A Driving Simulator Investigation of Road Safety Risk Mitigation under Reduced Visibility

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UNIVERSITY TRANSPORTATION CENTER

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Abstract

The effect of low visibility on both crash occurrence and severity is a major concern in the traffic safety field. It is known that crashes tend to be more severe in low visibility conditions than under normal clear conditions. Thus, there is a drastic need to evaluate low visibility countermeasures to improve driver safety and performance under reduced visibility conditions.

For this reason, the research team investigated the human factors issues relevant to implementing a visibility system on Florida's highways. Specifically, we designed driver simulator experiments to evaluate how drivers respond to low visibility warning strategies using an in-vehicle warning device.

The repeated-measures analysis of variance (ANOVA) models were employed to analyze the impacts of low visibility and fog countermeasures. It was found that the fog warning systems can significantly improve safety. The systems can also reduce drivers' throttle-release time and make the braking process more smooth. Meanwhile, age effects were observed during the braking process. Old drivers are prone to have harder braking than other drivers.

Further research was conducted based on the drivers' questionnaires. The results showed that drivers thought the head-up display had better effects than warning sounds. Also, drivers' travel frequency and education levels have significant impacts on their behaviors. Those who drive fewer than five times every week or have higher educational attainment rates (a bachelor's degree or higher) are more likely to have larger minimum time to collision.

1 Introduction

In Florida, a low visibility roadway environment due to fog is one of the major traffic safety concerns. It is known that in low visibility conditions, such as fog and smoke, crashes tend to be more severe than under normal clear conditions. Thus, there is a drastic need to test and develop countermeasures to improve traffic safety and driver performance under reduced visibility conditions. The research team studied the human factors issues relevant to implementing a visibility system on Florida's highways. Specifically, we designed driver simulator experiments to evaluate how drivers respond to low visibility warning strategies using an in-vehicle warning device.

To our knowledge, drivers may adjust their behaviors under fog conditions. It was found that drivers are prone to decrease their speeds under fog conditions, but the reduction was insufficient, especially when dangerous situations occurred, while age-related differences were also observed during fog.

Meanwhile, crash risks may increase under fog conditions, while rear-end crashes are among the most common crash types under fog conditions. Rear-end crashes are usually related to small headway, long response time, and insufficient brake force. However, those problems can be more severe under fog conditions. A general rear-end crash-avoidance process is a consecutive process that consists of a mental process and movement. Different measurements were employed in order to evaluate the process. One of the key components is the perception response time (PRT), which is the same as response time (RT) in most studies. Another indicator commonly employed in safety analysis is the time to collision (TTC). In order to improve traffic safety under low visibility conditions, it is necessary to evaluate different warning methods during low visibility conditions.

Above all, we try to investigate drivers' behavior under fog conditions and their response to warning systems, especially in emergency situations. Three warning strategies are compared in this project: warning with head-up display (HUD) and audio, warning with HUD only, and no warning. Therefore, the main research objectives of this project can be summarized as follows:

- Exploring driver behavior under low visibility conditions, and
- Investigating the impacts of fog warning systems and determining whether they could improve traffic safety.

Following the brief introduction and overview in Chapter 1, Chapter 2 summarizes the literature about driver behavior and safety treatments for low visibility conditions. Chapter 3 explains the experimental design for the study, and Chapter 4 describes the experimental procedure. Chapter 5 presents the data reduction and preliminary analysis. Chapters 6 and 7 present the methodology and results analysis, and Chapter 8 concludes the report and provides suggestions.

2 Literature Review

2.1 Driver Behavior in Low-Visibility Conditions

Previous analyses have revealed that weather conditions have a substantial impact on traffic accidents. This caused a specific interest in assessing driver behavior in low-visibility conditions from different points of view, but one in particular is about the driver's speed.

In recent years, different studies have focused on driver behavior in foggy conditions, employing a driving simulator to understand how the driver changes his speed in that case. According to Jeihani et al. (2016), their results showed that a significant difference in average speeds occurs before and after entering the foggy area and that the reduction of speed is more significantly detected for women than men.

The main issue is that drivers drive faster than current visibility permits, and this likely leads to crashes. One example is the survey conducted on a section of I-64 and I-77 in Virginia. McCann et al. (2016) analyzed speed and visibility data in that section and through a model they showed that there is a significant difference between observed speeds and the safe speed calculated from the stopping sight distance (SSD) while drivers are slowing down in low visibility.

For this reason, putting effort into limiting vehicle speed could enhance the safety of road networks. Yuhua et al. (2016) led a repeated measures system through different driving simulator experiments in order to examine the influence of fog on adaptation effects. The results showed that adverse weather conditions led to a decrease in vehicle speed.

Previous studies were carried out to understand how drivers perceive the rapidly changing driving environment (i.e., different weather conditions and road geometry configurations) and how they decide to conform their speed to the specific situation. The studies focused on drivers' car-following behavior, their headway selection, and also how the choice of headway affects safety. Hamdar et al. (2016) led a number of driving simulator experiments using a prospect theory acceleration-based model. They captured the drivers' decision-making process after processing the external information. Figure 2.1 presents the parameters incorporated in the model.

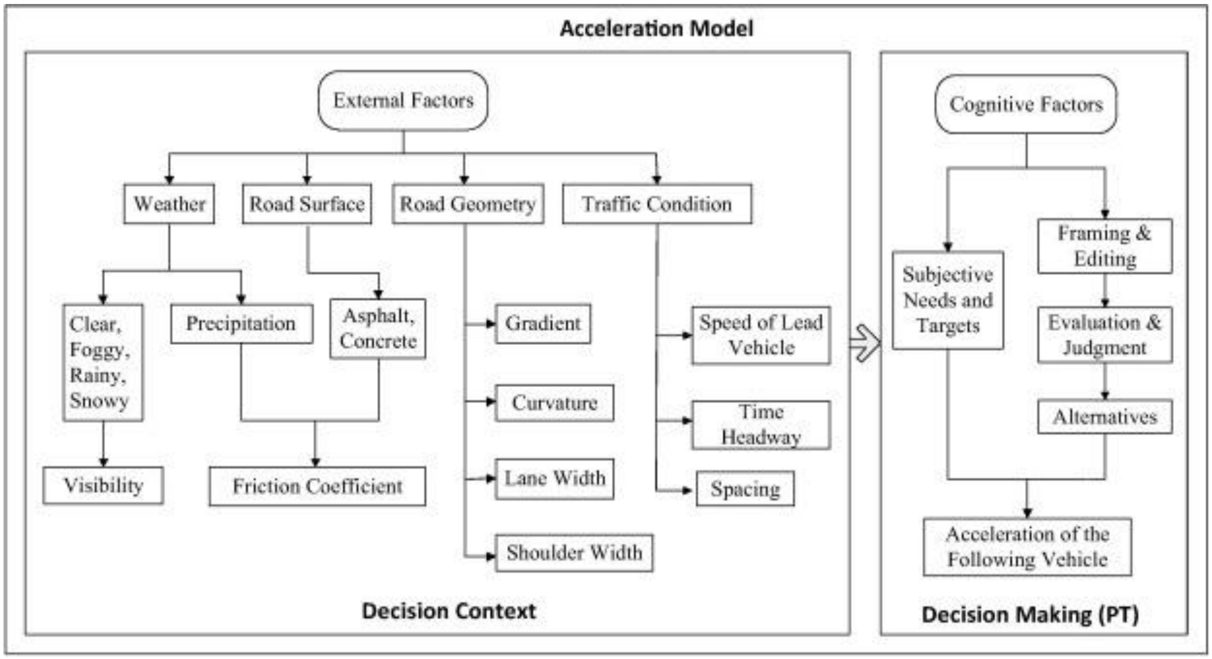


Figure 2.1 - Schematic of prospect theory acceleration model

The findings of the survey showed that the drivers' average speed, time headway, TTC, and distance headway are affected by both roadway-related factors and weather-related factors. Furthermore, they found that low visibility causes drivers to increase their distance from the vehicle ahead, while in the clear visibility condition, they tend to follow the leader more closely. The reason is most likely that drivers become more vigilant when they feel less safe.

2.2 Safety Treatments for Low-visibility Condition

Several recent studies have focused on improving drivers' safety in reduced visibility conditions. These studies can be classified into static and dynamic approaches; the first category refers to the systems that are fixed on highways or express roads (i.e., warning beacons), while the second category refers to the onboard systems fixed on or into the vehicle.

Regarding the first category, Bullough and Rea (2016) conducted a study about the flashing yellow warning beacons that alert drivers to potential hazards. They found that during perturbed atmospheric conditions, like fog, the scattered light from warning beacons can make it more difficult to see the potential hazards. Therefore, they analyzed the impact of flashing warning beacons under different fog conditions using a physically accurate model of the scattered light characteristics in a perturbed atmosphere. The results showed that it is important to reduce beacon intensity in fog so that hazards near the beacon can be seen more clearly.

