**Std. Dev.**	**F factor**	**Sig.**
Yes	0.1356	0.1944	0.056	0.814
No	0.1476	0.1566		

Additional analysis is performed further on driver deceleration behavior by observing the participant demographic effects. Table 60 shows the significant findings when an ANOVA analysis is performed on the demographic variables with mean and standard deviation of deceleration noted to see trends.

Table 60: Deceleration ANOVA Results of Demographic Variables

ANOVA (Deceleration by Demographic Variables)					
Variable	**Var Level**	**Mean**	**Std. Dev.**	**F factor**	**Sig.**
License Length	1	.1327	.18209	3.018	0.019
	2	.2081	.17088		
	3	.1797	.16791		
	4	.2599	.17491		
	5	.2525	.19348		
Recently in Fog	Yes	.2133	.18267	3.155	0.077
	No	.1593	.17200		
Driver Age	1	.1684	.17792	2.368	0.054
	2	.1816	.17211		
	3	.2281	.17696		
	4	.2787	.20363		
	5	.2457	.17375		
Learn to Drive in Florida	Yes	.1639	.16878	16.369	0
	No	.2651	.18512		
Drive Often	0	.2834	.10408	4.266	0.002
	1	.1266	.17035		
	2	.1695	.16676		
	3	.2335	.19291		
	4	.2922	.17119		

From Table 60, similar trends can be seen that are similar to the results from the regression analysis on average speed change between the clear and fog condition. The longer a driver owns a license, the greater deceleration becomes. This however correlates with the drivers' age where the older a driver is the longer they should hold their licenses. Based on the age mean declarations, it is noticed that declaration increases steadily within each age group but then suddenly decreases for drivers age 65 and older. A similar trend is seen based on how often a person drives as well where those who only drive a couple times a week is significantly lower than those who drive multiple times a day. Interestingly, those who almost never drive are noted to have almost the same deceleration rates as those who drive very often. This shows that the more often a person drives, the more experienced they are with how to handle conditions and perform with caution, similarly those who almost never drive are extremely cautious and also greatly decelerate and change speeds in a similar method. Of these findings, those who learned to drive in Florida showed the most extreme results, where those who learned in Florida decelerated about 0.1 MPH/sec slower than those who learned elsewhere. This again, demonstrates that drivers from Florida are more confident or possibly less experienced with traveling under extreme fog conditions.

Table 61: Deceleration ANOVA Analysis by 300ft Fog

ANOVA (Deceleration by Fog Level)						
Visibility Distance	**Variable**	**Var Level**	**Mean**	**Std. Dev.**	**F factor**	**Sig.**
300ft	Driver Age	1	0.0778	0.0677	2.815	0.031
		2	0.1096	0.0868		
		3	0.1348	0.0911		
		4	0.1169	0.1346		
		5	0.2049	0.1504		
	Learn to Drive in Florida	Yes	0.097	0.075	3.59	0.062
		No	0.139	0.125		
	Education	1	n/a	n/a	3.161	0.029
		2	0.0231	0.0705		
		3	0.0913	0.0706		
		4	0.0998	0.0893		
		5	0.1501	0.1146		
	Income	1	0.09	0.0763	3.007	0.015
		2	0.0904	0.0644		
		3	0.0693	0.067		
		4	0.1262	0.1022		
		5	0.1088	0.1086		
		6	0.1795	0.1221		
	Road Type	Freeway	0.1367	0.0947	6.844	0.011
		Arterial	0.0844	0.0907		
	Message	Null	0.1268	0.0929	4.12	0.02
		Warning	0.0754	0.079		
		Advised	0.137	0.1041		

Table 62: Deceleration ANOVA Analysis by 150ft Fog

ANOVA (Deceleration by Fog Level)						
Visibility Distance	**Variable**	**Var Level**	**Mean**	**Std. Dev.**	**F factor**	**Sig.**
150ft	License Length	1	0.2272	0.1362	2.52	0.047
		2	0.2326	0.1151		
		3	0.2035	0.1113		
		4	0.3156	0.1653		
		5	0.3257	0.1777		
	Recently in Fog	Yes	0.2697	0.1483	3.686	0.058
		No	0.1941	0.1102		
	Driver Age	1	0.2002	0.1184	2.494	0.049
		2	0.2352	0.1203		
		3	0.2771	0.1313		
		4	0.3114	0.1865		
		5	0.3759	0.1828		
	Learn to Drive in Florida	Yes	0.1999	0.122	21.907	0
		No	0.331	0.1393		
	How Often Drive	0	0.3162	0.0319	3.116	0.019
		1	0.1181	0.041		
		2	0.2429	0.1627		
		3	0.295	0.1362		
		4	0.2787	0.1229		
	Road Type	Freeway	0.2857	0.1411	3.756	0.056
		Arterial	0.2266	0.1433		
	Message	Null	0.2076	0.1554	2.736	0.071
		Warning	0.2392	0.1291		
		Advised	0.2967	0.1461		

