Human Factors Study on the Use of Colors for Express Lane Delineators

Final Report

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APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	Mega grams (or "metric ton")	Mg (or "t")

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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16. Abstract

The use of express lanes (ELs) in freeway traffic management has seen increasing popularity throughout the U.S., particularly in Florida. These lanes aim at increasing the efficiency of transportation system management and operations (TSM&O) to provide a more reliable trip. An important component of ELs is the channelizing devices used to delineate the separation between the ELs and the parallel freeway lanes. The current standards for colors of express lane markers, according to the 2009 Manual on Uniform Traffic Control Devices (MUTCD), Section 3H.01, is orange or the same color as the pavement marking that they supplement. However, the upcoming changes of the MUTCD seek to limit the colors only to match those of the pavement markings. Due to the state-wide impact on current and future ELs, it was important to understand the impacts to driver perception and performance in response to the color of the EL markers. It was also valuable to understand the differences between three main age groups (18-39, 40-64 and 65 and older) and gender in responding to markers under different driving conditions. The driving simulator in the Intelligent Transport Systems (ITS) lab at UCF was used to test the responses of the six demographic groups to changes in marker color and driving conditions. Furthermore, participants were tested for several factors relevant to driving performance, including several visual tests via the Optec machine, motion sickness questionnaires, and subjective responses to the changes in colors and driving conditions. The results showed that white was the optimal and most significant color for driver awareness, performance, and notice of the express lanes markers, in both the objective and subjective tests, followed by the yellow color, with black being the least desirable.

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EXECUTIVE SUMMARY

The use of express lanes (ELs) in freeway traffic management has seen growing popularity across the United States that aims at increasing the efficiency of transportation system management and operations (TSM&O) where lanes that are physically separated from existing general use or general toll lanes use vehicle eligibility, access control, and dynamic tolling to provide a more reliable trip. Examples of such applications range from logistical implementations such as truck lanes to sustainability-focused strategies such as high-occupancy vehicle lanes (HOV lanes, also known as carpool lanes), which improve efficiency, safety, and flexibility. They provide additional travel lanes to help serve longer, more regional trips by helping move traffic around congested urban areas, enhance transit services, accommodate future regional growth and development, enhance hurricane and other emergency evacuation, and improve system connectivity between key limited access facilities.

As of the 2009 edition of the Manual on Uniform Traffic Control Devices (MUTCD), Section 3H.01 (Channelizing Devices) states that "The color of channelizing devices used outside of temporary traffic control zones shall be either orange or the same color as the pavement marking that they supplement, or for which they are substituted." The planned changes to this section will impact the current use of orange retroreflective markers, removing the reference to orange and allowing only for the markers to be the same color as the pavement marking. With the upcoming changes to the MUTCD, this study provides an opportunity to recommend the most effective color to increase safety and efficiency on a statewide level, contributing to the protection of lives and the most efficient use of resources.

Driving is a highly complex task requiring constant awareness, and factors such as driving conditions, target colors, age groups (18-39, 40-64 and 65+) and gender are important to investigate in gauging drivers' subjective and objective performance-based reactions. The scale of the impact that the new MUTCD standards will have makes it crucial to implement channelizing devices in the most efficient manner for the safety and efficiency of freeways across the state. The study conducted sought to test drivers from a variety of demographics (six types, based on three age groups (18-39, 40-64 and 65+) and two genders) with respect to several objective performance standpoints, in addition to a subjective aspect carried out at the end of the task. Drivers were first tested on their vision to filter out candidates with poor visual acuity and color blindness and to allow correlations between performance and vision scores across several tests. Following the vision test, participants were asked to fill out surveys to document their experience with motion sickness and simulations. Participants also filled out simulator sickness questionnaires throughout the study to track their response to driving in a simulator over an extended period because the finalized study design required a significant amount of driving time (roughly three hours) with changes to the driving environment, which were time of day, road surface type, traffic density, visibility, and, most importantly, marker color.

After filling out the initial questionnaires, drivers underwent a series of driving scenarios with the aforementioned varying driving conditions. The aim of putting participants in the simulator was to objectively test their driving performance and perception factors, such as deceleration, braking behavior, lane deviation, and speed of perception (time to first notice). For determining

speed of perception, an eye-tracker was used in combination with the simulator to be able to determine where participants were looking on the screen(s). After the simulator runs, drivers were asked to fill out two questionnaires: the first with regards to demographic features which included age, gender and driving history and the second for determining the participants' own subjective responses to the changes in scenario variables and whether they noticed the change in the marker's color.

The data collection effort was the most extensive aspect of the study, requiring the collection and extraction of several datasets from the recruited participants. This proved to be quite time-consuming due to three main factors: the participant recruitment process which included the three age groups (18-39, 40-64 and 65+) and two genders; some participants were unable to complete the entire three-hour study without becoming motion sick; and the amount of data extracted from each scenario presented processing challenges. Furthermore, a few datasets were lost due to technical issues, ranging from eye-tracker calibration errors, corrupt video files, and corrupt simulator output files. As a result, the study required roughly 50% more recruits in order to meet the 120-participant target. The 176 participants were recruited to participate in the study through a variety of mechanisms, which included student recruitment (UCF SONA), Learning Longevity Research Network (LLRN), Learning Institute for Elders (LIFE), social media outreach, fliers, and personal connections. Participants were required to have a driver's license, with normal vision, and be over the age of 18.

Out of the 176, 134 participants successfully completed the scenarios, while the remaining 42 participants were unable to complete the experiment due to no show, motion sickness, dizziness, corrupted simulator files, simulator crashes, or inadequate vision, among other reasons. Data extraction for the visual tests and surveys consisted of simple manual entry into an Excel spreadsheet. Extraction of the eye-tracking data required a thorough frame-by-frame analysis of the eye-tracking recording for each participant. For extraction of the driving data, a MATLAB script provided by the simulator developers, the National Advanced Driving Simulator (NADS), was used to extract the raw data from the simulator output files at a rate of 60 Hz (60 data points per second) on a scenario-by-scenario basis. The raw files were then processed using a MATLAB script developed in-house to convert the data points into useful measures of driving performance, which were then used in the statistical analysis of performance factors using the SAS-based analysis software, JMP.

Six different datasets were examined and analyzed. They included motion sickness data, eyesight data, driving data, eye-tracking data, demographic data, and exit survey data. The statistical analysis for the driving data examined the impacts of the express lane marker color change on driver behavior among other traffic and environmental conditions at different sections along the ELs. Based on the average speed parameter, most of the marker colors showed consistent speeds, close to the speed limit. However, white markers showed a much wider variability in speed based on environmental conditions. Lane deviation showed how much a driver weaves before entering the express lane. Although white and black markers showed significance in terms of lane deviation, compared to the rest of the colors, drivers tended to align to the left side of the lane (away) while encountering white markers, which demonstrates strong awareness of the delineated lane line, while black markers showed vehicle alignments that were closer to the markers in all cases, especially during nighttime conditions, due to the undetectable black markers. The results also showed that the white markers were the most significant in the straight section, while yellow markers were the most significant in the curved section. In addition, deceleration and braking time were examined. Furthermore, the Time-To-First-Notice (TTFN) was also analyzed by age group and gender, which showed whether people noticed the markers before entering the ELs. Based on this parameter, the results indicated that most people noticed the white markers consistently before entering the ELs. The highest miss rates were for the black markers. The results showed that black markers consistently showed high significance and low optimality. White and yellow markers consistently had high significance and high optimality among all the models, with white always outperforming yellow except in the case of lane deviation. Purple and orange markers only appeared to be effective occasionally. Both the preliminary and final analyses came to the conclusion that **white markers** were the optimal and most significant color to notice the express lane markers, followed by the yellow markers, with black markers being the least desirable. Both the objective and subjective datasets agreed on this selection, with participants' survey results matching the analysis of the objective performance factors. Furthermore, the use of retroreflective sheets on the markers also proved to be crucial in implementation, expectedly resulting in significantly increased noticeability in nighttime scenarios.

These findings may prove to be extremely valuable in future EL implementations. ELs have important applications for emerging technologies like automated and alternatively powered vehicles, such as eco-lanes. It may be useful to investigate the impacts of color on perception for artificial intelligence and sensor applications. While the results of this research are conclusive in their relevance to human perception, machine perception of channelizing devices is an area that could potential need further research to quell uncertainties and ensure the safest, most efficient rollout of driverless technologies.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

I. INTRODUCTION

1.1 Background

The concept of express lanes (ELs) is an increasingly accepted traffic management tool that aims at improving the efficiency of transportation system management and operations (TSM&O) where lanes that are physically separated from existing general use or general toll lanes use vehicle eligibility, access control, and tolling to provide a more reliable trip. They provide additional travel lanes to help serve longer, more regional trips by helping move traffic around congested urban areas, enhance transit services, accommodate future regional growth and development, enhance hurricane and other emergency evacuation and improve system connectivity between key limited access facilities. Over the past decade, the ELs have been increasingly deployed all over the nation, especially in Florida. The 2009 Manual on Uniform Traffic Control Devices (MUTCD), section 3H.01, states that "The color of channelizing devices used outside of temporary traffic control zones shall be either orange or the same color as the pavement marking that they supplement, or for which they are substituted". However, the upcoming changes to the MUTCD, Section 3H.01 (Channelizing Devices), will impact the current use of the orange retroreflective markers, remove the reference to orange and only allow the delineator to use the same color as the pavement marking. This change will have a statewide impact to current and future ELs.

In addition, markers are available in the market as other colors, including blue, red, green, brown, and grey. The effectiveness of color use in traffic and roadway design is an important human factor issue that is directly related to driver's performance, comfort, and safety. Driving is a complex task that requires sensory, perceptual, cognitive, and psychomotor skills. Hence, a driver must be able to detect targets (see lanes, colors, signs, displays, warning systems, etc.), perceive (make sense of these static or moving targets), and act upon (decide and respond) in a timely manner in order to be optimal in his/her driving performance. Therefore, any ineffective use of color in traffic or roadway design can lead to an increase in driving errors and response time, driver fatigue, loss of situational awareness, and increased workload level. Consequently, this may also lead to an erosion of the safety margin.

Although the use of colors has long been studied in aviation, maritime, and surface transportation systems, further research is still needed as our transportation systems continue to evolve because of rapid technological advancements. Inappropriate use of colors can also impact drivers who may have problems with some colors. For example, over 7% of the male population suffers from color deficiencies (red-green), which is often referred to as color blindness. This group of drivers may be at risk for traffic-related crashes due to their color deficiency. Thus, it is important to understand the relevant human factors issues of color as applied to express lane markers and traffic safety to determine which color has the best performance and optimal effect on drivers for separating the ELs from the GPLs.

1.2 Project Objectives

The objectives of the proposed project can be summarized as follows:

1. Conduct a comprehensive literature search for published work related to human factors studies to identify methodologies, models and parameters.
2. Design a driving simulator experiment to test driver's behavior in response to different express lane marker colors. Invite enough subjects to participant in the experiment.
3. Identify several human factors to be studied and evaluate the effectiveness of the different colors of the express lane markers on the significant factors.
4. Develop a statistical model that will accurately analyze the impacts of the express lane marker color change on driver behavior.
5. Determine the optimal color choice for the express lane delineators.

1.3 Summary of Project Tasks

Task 1: Literature Review.

Task 2: Research Plan and Design of Experiment.

Task 3: Human Factors Experiment and Data Analysis.

Task 4: Develop Evaluation Model.

Task 5: Draft Report.

Task 6: Final Report.

II. LITERATURE REVIEW

To date, numerous studies have examined the various human factors issues related to driving (e.g., aging and driving, driver distraction and inattention, aggressive "road rage" driving, in-vehicle devices and display design, driver fatigue). While these issues continue to be a major concern for effective diver assessment, traffic safety, and public health, efforts to mitigate their impact on drivers' daily travel and commuting activities have not been extensively researched. In this task, we have conducted an extensive literature search using key human factors and engineering models. Based on our results we have synthesized these research articles using a taxonomic approach to better classify the models and understand the parameters' interrelationships. Moreover, since color is the core element of this research, the literature review also included both the theoretical and applied studies on the effects of color on visual scenes and driver behavior. The results of our review are presented below.

2.1 Delineators

In today's rapid and busy driving environments, drivers are often seeking better, faster, and safer ways to beat their daily traffic problems. Sometimes, drivers often use specific digital apps that can direct them to faster alternative routes. However, the majority of drivers rely on the well-established "express lanes" that are commonly used by drivers across the United States. With each location where express lanes are installed, the separation between general-purpose lanes and express lanes is essential to safely redirect drivers from the travel lanes. There are five main driving factors that affect the type of separation (Davis, 2011), as described below.

- Safety
- Right-of-Way
- Cost
- Express Lanes Roadway Characteristics
- Express Lanes Characteristics

Typically, rigid barriers, pavement markings, and delineators are the three main types of separations. Rigid barriers are hard physical separation devices that are still widely used. However, rigid barriers have some disadvantages, such as, access restriction to express lanes which affects incident management response time and the difficulty to vacate lanes under emergency conditions. Also, this separation type usually requires additional right of way for access provision which increases installation costs. Pavement marking is another method to separate the general-purpose lanes from the express lanes. This method is considered as a non-physical separation type and has several advantages such as, easy installation and emergency vehicles access. However, it is difficult to prevent or enforce illegal lane changes. From a safety stand point; there are more opportunities for side swipe crashes between general purpose lanes and express lanes. On the other hand, delineators also known as markers, are considered as the soft physical separation device with several advantages. Delineators are easy to install with low cost. In addition, it is easier for emergency vehicles access, and no additional right of way is needed. Therefore, delineators are very effective in separating the general-purpose lanes from the express lanes.

2.1.1 Manual on Uniform Traffic Control Devices (MUTCD)

MUTCD defines the delineators as follows:

"Delineators are particularly beneficial at locations where the alignment might be confusing or unexpected, such as at lane reduction transitions and curves. Delineators are effective guidance devices at night and during adverse weather. An important advantage of delineators in certain locations is that they remain visible when the roadway is wet, or snow covered. Delineators are considered guidance devices rather than warning devices".

Typical components of the delineators' assembly, as shown in Figure 2-1, consist of a pylon post, a curb, and fixtures (Stinson Equipment, 2011; Kuchangi et al., 2013). The posts and curbs are usually made of high impact flexible polymers, which provide high tensile and elongation properties. Generally, delineators with heights of 36 inches, 42 inches, and 48 inches are commonly used for high speed facilities for lane separation. The 2009 MUTCD, Section 6F.65, states that tubular markers shall be predominantly orange and shall be not less than 18 inches high, as well as 2 inches wide facing road users. They shall be made of a material that can be struck without causing damage to the impacting vehicle. Tubular markers shall be a minimum of 28 inches in height when they are used on freeways and other high-speed highways, on all highways during nighttime, or whenever more conspicuous guidance is needed.

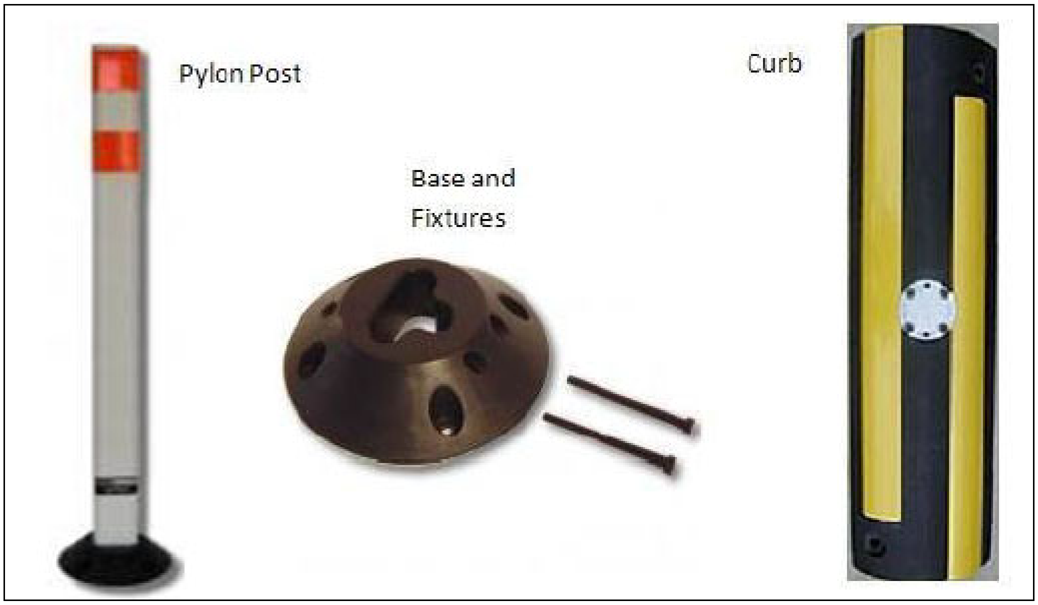

Figure 2-1: Components of a Typical Delineator

2.1.2 Applications

There are several applications for delineators. For example, the delineators are used for freeway exit ramps. They cause less damage to vehicles when hit compared to concrete barriers. Another use of delineators is at highway-railroad grade crossings. The use of delineators at highway-railroad grade crossings discourages motorists waiting at the highway-railroad grade crossing from the opposite lanes to illegally avoid the gates and reduce the number of illegal crossing maneuvers (Byungkon et al., 2003). In addition, delineators could also be used in work zones to channelize traffic. It helps in separating the work zones from the general lanes to provide a safer driving environment. Lastly, as mentioned earlier, delineators are widely used to separate the express lanes from the general-purpose lanes. Figure 2-2 shows the typical application for delineators.