Miclea and Silea (2015) studied a system of detecting visibility in a foggy environment that gives drivers advance notice to adapt their speed to the weather conditions, as well as a warning when an obstacle appears ahead so the vehicle can be stopped safely. This system is made up by a laser and a camera, each fixed on a pile. The laser projects a beam towards the camera's pile, and if the camera sees the laser, the visibility is good. If it does not, it measures the length of the laser beam and in this way estimates the visibility distance. After some measurements are taken, the system gives drivers feedback about the visibility distance by displaying it on highway display panels or sending it to drivers' smartphones. While using the same system of detecting visibility in the presence of fog, Ioan et al. (2016) tested the drivers' visual acuity using an eye chart. The model used has as input data the fog influence on light sources and the link between fog levels and visual acuity (Table 2.1).

Table 2.1- Levels of fog vs visual acuity

Levels of Fog	Visual Acuity
No Fog	20/20
Low Fog	20/30
Fog	20/50
Dense Fog	20/200

The model gets the fog level information from the light sources. The level is then converted into visualization distance by using the thresholds determined with the eye chart (Figure 2.2).

Figure 2.2 - Levels of fog vs visual acuity (converted visualization)

These findings showed that it is possible to develop different systems that allow the drivers to know about the weather condition just by calibrating the light sources used.

With respect to the second category (the dynamic one), the most recent surveys conducted have been about the use of different onboard systems fixed on or into the vehicle. Poirier et al. (2017) tested the use of Advanced Driving Assistance System (ADAS), which features a combination of cameras and sensors that are able to detect objects in order to warn the drivers in time when approaching an intersection in foggy weather. Employing a driving simulator, they tested and compared various types of warning systems (audio, visual, and a combination) to no warning system. The results showed a significant difference in the drivers' behavior, in particular between no warning system and the combination of audio/visual warning. In fact, it was possible to conclude that the combination is the most effective warning system that helps drivers safely approach an intersection in the presence of fog.

Cruz et al. (2016) introduced a warning system that detects vehicles by identifying tail lights. It then uses sensors on smart devices to avoid vehicle collisions in low-visibility environments (it was tested in night conditions).

Since the visual channel is useless due to poor visibility during fog conditions, it is important to provide drivers positive guidance. Lee et al. (2012) proposed the Fog Detect and Warning System (FDWS) (Figure 2.3), called the "fog lighthouse," to inform drivers of safe speeds and distances between each vehicle. The FDWS includes visibility meters, light bars, and vehicle detectors. The visibility meters calculate sight distances when fog occurs, and the estimated sight distances inform drivers through light bars that are installed at 30 m intervals. The light bars, which display red warning lights, inform a following vehicle of the position of the leading vehicle to keep a safe distance between the two vehicles. Due to the high visibility of main lights with high-bright light-emitting diode (LED), drivers can easily recognize them from far away. Also, microwave sensors are installed along with the light bars to detect the presence of vehicles at 30 m intervals. As a pilot study, FDWS was implemented on a 1 km section of National Highway No. 37 with a divided, four-lane, rural highway. The analysis of driver behavior was based on mean speed with standard deviation, and a questionnaire survey was conducted to estimate driver consciousness. The results indicate that FDWS led to an approximately 3 kph (for daytime) and 10 kph (for nighttime) reduction in mean speed compared to when the system was turned off, which is significant. Also, the consciousness survey shows that FDWS was useful, helping guide drivers safely in fog.

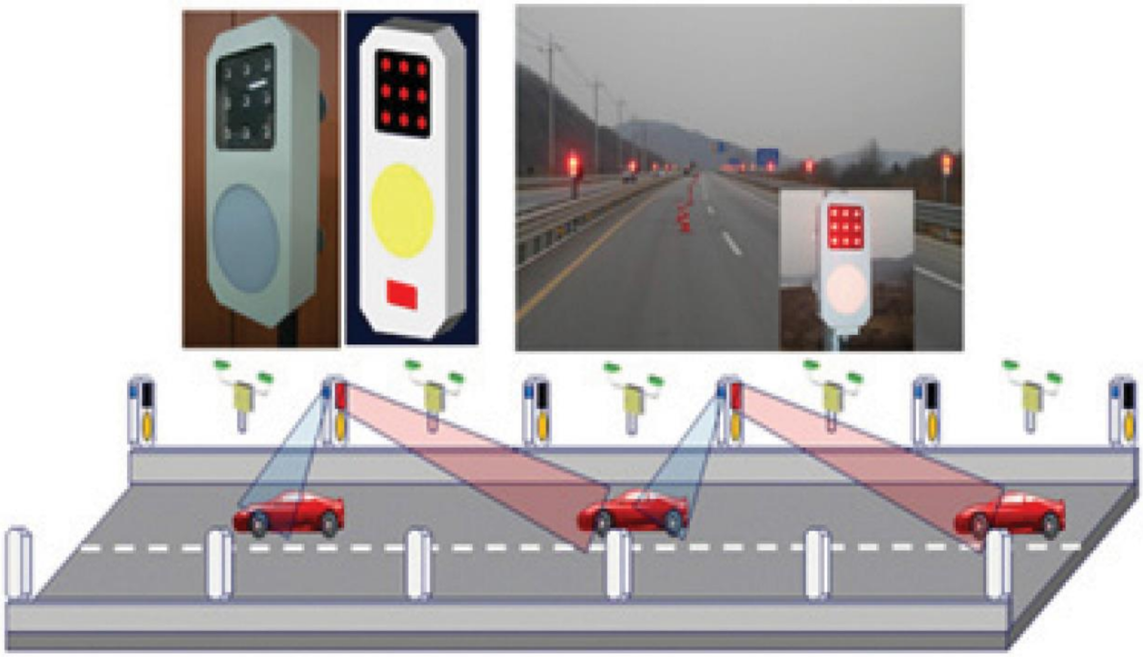


Figure 2.3 – Fog Detect and Warning System

3 Experimental Design

3.1 Geometric Design

The experimental road in this study was based on the northbound sections of SR441 in Gainesville, Florida. The selected sections are located in a high fog crash risk area where 11 people were killed in a multi-vehicle crash in January 2012 (Ahmed et al. 2014). The speed limit of the studied roadway is 65 mph. The layout design is shown in Figure 3.1. One platoon of vehicles stops in the clear zone section, waiting for the external driver to join the road. The experiment tested emergency brake behaviors under fog conditions with different countermeasures.

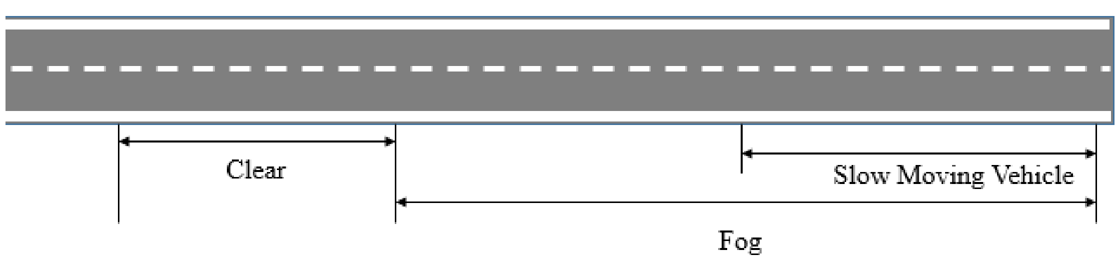


Figure 3.1 - Study zones

Based on previous research, if the alarm is presented when drivers have recognized dangerous situations, the alarm may not have any value (Abe and Richardson 2004). Thus, relatively dangerous situations are preferred in this study. Broughton et al. (2007) found that drivers are prone to have shorter headways under dense fog conditions (i.e., when the visibility is 41 m). Thus, dense fog conditions will be selected in this research (Figure 3.2). For the “slow moving vehicle” zone, a deceleration that is higher than 0.5 g is expected for the lead vehicle (Wang et al., 2016).

Figure 3.2 - Heavy fog level example

3.2 Scenario Parameters

Generally, three types of scenario design have been used by researchers. The detailed definitions of these methods are shown in Table 3.1.

Table 3.1 - Summary of different scenario design methods

Scenario design	Number of factors (number of levels in each factor)	Number of scenarios for each subject	Description
Full Factorial Design	K (a)	a^K	-
Fractional (Partial) Factorial Design	K (a)	a^{K-I}	I is the number of main effects that have been confounded
Mixed Factorial	K (a)	a^{K-J}	J is the number of

Design			between-group factors

In this study, the mixed-factorial design is employed in order to reduce the number of scenarios for each participant. A mixed-factorial design includes two or more independent variables, of which at least one is a within-subjects (repeated measures) factor and at least one is a between-groups factor. The factors for this experiment include fog levels (two levels: moderate fog, dense fog) and warning type (three levels: no warning, image warning only, and image & audio warning). Table 3.2 provides the summary of scenario parameters in this study. Drivers' braking behaviors will be recorded to analyze drivers' reactions under fog conditions.