Tables 61 and 62 further analyze the decelerations of each significant variables based on the visibility distance present to see how the level of fog impacts this behavior. Between the two fog levels, similar trends are found for driver age, learning in Florida, and the road type; however interesting results occur for the massage type between the two models. As previously determined from the study of speed change, advised messages resulted in greater reductions in speed compared to just a simple warning, but when a message is not present an interesting occurrence is seen based on the fog level. Under the 300ft visibility distance, having no message given to the drivers resulted in similar deceleration behaviors as having a ‘reduce speed’ advisement posted. This could indicate that by just warning drivers of fog could negatively impact how cautious they are when entering a fog condition. Additionally, the drivers’ income level and education are also indicated to be significant factors in their deceleration behaviors, while how often they drove and if they recently were in fog showed significance under 150ft visibility. Ideally the latter factors would be expected to provide the most benefit when traversing a fog hazard rather than something such as income level. Assuming that those who are of higher income and education are older drivers would explain this result as those in the higher levels of these variables show greater deceleration rates than those in the lower levels.

CHAPTER 7: CONCLUSION AND RECOMMENDATIONS

7.1 Research Findings

Driver behavior by speed, braking, and deceleration when entering an obscured visibility environment is affected by many factors from an early warning system as well as the roadway itself. When viewing speed change as either a continuous, ratio, or categorized variable, the type of roadway drivers traveled along had an impact on their change in driving behavior between the clear and foggy conditions. Those who drove on the arterial roadways, which possessed one less lane per direction and a 5 MPH lower speed limit compared to the freeway, showed significantly lower speed deceleration and speed difference between the two road types. The cause of this occurrence stems from the fact that when a driver's visibility is restricted they would reduce their speeds down to a rate that makes them feel comfortable and safe rather than reduce down to a specific speed. Since drivers travel down the clear segment of the arterial road at lower speeds (almost 6MPH less than freeways) they can achieve their desired 'safe speed' faster than the freeway. As seen in Tables 28 and 29 of chapter 6, both road types have an average fog speed of approximately 60MPH. Although this is a significant decrease in speed, about 10MPH for the arterial and 15MPH for the freeway, this is considered a high speed to be traveling in more severe fog conditions. Even under the most severe fog condition, the greatest average speed change was 20MPH for the freeway with a speed limit of 70MPH as seen in Table 63, resulting in the typical speed under 150ft visibility being 50MPH.

Table 63: Speed Change Under 150ft Visibility

Road Type	Minimum	Maximum	Mean	Std. Dev
Freeway	2.7	41.23	20.7	9.95
Arterial	-0.58	35.89	15.15	9.26

Dynamic message signs, being the most important aspect of this early warning system design show very interesting results based on the presence, number, and message of the signs. Overall, the presence of DMS does not have a significant impact on the average change in driver speed until the fog condition becomes the most severe. However, it is noted in multiple analysis models that the message of the DMS is significant. Also taking into account the finding that 33% of the subjects could not accurately recall the number of DMS encountered, it is concluded that the message is much more important than the number of DMS used. Advised messages which instructed drivers to reduce speed resulted in higher speed reductions and decelerations than when a simple warning is used. With this in mind, it is better to instruct drivers on how to perform under reduced visibility conditions rather than simply alerting them to the hazard. This is also helpful for drivers who are more inexperienced with handling these hazardous conditions or who have little exposure to driving such as younger drivers.

The remaining scenario variables observed, traffic level and beacon presence, overall appeared to have no significant impact on altering a driver's behavior when entering a low visibility condition. In terms of traffic this result is expected as the traffic levels were quite low and did not impede the participants travel. Typically, drivers traveled at the same or lower speed compared to the simulated traffic while faster drivers were easily able to pass the traffic by changing lanes. Beacons did not impact driver speed reductions or decelerations as effectively as the DMS and messages used and only appeared to cause drivers to forget how many DMS they encountered on their trip. Even when no DMS is present, beacons did not impact speed reductions or decelerations as indicated by the results in Table 64.