Figure 2-2: Typical Applications for Delineators

The delineators' color is the main focus of this study. Generally, white, yellow, and orange are typically used for lane separation on roadways. The current study was to test two more colors (purple and black) in addition to the three colors mentioned above. The 2009 MUTCD, section 3H.01, states that for nighttime use, channelizing devices shall be retroreflective or internally illuminated. On channelizing devices used outside of temporary traffic control zones, retroreflective sheeting or bands shall be white if the devices separate traffic flows in the same direction, and shall be yellow if the devices separate traffic flows in the opposite direction, or are placed along the left-hand edge line of a one-way roadway or ramp. In addition, the 2009 MUTCD, Chapter 3A shows that the use of black pavement marking with other color marking could enhance the visibility of the marking. Similarly, the black and white retroreflective sheeting could also make delineators more conspicuous.

2.1.3 Florida Standards

There is no federally mandated national standard for testing and evaluating delineators. The MUTCD (2012) sets standards for color and retroreflective sheeting, but does not address testing and evaluation. The American Association of State Highway and Transportation Officials (AASHTO) Manual for the Assessment of Safety Hardware (MASH, 2009) requires that all delineators are crashworthy. There is a national standard developed by the AASHTO National Transportation Product Evaluation Program (NTPEP) Temporary Traffic Control Devices (TTCD) committee, however it is not a federally mandated standard. Therefore, it is up to each state to either develop its own evaluation criteria or adopt the NTPEP evaluation standard. Many states have adopted the NTPEP testing standard including Florida. However, the initial products installed on the I-95 managed lanes in District 6 were being replace approximately 5 times per year leading to high maintenance and replacement costs. For this reason, Florida among other states, have established additional evaluation criteria beyond the standard NTPEP testing criteria to fully evaluate the delineators before installation, such as Section 993-2.7 of Florida Specification 993 Object Markers and Delineators, also known in the industry as the "High Durability Delineator Specification". For example, a minimum of 150 tire impacts and 45 bumper impacts resisted among other standards are recommended as a pass/fail criterion for managed lanes delineator durability. The height is 36 inch and minimum diameter of 3 inch. Florida also removed the requirement for low temperature testing due to its warmer climate. All testing is performed at a temperature of 65°F or greater. The delineator is also required to be mechanically anchored and return to within 5° of vertical post to ensure quality products are selected on FDOT roadways.

2.2 Human Factors

Human Factors is the study of how humans accomplish work-related tasks in the context of human-machine system operation, and how behavioral and nonbehavioral variables affect that accomplishment (Meister, 1989). The goal of human factors engineering is to reduce error, increase productivity, and enhance safety and comfort when the human interacts with a system (Wickens & Hollands, 2000). Human factors are influenced by several elements related to the driving task and the environment which are explained in the following sections.

2.2.1 Driving task

The driving task consists of the various activities required to safely operate a vehicle. Thus, it is important to examine the human factors issues related to driver behavior and traffic safety. Michon (1985) proposed a theoretical approach to build the driving task hierarchy model. Based on this model, the driving task is divided into three levels: strategic, maneuvering and control levels. Strategic level refers to the planning of the route. For example, drivers need to plan the exact route from origin to destination (Becher et al, 2006; Michon, 1985). The maneuvering level would be turning, responding to traffic signs, and overtaking. The control level means maintaining the vehicle stability, such as braking, shifting, and steering. Rasmussen (1983, 1985) also proposed three levels of driving task performance level, including knowledge, rule, and skill. The knowledge level is like the strategic level. Drivers need to get familiar with the environment and find way to get to the destination. The rule level is controlled by the memory rules, which means drivers could retrieve from the memory simply based on previous successful experiences (Theeuwes, 2001). At the skill level, behavior represents sensory-motor performance during the activities, such as braking, steering, and accelerating (Rasmussen, 1983). The main difference between rule level and skill level is that rule level is based on know-how and the driver can report the applied rules. However, the skill level is related to the variability of force, space, or time coordination (Reason, 1990). Skill level corresponds to the control level proposed by Michon (1985).

2.2.2 Driver's perception

The driver's perception mainly consists of speed perception, time to collision, and field of view perception. Speed is one of the most important factors related to traffic safety. Previous research reported that there are many ways that affect the drivers' speeding behavior by affecting the drivers' speed perception. Usually, people think that drivers would check the speedometer to precept the speed. However, Recarte and Nunes (2002) found that drivers tend to choose an optimum preferred speed to minimize mental effort dedicated to speed control, not referring to the speedometer to regulate their speed. Three factors were found to be related to the speeding perception, including edge rate, global optic flow rate (Chatziastros, 2003; François et al., 2011; Larish & Flach, 1990; Recarte & Nunes, 2002), as well as the contrast and the spatial frequency in a scene (Blakemore & Snowden, 1999; Distler & Bülthoff, 1996; Johnston & Clifford, 1995; Pretto & Chatziastros, 2006; Stone & Thompson, 1992; Thompson, Brooks, & Hammett, 2006). The definition of the edge rate is the number of texture elements that pass by the observation point in each visual direction in a unit of time and is expressed in edges per second (François et al., 2011). Several studies confirmed that the edge rate corresponds to road safety. Fajen (2005) found that a decrease in texture density had negative effects on the brake reaction time. In addition, two studies also confirmed that different visual patterns could affect the driver's speeding (Manser and Hancock, 2007; Denton, 1980). For example, when decreasing width visual patterns, drivers are more likely to decrease their speed. In contrast, drivers would increase their speed under increasing width condition. Although some studies pointed out that the edge rate might have positive effects on speeding perception (Anderson et al., 1999; Lewis-Evans and Charlton, 2006; Bing et al., 2008), Chatziastros (2003) investigated that the effect might be temporary. When drivers get familiar with the new environment, drivers would return to their preferred speed. The definition of the global optic flow rate is the optical velocity of ground surface texture elements in a given visual direction and is proportional to the observer speed assuming constant eye height (Fajen, 2005). This concept is different from the edge rate. Global optic flow rate is related to the driver's eye height. For example, large vehicle drivers such as SUVs or trucks have different speed perception with small vehicle drivers such as a sedan (Rudin-Brown, 2004). Also, the spatial and contrast frequency have strong effects on the speed perception in the peripheral vision over the foveal vision (Jamson et al., 2008).

The time to collision (TTC) is defined as "the time required for two vehicles to collide if they continue the same path at their present speed" (Hayward, 1972). TTC is one of the factors that could be used to estimate traffic safety. The smaller the TTC is, the more likely that two drivers could have a crash. Therefore, it is important for drivers to estimate TTC when two vehicles are in motion. Hoffmann & Mortimer (1994) found that drivers usually underestimate TTC when TTC values are at low level. However, there were also a small percentage of situations that drivers overestimated TTC. This is a dangerous situation, and it may lead to collision when overestimating TTC.

The field view perception has two parts. One is the useful field of view (UFOV), while the other is driver's eye movement. UFOV is defined as "the region of the visual field, from which information can be acquired without any movement of the eyes or the head (Ball et al., 1988) and consists of the central and peripheral vision (Ball et al., 1993)." The size of the UFOV is related to luminance level, light wavelengths, stimulus salience, and execution of secondary tasks. With respect to UFOV, humans usually scan the surrounding environment by moving their eyes, even moving their head. Singularities are required to attract the driver's attention. During the driving task, singularities include dynamic singularities, geometric singularities, and symbolic singularities (Dahmen-Zimmer and Zimmer, 1997). Previous studies pointed out that different singularities could be perceived parallel to focal visual attention (Braun & Sagi, 1990). For example, conspicuous color is not the important factor that affects the driver's visual scanning behavior (Theeuwes, 2001). Theeuwes et al. (2000) conducted an experiment and found that drivers searched randomly no matter the target is red or green. In addition, the results also indicated that even conspicuous road signs can be overseen by drivers unless they searched for a specific sign.

2.2.3 Driver Information processing

It is very important to understand how drivers process information. Generally, perception can be divided into two processes, including bottom-up and top-down processing (Matthew et al., 2008). Bottom-up processing refers to "stimulus analysis driven by the input data alone" and top-down processing refers to "sensory input that activates the person's relevant knowledge, motivation and expectations (Weller et al., 2006)". Perception means the interaction between these two processes. For example, the minor adjustment during the driving process, such as minor acceleration, minor steering can be driven by the bottom-up processing. The speed control can be considered as the top-down processing. Driving experience is one of the most important factors that affect the information processing. Drivers with rich driving experience are more likely to relate the singularities to their experience, thus they can make appropriate decisions when facing a potential crash (Cohen, 2009). On the contrary, if drivers don't have sufficient driving experience, they may not be able to process the information promptly and correctly.

Situation awareness is another important concept in terms of information processing. Situation awareness is defined as "the perception of elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future (Endsley, 1988)". For example, when people drive to their destination, there are several steps that drivers need to take to arrive at the destination. During each step, drivers need to compare the current state to the desired state and try to control the vehicle to the desired state. This process is considered as the situation awareness. There are three components of situation awareness, including perception of elements in the environment, comprehension of their meaning in relation to task goal, and projection of their status presently (Endsley, 1995). The perception of elements in the environment is the most fundamental part. The environmental information is perceived by drivers. The information that drivers perceive depends on driver's behavior as well as the driver's sensory system. However, it is very easy for drivers to ignore important information (Otte and Kuhnel, 1982), which affects the interpretation process. The more information the drivers perceive, the more demanding the process is. Based on the perceived information and interpreted information, drivers forecast the future situations, which is the projection of their status in the near future.

2.2.4 Driver behavior models

Driver's behavior models assume that drivers don't only respond to stimuli, but also actively determine their driving behavior (Staubach, 2009). Generally, the driver behavior models can be summarized into three categories: risk threshold models, risk compensation models, and risk avoidance models (Michon, 1985).

The risk threshold model was first proposed by Klebelsberg (1977). There are two concepts in this model. One is objective safety, and the other is subjective safety. Objective safety mainly refers to the physical environment, while subjective safety is the safety perceived by drivers. If objective safety equals to subjective safety, the situation is ideal. However, in real life, it is hard to maintain a balance between subjective safety and objective safety. When subjective safety is greater than objective safety, a dangerous situation may occur. When subjective safety is lower than objective safety, it provides a surplus safety margin.

The most famous compensation model was presented by Wilde (1988, 2001, and 2002). Each driver has their own target risk level, which is also called accepted risk. Drivers would adjust the perceived risk under the accepted risk (Panou et al., 2007). The compensation model is that when supplementary safety features are added, drivers would take advantage of these safety features by engaging in more risky driving behavior.

Fuller (1984) proposed the risk avoidance model, which integrates most elements of the perceived models. The key of this model is that drivers experience subjective risk and try to avoid it in the future. According to the model, drivers usually respond to the stimulus during the driving task. The drivers' reaction depends on different factors, such as expectation, motivation, and usefulness. Furthermore, Fuller (2000, 2002) took the task difficulty into consideration.

2.3 Effects of Color on Visual Scenes

Previous research on the effects of color on the detection of visual stimuli and scenes have used a variety of methodological approaches including controlled laboratory experiments, observational studies, simulated, and real-world environments. These studies have contributed a great deal of scientific knowledge at both the basic perceptual and cognitive levels, as well as the practical application levels. Understanding the various human factors properties of color scheme, and redundant color coding effects on human performance is very important for cockpit display design (Yeh and Wickens, 2001; Molloy and Parasuraman, 1994; Christ 1975), air traffic control (ATC) management tasks (Thackray and Touchstone, 1991), and roadway and traffic signs design (Ben-Bassat and Shinar, 2006). For example, an early study by Lit, Yung, and Shaffer (1971) examined the effects of color on visual stimuli using a laboratory-basic perceptual experiment. In this study, participants were exposed to colors of varying wavelength (blue, green, yellow, red) under conditions of varying illumination levels. Results indicated that participants' reaction time (RT) was longer at low target illumination for the color sets, but became faster (RT values decreased) as illumination level was increased. However, stimulus wavelength (color) had no differential effect on RT by itself. Thus, illumination was attributed to the effect of color on participants' reaction time. In addition, another laboratory study by Haines et al. (1975) also examined peripheral visual response time in relation to colored visual stimuli matched for brightness and appearing at an unexpected time and location. Their results indicated that participants' mean foveal response time was faster for yellow (288 ms) than blue (341 ms) visual colored stimuli. However, a study by Thones, von Castell, Iflinger, and Oberfeld (1991) examined the effects of color on time estimation of visual stimuli related to behavioral control. They presented their participants with 3 (yellow, green, and red) colored visual stimuli and recorded their reaction time. The results indicated that the yellow visual stimuli had significantly longer RTs compared to either red or green visual stimuli. Their findings were interpreted in terms of the processing requirement load imposed by yellow color compared to red and green. Also, another study by Gorn et al., (2004) examined whether the perceived time (fast versus slow download of a page) duration for a web page's background screen is affected by color. They had 49 participants browse a series of real estate properties pages presented against a background (yellow or blue) screen, and required them to indicate the perceived quickness (three 9-point scales: 1 being slow, not speedy, or not quick, and 9 being fast, speedy, or quick) of the page download. The results from their experiment showed that participants who were assigned to the blue hue condition reported significantly faster perceived quickness (3.65) than those assigned to the yellow (3.04) hue condition. In the second experiment, they tested 61 participants who were either assigned to a blue or red background screen like. The results from experiment 2 showed that participants who were assigned to the blue background screen reported significantly faster perceived quickness (5.92) than those assigned to the red (5.09) background screen. However, a study by Shibasaki and Masataka (2014) examined the difference in time perception between blue screen and red screen at different time intervals. Their findings reported an overestimation of red screen color compared to blue screen color. Nevertheless, this effect was restricted to only the male participants. The female participants' perceived time estimation did not significantly vary as a function of color.

A more recent study by Thones, von Castell, Infringe, and Oberfeld (2018) also examined the effects of color on time perception using a two- interval duration-discrimination. Participants in this study were presented with a series of visual stimuli consisting of red and blue color combinations (b-r, r-b, b-b, and r-r). These two stimuli varied slightly in duration and were presented in a successive manner, and all of the participants were required to indicate which stimulus was longer in duration. All other factors known as moderating the effects of color on this type discrimination task (e.g., brightness, saturation, etc.) were kept the same across all of the experimental conditions. They were brightness-matched for each individual participant and the saturation was controlled colorimetrically as well in order to overcome some of the problems resulting from previous studies. Their results showed an overestimation of the blue stimuli over the red stimuli by 12%, although the red visual stimuli resulted in higher levels of arousal based on the participants' emotion ratings.

Zwahlen and Schnell (2014) studied how the use of yellow pavement markings on the left edge of the road as a warning to indicate opposing traffic (yellow for caution), compares with the visibility of similar white pavement markings on the right edge of the road and how well the general driver population understands the message conveyed by yellow pavement markings. The effects of color (white and yellow) and material retro-reflectivity (low, medium, and high) on the end detection distance of finite-length center lines at night under automobile low-beam illumination were determined. Ten subjects were used in a field experiment (rural, automobile low-beam conditions) to obtain the end detection distances of finite-length center stripes of 0.1-m width. The data showed that the end detection distances of new yellow dashed center stripes and new white dashed center stripes are about the same. The average end detection distance was 30 to 35 m for the low retro-reflectivity material and about 62 m for the high retro-reflectivity material (four-to fivefold retro-reflectivity increase). It is tentatively concluded that the use of white center stripes most likely will not result in a significant increase in the end detection distance when compared with the use of similar yellow center stripes.

Rosli et al. (2016) compared the visibility threshold of eight plates with different chromatic contrast. The staircase psychophysics method was used to determine the average visibility threshold. It was found that the white on blue background combinations provided the highest visibility, which indicated the white on blue was much easier to see and detect. However, red on blue background was difficult to see and could only be detected at closer distance.

2.4 Effects of Color and Luminance Level on Driver Behavior

Early research by Reynolds et al., (1972) examined the detection and recognition of colored signal lights in a driving simulation environment. They examined color contrast between target and background which is very important for driving. This could be related to the contrast between the delineator and the road/surrounding environment, or between a sign and the sky/foliage. For example, red is thought to provide strong contrast against white and bright green, while bright yellow is thought to provide strong contrast against black or blue (Hilgendorf, 1969). In this study, participants were required to identify colored lights (red, green, yellow, or white) against dark green, tan, dark blue, and copper backgrounds at 2 (dim or bright) levels of ambient illumination. The results showed that participants' reaction time (RT) was slow across all of the colored signal lights in the dim ambient illumination; however, participants' RTs increased significantly for all stimulus colors in the bright ambient illumination condition. Under bright ambient illumination, red stimulus color resulted in the lowest reaction time, followed by green, yellow, and white. Overall, red and green stimulus colors resulted in shortest RT across trials, with the RT for green rising significantly in the green background condition. Patterns of stimulus recognition errors also showed that green and red resulted in the lowest rates of stimulus color recognition errors (Reynolds, White, & Hilgendorf, 1972).