Table 3.2 - Summary of scenario parameters

Level	Slow Moving Vehicle Warning	Fog Level
0	Head-up display (HUD) with warning sound (Text: Slow vehicle ahead) (Images: Slow vehicle ahead)	Moderate fog (300 ft.)
1	Head-up display (HUD) without warning sound (Text: Slow vehicle ahead) (Images: Slow vehicle ahead)	Dense fog (100 ft.)
2	None	N/A

3.3 Participants

In order to select participants who represent the general driving population in the sites and in all of Florida, the crash data for the years 2010 to 2014 were collected from the Florida Department of Transportation (FDOT) Crash Analysis Reporting System (CARS). The drivers' age and gender distributions were obtained from the crash data after excluding at-fault drivers. Table 3.3 displays the age distribution of State Road 441 (Paynes Prairie).

Table 3.3 - Age distribution of the non-fault drivers on SR-441 near Paynes Prarie (2010-2014)

Age Group	Range	Representation	Frequency	Percentage
1	18-24	Young drivers	948	34%
2	25-54	Working-age drivers	1,312	48%
3	55+	Elderly drivers	501	18%

Total	2,761	100%

The research team identified the number of participants that can commonly represent these distributions as shown in Table 3.4. The chi-square tests of independence (p value=0.145, then accept null hypothesis) show that the distribution in Table 3.4 is consistent with the age distributions in Table 3.3 at significance level 10%.

Table 3.4 - Participant age distribution

Age Group	Range	Representation	Number	Percentage
1	18-24	Young drivers	12	22%
2	25-54	Working-age drivers	32	59%
3	55+	Elderly drivers	10	19%

In the same way, the real gender distribution was investigated (Table 3.5). In this experiment, twenty-seven males and twenty-seven females were recruited. The chi-square tests of independence (p value=0.983, then accept null hypothesis) show that an equivalent number of participants by gender is consistent with the gender distributions in Table 3.5 at significance level 10%.

Table 3.5 - Gender distribution of SR-441 near Paynes Prarie (2010-2014)

Gender	Frequency	Percentage
Male	789	49%
Female	833	51%
Total	1,622	100%

3.4 Scenario Arrangement

Table 3.6 presents the scenario arrangement of the driving simulator experiment based on treatment types and fog levels. The participants were divided into two groups: dense fog and moderate fog. Each participant drove three different scenarios with different types of warning systems.

Table 3.6 - Scenario arrangement

Group	Scenario		
	HUD & Audio	HUD & Non-audio	No Warning
B1 (dense fog)	B11	B12	B13
B2 (moderate fog)	B21	B22	B23

4 Fog Experiment

4.1 Apparatus

The National Advanced Driving Simulator (NADS) MiniSim driving simulator was used to conduct the experiment and collect the data, as shown in Figure 4.1. The simulator has three screens (22.5 inch high and 40.1 inch wide) with a 110 degree front field of view and left, middle, and right rear-view mirrors.

Figure 4.1 - NADS MiniSim at UCF

4.2 Experiment Procedure

Forty-eight subjects were recruited for this research (average age=38.44, age standard deviation=19.36). Each subject was required to hold a valid driver's license and have at least two years of driving experience. Upon arrival, each subject was briefed on the requirements of the experiment and asked to read and sign an informed consent form. The subjects were advised to drive as they normally did in real-life situations. Before the formal test, each subject performed a practice drive of at least 5 min to become familiar with the driving simulator (with automatic transmission). In this practice session, the subjects exercised maneuvers including straight driving, acceleration, deceleration, left/right turn, and other basic driving behaviors.

In addition, subjects were also notified that they could quit the experiment at any time in case of motion sickness or any kind of discomfort. The experiment was reviewed and approved by the University of Central Florida Institutional Review Board (IRB) (Appendix A).

5 Data Reduction and Preliminary Analysis

5.1 Data Reduction

The NADS now provides a functional MATLAB-based data reduction tool named ndaqTools (Figure 5.1). In this study, we used the NADS ndaqTools to run the data reduction process. We first generated the data disposition table as required. Then we selected the elements list for the DAQ files based on the variables to be investigated. The frequency of data reduction was set to 60 Hz. Afterwards we got the structured '.mat' files of the DAQ files generated in all the experiments. Lastly, the '.mat' files were transformed into '.csv' files in order to load the data file in statistical software to conduct analysis.

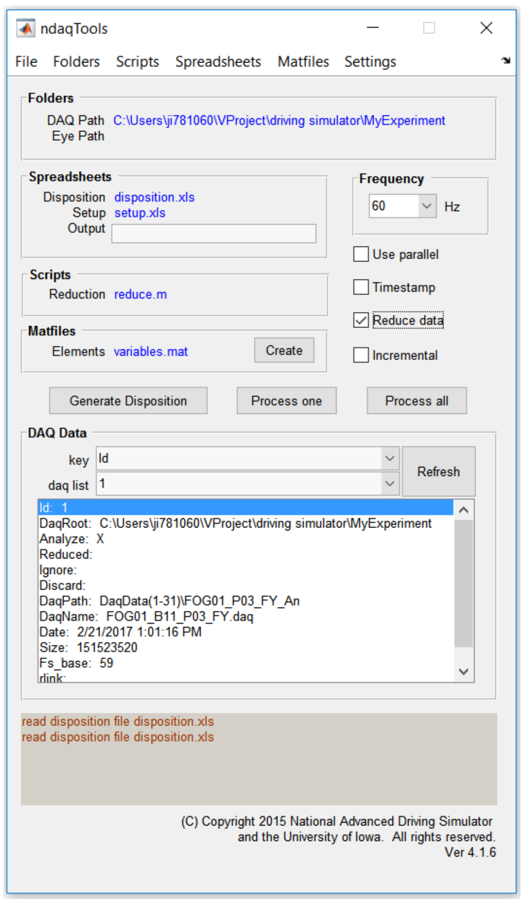


Figure 5.1 - ndaqTools

5.2 Preliminary Analysis

In order to select dependent variables, preliminary analysis was conducted for 7 different dependent variables. Thirty-one participants' performances were used in the preliminary analysis. During the experiment, 93 (31*3) trials were conducted and 3 trials were dropped because the participants had motion sickness during driving. The scenarios related to explanatory variables and dependent variables were collected and are shown in Table 5.1 and Table 5.2. In this study, the onset of the event is defined as follows: (1) if the scenario includes a HUD warning, then the event starts at the beginning of the waring; (2) otherwise, the event starts when the participant is able to see the lead vehicle, when the lead vehicle has started to decelerate.

Table 5.1 - Definitions of scenario-related variables and their codes

Name	**Description**
Warning Type	
WARNING	Warning=1: head-up display warning with audio warning; Warning=2: head-up display warning without audio warning; Warning=3: no warning.
Fog Level	
DENSE	Dense=1: dense fog; Dense=0: moderate fog.

Table 5.2 - Definitions of dependent variables and their codes

Variable	**Explanation**
$t_{initial}$	*Time to initial throttle release:* time between when the event begins and the participant begins to release the throttle pedal.
$t_{Release}$	*Time to final throttle release*: time between when the participant begins to release and the moment when the participant completely releases the throttle pedal.
t_{brake}	*Time to initial braking* : time between when the participant completely releases the throttle pedal and the moment when the participant begins to brake.
$t_{25\%brake}$	*Time to 25% braking* : time between when the participant begins to brake and the moment when the brake pedal position reaches 25% of the maximum brake pedal force of the participant.
$t_{50\%brake}$	*Time to 50% braking* : time between when the participant begins to brake

	and the moment when the brake pedal position reaches 50% of the maximum brake pedal force of the participant.
$t_{75\%brake}$	*Time to 75% braking* : time between when the participant begins to brake and the moment when the brake pedal position reaches 75% of the maximum brake pedal force of the participant.
$t_{maxbrake}$	*Time to maximum braking* : time between when the participant begins to brake and the moment when the brake pedal position reaches the maximum brake pedal force of the participant.

Repeated-measures ANOVAs were carried out with fog levels as between-subjects variables and warning types as within-subjects variables. Figure 5.2 shows an example of accelerator release behavior and brake behavior during a collision avoidance event.