Table 64: Chi-Square of Beacon Presence by Behavior with No DMS

Variable	Value	Significance
Ratio Speed Change	54	0.436
Deceleration Rates	54	0.436

Based on the driver demographic variables, overall it is found that an individual's experience and exposure to driving has the biggest impact on speed reductions. People who are older, drive often, and have recent experience in fog conditions demonstrate high speed reductions and decelerations compared to their counterparts. Education and income level also appear to have a minor influence in this behavior as well. Income's effect primarily stems from the fact that older aged participants typically possess higher income than the younger drivers who were primarily college students. High education level participants however contained a wide range of driver ages and indicate that those who pursued higher learning tend to understand and analyze the risk present in the environment and modify their behavior to better navigate the fog. Of all the demographic variables observed, whether a person learned to drive in Florida or elsewhere provided the most interesting findings. Those who learned to drive in Florida are found to have significantly less speed reductions and decelerations. This could stem from multiple reasons including Florida drivers being too confident or comfortable in the environment or that they are not accustomed to driving under severe visibility reductions due to fog. If the latter is true, this indicates that Florida drivers require more education or warning when a severe visibility condition is present and how to handle the situation. Additionally, since Florida rarely encounters severe visibility reductions due to fog, many young Florida drivers lack the experience of navigating these conditions and are likely to not know how much speed reduction is necessary to allow for adequate safety.

In terms of car following and 'lag' behavior, no notable trend is observed from the participant data. Under the clear condition, a majority of participants traveled at the average speed of the simulated traffic at a distance. Due to this, many participants encountered a situation where they had to either slow down or pass the vehicle. Those who drove over the average speed however, always chose to switch lanes and pass the slower moving traffic in front of them. A similar situation occurs within the fog condition as well. Since many drivers drove close to the average speed of the traffic and visibility was limited, some participant did not encounter any vehicles within the fog condition. Those who did were noted to not change their speed and were either passed by the simulated traffic or overtook slower moving vehicles in front of them.

7.2 Future Study Recommendations

The research findings and simulation experiment offer several recommendations for improvement of future studies.

- With the findings on DMS and the message presented, further study of DMS usage with different messages could identify additional aspects on the impact of driver behavior. Specifically, the location of the DMS from or within the fog and different forms of advisement messages, such as specifying or recommending a certain travel speed, provide potential for future analysis.
- Testing heavier traffic volumes could identify when driver speeds begin to be influenced under fog conditions. Also, testing additional traffic behaviors, such as speed and lane change, under the fog condition could also provide important findings on driver reactions based on the warnings provided.

- Additional driver behavior within the hazardous visibility condition would also provide further insight to how the early warning system impacts driver behavior change. One example includes testing a driver's ability to react within the fog condition where a sudden emergency stop or maneuver would be required. Doing so would show if a driver compensated for the increased risk based off the DMS warning provided.
- Future study of the drivers speed within the fog also warrants additional research. Many participants are noted to increase their speed as they traveled through the fog condition, possibly due to becoming comfortable with the limited visibility. Further study of this behavior could produce interesting results in terms of how drivers cope over time within hazardous conditions.
- Using DMS models that have built in beacons could improve driver recognition or their ability to remember the DMS. Doing so could improve the impact of the number of DMS present and its impact on driver speed reductions.

APPENDIX A SIMULATION CONSENT FORM

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: We will limit your personal data collected in this study to people who have a need to review this information. We cannot promise complete secrecy. Organizations that may inspect and copy your information include the IRB .

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 participants 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.

APPENDIX B SIMULATION 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/E-Pass?
   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:

FOG SCENARIOS

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
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?

APPENDIX C IRB PROPOSAL

Evaluating Toll Plazas and Visibility Conditions Using Driving Simulation

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April 2015

1. PROTOCOL TITLE

Evaluating Toll Plazas and Visibility Conditions Using Driving Simulation

2. PRINCIPAL INVESTIGATOR

Mohamed Abdel-Aty, Ph.D., P.E.

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, participants 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 participants, 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 participant'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 participants 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 participants 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 participants 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, participants will be asked addition questions in regards to the scenario they just ran. These questions include how the participant performed in the given scenario, what they observed, how they reacted, and how they felt about the situation. The participants 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 participant 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 participants 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 participants 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 participants 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 participant time to practice to become more acquainted with the simulator. Three questionnaires will be given to the participants 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 participant, run the tests, and even allow some time in between tests for the participant 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, participants 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 participants’ 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. Participants 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 participant 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.

Participants 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 participants will not be a difficult task for this research because the only requirements are as follows: The participant 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 participants. 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 participants, no compensation is planned on being offered.

7c) Inclusion and Exclusion Criteria

In order to be eligible for this research experiment, participants 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 participants 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 participant meets the required criteria and performs the simulation, additional variables and information will be gathered from the participant 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 participant 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 participants 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 participant or an error occurred during the simulation. Since the experiment requires the participants 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 participant, and each run will aim to be as consistent as possible. Before the simulation is started, each participant 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 participant before any testing can begin so each participant 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 participant gets 5 minutes of test driving in the simulator.