However, a study by Chang, Lin, and Lin (2001) examined perception time (time to decide to break) and movement time (time to place foot on the pedal) in a driving simulator with 20 male participants aged between 21 and 25 years old. They used color filters to produce different color lights (red, yellow, and blue) using either LED 4W, Incandescent 5W, or Incandescent 10W brake lights. Participants were required to respond to the brake lights within a 1.5 seconds window or they would miss that response. If their response to the light was incorrect, it was recorded as a false alarm. Their results indicated that both ambient illumination and lighting colors had a significant effect on participant reaction time. These findings indicated that for lighting, the dark blue resulted in a faster reaction time. Also, for both day and night time driving environments, the yellow color resulted in the shortest reaction time which was consistent with previous research (Lu, 1996).

Luoma et al. (1997) investigated the effects of turn-signal color on reaction times to brake signals. Three-lamp conditions were tested, including brake lamps alone, brake lamps while turn signal was on, and a turn-signal lamp alone. The results showed that different brake signal with different colors of turn signals have different reaction times. The drivers' reaction time to brake signal in the context of yellow turn signals is shorter than that in the context of red turn signals. The difference is around 110 ms. The colors of turn signals had an effect whether or not the turn signal was on, but the effect was greater when it was. Bullough et al. (2013) also investigated whether the use of lighting and visual information could alter driver behavior. It was found that chevron size and spacing modifications could impact the driving speed based on a controlled field experiment. Therefore, they suggested that chevron size and spacing modifications can be readily implemented. Summala (1981) tested the driver's steering reaction to the light stimulus on a dark road. It was found that typical steering response latency of the driver in a fully unexpected situation on a dark road is of the order of 2.5 second. The safe limit is a little more than 3 second.

Similarly, another study by Alferdinck (2006) using a high-fidelity driving simulator was also conducted to assess time perception and driving behavior in low lighting conditions. Targets were presented on a screen that participants had to respond to. The targets were varied in luminance level and color. The results showed that color (red, blue, white, yellow) and luminance level had significant impacts on reaction time and accuracy (total number of missed targets). Low light levels had a negative impact on performance for both reaction time and target detection. As luminance increased, RT and missed targets decreased. It was found that performance using red targets was worse than the other types (blue, white, or yellow) of color under low luminance.

Another on-road experiment was conducted by Wang et al., (2016) to examine the effects of drive time and roadside landscape colors on drivers' mean heart rate (MHR) scores. Results indicated that landscape colors were negatively correlated with the MHR scores. This indicated that an increase in color brightness was significantly associated with a decrease in driver passive fatigue level (Wang, Bie, and Li, 2016). Li et al. (2017) investigated whether the landscape color of expressways has significant impact on a driver's visual response. The simulation experiment showed that the colors and stroboflash of fog lamps have a positive effect on the drivers' safety. In addition, the red and yellow were found to have the largest influence among the studied color in terms of drivers' safety. A recent study conducted by Lai (2010) investigated the impact of color use in conjunction with variable message signs on driver performance. They manipulated 3-color (green, yellow & red) scheme and number of message (single, double, or triple) lines using a simulated driving environment. The results indicated that participants had faster response times when they performed double line message combined with 2 colors. However, they were slower when they completed the 3-colors scheme combined with triple line message. Because variable message lines are very important for directing traffic, providing warning signs, signaling for traffic and merging lines, informing of traffic congestion, alerting drivers for potential hazards, they also share the same physical characteristics used by delineators in terms of color scheme attributed to the physical environment.

In summary, these findings point to the need of choosing the most effective color for a visual scene situation, considering the background color, background brightness, and the amount of ambient illumination required for accurate and fast recognition of color and signal lights.

2.5 Driving Simulator and Eye-Tracking

In recent years, the driving simulator has been widely used in safety as well as human factors research. The modern driving simulator is usually built, using a sophisticated driver environment, which can give drivers an onboard impression as if they are in an actual environment. In addition, driving simulators usually include visual systems, audio systems, and vibration systems, which provide a realistic feel of all controls. Therefore, a driving simulator is one of the research tools which enable researchers to conduct multi-disciplinary investigations and analyses on a wide range of issues (Abdel-Aty et al., 2006; Godley et al., 2002).

The use of a driving simulator for human factors research has many advantages. The driving simulator has controllability, reproducibility, and standardization compared to real vehicles (Yan, 2005). The behavior of vehicles, pedestrians and other environmental conditions can be controlled based on the research purposes. Especially, the driving simulator can simulate dangerous driving situations in a safe environment, which facilitates testing different driving behaviors (Underwood et al., 2011; Tu et al., 2015; Yan et al., 2016; Chang et al., 2009). Also the data can be collected accurately and efficiently (De Winter et al., 2009). It is difficult to collect accurate data from a real vehicle in the real world. Compared to the real conditions, the driving simulator has the capability to produce data in less than a second. Researchers can get an accurate data up to 100 data points per second based on the different types of driving simulators. Furthermore, the driving simulator can test novel instructions and functions for feedback (Yan & Wu, 2014; Yan et al., 2015; Larue et al., 2015). Some new technologies and instructions cannot be easily tested in real vehicles due to safety concerns. Therefore, the driving simulator is a viable alternative to achieve significant feedback of new technologies and instructions.

However, there are also some disadvantages of driving simulator researches. For example, the simulator fidelity is one of the factors that impact the research results. Some researches pointed out that some low-fidelity simulators may evoke unrealistic driving behavior so that the research outcomes may be invalid (De Winter et al., 2012). To reduce the fidelity impact, a high-fidelity simulator is used in this study. Another important disadvantage is simulator motion sickness (Kennedy et al., 1992; Frank et al., 1988; Brooks et al., 2010). The data collected from the simulator may be biased due to the sickness symptoms. Some participants might not complete the experiments because of the motion sickness, especially for the older participants. However, this issue can be solved by familiarizing the participants with the driving simulator to get used to it and overcome the motion sickness effect.

In addition, eye tracking equipment is also widely used in the transportation field for understanding the nature of the driving behavior task. The first eye tracking equipment can be traced back to 1940s, which is equipped with a mini-camera on the helmet (Hartridge &

Thompson, 1948). However, the first eye tracking equipment used for observing the driver's behavior was in the 1970s (Soliday, 1971).

Generally, there are three main types of apparatus for testing visual strategy. They include helmet devices, contactless devices, and special equipment. Helmet has a high accuracy of measurements, which can be designed for use either with an immobilized or freely moveable head. It is suitable to use the helmet in the lab to record biological signals, such as electroencephalography (EEG), electromyography (EMG), magnetic resonance imaging (MRI). Contactless devices usually consist of 2 or more HD cameras and the cameras are usually placed in front of the driver. This kind of device is primarily for reading the screen; therefore, it is suitable for driving simulator, not for real-time test driving. Special devices refer to neurophysiology device, which track eye movement in a tunnel, or in other similar conditions, such as Positron Emission Tomography (PET), computed tomography, magnetic resonance imaging (MRI) which are not suitable for this study.

During the driving task, drivers usually try to find a target point in the field of view to anticipate direction of traveling. Trivedi et al. (2007) used the vision system to test drivers and found that the most important information for drivers is moving elements which appear in a driver's field of vision. Edquist et al. (2011) used driving simulator and eye tracking equipment to examine driver's visual behavior and response to road signs in presence and absence of billboards. They found that the presence of billboard increased the driver's fixation time so that drivers need more time to respond to road signs, which could increase the number of errors during driving. Burns et al. (2005) also investigated the lane change behavior for the distraction of the road signs. It was indicated that drivers required more visual fixation and cognitive processing and the distraction to the road sign would impair the driver's ability to lane changing behavior. Similar findings are also reported by Engstrom et al. (2005). Parkes et al. (2007) also used driving simulator and eye tracking equipment to examine the visual behavior under the conversation condition. Drivers spent less time on the road when they were involved in conversation either from the front seat passenger or hands-free phone talk. In addition, the number of glances to the speedometer was also reduced and drivers were more likely to miss the road signs compared to the non-conversation condition. Fildes et al. (2007) also applied the eye tracking equipment for testing the difference between young drivers and old drivers. It was found that older drivers had a longer fixation time and less precision than younger drivers.

2.6 Literature Summary and Conclusions

The present review of literature consisted of a synthesis of the major theoretical trends and models related to driver perception, driver behavior, human factors parameters, and experimental studies using simulators and eye tracking systems regarding the use of colors in designing effective delineators. Figure 2-3 provides a synthesis of the most studied models and parameters used in the literature using a taxonomic approach.

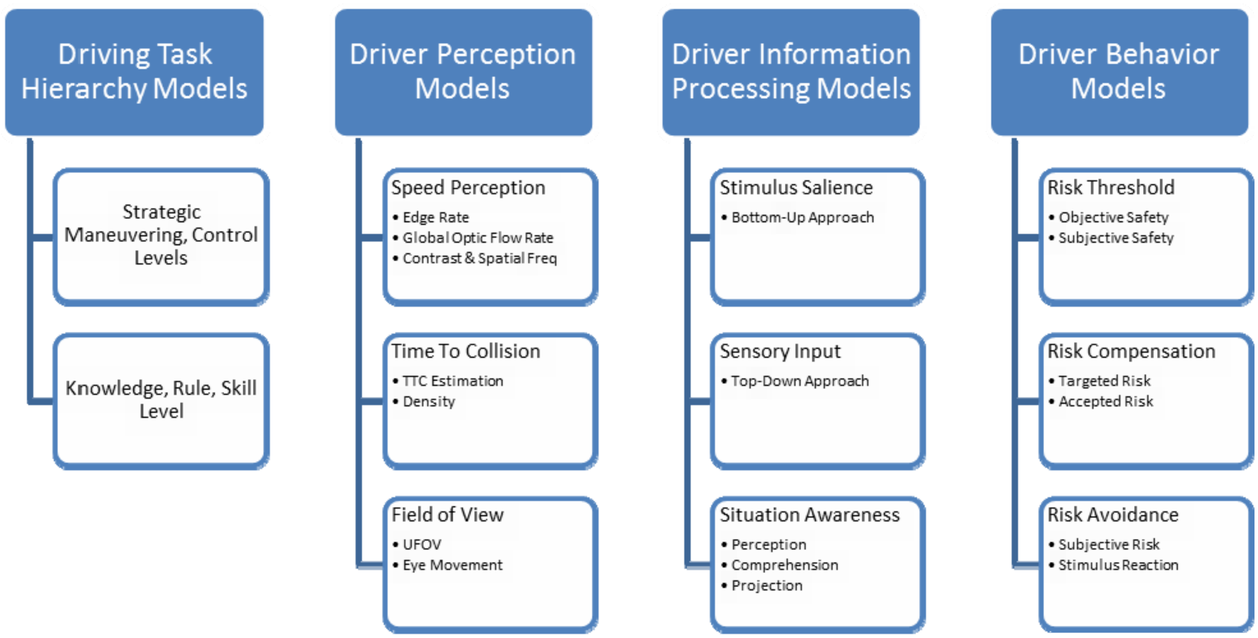

Figure 2-3: A Synthesis of the Studied Models and Parameters Using A Taxonomic Approach

The literature review also included both the theoretical and applied studies on the effects of color on visual scenes and driver behavior. The studies included different types of stimuli, colors, methodology and a number of other factors. While some of these studies have reported significant effects of color on driver reaction time or time perception, others have failed to obtain such effects. In addition, some of the effects of color on driver reaction time were also moderated by individual factors such as participants' sex. The discrepancy in the results could be partially attributed to the lack of experimental control. Without a rigorous control of these variables, one cannot determine with certainty that color is the sole factor influencing reaction time. Based on these studies, we have developed a matrix/taxonomy (Table 2-1) which highlights the effects of color and luminance level on visual stimuli as well as driver's perception and reaction time (PRT). The table is organized based on (1) Study methodology (laboratory, driving simulator, or on-road study with real environment, (2) Type of stimulus used (e.g., lights, Scheme , digit/letter targets, etc.), (3) Type of colors used in the study (red, green, yellow, blue, etc.), (4) Measures (RT, Accuracy, physiological, subjective, etc.), (5) Background color, Illuminations, Day/night, etc. The last column indicates whether the results showed an effect of color (solid circle) or absence of an effect of color (open circle) or a combination of an effect of color and illumination level (intersection of both circles).

Table 2-1: Taxonomy of Color Scheme Effects on Visual Stimuli and Driver Behavior

Authors	Study Methodology	Type of Stimulus	Type of Colors	Measures	Background color, illuminations, day/night	Contributing Factor	Effect of Color
Lit, Yung, and Shaffer (1971)	laboratory-basic perceptual experiment	Photometr-ically colored targets	blue, green, yellow, red	Reaction time	A wide range of scotopic and photopic retinal illuminance levels	Luminance level	○
Haines, Dawson, Galvan & Reid (1975)	Laboratory experiment	colored visual stimuli	blue, yellow, green, red	Peripheral visual response time	brightness at about 2.6 sub log 10 units above their absolute light threshold	Yellow faster than blue	●
Thones, von Castell, Iflinger, and Oberfeld (1991)	Laboratory experiment	visual stimuli related to behavioral control	yellow, green, and red	reaction time	Processing requirement load imposed by color	Yellow longer RT than red and green	●
Gorn et al., (2004)	Laboratory experiment	Screen	Yellow, blue & red	perceived time duration	Background color	Blue faster than yellow & red	●
Shibasaki and Masataka (2014)	Laboratory experiment	screen	Blue and red	Perception time	Background	Red faster than blue (males only)	●

Table 2-1: Taxonomy of Color Scheme Effects on Visual Stimuli and Driver Behavior (continued)

Thones, von Castell, Iflinger, and Oberfeld (2018)	Laboratory experiment	visual stimuli of 2 interval duration discrimina-tion	Blue and red	perception time	Saturation controlled colorimetrically	Blue stimuli over red	●
Zwahlen and Schnell (2014)	Field experiment	material retro-reflectivity (low, medium, and high)	Yellow and white pavement markings	end detection distances of center stripes of 0.1-m width	at night under automobile low-beam illumination	Material retro-reflectivity	○
Rosli et al. (2016)	Laboratory experiment	staircase psychophysics method	White versus red on blue background	average visibility threshold	Plates with different chromatic contrast	White with blue background	●
Reynolds, White, & Hilgendorf (1972)	Laboratory experiment	Contrast between target and backgroun-d of colored signal lights	red, green, yellow, and white	speed of detection and accuracy of identificati-on	dim & bright levels of ambient illumination	bright ambient illumination condition	○
Alferdinck (2006)	Driving simulator	Targets on screen	red, blue, white, yellow	Reaction time	low lighting conditions	Color and Luminance level	●○

Table 2-1: Taxonomy of Color Scheme Effects on Visual Stimuli and Driver Behavior (continued)

Lai (2010)	Driving simulator	variable message signs	Green, yellow & red	Driver response time	3-color scheme and number of message lines	Color and message lines	●○
Wang, Bie, and Li, 2016	on-road experiment	roadside landscape colors	landscape colors (green)	drivers' mean heart rate scores	Color brightness	Color brightness	○
Luoma et al. (1997)	Driving simulator	turn signal and brake colors	red or yellow	reaction times		Yellow had shorter RT than red	●
Bullough et al. (2013)	on-road experiment	the size and spacing of traditional chevron signs		Driving speed	lighting and visual information	Size and spacing	○
Summala (1981)	Field observation	light stimulus		driver's steering reaction	Amount of light on a dark road	Light stimulus	○
Li, X., Tang, B., & Song, Q. (2017).	Driving Simulator	Landscape colors	Red and yellow	Driver's safety & visual response	Fog time	Red and yellow stroboflash of fog lamps	●
Chang, Lin, and Lin (2001)	Driving Simulator	Color filters	Red, yellow & blue	Perception & reaction time	LED & Incandescent brake lights (day & night)	ambient illumination and lighting colors	●○

No Effect of Color ○ Effect of Color ● Effect of Color and Illumination Level ●○

Based on the taxonomy results presented above, it is clear that several factors are involved in the relationship between color effects and driver behavior. This taxonomy highlights the importance of various task characteristics, environmental factors, testing platforms, and individual variables that are relevant for the assessment of color effects on driver behavior. In addition, the literature review also showed that the effects of color on driver reaction time were not universally conclusive. Consequently, these results varied as a function of a number of factors such as color background, illumination, saturation, etc. A total of 17 studies were selected for inclusion in the initial coding and analysis of various task characteristics, testing platforms, and individual variables described above. About 47% of the evaluated studies (laboratory, on-road testing, and simulated driving environments) reported significant effects of color on driver reaction time or perception time, while six studies (35%) failed to obtain such color effects, and two studies (12%) obtained color effects only when combined with other factors such as luminance. Overall, the results of this taxonomy showed a consensus in supporting the effects of color on driver behavior in simulated environments. Four out of the five simulation studies reported significant effects on driver reaction time. However, none of the other four (on-road testing) studies obtained such effects of color on driver behavior. These findings clearly indicate that the driving simulator may serve as a strong and suitable method for investigating the effects of color on driver behavior, particularly when driving along express lanes using colored pole delineators. Furthermore, the literature findings also identified the most studied parameters, including environmental factors, driving behavior factors, and participants' individual characteristics. Therefore, based on the literature review results, a driving simulation experiment was designed to investigate the effects of express lane delineator colors on driver behavior. The selected colors of delineator poles to be used in this study were yellow, white, black, purple, and orange. Both bio-behavioral measures consisting of drivers' attention responses, driving performance accuracy, and eye movements were recorded in a series of simulated driving environments. These measures included vehicle speed, deceleration, and lane changing behavior from the driving simulator, while first fixation time, perception-reaction time, and average blink duration were identified from the eye-tracking device. Finally, the methods of this project are intended to serve as a benchmark for how to determine the best color for delineators to safely separate traffic between general purpose and express lanes.