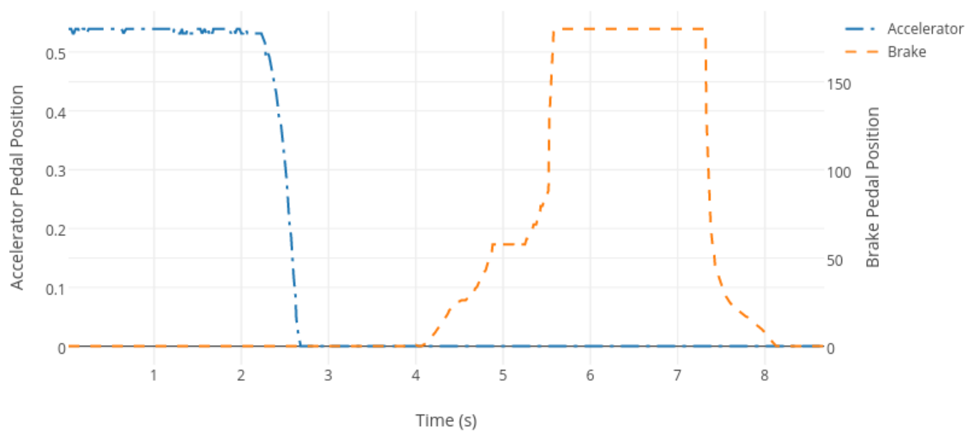
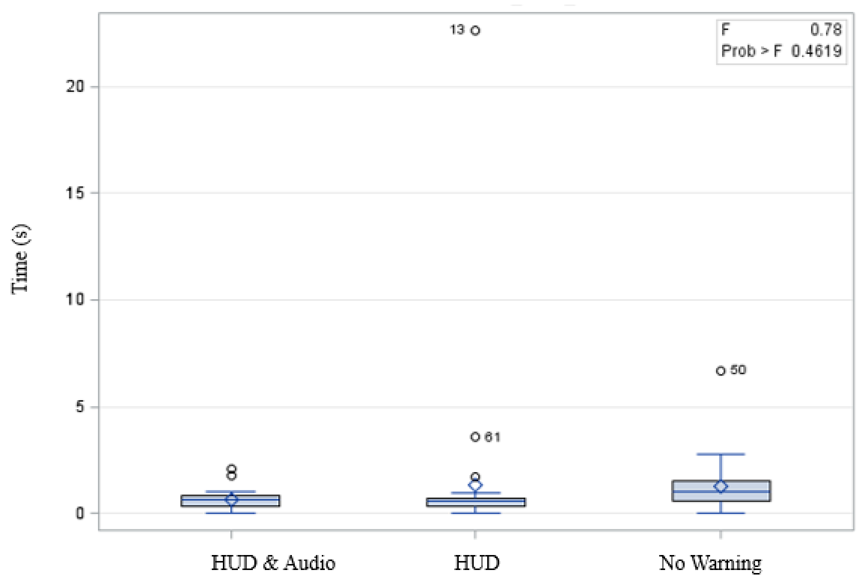


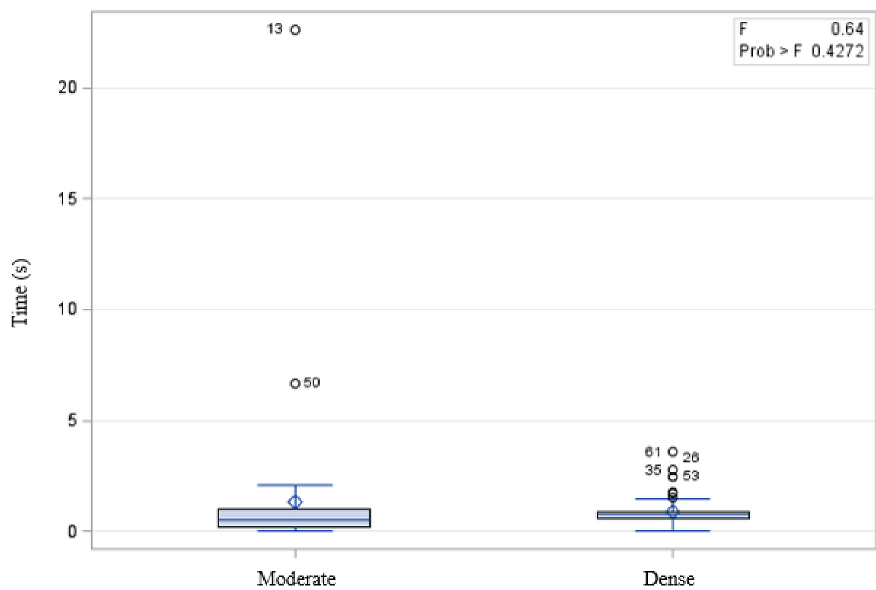
Figure 5.2 - An example of collision avoidance event sequence

1) Time to initial throttle release

No significant difference was observed for time to initial throttle release by different warning types (F-value=0.78, P-value=0.47) and fog levels (F-value=0.64, P-value=0.43) (see Figure 5.3).



(a) Warning type

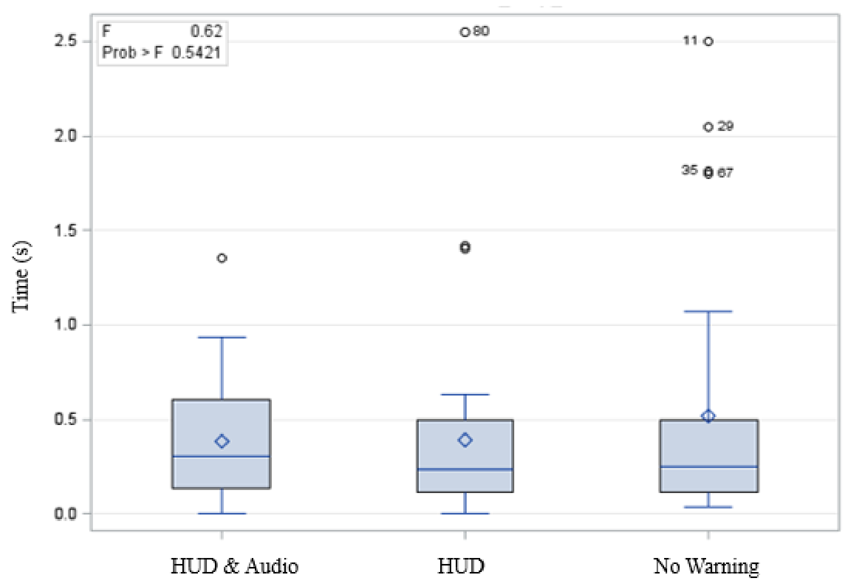


(b) Fog level

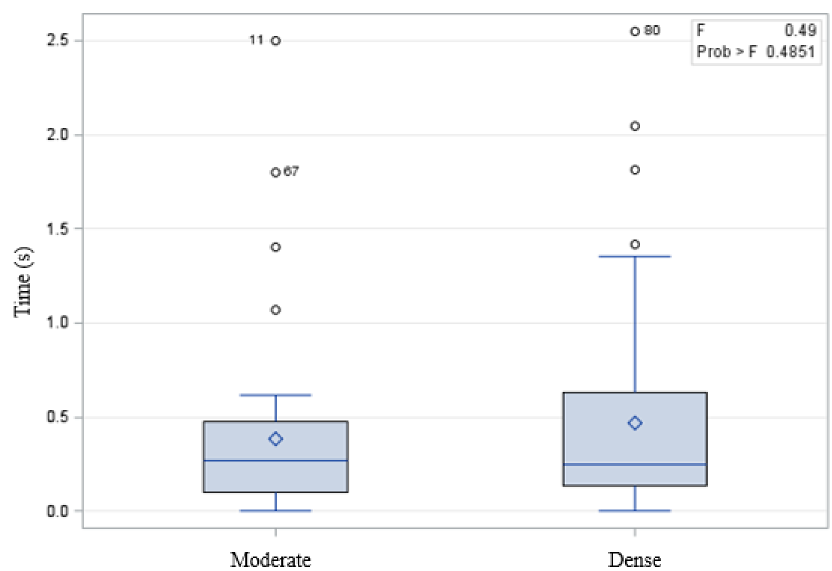
Figure 5.3 - Time to initial throttle release

2) Time to final throttle release

No significant difference was observed for time to final throttle release by different warning types (F-value=0.62, P-value=0.54) and fog levels (F-value=0.49, P-value=0.49) (see Figure 5.4).



(a) Warning type

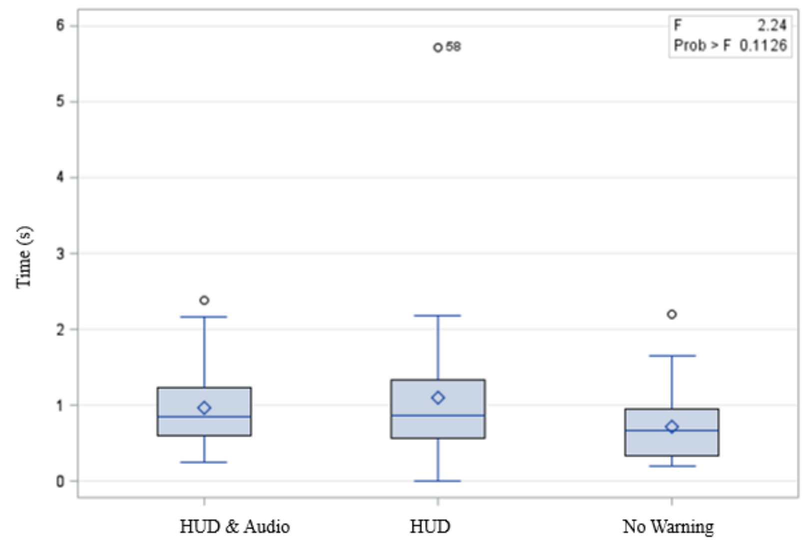


(b) Fog level

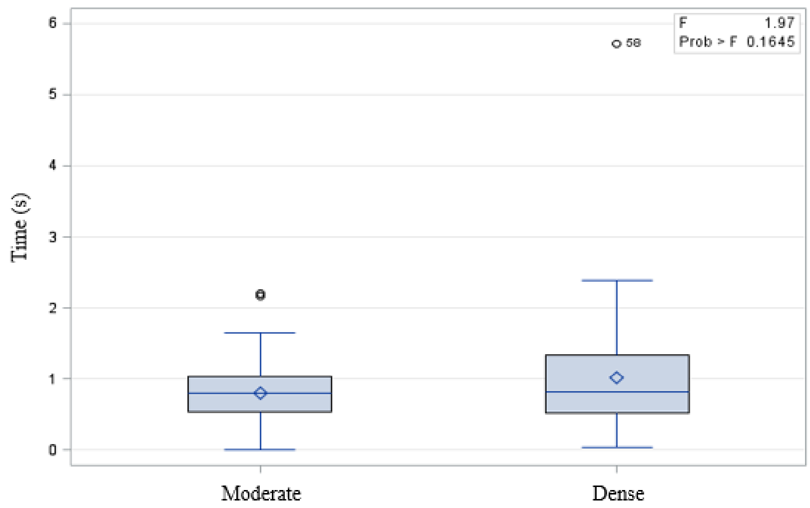
Figure 5.4 - Time to final throttle release

3) Time to initial braking

No significant difference was observed for time to initial braking by different warning types (F-value=2.24, P-value=0.11) and fog levels (F-value=1.97, P-value=0.17) (see Figure 5.6).