Following this initial practice, the participant will be given short rest if needed and then the actual study scenarios will be provided. Prior to starting the group of scenarios, the participant will be reminded of what their task is in the simulation; and following the scenarios, each participant will be questioned in regards to the scenarios they just ran. Between each scenario group, the participant 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 participant. 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 participant 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 participant data.

There are four recording devices that are used by this simulator. One device is pointed directly at the participant'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 participant, 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 participant 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 participant 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 participant 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 participants show continuous or extreme signs of motion sickness, he or she will be withdrawn from the simulation test. Once withdrawn, the participant will be given a place to rest and water until they feel well enough to leave.

In a situation where a participant was withdrawn from a test, the data collected will most likely be invalidated and will not be used. However, if the participant 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 participants should never be along for long periods of time.

9. POTENTIAL BENEFITS

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

10. PROVISIONS TO PROTECT PRIVACY OF PARTICIPANT

The simulation tests will be conducted behind closed doors with only the research assistants and participant present. The data collected from the subject will be completely confidential, where no information collected from the participant 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 participant 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 participants, 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 participants 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 PARTICIPANTS

Participants 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 participant. Each participant will be given an informed consent form that they are to go over before any testing can begin. While the participant 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 participant to ensure that they understand what is being discussed. This means that before any testing has begun, the participant will have been given a verbal form of consent for both what is expected of the simulation as well as understanding. The potential participants 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 participant if free to withdraw from the simulation at any time, a person’s willingness to continue shows adequate ongoing consent.

Since all the participants expected to take part in this experiment are Florida residents, we can assume that practically all of the participants 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 participants 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 participant understands everything. Before the simulation is started, each participant 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 participant before any testing can begin so each participant knows what to expect. The assistant conducting the research will also be available to answer any questions the participant may have and go over the consent form with them. Once this is done, the participant 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 PARTICIPANTS

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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APPENDIX D IRB APPROVAL LETTER

University of Central Florida Institutional Review Board
Office of Research & Commercialization
12201 Research Parkway, Suite 501
Orlando, Florida 32826-3246
Telephone: 407-823-2901 or 407-882-2276
www.research.ucf.edu/compliance/irb.html

Approval of Human Research

From: **UCF Institutional Review Board #1**
FWA00000351, IRB00001138

To: **Mohamed A. Abdel-Aty** and Co-PIs: **Kali Marie Carroll, Ryan Michael Selby**

Date: **April 14, 2015**

Dear Researcher:

On 4/14/2015 the IRB approved the following human participant research until 04/13/2016 inclusive:

Type of Review:	Submission Response for UCF Initial Review Submission Form Expedited Review
Project Title:	Evaluating Toll Plazas and Visibility Conditions Using Driving Simulation
Investigator:	Mohamed A. Abdel-Aty
IRB Number:	SBE-15-11026
Funding Agency:	Florida Department of Transportation(FLDOT), Georgia Institute of Technology, University of Iowa
Grant Title:	
Research ID:	16508026, 16508025 & 1058231

The scientific merit of the research was considered during the IRB review. The Continuing Review Application must be submitted 30days prior to the expiration date for studies that were previously expedited, and 60 days prior to the expiration date for research that was previously reviewed at a convened meeting. Do not make changes to the study (i.e., protocol, methodology, consent form, personnel, site, etc.) before obtaining IRB approval. A Modification Form **cannot** be used to extend the approval period of a study. All forms may be completed and submitted online at https://iris.research.ucf.edu .

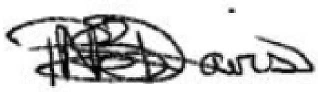
If continuing review approval is not granted before the expiration date of 04/13/2016, approval of this research expires on that date. When you have completed your research, please submit a Study Closure request in iRIS so that IRB records will be accurate.

Use of the approved, stamped consent document(s) is required. The new form supersedes all previous versions, which are now invalid for further use. Only approved investigators (or other approved key study personnel) may solicit consent for research participation. Participants or their representatives must receive a copy of the consent form(s).

All data, including signed consent forms if applicable, must be retained and secured per protocol for a minimum of five years (six if HIPAA applies) past the completion of this research. Any links to the identification of participants should be maintained and secured per protocol. Additional requirements may be imposed by your funding agency, your department, or other entities. Access to data is limited to authorized individuals listed as key study personnel.

In the conduct of this research, you are responsible to follow the requirements of the Investigator Manual.

On behalf of Sophia Dziegielewski, Ph.D., L.C.S.W., UCF IRB Chair, this letter is signed by:



Signature applied by Patria Davis on 04/14/2015 03:34:32 PM EDT

IRB Coordinator

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