III. RESEARCH PLAN AND DESIGN OF EXPERIMENT

This chapter explains the research plan, procedures and protocols needed to design a driving simulator experiment to evaluate different colors of express lane markers on driver behavior in preparation for the actual experiment.

3.1 Institutional Review Board (IRB) Addendum and Approval

It should be noted that review and approval is required for all research involving human participants conducted by the University of Central Florida (UCF) through the Institutional Review Board (IRB). Approval must be obtained prior to including human participants in an investigation to ensure that the guiding ethical principles for human subject protection are met. A preliminary approval was received in March 2018. However, significant changes were made to the simulator's roadway layout developed in order to both modify the geometry involved and combine different driving conditions into a single unified scenario based on comments received from the FDOT project team during the review process. The modifications required an increase in the length of each simulation run, which doubled the time required to complete the experiments from just over an hour to 2.5 hours per participant. The final configuration spanned approximately 6 miles and included two entrances. The first entrance included a single express lane entrance with markers between the express lane and the general-purpose travel lanes. The second entrance included a similar configuration but with two ELs. An addendum was submitted to the Institutional Review Board (IRB) in May 2018. However, the approval was received on August 9th, 2018. The addendum also required the addition of new researchers to be added to the team and approved by the IRB. Due to the delay in receiving the final IRB approval, a no-cost time extension was approved by FDOT and the project schedule was extended till end of September. The no-cost time extension form and the IRB approvals are included in Appendix A.

Participants were screened for eligibility using an OPTEC machine. They also had to go through a series of surveys to identify any motion or simulation sickness before, during and after the experiment. A specific protocol was designed and given to each participant to explain the experimental process. Both bio-behavioral measures were recorded in a series of simulated driving environments. The experiment included several procedures which are explained in details in the following sections.

3.2 Equipment

3.2.1 Driving Simulator

The study utilized a driving simulator for the experiment and data collection, located at the University of Central Florida as shown in Figure 3-1. The driving simulator was developed by NADS – the National Advanced Driving Simulator group from the University of Iowa, which provides a high fidelity driving testing environment. It includes a visual system (three 42" flat panel displays), a quarter-cab of actual vehicle hardware including a steering wheel, pedals, adjustable seat, and shifter from a real vehicle, a digital sound simulation system and a central console. The data sampling frequency reaches 60 Hz along with a recording system. The simulator was also equipped with four recording cameras to ensure subjects' safety and to capture the participants' performance while driving in the simulator. One device was pointed directly at the participant's feet to record their gas and brake-pedal usage. One was directed towards their face to record head movements and another towards their hands. The last recording device was located behind the participant, recording the monitors and where they direct the simulated vehicle.

Figure 3-1: UCF Driving Simulator

3.2.2 Eye Tracking System (ISCAN ETL-500 Eye-tracker)

The eye tracking system was also utilized in this study. Eye movements were recorded using an ISCAN ETL-500 eye-tracker. This eye-tracker is light weight and comes affixed to a baseball cap as seen in Figure 3-2. The monocular headset contained both eye and scene imaging cameras, an infrared source, and a dichroic mirror which connect to an eye-tracking computer via a 20’ cable. The eye-tracking computer has a pupil/corneal reflection tracking processor which samples the data at a rate of 60 Hz as shown in Figure 3-3. Additionally, eye movement data was recorded on HP laptop using Cyber Link Media Suite 10 Power Producer video recording software as shown in Figure 3-4.

Figure 3-2: ISCAN ETL-500 Eye-Tracker

Figure 3-3: Eye-Tracking Computer and Pupil/Corneal Reflection Tracking Software

Figure 3-4: Cyber Link Power Producer Video Recording Software

3.3 Participants

At least 120 drivers, who have valid driver licenses, were to be selected to participate in the experiment. The subjects' ages ranged from 18 to over 65. Since most of the variables of interest in this study are based on the participants' demographics, a nice even distribution was needed to ensure unbiased results. Therefore, a variety of subjects with varying age, gender, education, ethnicities, and backgrounds were recruited. Participants ran the simulations through voluntary means and were free to withdraw from the simulation at any time and from partaking in the study for any reason. In order to ensure the minimum number of 120 participants was achieved, the sample size was to be increased by 20% to account for any participant's attrition, however, this number inflated to roughly 50%, mainly due to difficulty recruiting working-age (40-64) males and elderly (65+) females. The planned distribution of the participants' age and gender is shown in Table 3-1.

Table 3-1: Participants Demographics

Age Group	**Gender**	
	Male	Female
Between 18 and 39	20	20
Between 40 and 64	20	20
65+	20	20

3.4 Recruitment process

Identifying potential participants was not a particularly difficult task for this research as the main requirements were to be above 18 years old with a valid driver's license, and must not have a history of severe motion sickness. The participants who met the age requirement underwent a preliminary screening test without issues. For example, individuals who have at least 20/40 normal or corrected visual acuity, who are not color blind based on the Ishihara color blindness test, with normal depth perception and contrast sensitivity were included in this study. Those who could not pass the screening test were excluded. We provided monetary incentive of $25 each, provided that they finished all the scenarios. We also utilized the UCF Psychology Research Participation System (SONA) where students can earn extra credits in their course work or choose to get the $25.

The family and friends of the researchers were recruited by word of mouth or by e-mail. Older adults were recruited through the Learning Longevity Research Network via e-mail. Likewise, faculty and staff were also be recruited by word of mouth or by e-mail. A description was given to explain the basis of the research and was sent out through these e-mails. In addition, flyers were sent out of the campus to companies, as well as religious institutions in the Orlando area. These flyers were also posted on social media to help advertise the study. The advertisement is attached in Appendix B.

3.4.1 SONA Systems

SONA Systems is the University of Central Florida's online research participation system for the Psychology Department. This system provides undergraduate UCF Psychology students a way to easily view and sign up for studies within or partnering with the psychology department. In return for volunteering their time participating in a study registered on SONA Systems, individuals typically receive extra credit in one of their Psychology courses. However, other means of payment can be used instead of course credit as determined by the researcher.

3.4.2 Learning Longevity Research Network

The Learning Longevity Research Network is a database comprised of contact information for older adults who are interested in participating in research conducted at the University of Central Florida in the greater Orlando, Florida area. This network allows researchers at the University of

Central Florida to email older adults in the database about research participation opportunities that may be of interest to the individual.

3.5 Experiment Protocol

Upon arrival, all participants were asked to read and sign an informed consent form per the IRB to make sure each participant knew what to expect. Then, each participant was asked to take a demographic survey including questions on the variables of interest (age, gender, etc.), before they enter the driving simulator room. The demographic survey is included in Appendix C. The subjects were then screened for Motion Sickness using Kennedy et al.'s Motion History Questionnaire (MHQ) which is attached in Appendix D and was monitored to make sure they did not become motion sick three (3) times throughout the study (before, during and after) using Kennedy et al.'s Simulator Sickness Questionnaire (SSQ) which is attached in Appendix E. In the event that the participant becomes motion sick, they were provided water and a cool place to sit, until their motion sickness subsides as defined by the SSQ. The motion sickness was monitored by the research assistants who watched for signs of uneasiness.

Driving simulator systems may induce a variety of simulation/virtual reality sickness symptoms (e.g., nausea, dizziness, and disorientation) a result of a system exposure and/or longer exposure durations, especially for the older adults who may be more susceptible to simulation sickness (SS) than their younger counterparts.

Before starting the driving simulator scenarios, each participant was asked to take a short training session, including the Traffic Regulation Education, the Safety Notice and the Familiarity Training. In the Traffic Regulation Education session, all participants were advised to drive, follow traffic rules and behave as they normally do in real driving situations. In addition, participants were not informed about color or color changes before the experiment. In the Safety Notice session, each participant was told that they can quit the experiment at any time if they have any motion sickness symptoms or any kind of discomfort. In the Familiarity Training session, each participant was given about 10 minutes training to familiarize them with the driving simulator operation, such as straight driving, acceleration, deceleration, left/right turns, and other basic driving behaviors.

After completing the short training session, participants started the formal experiment and went through ten different scenarios in a random sequence so as to eliminate the time order effect. In addition, all participants were encouraged to rest about 3 minutes between the scenarios.

After completing all the scenarios, each participant completed an exit survey to determine whether they noticed the change in marker color and to get their opinion on the most noticeable color. The exit survey is included in Appendix F. The summary of the procedure is shown in Table 3-2. The anticipated time duration of each participant in the experiment was estimated around 120 minutes.

Table 3-2: Procedure Summary

No.	Procedure	Time duration
1	Fill in three surveys (Demographic survey, MHQ, SSQ)	15 mins
2	Training session (Traffic regulation education, safety notice, and familiarity training)	10 mins
3	Formal experiment (10 runs, including two SSQ)	90 mins
4	Exit survey	5 mins

3.6 Design of Experiment

3.6.1 Scenario Matrix

In many scientific investigations, the concern is to optimize the system. Experimentation is one of the popular activities used to understand and/or improve a system. This can be achieved by studying the simultaneous effects of two or more factors on the response at two or more values known as "levels" or settings. This type of standard experiment is known as factorial design. Cost and practical constraints must be considered in choosing factors and levels. Therefore, two-level factorial designs are common for factor screening in industrial applications. However, if a non-standard model is required to adequately explain the response or the model contains a mix of factors with different levels, the experiment results in an enormous number of runs. In this study, the parameters consisted of four (4) two-level factors and one (1) five-level factor. The standard number of runs for a full factorial design needed to cover all cases would amount to 80 runs for each applicant. For 120 applicants, the total would be 9,600 runs. Under such conditions, optimal custom designs are the recommended design approach. Choosing an optimality criterion to select the design points is another requirement. Accordingly, the D-optimality and l-optimality criteria were the two custom designs employed for this experiment.

Optimal designs fall under two main categories. One is optimized with respect to the regression coefficients (D-Optimality Criteria) and the other is optimized with respect to the prediction variance of the response (l-Optimality Criteria). D-Optimal designs are more appropriate for screening experiments because the optimality criterion focuses on estimating the coefficients precisely. The D-optimal design criterion minimizes the volume of the simultaneous confidence region of the regression coefficients when selecting the design points. This is achieved by maximizing the determinant of X'X over all possible designs with specific number of runs. Since the volume of the confidence region is related to the accuracy of the regression coefficients, a smaller confidence region means more precise estimates even for the same level of confidence. Therefore, this experiment utilized the D-Optimal design. Table 3-3 provides the layout of the scenario matrix which describes the experimental plan in terms of the study factors.

Table 3-3: Scenario Matrix

No.	TOD	Traffic Density	Weather	Road Surface Type	Color
1	Day	Low Density	High Visibility	Asphalt	Yellow
2	Night	Low Density	Low Visibility	Asphalt	Orange
3	Night	Low Density	High Visibility	Concrete	White
4	Day	High Density	Low Visibility	Asphalt	White
5	Day	High Density	High Visibility	Asphalt	Purple
6	Day	High Density	High Visibility	Concrete	Orange
7	Night	High Density	High Visibility	Concrete	Black
8	Night	Low Density	Low Visibility	Concrete	Purple
9	Day	Low Density	Low Visibility	Asphalt	Black
10	Night	High Density	Low Visibility	Concrete	Yellow

Each participant went through the 10 scenario. Each row of the table represents one set of experimental conditions that were analyzed against objective response variables, as will be described later in this section.

The response variable entailed both bio-behavioral measures consisting of drivers' attention responses, driving performance accuracy, and eye movements. They were recorded in a series of simulated driving environments, where vehicle speed, deceleration, and lane changing behavior were extracted from the driving simulator, while first fixation time, perception-reaction time, and average blink duration were identified from the eye tracking device.

3.6.2 Driving Simulator

The driving simulator software which includes Tile Mosaic Tool (TMT), Interactive Scenario Authoring Tool (ISAT) and Minisim, are used to create the driving scenarios within virtual traffic environments and virtual road networks. The models and tiles are developed by the NADS staff at the University of Iowa.

The model includes one static object representing flexible lane delineator post. The model contains five (5) color options; orange, yellow, black, white, and purple. The delineator's height is constructed 36 inches for straight sections and 24 inch height along curves not meeting stopping sight distance, with a white retroreflective sheeting requirement of 30 square inch (3" diameter * 10" length) omni-directional single wrap around the post. The top of the sheeting is 1.5 inches below the top of the post. The spacing between the posts is 5 feet.

In addition, six (6) tile models are constructed with 12-foot lanes, consistent in appearance with existing NADS Tile Library Models. These tiles contain features consistent with an urban environment with a center barrier median, straight section, curved section, and transitioning sections. Each tile is 0.5 miles in length (4*660 foot tile units). Longer road sections were constructed using the NADS Tile Mosaic Tool (TMT) by placing additional tiles adjacent to each other in the TMT workspace. The developed roadway type was for asphalt and concrete surfaces. Figure 3-5 shows a snapshot of the driving simulator model with 36" orange delineators on a straight section and asphalt road surface type with 2 express lanes. Figure 3-6 shows 24" orange delineators on a curved section and concrete road surface type with 2 express lanes.

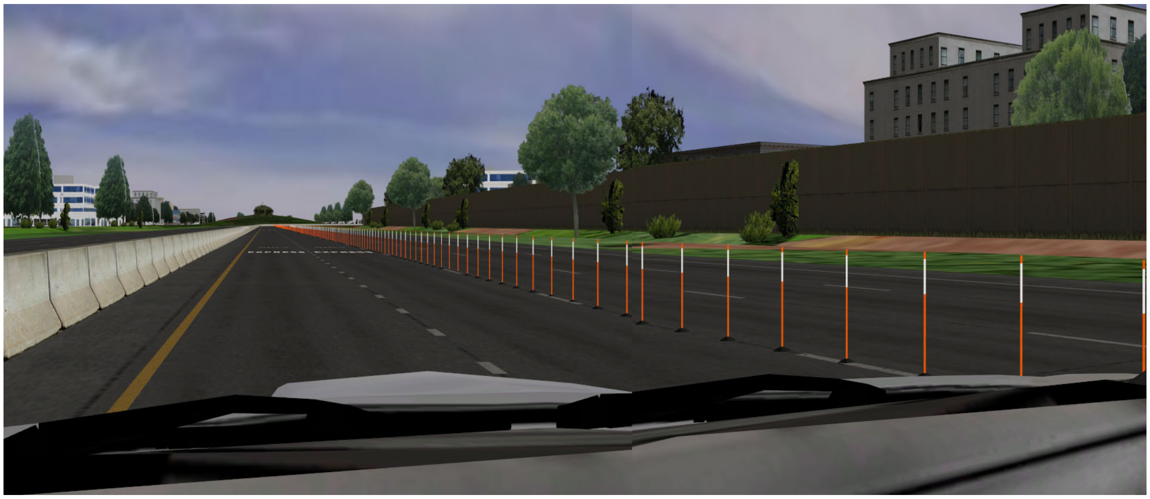

Figure 3-5: Orange Delineators with White Reflective Sheet and Asphalt Surface

Figure 3-6: Orange Delineators with White Reflective Sheet and Concrete Surface

The model consists of a 4-lane section with a transitioning taper to a 5-lane section with one lane entrance to the express lane (4 GPL + 1 EL). The 4 lane section length is 1.25 miles to account for advance guide signs for the point of entry to the express lane per Express Lanes Signing section 2.42 of the Traffic Engineering Manual (TEM). Sequential overhead guide signs are located at one mile, one-half mile, and at the express lane point of entry as shown in Figure 3-7. The express lane consists of a straight section with 36" delineators as well as a curved section with 24" delineators. The total length of the one express lane is 1.5 miles which then transitions into the GPL for another 1.0 mile to account for another set of advance signs to another point of entry to the express lanes. The second entry is for a 2-lane expressway with two-lane entrances (3 GPL + 2 EL) which extends 1.5 miles with a straight and curved sections then exits into the GPL for 0.25 miles. A schematic diagram of the roadbed and lane configurations is shown in Figure 3-8. The total length of the scenario is around 6 miles.

Figure 3-7: Overhead Guide Sign Located at Half Mile from Express Lane Entry

Each participant was asked to drive the total length of the scenario to experience all conditions (straight, curved, one lane expressway, and two lane expressways). The speed limit is 70 mph and the driving speed of the participants varied with the traffic density. Participants took approximately 6 to 8 minutes to finish each scenario.

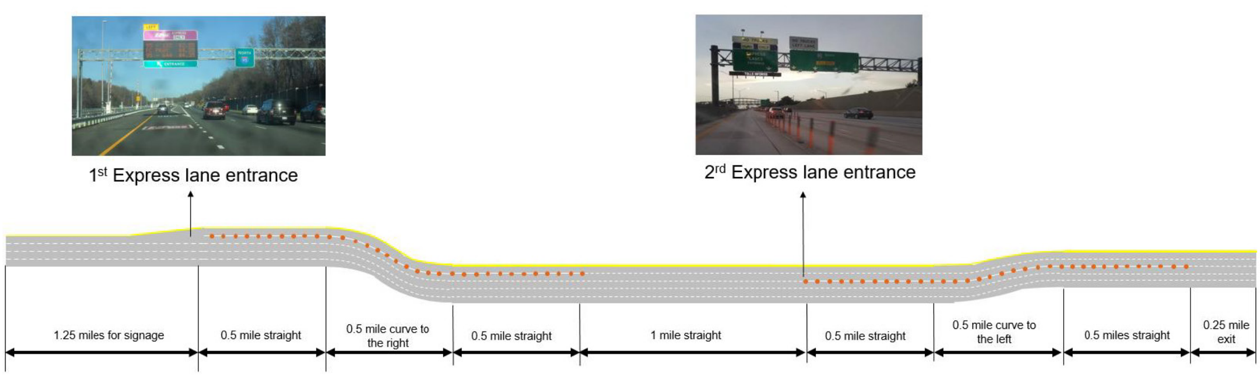

Figure 3-8: Roadbed and Lane Configurations

There are four factors that were included in the design of experiment in addition to the delineators' color factor that can influence the driving behavior. The factors are time of day, traffic density, weather, and road surface type. Time of day includes daytime and nighttime, and traffic density refers to low and high traffic densities ranging from 5 to 30 vehicles per lane per mile. Weather includes high visibility with clear skies and low visibility with foggy skies, and road surface types are asphalt and concrete.