(a) Warning type

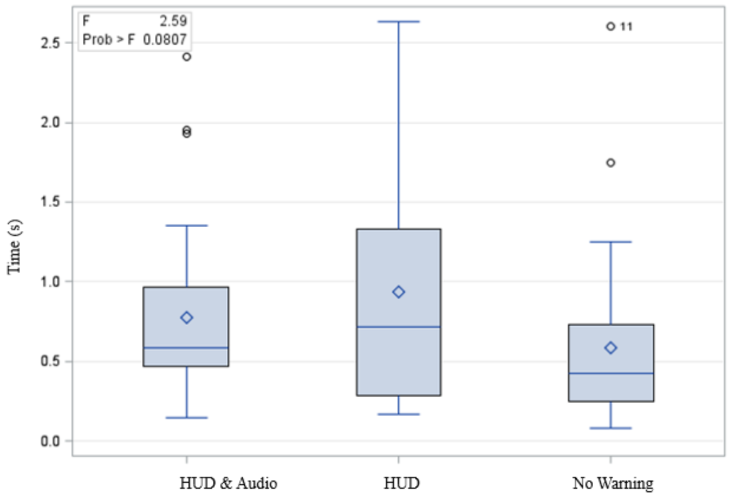


(b) Fog level

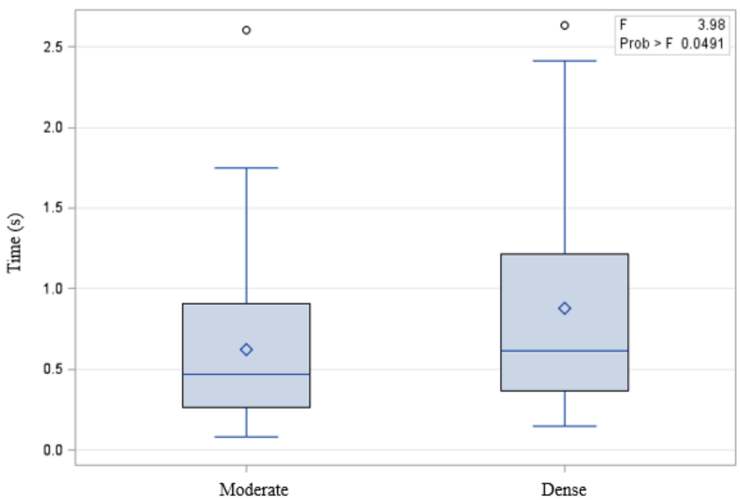
Figure 5.5 - Time to initial braking

4) Time to 25% braking

Significant difference was observed for time to 25% braking by different warning types (F-value=2.56, P-value=0.08) and fog levels (F-value=3.98, P-value=0.05) (see Figure 5.6).



(a) Warning type

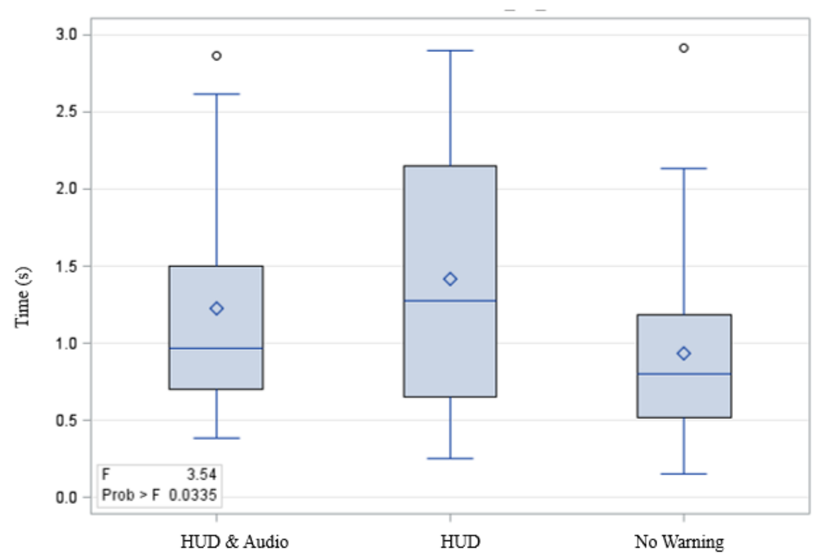


(b) Fog level

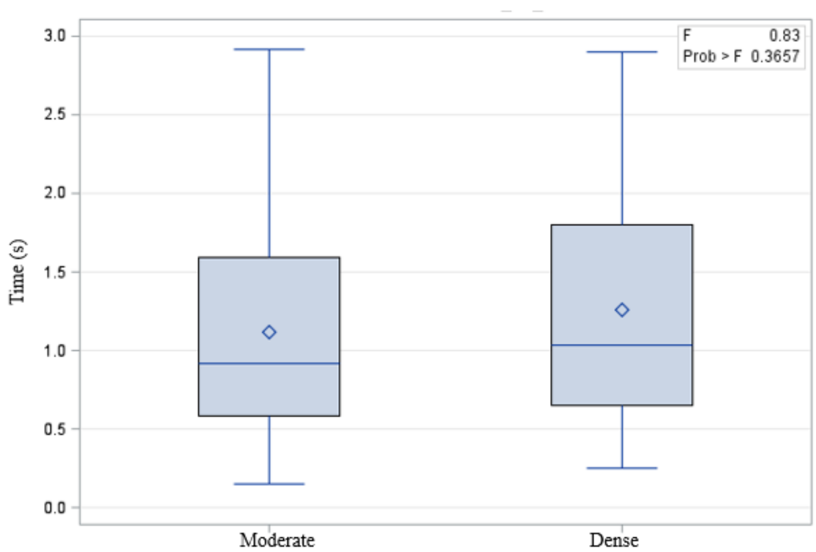
Figure 5.6 - Time to 25% braking

5) Time to 50% braking

Significant difference was observed for time to 75% braking by different fog levels (F-value=3.54, P-value=0.03), while no significant difference was observed by warning types (F-value=0.83, P-value=0.37) (See Figure 5.7).



(a) Warning type

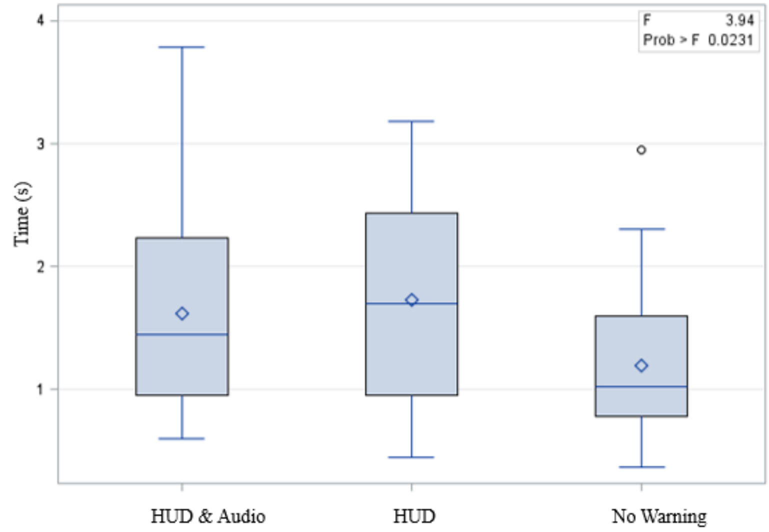


(b) Fog level

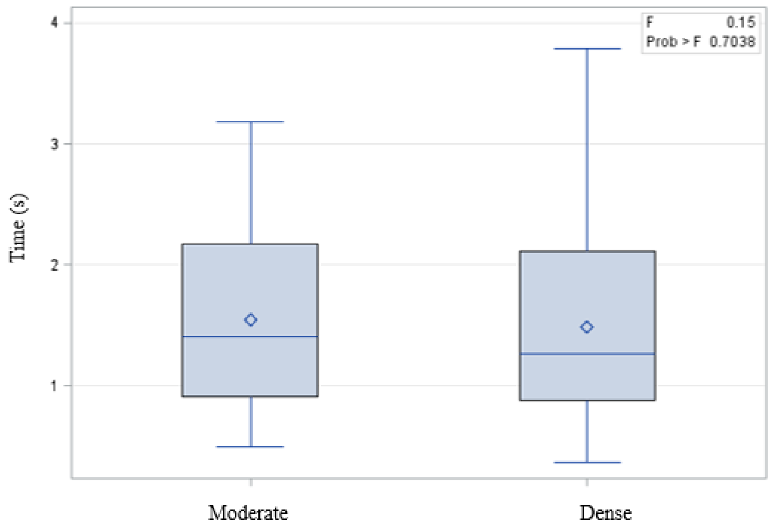
Figure 5.7 - Time to 50% braking

6) Time to 75% braking

No significant difference was observed for time to 75% braking by different fog levels (F-value=0.15, P-value=0.70), while significant difference was observed by warning types (F-value=3.94, P-value=0.02) (see Figure 5.8).



(a) Warning Type

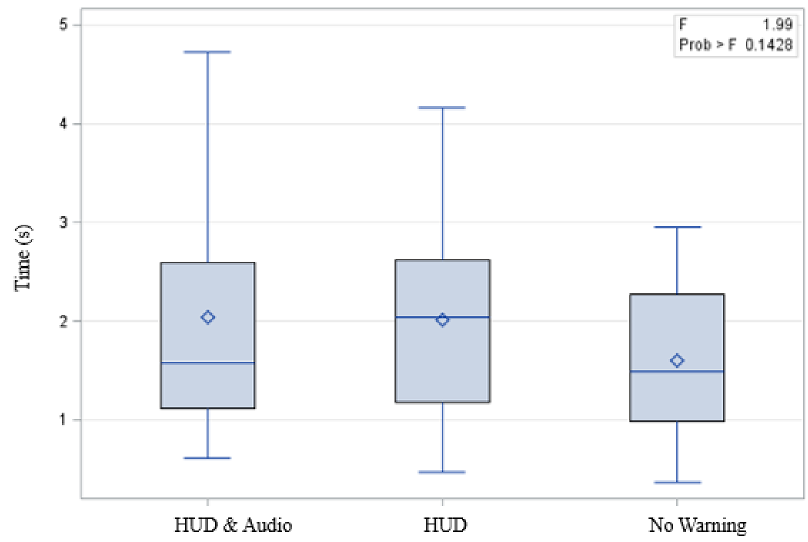


(b) Fog level

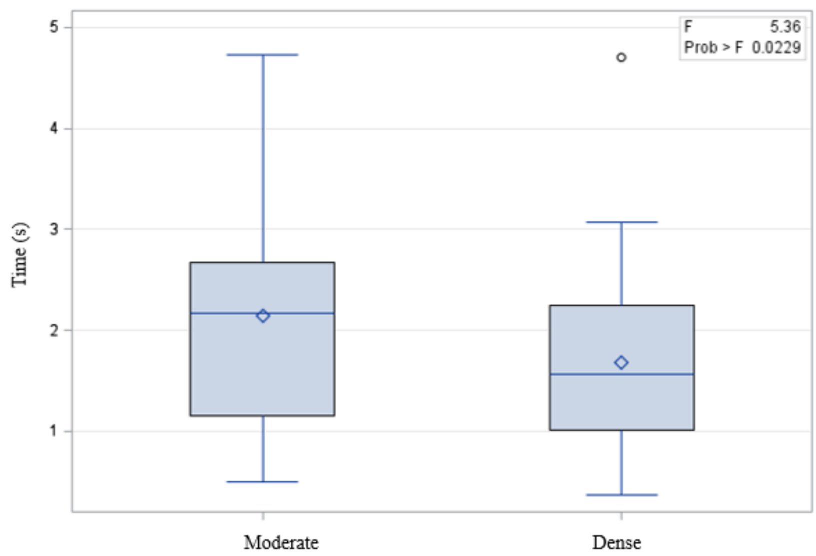
Figure 5.8 - Time to 75% braking

7) Time to maximum braking

Significant difference was observed for time to maximum braking by different fog levels (F-value=5.36, P-value=0.02), while no significant difference was observed by warning types (F-value=1.99, P-value=0.14) (see Figure 5.9).



(a) Warning type



(b) Fog level

Figure 5.9 - Time to maximum braking

Based on the above analysis results, the braking behaviors tend to have significant relationships with different warning strategies, while no significant relationship was found between pedal release behavior and warning systems. More detailed analysis of fog impacts is conducted in Section 7.

6 Methodology

6.1 Analysis of Variance (ANOVA)

Analysis of variance has been widely employed to analyze the differences among group means and their associated procedures when comparing samples with more than two groups. One of the assumptions when using ANOVA is that the observations should be independent from each other. Meanwhile, ANOVA also assumes homoscedasticity of error variances.

During the experiment, each participant drove three different scenarios, and the sample in this research didn't meet the independence requirement of ANOVA. Thus, the repeated-measures ANOVA model is used in this analysis. Repeated-measures ANOVA is commonly used for repeated-measure designs; the repeated-measures factor is the within-subject factors.

Meanwhile, Welch's ANOVA is an alternative to the classic ANOVA, which is employed to compare means even if the data violates the assumption of homogeneity of variances. In this research, the sample sizes of different age groups are not the same. Therefore, Welch's ANOVA is used to analyze the age effects.

Moreover, multivariate analysis of variance (MANOVA) is an ANOVA that includes several dependent variables, which controls the Type I error rate. A MANOVA also can consider inter-dependencies among the dependent variables, enhancing the power to detect significant differences between groups. In this research, MANOVA is employed for both the throttling releasing process and the braking process.

6.2 6.2 Linear Regression Model with Random Effects

Since the minimum TTC is a continuous variable, a linear model with random effects is adopted to analyze drivers' crash-avoidance process. The model can be represented by

$$y_{ij} = \alpha + \boldsymbol{\beta x} + \varepsilon_i$$

$$\varepsilon_i \sim N(0, \sigma_i^2)$$

where y_{ij} is the dependent variable of experiment *j* by participant *i* and α is the fixed intercept. $\boldsymbol{x}$ represents independent variables, and $\boldsymbol{\beta}$ the corresponding parameters. In addition, ε_i is the random effects for participant *i* with normal distribution. Since each participant was asked to drive three scenarios, the random term can be used to account for the effects of repeated observations.

7 Analysis Results

The independent variables for this design included gender (two levels: male and female), warning types (three levels: HUD only, HUD & warning sound, no warning), and fog levels (two levels: dense fog (100 ft.) and moderate fog (300 ft.). Each participant drove through warning types (the within-subject effect) for a randomly assigned fog condition (the between-subject effect), giving a repeated-measures design.

7.1 Speed-Decreasing Behavior

Two-repeated-measure MANOVA analysis was conducted in order to analyze gender and warning type impacts on speed-decreasing behaviors. Table 7.1 and Table 7.2 show the variables that were considered in MANOVA.

Table 7.1 - Dependent variables for throttle-release process

Time to initial throttle release	
$t_{initial}$	Time between when the event begins and when the participant begins to release the throttle pedal.
Time to final throttle release	
$t_{Release}$	Time between when the participant begins to release and the moment when the participant completely releases the throttle pedal.
Time to initial Braking	
t_{brake}	Time between when the participant completely releases the throttle pedal and the moment when the participant begins to brake.

Table 7.2 - Dependent variables for braking process

Time to 25% Braking	
$t_{25\%brake}$	Time between when the participant begins to brake and the moment when the brake pedal position reaches 25% of the maximum brake pedal force of the participant.
Time to 50% Braking	
$t_{50\%brake}$	Time between when the participant begins to brake and the moment when the brake pedal position reaches 50% of the maximum brake pedal force of the participant.
Time to 75% Braking	
$t_{75\%brake}$	Time between when the participant begins to brake and the moment when the brake pedal position reaches 75% of the maximum brake pedal force of the participant.

Time to maximum Braking	
$t_{maxbrake}$	Time between when the participant begins to brake and the moment when the brake pedal position reaches the maximum brake pedal force of the participant.

7.2 Throttle-Release Behavior

The MANOVA revealed a significant main effect for warning type (*F(2, 134)=6.18, p=0.003*), while no significant effect was observed for gender (*F(2, 134)=* 0.47, *p=0.50*) and fog levels (*F(2, 134)=0.06, p=0.81*). Table 7.3 shows the summary of warning type, gender, and fog level effects on braking behavior.

Table 7.3 - Effects on throttle-release behavior

	DF	F value	P value	Wilks' Lambda		
				F Value	DF	P value
Warning	2	6.18	0.003	2.4	4	0.05
Gender	1	0.47	0.50	1.86	3	0.14
Fog level	1	0.06	0.81	0.42	3	0.74

Univariate ANOVAs showed that this difference was due to $t_{Release}$ (F(2,134)=4.09, p=0.02) (Figure 7.1), and $t_{initial}$ (F(2,134)= 5.97, p=0.003) (Figure 7.2).