The data was examined at several locations or areas as shown in Figure 3-9. The locations were before the participant enters the one-lane expressway, at the curved section and after exiting to evaluate the driving behavior. Data collection included the experiment sampling time, vehicle speed, acceleration, deceleration, lane changes, vehicle position, and steering angle. The data were complemented with the eye movement, time to first fixation and areas of attention. Similarly, data were collected before the participant enters the two-lane expressway, at the curved section and after exiting. Each response variable was analyzed comprehensively.

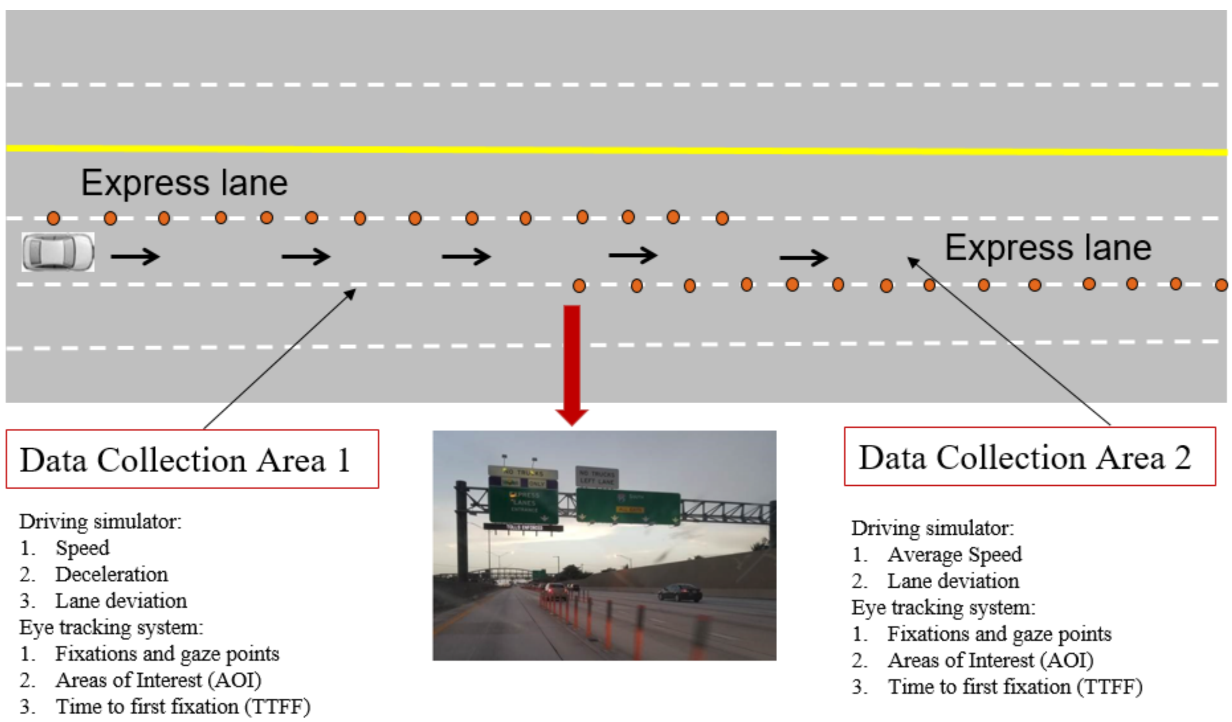

Figure 3-9: Data Collection Locations

IV. HUMAN FACTORS EXPERIMENT AND PRELIMINARY DATA ANALYSIS

This Chapter involved conducting the human factors experiment based on the design of experiment and roadway layout developed in Chapter 3.

4.1 Participant Recruitment

A total of 176 participants across the three age groups (18-39, 40-64, 65+) were recruited to participate in the study through a variety of resources, which included student recruitment (UCF SONA), Learning Longevity Research Network (LLRN), Learning Institute For Elders (LIFE), social media outreach, fliers, and personal connections. Participants were required to have normal vision and be over the age of 18. Many participants were unable to complete the experiment due to motion sickness, dizziness, or inadequate vision. Furthermore, 10 participants did not show up for the experiment. Therefore, the total number of participants that actually attempted the experiment was 166.

4.2 UCF SONA Systems

UCF SONA Systems is an undergraduate research participation network used by the UCF Psychology Department. The purpose of this program is to give students an opportunity to participate in the experimental process as a part of their grade. Students have a wide range of experiments to choose from but are required as part of these classes to participate in a minimum number of hours for each class. This was one of the primary methods used to recruit participants from the 18-39 age group age demographic (ages 18-39) and therefore many were between 18 and 22 years of age. Class credit was given to any SONA student that attempted the experiment whether they completed the study or not. Nearly all of the participants in this age group were recruited using this system.

4.2.1 Learning Longevity Research Network and LIFE University

The Learning Longevity Research Network (LLRN) and the Learning Institute For Elders (LIFE) University are two programs at UCF that support senior adults with ongoing learning activities. The LLRN has a website and an email database of senior adults that are available for aging research. LIFE University is a 503c organization created by UCF that provides weekly learning opportunities for adults 50 and over in a university setting. The majority of the participants aged 65+ in this study was recruited from these sources.

4.2.2 Social Media

To augment recruitment for the 40-64 year old demographic group, several social media platforms were used which included Facebook and Linked-In. The local Central Florida Institute of Transportation Engineers (CFITE) chapter also allowed us to send out a Mail Chimp advertisement to their members. Many of the working-aged participants were recruited from this source.

4.2.3 Flyers

The flyer used during the course of the experiment is shown in Appendix B to recruit the remaining participants. The flyers were placed in various public locations like Panera, barber shops, the YMCA, churches, mosques, and libraries. Very few participants were recruited using this method, although the flyers were useful for distributing contact information at events like LIFE University. Out of the three means of recruitment, this was the least effective way to obtain participants.

4.2.4 Personal Connections

Several participants were recruited from friends, family, and colleagues of the researchers. Many of the working-age participants were from this group.

4.3 Experiment Process and Descriptive Statistics

4.3.1 Researcher Script for Vision Screening, Calibration, and Driving Simulator

A script was developed to ensure that each researcher conducted the experiment in an unbiased and consistent manner. The script includes how to set up the simulator room before the participant arrives, the informed consent requirements, vision screening, surveys, the calibration process, the practice drive, the first five drives, procedures the researcher needs to do during the break, the second five drives, post study surveys, and cleaning up the room for the next participant.

4.3.2 Vision Screening

All participants were given a vision screening test using Optec machine as shown in Figure 4-1.

Figure 4-1: Optec Machine Used for Visual Testing and Screening

The Optec system was used to test the following capabilities:

- Near and far visual acuity: with a minimum of 20/40 vision required after correction
- Color blindness: which included tests for red/green and blue/yellow color blindness
- Lateral phoria: the horizontal alignment of the eyes
- Vertical phoria: vertical eye alignment
- Depth perception: the ability to perceive three dimensions in space
- Fusion: the blending of sight from both eyes to generate a single image, and
- Contrast sensitivity: the ability to distinguish patterns when color differences are small.

Several of these factors may have a direct impact on the results of the study, particularly for the 65+ adults demographic group. Contrast sensitivity declines with age and this can interfere with night driving (Barten, 1999; Campbell, 1983). Depth perception may decline with age, particularly after some corrective surgeries that allot near vision acuity to one eye and far vision acuity in the other (Bell, 1972) and this may make drivers more prone to accidents (Hill, 1980). Problems with phoria, especially vertical phoria, may increase a person's susceptibility to visually induced motion sickness (Jackson, 2012).

Although these factors may have an impact on driving, they were not criteria for exclusion. Participants were only excluded from the study if they were unable to pass the visual acuity or color blindness tests. Out of the 166 who participated in the experiment, seven failed the vision screening process, either due to lacking visual acuity or color blindness. The remaining participants that continued the experiment amounted to 159.

4.3.3 Motion and Simulator Sickness Surveys

Since simulators can cause motion sickness, a series of surveys were used to screen for motion sickness. These surveys included the motion history questionnaire (MHQ) and simulator sickness questionnaire (SSQ). If participants stated that they develop symptoms with these exposures, they were not able to take part of the study due to potential symptoms that could skew their reaction or perception time of noticing the markers. Participants were asked if they got sick on ships, airplanes, roller coasters, or virtual reality devices. Participants were also periodically asked neutral questions like "How are you feeling?" throughout the experiment to establish whether any of the symptoms of motion sickness were beginning to manifest that would make the participant uncomfortable.

4.3.4 Eye Tracking Process and Calibration

If the participant passed both vision and motion sickness screening, the participant was asked to sit in the driving simulator chair, shown in Figure 4-2.

Figure 4-2: UCF NADS Driving Simulator

Once the participant was seated and adjusted the chair to where they can reach the pedals, the ISCAN- ETL-500 Eye-Tracker was placed on the subject's head as shown in Figure 4-3. The monocle and camera were positioned such that both the screen and the participant's eye could be clearly seen by the eye tracking software. After adjustments to the corneal and pupil reflection parameters, the participant was asked to look at a series of dots on the screen as shown in Figure 4-4 to calibrate the reflections with the video, as denoted by a crosshair shown in Figure 4-5.

Figure 4-3: ISCAN ETL-500 Eye-Tracker

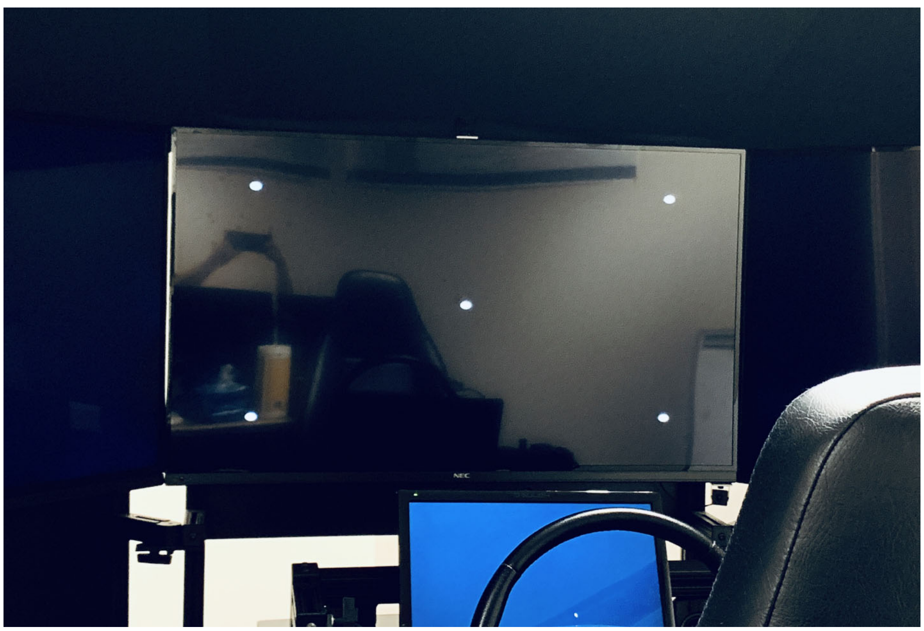

Figure 4-4: Dot Configuration for the Calibration Process

Figure 4-5: Participant Looking at the Bottom Right Dot as Shown by the Crosshair

After the calibration was entered into the eye-tracking computer, it was cross checked against the video output to assure that the calibration is accurate.

4.3.5 Calibration Challenges

The time to calibrate the participant varied from 5 to 40 minutes. Problems occurred when the size of the participant's head was too big or small or when the participant's eyelashes or eye reflections provided overly bright reflections that could be mistaken by the tracking computer. The monocle of the eye tracker needed to be a certain distance away from the person's eye for the eye tracking software to track where the participant was looking. If the person's head was too small, the monocle would be too low. To solve this problem, hair clips were used to raise the eye tracker to prevent it from slipping during the experiment. On the other hand, if the person had a large head, the monocle would be too high on the person's head. This was solved by asking the participant to push the eye tracker as far down as possible on their head. The monocle was then adjusted to an almost vertical angle to account for the high placement. In addition, glasses tended to reflect light off the monocle and produce extra glare. Any additional glare could be translated by the eye tracker as a pupil location. Glasses also come in different sizes. If the glasses covered their entire eye, the calibration was easier since the glare was uniform. However, if the participant had small frames, part of their eye would be exposed and other parts would be covered by the glasses. This issue was solved by turning off the lights to eliminate the unnecessary glare. Calibration issues that eliminated data points (either for the entirety of the 10 scenarios, or for individual scenarios) occurred in 19 of the 157 participants that attempted the study (12%). Other computer errors removed all or part of the data from another 11 attempts (7%). It should be noted that calibration data was mainly needed for the eye tracking device and not for the driving simulator.

4.4 Driving Simulator Scenarios

Once the participant's eye movements were calibrated by the eye tracking device, the researcher explained the rules for the practice scenario and initiated it. The practice scenario had no cars or markers and was just used to familiarize the participant with the simulator. In addition, the researcher also explained the simulator controls, including the start button, the gear buttons and the windshield wipers. The subject was then allowed to drive for an allotted time of 3 minutes, obeying all traffic laws. The practice scenario is shown in Figure 4-6.

The scenarios were composed of various conditions that include: time of day (TOD), low and high visibility related to weather conditions, markers' colors, traffic density, and roadway surface types. Since there were 10 scenarios total and 5 colors, each color had two scenarios. Each roadway surface type (asphalt and concrete) had 5 scenarios as well as both low and high traffic density. Low traffic density is defined as 11 veh/mile/lane which reflect Level of Service (LOS) "B" and high traffic density is defined as 26 veh/mi/ln (LOS "D"). Level of service is a qualitative measure used to describe the operating conditions of a roadway based on factors such as speed, density, travel time, maneuverability, delay, and safety. The level of service of a facility is designated with 6 letters, A to F, with A representing the best operating conditions and F the worst.

Figure 4-6: NADS Practice Scenario

4.4.1 Completing the Driving Scenario Experiments

During the first half of the experiment, the participants drove through 5 randomly selected scenarios. Between each drive, the researcher checked the five dots to see if the calibration remained accurate. If not, a recalibration was done. Prior to scenarios 2, 4, 8, 9, and 10, the participant was notified that this scenario would have rain in it, and the wipers would need to be used. Table 4-1 shows the scenario matrix that each participant ran through.

Table 4-1: Scenario Matrix

No.	TOD	Traffic Density	Weather	Road Surface Type	Color
1	Day	Low Density	High Visibility	Asphalt	Yellow
2	Night	Low Density	Low Visibility	Asphalt	Orange
3	Night	Low Density	High Visibility	Concrete	White
4	Day	High Density	Low Visibility	Asphalt	White
5	Day	High Density	High Visibility	Asphalt	Purple
6	Day	High Density	High Visibility	Concrete	Orange
7	Night	High Density	High Visibility	Concrete	Black
8	Night	Low Density	Low Visibility	Concrete	Purple
9	Day	Low Density	Low Visibility	Asphalt	Black
10	Night	High Density	Low Visibility	Concrete	Yellow

Once the participant completed the first 5 drives, they were given a 10-minute break. This allowed the participant to have water and chips if they wanted to calm down any symptoms of motion sickness. This also gave time for the researcher to save the eye tracking data that was done for the first 5 scenarios. In addition, the participant filled out the mid symptom's exposure survey to screen for motion sickness again. Table 4-2 shows the number of participants that could not make it through the study due to motion sickness as well as the ones that completed the study.

Table 4-2: Participants Who Completed the Study and Those Who Failed Due to Motion Sickness

Participants that Failed due to motion sickness after the first couple of scenarios	11
Participants that completed the study without motion sickness or got motion sick towards the last scenarios	148

Once the 10-minute break has ended, the participant returned to the driving chair and was calibrated again. Once calibrated, the subject repeated the same process for the remaining 5 drives, again in random order. After the 10th drive, the participant filled out a demographic questionnaire, a driving behavior questionnaire, a final symptoms exposure survey, and an exit survey. During this time, the researcher saved the second half of the eye tracking data.

4.5 Demographics Data

4.5.1 Data Examination

The participants' demographics data as well as their scenario files were first examined to verify whether it is satisfactory and in useable format to be analyzed. Useable data is defined as scenario files for each participant that have complete information in the four (4) data sets; demographics (age, gender, driving records, vision records, motion sickness questionnaires), eye tracking data (good calibration in each scenario with working video files), driving simulator data (working files for each driving scenario along the different sections of the express lanes) and exit survey data (participants completed the survey questions). There were situations that deemed to exclude the participant from the whole study such as failing the vision test or being color blind. Other situations included motion sickness or health issues experienced after the first or second scenario. In these cases, the participant was totally excluded from the experiment along with all the scenario files as explained earlier in sections 3, 4 and 5. Conversely, there were situations that excluded only few of the participant's scenarios such as getting motion sick in the eighth or ninth scenario or the computer crashed in one or two scenarios or couple of scenario files got corrupted and couldn't be extracted. The data were still useable but categorized as incomplete since it comprised at least 8 scenarios out of the 10.