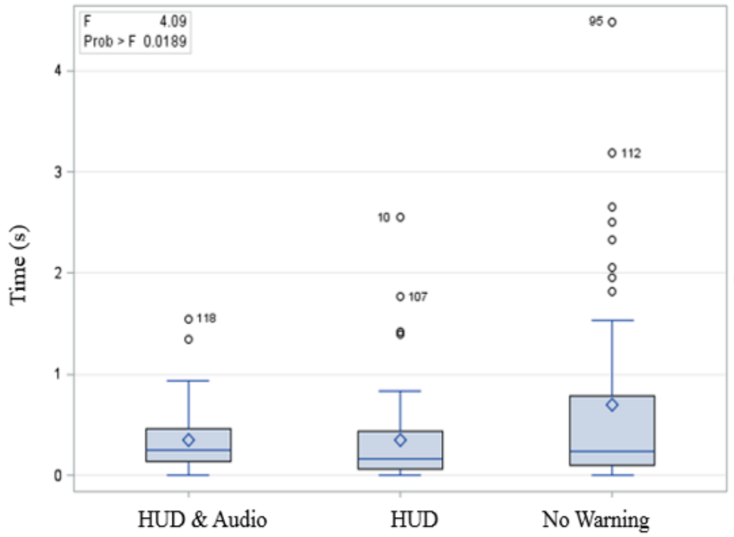


Figure 7.1- Time to final throttle release by warning type

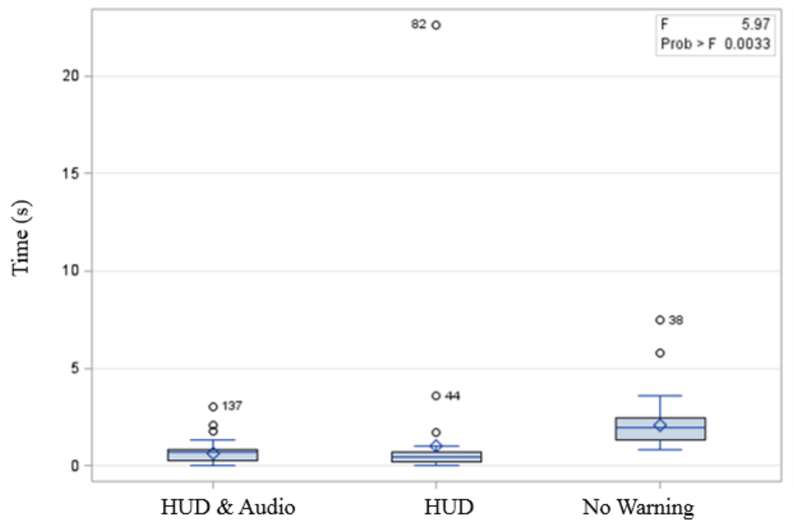


Figure 7.2 - Time to initial throttle release by warning type

7.3 Brake Behavior

The MANOVA revealed a significant main effect for warning type (*F(2, 134)=3.06, p=0.05*), while no significant effect was observed for gender (*F(2, 134)=* 0.02*, p=0.89*) and fog levels (*F(2, 134)=0.02, p=0.89*). Table 7.4 shows the summary of warning type and fog level effects on braking behavior.

Table 7.4 - Effects on braking behavior

	DF	F value	P value	Wilks' Lambda		
				F Value	DF	P value
Warning	2	3.06	0.05	73.69	3	<0.0001
Gender	1	0.02	0.89	10.16	4	0.96
Dense	1	0.02	0.89	3.75	4	0.0064

Univariate ANOVAs showed that this difference was due to $t_{75\%brake}$ (F(2,134)=2.66, p=0.07) (Figure 7.3), and $t_{maxbrake}$ (F(2,134)= 2.79, p=0.06) (Figure 7.4).

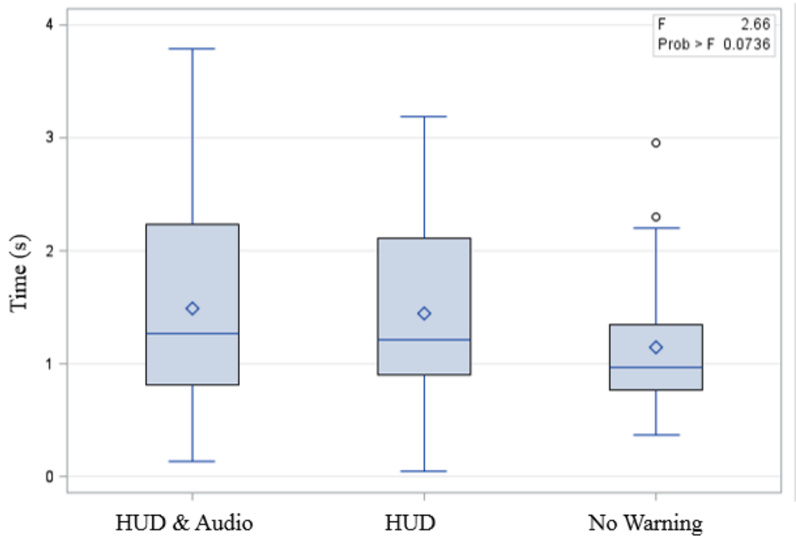


Figure 7.3 - Time to 75% braking by warning type

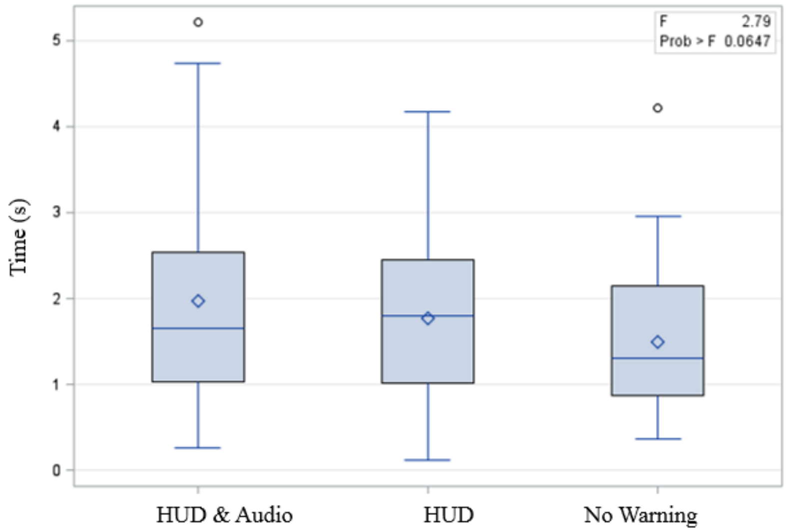


Figure 7.4 - Time to maximum braking by warning type

7.4 Safety Evaluation Variables

Table 7.5 shows the variables that are used to analyze the safety impacts of fog, warning, and gender. Repeated-measure ANOVA was employed in this analysis.

Table 7.5 - Dependent variables for safety evaluation

Variable	Explanation
t_{PRT}	*Perception response time (PRT)*: The time between when the event begins and the moment when the participant begins to brake.
$t_{response}$	*Response time*: The time between when the lead vehicles begins to brake and the moment when the participant begins to brake.
Min_TTC	*Minimum time to collision (TTC)*: Minimum TTC with the lead vehicle.
Peak_brake	Peak braking value during the event.

Warning type has significant impacts on both PRT and minimum TTC, while fog level has significant impacts on minimum TTC and brake peak value (see Table 7.6).

Table 7.6 - Summary of impacts on safety evaluation variables

	$t_{response}$	t_{PRT}	*Min_TTC*	Brake_Peak
Warning	**		**	
Fog level			**	*
gender				

**: significant at 0.05 level; *: significant at 0.10 level

7.4.1 Dense Fog Conditions

Table 7.7 shows warning type has significant impacts on PRT and minimum TTC, while gender has significant impacts on PRT.

Table 7.7 - Summary of impacts on safety evaluation variables

	$t_{response}$	t_{PRT}	*Min_TTC*	Brake_Peak
Warning	*		**	
gender		**		

**: significant at 0.05 level; *: significant at 0.10 level

7.4.2 Moderate Fog Conditions

Table 7.8 shows warning type has significant impacts on PRT.

Table 7.8 - Summary of impacts on safety evaluation variables

	$t_{response}$	t_{PRT}	*Min_TTC*	Brake_Peak
Warning	**	*		
gender				

**: significant at 0.05 level; *: significant at 0.10 level

7.5 Age Effects

Table 7.9 shows the age distribution of the experiment. Since participant numbers are not equal in different age groups, a Welch's ANOVA was conducted in this analysis. Welch's ANOVA is an alternative to the classic ANOVA analysis and can be used even if the data violates the assumption of homogeneity of variances.

Table 7.9 - Age distribution

Age group	Count
Young	18
Work age	18
Old	12

Welch's ANOVA was conducted in order to analyze the age effects on driver behavior. The result indicates that older drivers are prone to brake harder (Table 7.10).

Table 7.10 - Summary of age effects

	Brake_peak	t_{brake}	$t_{25\%brake}$	$t_{50\%brake}$	$t_{75\%brake}$	$t_{maxbrake}$	t_{PRT}	$t_{response}$
Total	**		*			**		**
Dense	**		*	**	**	**		**
Moderate	**					**		

**: significant at 0.05 level; *: significant at 0.10 level

7.6 Survey Results

7.6.1 Paired t-test Analysis

Paired t-test analysis was conducted based on the questionnaire. The participants were asked to rate the effects of HUD and audio, separately. The average score of audio is 3.66 out of 5, and the average score of HUD is 4.64 out of 5. Paired t-test results reveal that there is significant difference between the effects of HUD and audio ($p<0.0001$).

7.6.2 Linear Regression with Random Effects

In order to gain a better understanding of participants' crash-avoidance process, a linear regression with random effects model was employed in this study, while minimum TTC was the dependent variable in the analysis.

The results show the participants who drive more than 5 times every week were prone to have smaller minimum TTC, while participants with a bachelor's degree or higher were more likely to have larger minimum TTC (Table 7.11).

Table 7.11 - Model results

Effect	Estimate	Standard Error	Pr > |t|
Intercept	3.2206	0.4865	<.0001
often	-0.7649	0.4514	0.0937
dense	-1.2185	0.2865	<.0001
HUD	0.4794	0.2344	0.0438
high_edu	0.9889	0.3393	0.0045
AIC	484.34		
BIC	488.08		

8 Conclusion

This research project conducted at UCF aimed to evaluate driver behavior under fog conditions and how drivers respond to low-visibility warning strategies. Also, the effects of different fog levels were investigated in this study. Two different fog levels were considered: 300 ft and 100 ft. In addition, three types of warning strategies were included in the experiment. In total, six scenarios were designed and 48 participants were recruited for this experiment.

Drivers' speed-decreasing behaviors were divided into two parts: the throttle-release process and the braking process. It was found that drivers' throttle-release reactions were faster with the provision of warning strategies. Meanwhile, drivers' braking process was smoother when warning systems were present. No significant effects were observed by gender and fog levels.

Four indicators were employed in order to evaluate traffic safety: PRT, minimum TTC, response time, and brake peak. The results show that driver safety was related to both fog levels and the presence of warning systems, while significant impacts of gender were observed only under dense fog conditions.

The results indicate that older drivers are prone to brake harder in emergency situations, and that drivers thought HUD had better effects than warning sounds. The results also reveal that the participants who drove more than 5 times every week were prone to have smaller minimum TTC, while those who drove fewer than 5 times every week or had higher educational attainment rates (a bachelor's degree or higher) were more likely to have larger minimum TTC.

Considering the results of drivers' crash-avoidance behavior under low-visibility conditions, we can conclude that a warning system could improve safety. It was also found that traffic safety in low-visibility conditions was related to visibility levels, driver age, travel frequency, and education levels. Moreover, different fog warning systems that could be deployed, such as the FDWS (Lee et al, 2012) and the Intelligent Guidance System (Li et al., 2011) , could be considered in a follow-up study.

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Appendix A: Protocol and Study Materials

Evaluating Managed Lane and Fog Systems Conditions Using Driving Simulation

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February 2017

1. PROTOCOL TITLE

Evaluating Managed Lane and Fog Systems Conditions Using Driving Simulation

2. PRINCIPAL INVESTIGATOR

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3. OBJECTIVE

There are two main objectives for this driving simulator experiment. The first is to determine driver behavior in varying fog conditions and explore the impacts of different fog warning systems on driver behavior. The second is to study driver behavior while driving from general purpose lane to managed lane. 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 confidential 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. Further, a questionnaire survey will be also conducted to investigate users' preference on HUD design under fog condition.

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 managed lane, 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. 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 warning systems, as well as managed lane. 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 warning system 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.

Besides, the research team will investigate the effectiveness of warning strategies on low visibility conditions utilizing driving simulator. Various low visibility warning systems will be tested for different combinations of scenarios to assistant drivers' decisions or avoid certain type of crashes. Based on the tested results of driver behaviors, we can examine which warning types are the most safety effective among the various types such as messages (e.g., sentence, pictogram, etc.), sound, and vibration. It is expected that appropriate warning systems can be suggested to enhance safety in fog condition based on our driving simulator experiment.

Besides the fog conditions, the managed lane is also studied in our experiment. Managed Lanes are designated lanes where the flow of traffic is managed by limiting vehicle eligibility, restricting facility access, or variable price tolls. The managed lanes have emerged as an effective dynamic traffic management strategy. In recent years, several major cities in the United States have introduced managed lane systems such as ETLs (Express Toll Lanes), HOT (High-Occupancy Toll) lanes, or HOV (High Occupancy Vehicle) lanes.

In order to efficiently and safely operate the managed lane system, it is necessary to determine the safe length and location of weave access zones nearby on- or off- ramps. Although many managed lanes have been built and various safe length has been recommended (4-5), most of studies were based on microsimulation. In our driving simulator experiment, we aim to test drivers' lane changing behavior and investigate whether the length is sufficient for the drivers to merge into or out from the managed lane. Drivers require enough time (distance) to decide to use (leave) the managed lane. This decision-making process should take more time compared to general lane changing, merging or diverging, since they need to reasonably think if they have a willingness to pay the current toll rate in improve mobility (e.g., reduced travel time). Thus, there are two major cases we need to consider: fist, a distance from an upstream managed lane exit to the next downstream off-ramp; second, a minimum distance from an upstream on-ramp to the next downstream managed lane entrance.

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 is before driving the simulator, and two are after the experiment. Following these preliminary procedures, each subject will then run through 7 scenarios chosen at a random order from a pool of created scenarios. The scenarios chosen will vary between the managed lane and fog related scenarios. Assuming each scenario lasts 4-6 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 Amherst and the University of Puerto Rico 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 126 subjects will be needed to run the simulation and be tested. The subjects will ideally range from ages 18 to 65, and each will be a Florida resident. Since most of the variables of interested 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 February, March, and possibly April. 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, 54 subjects will be needed to complete this research study.

7b) Compensation

Since this experiment will only last one hour in total 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 65. 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 half 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, 126 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 driver 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 participants are expected to come to do the experiment twice, at the very most, 30 minutes for each time. 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 May 2017.

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 and sign 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, etc.), 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. 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. After driving the simulator, the participant will be questioned in regards to the scenarios they just ran and their preference of head-up display design for fog conditions. Attached is a copy of each questionnaire used.

Since this simulation study is looking at both fog warning systems and managed lane 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 managed lane as multiple conditions could be present and needs to be tested.

Ideally seven random scenarios will be chosen for both the fog and managed lane simulations, each taking around 4 to 6 minutes. 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.

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 fog related scenarios, the participant will drive through arterial lanes with varying fog and warning system 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 and warning system presence. 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, 3 scenarios will be randomly selected for each participant to run.

The managed lane simulation will be based on the managed lane on Interstate Road 95 in Miami, Florida. In order to merge into managed lane, drivers need to change multiple lanes. Thus, it could be extremely dangerous if the length for drivers to change lanes from ramp to managed lane or from managed lane to ramp is not enough. There are two major cases we need to consider: first, a distance from an upstream managed lane exit to the next downstream off-ramp; second, a minimum distance from an upstream on-ramp to the next downstream managed lane entry. Drivers require sufficient time to decide to use (or leave) the managed lane. This decision making process takes more time compared to general lane changing, merging or diverging, as they need to reasonably think if they have a willingness to pay the current toll rate to improve mobility (e.g., reduced travel time).

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 warning systems for adverse weather conditions, as well as improve efficiencies at managed lane. 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 warning systems used. These managed lane studies will comprise of determining safe length of location of weave access zones nearby on- or off- ramps. 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.

REFERENCES

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Appendix B: Simulation Questionnaire

SIMULATOR QUESTIONNAIRE

Before the Experiment

1. How old are you?

   ____

2. What is your ZIP code (9-digit, on your driver license)?

					--				

3. What is your highest level of education?
   a. Less than high school diploma
   b. High school diploma
   c. Associate bachelors' degree
   d. Bachelor's degree
   e. Advanced degree or professional degree

4. Are you a professional driver / Does your job involve driving?
   a. Yes
   b. No

5. How long have you been driving a car?

   ____

6. How many years have you been driving in Florida?

   ____

7. Where did you learn how to drive?

   a. In Florida
   b. Outside Florida, but in United States
   c. Outside United States

8. What vehicle do you usually drive?

a. Passenger Car
b. Light Truck or Van
c. Motorcycle
d. Recreational Vehicle (RV)
e. Other. If so, what is the vehicle type: ____________

9. 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:

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

11. Have you ever driven a car with Head-up display (HUD)?
    a. Yes
    b. No

12. Have you been involved in any vehicular crash in the last 5 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.)?

    Did you receive a citation when you were involved in the crash?

SIMULATOR QUESTIONNAIRE

After the Experiment

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 realistic to an actual life situation?

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

5. Under the connected vehicle environment, how helpful was the "Slow Vehicle Ahead" warning in the Head-up Display?

1	2	3	4	5
Not at all helpful	Not very helpful	Somewhat helpful	Helpful	Very helpful

6. Under the connected vehicle environment, how helpful was the warning sounds with the Head-up Display?

1	2	3	4	5
Not at all helpful	Not very helpful	Somewhat helpful	Helpful	Very helpful