Table 4-3 summarizes the participants that were excluded from the study along with all their data scenario files. Out of the 176 participants attempted, 42 could not complete the study with adequate and useable data. Besides the tabulated reasons for not completing the study, other factors included back pain, short participants that did not reach the gas pedals, eye tracking computer issues or scenario generation issues.

Table 4-3: Participants That Did Not Complete the Study with Useable Data

No Show	10
Failed Vision Screening	7
Motion Sickness during study	11
Eye Tracking Calibration Error	2
Driving Simulator or video files Corrupted	12
Failed participants (total)	**42**

Table 4-4 summarizes the demographics of the total number of participants that completed the study (134) with usable data for each gender and age group.

Table 4-4: Participants That Completed the Study with Usable Data

Male (18-39)	25
Female (18-39)	23
Male (40-64)	19
Female (40-64)	23
Male (65+)	26
Female (65+)	18
Total	**134**

Out of the 134 participants with usable data, 65+ women were the most difficult to recruit. Many of them failed the vision screening or were not able to complete a full study because of motion sickness. This demographic group was prioritized for recruitment until the end of task 4.

4.5.2 Participant Driving Records

Fourteen (14) participants across the age groups were involved in minor accidents in the last three years out of the 137 participants who completed the exit survey. Eight (8) were involved in major accidents, two of which involved pedestrians. Table 4-5 summarizes the number of participants involved in each accident type. The remainder of the participants was not involved in any accidents.

Table 4-5: Driving Record of Completed Participants

Minor Accident (last 3 years)	14
Major Accident (last 3 years)	8
Involved Pedestrians	2
No Accidents	28

4.6 Exit Survey Data

Each participant was asked questions at the end of the study in an exit survey regarding the color of the marker as well as whether they noticed the change in colors of the markers themselves. Table 4-6 shows the questions that each person was asked in the survey regarding the marker color.

Table 4-6: Exit Survey Questions

Did you notice the change of the delineator's colors? (Y/N)	If yes, which color attracted you the most or the most conspicuous (noticeable) color?	Which color was more noticeable in the night?	Which color was more noticeable in the low visibility scenarios?	Which color was more noticeable under asphalt roadway surface?

The first two questions were divided into questions 1A and 1B. 1A asked "Did you notice the change of the delineator's colors? (Y/N)". Question 1B asked "If yes, which color attracted you the most or the most conspicuous (noticeable) color?" Table 4-7 shows the number of participants that answered yes and no to question 1A. 137 participants completed the exit survey as mentioned earlier. However, color changes were noticed by 119 out of the 137 participants. Few participants (3) selected multiple colors for the same question, twelve (12) did not notice the change, while three (3) were nonresponsive. Multiple answers were not considered for the frequency analysis done on the survey data.

Table 4-7: Notice of Change in Marker Color

Did you notice the change in the color of marker? (Y/N)	
Yes	119
No	12
Non-Responsive	3
Multiple responses	3

4.6.1 Frequency Analysis

A frequency analysis was conducted for the 137 participants who completed the exit survey to examine which marker color was the most noticeable under certain conditions. These conditions included most conspicuous color, most noticeable at night, most noticeable under low-visibility conditions, and most noticeable against asphalt roadway surfaces. Figure 4-7 shows a visual representation of the frequency analysis done for each color under each condition. In general, the most noticeable color was Purple followed by Orange. However, as more participants joined the experiment, the Orange markers (37) exceeded the Purple markers (32) by 5 out of the 119 responses.

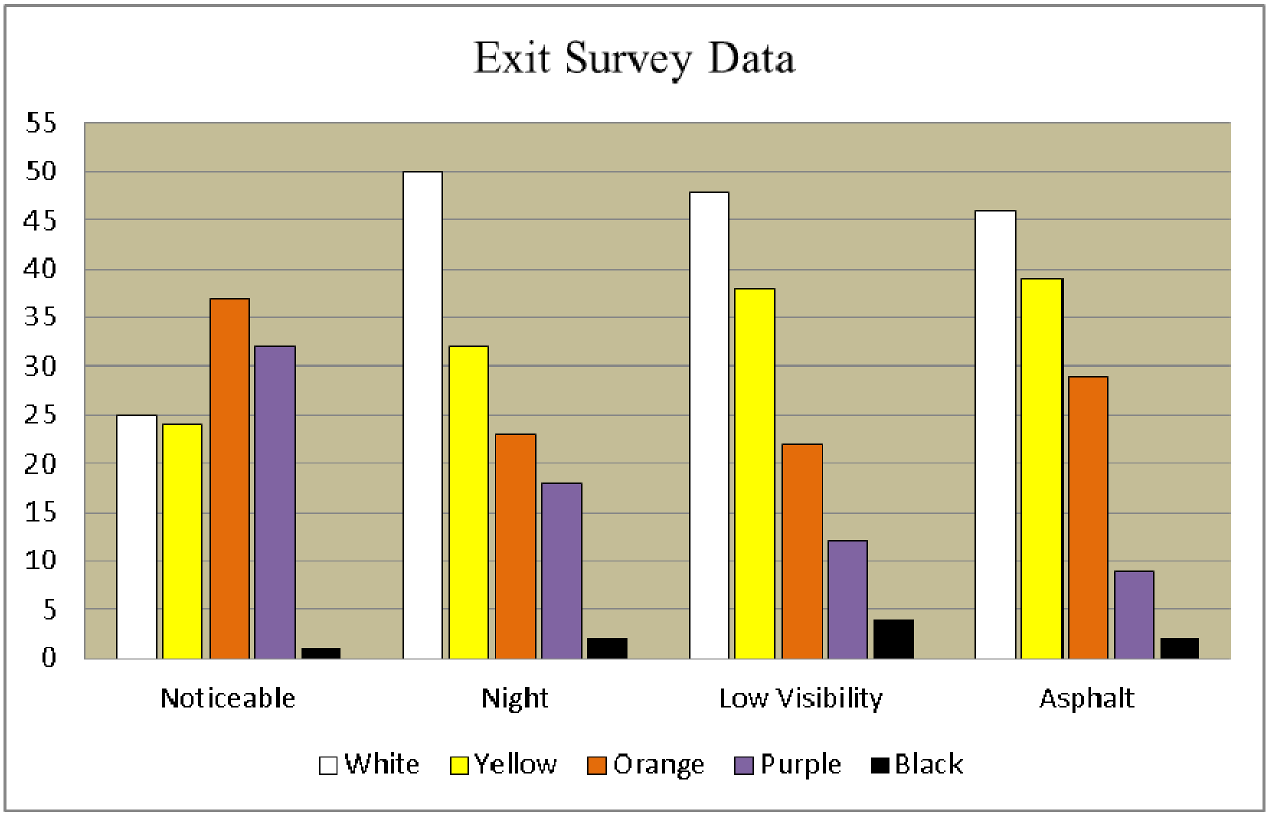

Figure 4-7: Exit Survey Responses

Questions 2 through 4 were answered regardless of whether the person answered yes or no on question 1A. Table 4-8 summarizes the frequency data and also shows a total value for each color. To obtain the total value, the four frequencies for each color were added up. The color with the highest total number shows the most noticeable color overall according to the participants. Based on the results, the three questions related to the time of day, weather, and road surface type conditions showed that the most frequently selected marker color was white followed by yellow.

Table 4-8: Exit Survey Response Data

Marker Color	Most Conspicuous	Nighttime	Low Visibility	Asphalt	*Total*
Orange	**37**	23	22	29	*111*
White	25	**50**	**48**	**46**	***169***
Purple	32	18	12	9	*71*
Black	1	2	4	2	*9*
Yellow	24	32	38	39	*133*
Total	*119*	*125*	*124*	*125*	***493***

4.6.2 Distribution by Age Group and Gender

The exit survey results were also summarized by age group and gender. Figures 4-8 and 4-9 show the color distribution based on the 4 questions for the different female and male age groups respectively. It should be noted that the figure color represents the most marker color selected in each age group. The results on Figure 4-8 showed that female age group 18-39 preferred the yellow marker under different driving conditions. However, they selected the purple as the most noticeable color. Females 40-64 showed a tie between the white marker and yellow marker. Females 65+ preferred the white marker in all the scenarios.

On the other hand, the results on Figure 4-9 showed that males across all age groups preferred the white marker under different driving conditions. However, male 18-39 and males 40-64 preferred purple and orange markers as the most noticeable colors.

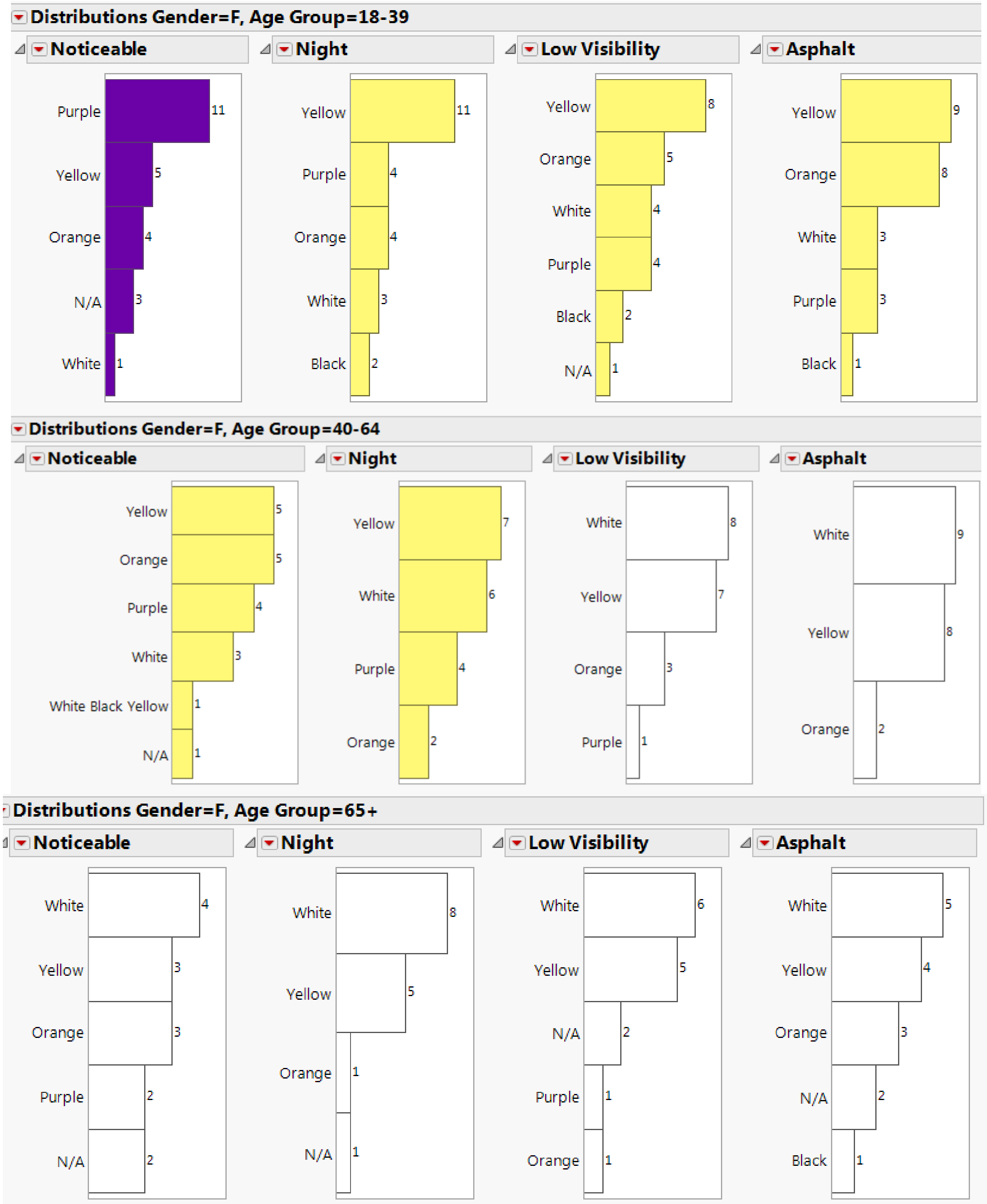

Figure 4-8: Color Distribution by Female Age Groups

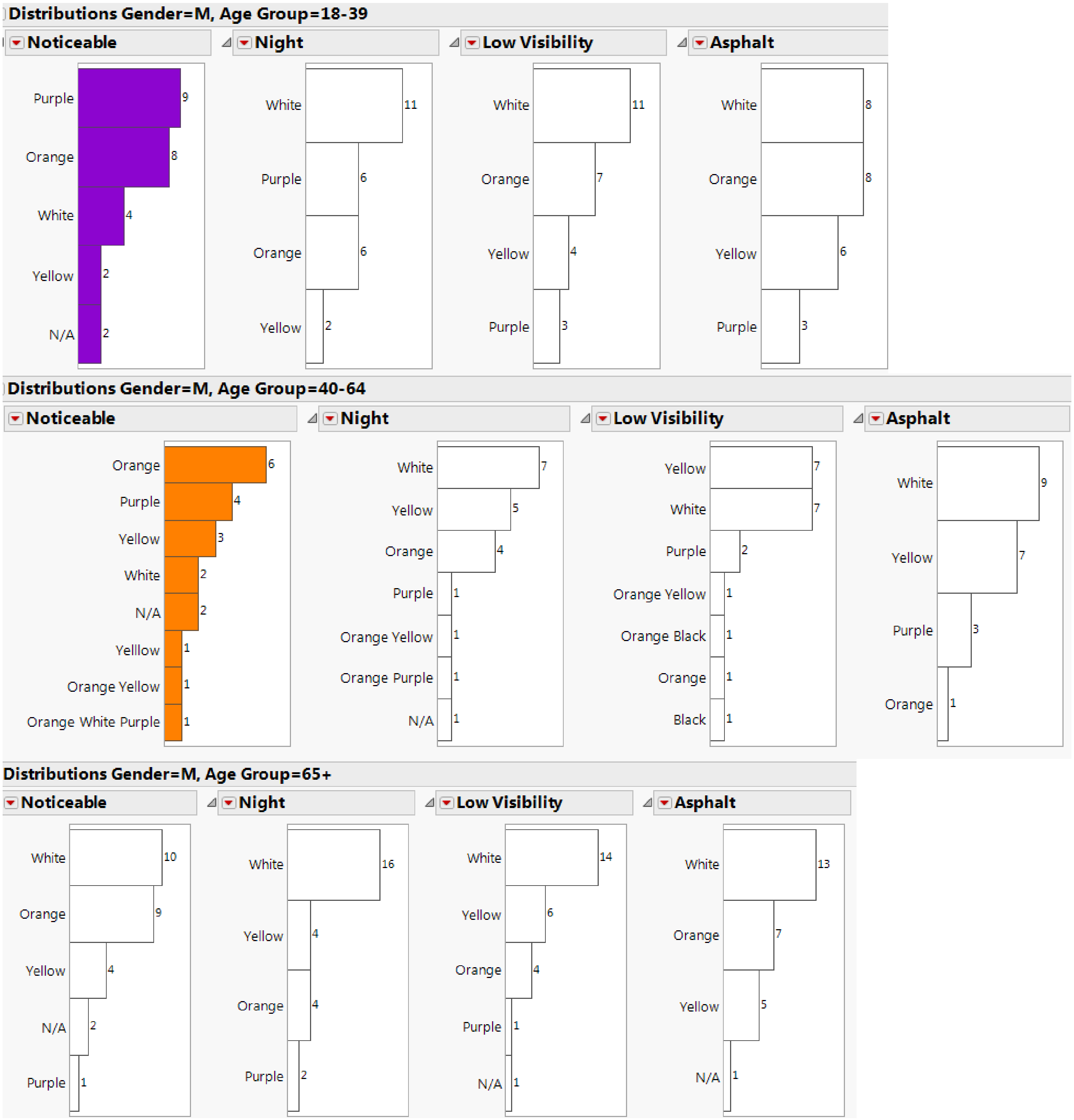

Figure 4-9: Color Distribution by Male Age Groups

4.7 Data Analysis and Statistical Results

4.7.1 Sensory and Perceptual Assessment (Behavioral Data)

All participants were screened on various sensory and perceptual tests as part of the study requirements. These vision tests were used to determine the level of their visual processing (e.g., Phoria, Contrast Sensitivity, and Perception of Depth). It should be noted that the contrast sensitivity test included 5 different levels (A-E) with level E as the hardest with higher contrasts. They were required to pass the visual acuity and color deficiency tests in order to be able to participate in this study. Data from the visual processing tests were subjected to a series of analysis of variance (ANOVAs) as a function of age group and gender.

Age-related correlations were observed within the study data collected. A series of multivariate statistical analyses were conducted to examine the effects of visual sensory processing tests as a function of age group. Results showed a significant effect of contrast sensitivity measure "C" on age groups scores [$F_{(2,110)} = 3.98$, $p < .05$, $\eta^2 = .06$]. This indicated that the age group 18-39 (Mean= 6.26; SD=1.59) performed significantly better on this test than the 65+ drivers (Mean= 5.25; SD=1.59). However, there was no significant difference between the 18-39 and 40-64 and between the 40-64 and 65+ drivers as shown on Figure 4-10.

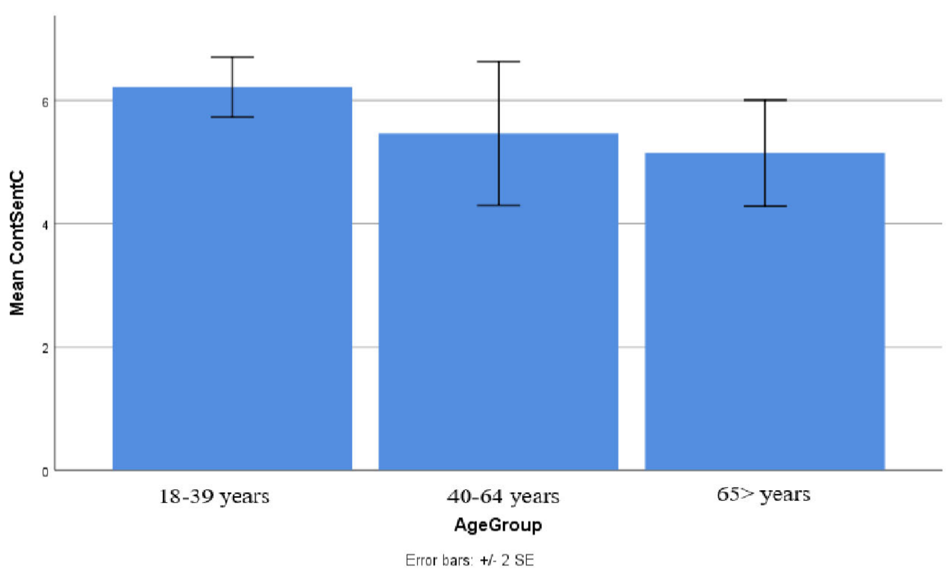

Figure 4-10: Contrast Sensitivity "C" Effect on Age Group

In addition, a significant effect of age group on contrast sensitivity measure “D“, scored [$F_{(2,110)} = 4.96$, $p < .01$, $\eta^2 = .08$]. This indicated that the 18-39 age group (Mean= 5.05; SD=1.43) performed significantly better on this test than the 40-64 age group and 65+ drivers (Mean= 3.69; SD=2.05). However, there were no significant differences between the 18-39 age group and 65+, and the 40-64 and 65+ drivers (p>.05) as depicted in Figure 4-11.

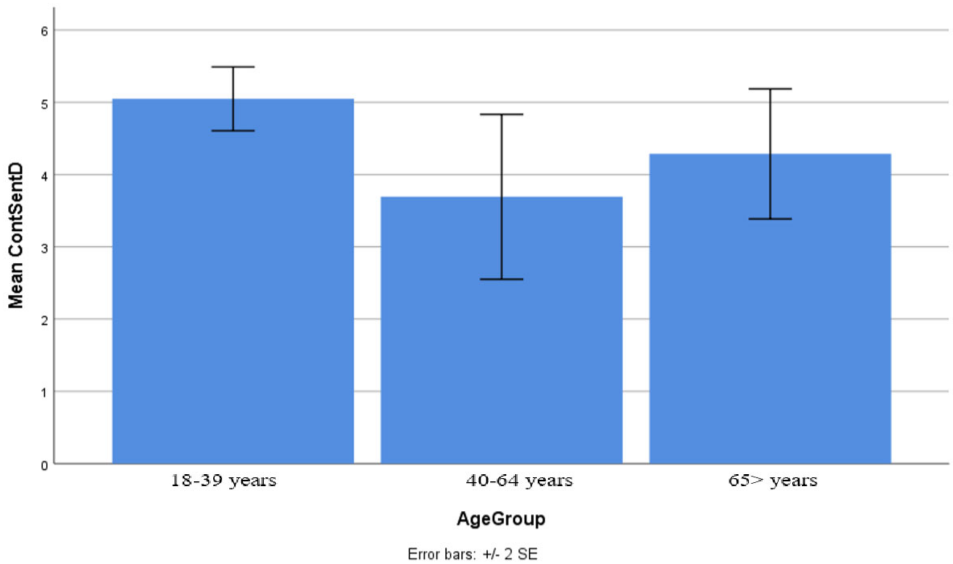

Figure 4-11: Contrast Sensitivity “D” Effect on Age Group

Finally, there was a significant effect of age group on contrast sensitivity measure “E “, which scored [$F_{(2,110)} = 8.30$, $p < .01$, $\eta^2 = .13$]. This indicated that the 18-39 age group (Mean= 3.26; SD=1.60) performed significantly better on this test than the 40-64 age group and 65+ drivers (Mean= 2.43; SD=1.60). However, there were no other significant differences between the other pairwise comparisons (p>.05) as shown in Figure 4-12.

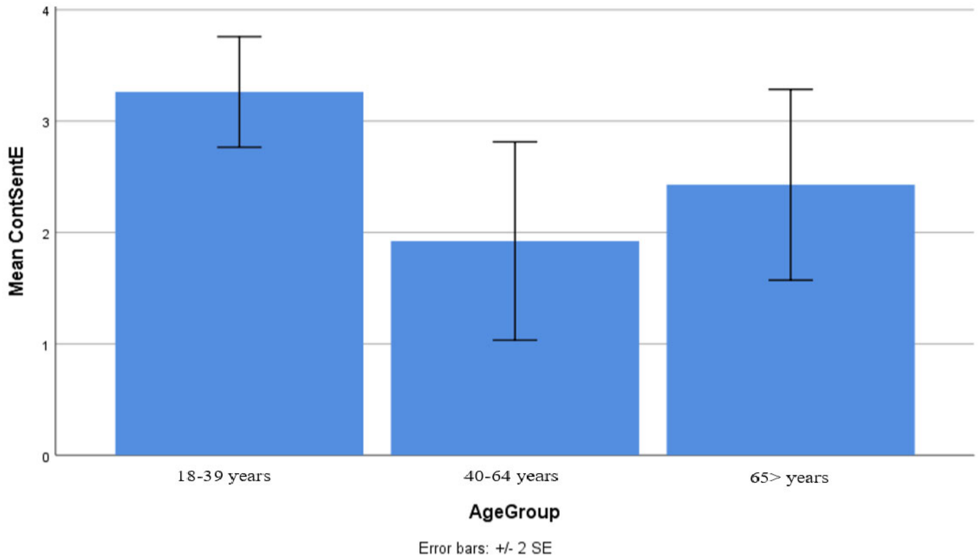

Figure 4-12: Contrast Sensitivity "E" Effect on Age Group

The effect of age was also examined for lateral and vertical Phoria measures. Results showed a significant effect of age only for lateral Phoria [$F(2,110) = 8.30$, $p < .01$, $\eta^2 = .13$]. This indicated that the 18-39 age group (Mean= 10.02; SD=1.94) performed significantly better on this test than the 65+ drivers (Mean= 8.44; SD=2.5), and the 40-64 age group (Mean=9.82; SD=1.99) had significantly higher lateral Phoria scores than the 65+ (Mean= 8.44; SD=2.5) drivers. This effect is depicted in Figure 4-13.

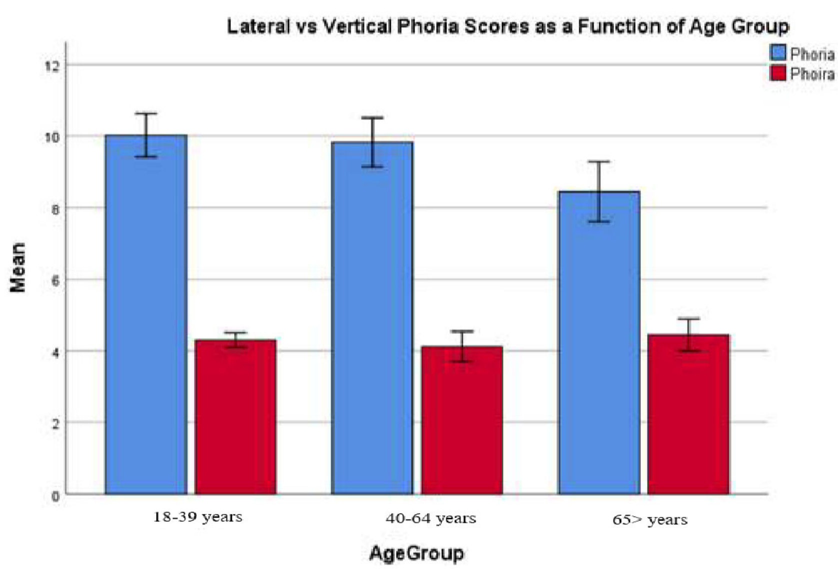

Figure 4-13: Lateral and Vertical Phoria Effect on Age Groups

4.7.2 Simulation Sickness Assessment

As described earlier, all 3 groups of drivers were initially tested on a variety of sensory and perceptual skills prior to their participation in the simulated driving experiment. This allowed the investigators to screen for any acuity issues or color deficiency. Once they passed this initial vision screening, the SSQ and MHQ survey instruments were administered to the participants. The SSQ and MHQ were developed by Kennedy et al. (1992) to measure a participant's predispositions to motion induced discomfort, as well as their susceptibility to the effects of simulation sickness prior (baseline assessment) and immediately after (0-Minute, 15- mins, and 30-mins, etc.) completing the driving experiment. Participants' scores were computed and statistically analyzed using SPSS. A total of 10 participants did not complete the experiment because of severe symptoms.

A series of multivariate statistics were conducted to examine the propensity for simulation sickness for nausea, disorientation, and oculomotor scores across the three age groups. Results showed a significant effect of age group only on Oculomotor scores [$F(2,111) = 11.86$, $p < .001$, $\eta^2 = .17$]. Post hoc comparisons indicated that the 18-39 age group drivers reported higher levels of oculomotor simulation symptoms (Mean = 2.67; SD = 2.41) than the 40-64 drivers (Mean = 1.33; SD = 1.61) as well as higher than the 65+ drivers (Mean = 1.92; SD = 0.43). There was no significant difference between 40-64 age group and 65+ drivers in oculomotor sickness. The statistical effect is summarized in Table 4-9 and depicted on Figure 4-14.

Table 4-9: Simulation Sickness Symptoms Statistics

SSTYPE	AgeGroup	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Nausea	18-39	1.196	.242	.717	1.675
	40-64	.719	.290	.144	1.293
	65+	1.417	.273	.875	1.958
Disorientation	18-39	.870	.252	.371	1.368
	40-64	.844	.302	.246	1.442
	65+	1.333	.284	.770	1.897
Oculomotor	18-39	2.674	.280	2.119	3.229
	40-64	.750	.336	.084	1.416
	65+	1.083	.317	.456	1.711

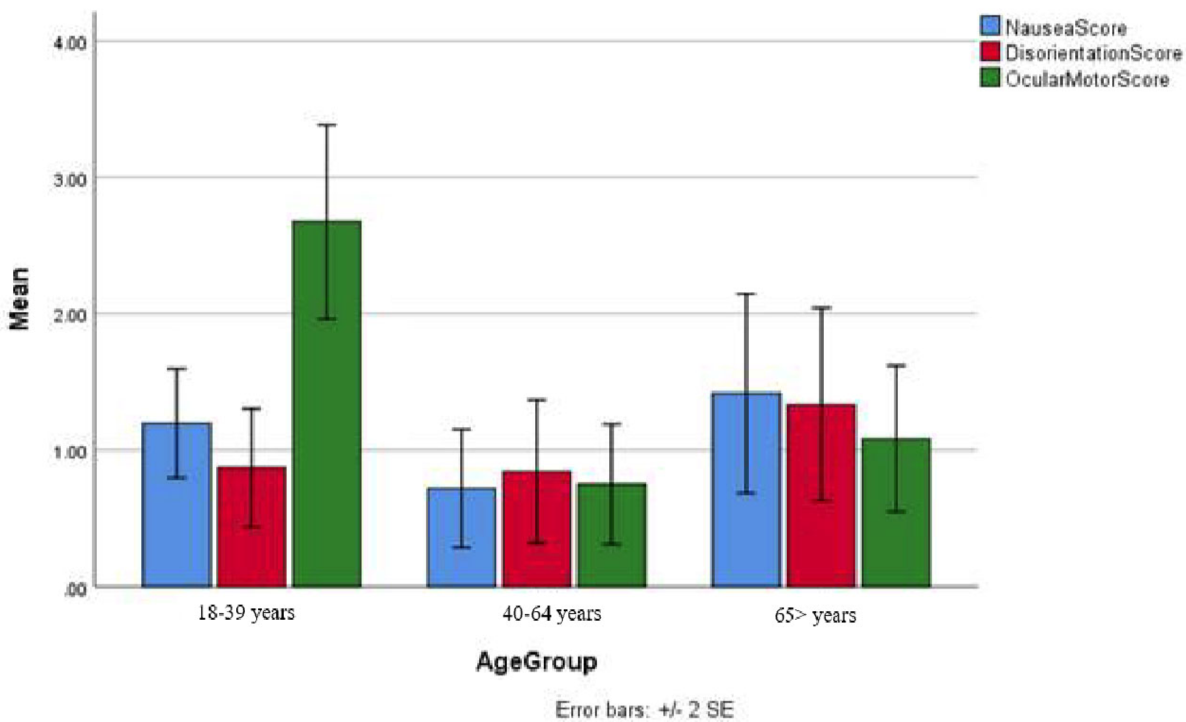

Figure 4-14: Effect of Simulation Sickness on Different Age Groups

4.7.3 Driving Simulator Data and Eye Tracking Data

Two more sets of objective data were examined from the experiment. These included data that were extracted from the driving simulator and the eye tracking computer. This data was used to validate or refute the participant's subjective responses. Five parameters were examined which included:

- Four velocity measurements within critical sections of the delineated lanes
- Four lane deviation measurements within critical sections of the delineated lanes
- Deceleration
- The brake-time during that deceleration
- Time To First Notice (TTFN)

The first four parameters were extracted and processed from the NADS (National Advanced Driving Simulator) driving simulator outputs and depict the driving behavior of the participants towards the different colors of the markers. The fifth parameter, Time to First Notice (TTFN), demonstrates whether the participants noticed the color change and, if they did, how long it took them to notice. The TTFN parameter was identified using a frame by frame analysis from the eye tracking computer and Cyberlink Media Suite as mentioned before.

4.7.4 NADS Driving Simulator Data Parameters

NADS outputs a Data Acquisition (DAQ) file for each scenario run. The DAQ file holds records of various simulator data parameters, including acceleration, velocity, location coordinates and lane deviation. These variables were extracted into tabulated format at 60-Hz fidelity (a time-step of 1/60 seconds) using the NADS DaqViewer script. These were then processed into useful driving parameters using a MATLAB script developed in-house. MATLAB (matrix laboratory) is a multi-paradigm numerical computing environment and proprietary programming language developed by MathWorks. Velocity and lane deviation at critical points along the roadway were extracted from the NADS Driving Simulator Data. Participants' physical reactions to the markers were analyzed by observing the brake-time and deceleration during the final instance of braking prior to the participant passing the first marker, in addition to the aforementioned TTFN, velocity, and lane deviation measurements. Table 4-10 shows excerpts from the driving data and eye tracking data used in the statistical analysis along with the participant ID, gender, age group and the different driving conditions in each scenario.

Table 4-10: Driving Data and Eye-Tracking Data Sample

Participant ID	Scenario ID	Deceleration	Brake Time	Speed	Lane Dev	TTFN	Age Group	Gender	TOD	Traffic	Weather	Rd Type	Color
2	1	-0.123	9.85	77.91	0.05	4.13	18-39	M	Day	Low	HV	Asphalt	Yellow
2	2	-0.327	4.233	80.65	-0.22	0	18-39	M	Night	Low	LV	Asphalt	Orange
2	3	-0.66	13.067	83.32	0.08	0	18-39	M	Night	Low	HV	Concrete	White
2	4	-0.468	9.017	72.44	0.76	4.3	18-39	M	Day	High	LV	Asphalt	White
2	5	-0.585	9.317	61.91	0.94	0	18-39	M	Day	High	HV	Asphalt	Purple
2	6	-0.506	12.083	70.58	0.58	4.4	18-39	M	Day	High	HV	Concrete	Orange
2	7	-0.018	0.683	70.99	-0.65	0	18-39	M	Night	High	HV	Concrete	Black
2	8	-0.607	23.217	85.52	0.04	0	18-39	M	Night	Low	LV	Concrete	Purple
2	9	-0.46	29.4	70.12	-0.73	0	18-39	M	Day	Low	LV	Asphalt	Black
2	10	-0.015	0.4	76.58	-0.9	0	18-39	M	Night	High	LV	Concrete	Yellow
5	1	-0.519	1.95	70.87	-1.35	4.6	18-39	M	Day	Low	HV	Asphalt	Yellow
5	2	-0.748	10.783	75.5	0.17	5.3	18-39	M	Night	Low	LV	Asphalt	Orange
5	3	-0.675	2.583	71.39	0.68	0	18-39	M	Night	Low	HV	Concrete	White
5	4	-0.557	8.267	63.7	-1.52	2.1	18-39	M	Day	High	LV	Asphalt	White
5	5	-0.7	5.067	66.58	-1.83	2.83	18-39	M	Day	High	HV	Asphalt	Purple
5	6	-0.599	7.983	74.02	-0.17	0	18-39	M	Day	High	HV	Concrete	Orange
5	7	-0.701	5.867	64.88	0.35	5.1	18-39	M	Night	High	HV	Concrete	Black
5	8	-0.489	8.483	63.05	-2.61	0	18-39	M	Night	Low	LV	Concrete	Purple
5	9	-0.478	16.25	56.86	-1.05	6.13	18-39	M	Day	Low	LV	Asphalt	Black
5	10	-0.334	4.7	71.79	-0.53	1.3	18-39	M	Night	High	LV	Concrete	Yellow
6	1	-0.019	3.683	70.41	0.78	1	18-39	M	Day	Low	HV	Asphalt	Yellow
6	2	-0.472	0.883	66.02	0.16	0.67	18-39	M	Night	Low	LV	Asphalt	Orange
6	3	-0.614	6.683	69.41	1.19	4.83	18-39	M	Night	Low	HV	Concrete	White
6	4	-0.565	1.65	67.09	-0.25	1.9	18-39	M	Day	High	LV	Asphalt	White
6	5	-0.609	5.3	65.52	0.53	3.2	18-39	M	Day	High	HV	Asphalt	Purple
6	6	-0.581	1.617	69.24	1.33	6.8	18-39	M	Day	High	HV	Concrete	Orange
6	7	-0.718	6.233	69.01	0.08	4.07	18-39	M	Night	High	HV	Concrete	Black
6	8	-0.645	7.95	67.06	2.36	4.67	18-39	M	Night	Low	LV	Concrete	Purple
6	9	-0.605	2.617	70.05	2.49	2.37	18-39	M	Day	Low	LV	Asphalt	Black
6	10	-0.63	1.683	71.17	-0.1	0.37	18-39	M	Night	High	LV	Concrete	Yellow
8	1	-0.069	9.633	67.84	-1.21	2.63	18-39	M	Day	Low	HV	Asphalt	Yellow
8	2	-0.367	14.65	67.88	-1.49	2.97	18-39	M	Night	Low	LV	Asphalt	Orange
8	3	-0.003	0.033	71.41	0.86	-1	18-39	M	Night	Low	HV	Concrete	White

Each scenario included two sets of markers, each with three sub-sections. The first set of markers comprises a one-lane express lane and the second set of markers comprises a two-lane express lane. For data analysis for both the driving simulator and the frame by frame analysis, each of the two delineator sections are broken into 6 sections, identified as 1A, 1-24, 1B, 2A, 2-24, and 2B. These sections are shown in Figure 4-15 and summarized in Table 4-11.

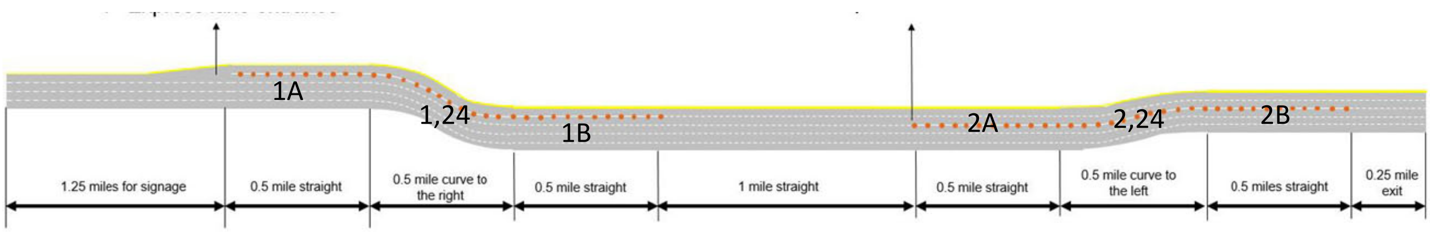

Figure 4-15: Express Lanes Layout

4.7.5 Operational Definitions for Driving Performance Factors

The following operational definitions describe how the in-house script was used to take measurements from the simulator for each performance factor:

Brake-time (s): The script determines the <u>last instance of braking</u> of the driver prior to entering the first delineated section and records the period of deceleration in seconds. (Lower brake-time is better for smoother traffic flow)

Deceleration (ft/s^2): The average deceleration over the brake-time period. (i.e. <u>how strongly the brakes are applied</u>) (Lower deceleration is better for smoother traffic flow)

Velocity (mph): Multiple speed measurements were taken along critical points on the roadway (starting points of: section 1 straight [v1s], section 1 curved [v1c], section 2 straight [v2s], section 2 curved [v2c]). (Between 65 mph and 75 mph is ideal for smooth traffic flow)

Lane deviation (ft [negative is to the left, positive to the right]): Multiple lane deviation measurements (deviation from center of lane) were taken along the same critical points on the roadway. (Closer to 0 [center of lane] or slightly less than 0 [left of center] is ideal)

Table 4-11: Roadway Section Labels

Code	Description
1A	First straight section of 36” markers in the one lane express lane
1,24	Section of 24” markers in the curved section of the one lane express lane
1B	Second straight section of 36” markers in the one lane express lane
2A	First straight section of 36” markers in the two lane ELs
2,24	Section of 24” markers in the curved section of the two lane ELs
2B	Second straight section of 36” markers in the two lane ELs

4.7.6 Driving Data Statistical Analysis

Standard experimental designs either using full factorial or fractional factorial did not fit this research requirements and therefore, optimal custom designs were selected as the recommended design approach. Also, choosing an optimality criterion to select the design points to be run was another requirement. JMP statistical software was used to generate the custom design for this experiment. The custom design approach in JMP (statistical software developed by the JMP business unit of the SAS Institute) generates designs using a mathematical optimality criterion. Optimal designs are computer-generated designs that aim at solving specific research problem to optimize the respective criterion. The optimal designs fall under two main categories:

1. Designs that are optimized with respect to the regression coefficients (D-Optimality Criteria) and
2. Designs that are optimized with respect to the prediction variance of the response (I-Optimality Criteria).

D-optimal designs are most appropriate for screening experiments because the optimality criterion focuses on estimating the coefficients precisely. The D-optimal design criterion minimized the volume of the simultaneous confidence region of the regression coefficients when selecting the design points (Johnson et al., 2011). This was achieved by maximizing the determinant of X‘X over all possible designs with specific number of runs. Since the volume of the confidence region is related to the accuracy of the regression coefficients, a smaller confidence region means more precise estimates even for the same level of confidence (Johnson et al., 2011).

Statistical analysis was conducted for the 131 participants of processed DAQ data (including incomplete sets because the data were corrupt or the simulator crashed) using JMP's forward stepwise regression approach with all main effects and interactions as candidate effects, according to the effect hierarchy principle. Stepwise regression is a very basic way of handling variable inclusion issues when there are a large number of variables. This step-by-step iterative construction of the regression model that involves automatic selection of independent variables can be achieved either by trying out one independent variable at a time and including it in the regression model if it is statistically significant, or by including all potential independent variables in the model and eliminating those that are not statistically significant, or by a combination of both methods. Each of these performance measures was tabulated and the following figures show how each measure changed based on the participants driving behavior.

4.7.7 Deceleration and Brake Time

Figures 4-16 and 4-17 show a comparison for deceleration and brake time conditions between daytime and nighttime conditions for the different marker colors. Please note that the deceleration in this analysis is multiplied by (-1), therefore a higher number is indicative of stronger braking, suggesting a more noticeable color. In general, the deceleration and brake time show inverse relationships for each of the major comparison conditions. A rapid deceleration is likely to happen over a shorter brake time if the participant didn't notice the marker and was surprised, while a lower deceleration over a longer time would be needed to produce the same change in speed. The results show that the white, yellow, and black markers have significant effect on the deceleration rate during daytime compared to nighttime conditions. It should be noted that two main criteria were used to evaluate the results. First, the significance effect is examined. If there was more than one color, then the color with the higher significance was selected. The second criterion examined the driving condition and selected the color that produced the optimal driving condition along the express lane. For example, as seen on Figure 4-18, white and yellow markers show higher significance than the black marker. In addition, white marker results in lower deceleration rate than yellow marker which is a favorable driving condition than higher deceleration rates which can affect traffic operations along the express lane. The JMP prediction profiles in Figure 4-18 are dynamic and display the settings at which deceleration rate can be predicted depending on time of day condition with respect to each color. Figure 4-19 also shows that the white marker is significant with the lowest brake time compared to the rest of the colors.

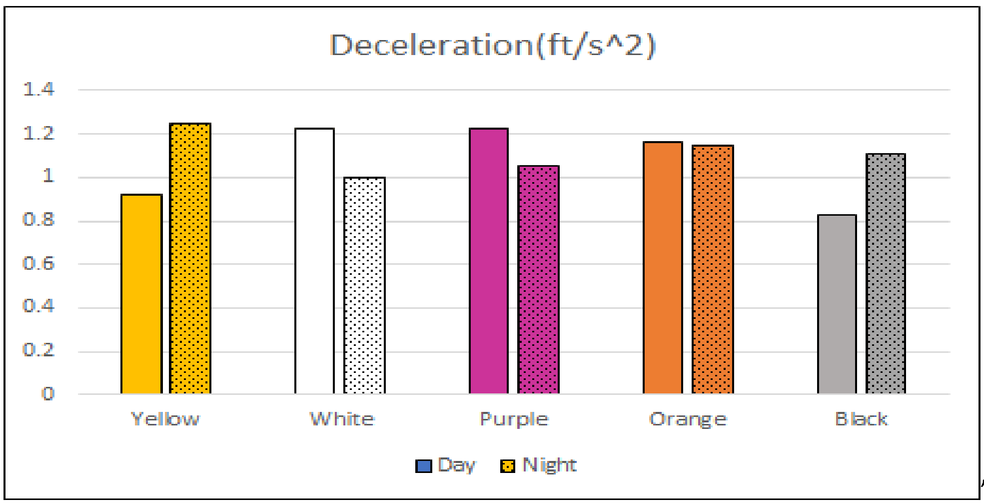

Figure 4-16: Average Deceleration Rates for Marker Colors by Time of Day

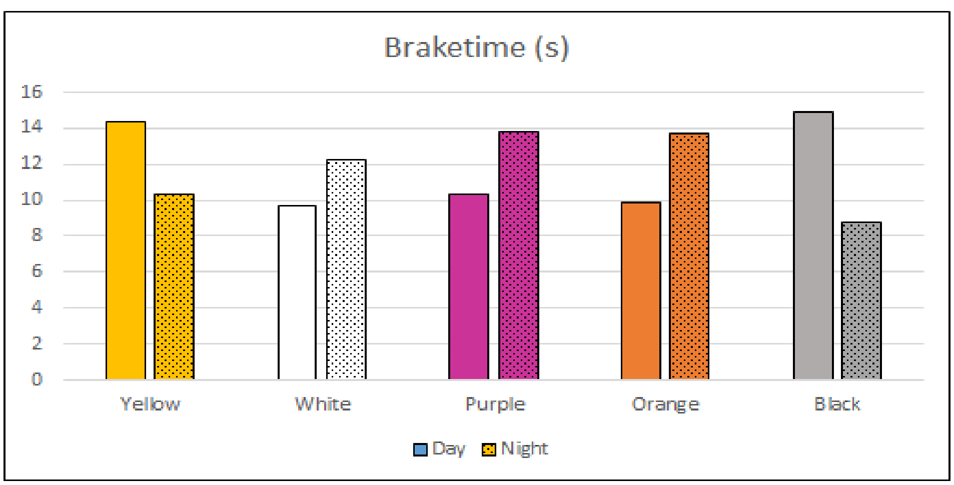

Figure 4-17: Average Brake Time for Marker Colors by Time of Day

Response Deceleration (m/s2)

Scaled Estimates

Term	Scaled Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.331171	0.007306	-45.33	<.0001*
TOD[Day]	0.0047629	0.007306	0.65	0.5146
TOD[Night]	-0.004763	0.007306	-0.65	0.5146
Color[Black]	0.0345496	0.014605	2.37	0.0182*
Color[Orange]	-0.023042	0.014631	-1.57	0.1156
Color[Purple]	-0.009293	0.014656	-0.63	0.5261
Color[White]	-0.00992	0.014533	-0.68	0.4950
Color[Yellow]	0.0077054	0.014631	0.53	0.5985
TOD[Day]*Color[Black]	0.0299655	0.014605	2.05	0.0404*
TOD[Day]*Color[Orange]	-0.009863	0.014631	-0.67	0.5004
TOD[Day]*Color[Purple]	-0.02208	0.014656	-1.51	0.1322
TOD[Day]*Color[White]	-0.043852	0.014533	-3.02	0.0026*
TOD[Day]*Color[Yellow]	0.0458289	0.014631	3.13	0.0018*
TOD[Night]*Color[Black]	-0.029966	0.014605	-2.05	0.0404*
TOD[Night]*Color[Orange]	0.0098633	0.014631	0.67	0.5004
TOD[Night]*Color[Purple]	0.0220796	0.014656	1.51	0.1322
TOD[Night]*Color[White]	0.0438516	0.014533	3.02	0.0026*
TOD[Night]*Color[Yellow]	-0.045829	0.014631	-3.13	0.0018*

Prediction Profiler

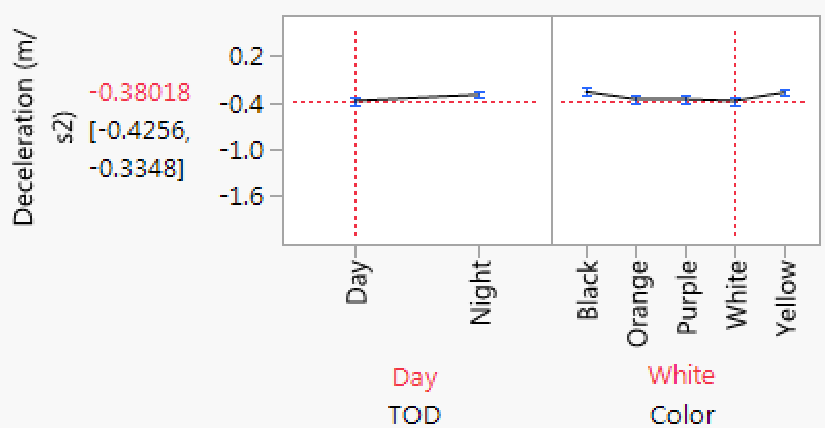

Figure 4-18: Time of Day and Color Effect on Deceleration Rates

Response Braketime (s)

Scaled Estimates

Term	Scaled Estimate	Std Error	t Ratio	Prob>|t|
Intercept	11.592225	0.297213	39.00	<.0001*
TOD[Day]	-0.00445	0.297213	-0.01	0.9881
TOD[Night]	0.0044504	0.297213	0.01	0.9881
Color[Black]	0.1581871	0.594191	0.27	0.7901
Color[Orange]	-0.364214	0.595226	-0.61	0.5407
Color[Purple]	0.3701702	0.59624	0.62	0.5348
Color[White]	-0.734537	0.59124	-1.24	0.2144
Color[Yellow]	0.5703939	0.595226	0.96	0.3381
TOD[Day]*Color[Black]	3.1305536	0.594191	5.27	<.0001*
TOD[Day]*Color[Orange]	-2.034206	0.595226	-3.42	0.0007*
TOD[Day]*Color[Purple]	-1.424148	0.59624	-2.39	0.0171*
TOD[Day]*Color[White]	-1.573861	0.59124	-2.66	0.0079*
TOD[Day]*Color[Yellow]	1.9016619	0.595226	3.19	0.0014*
TOD[Night]*Color[Black]	-3.130554	0.594191	-5.27	<.0001*
TOD[Night]*Color[Orange]	2.0342056	0.595226	3.42	0.0007*
TOD[Night]*Color[Purple]	1.4241484	0.59624	2.39	0.0171*
TOD[Night]*Color[White]	1.5738615	0.59124	2.66	0.0079*
TOD[Night]*Color[Yellow]	-1.901662	0.595226	-3.19	0.0014*

Prediction Profiler

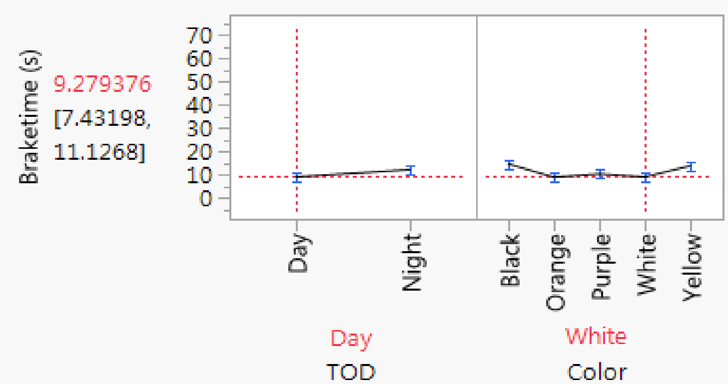

Figure 4-19: Time of Day and Color Effect on Brake Time

Figure 4-20 shows the effect of Weather conditions and color on brake time. The results showed that both white and yellow markers were the most significant with the white marker providing lower brake time than yellow although the difference is insignificant especially during low visibility conditions. Figure 4-21 shows the effect of color change on deceleration rates during different driving conditions (time of day, weather, road surface type). Similar results were obtained regarding the white marker followed by the yellow marker.

Scaled Estimates

Nominal factors expanded to all levels

Term	Scaled Estimate	Std Error	t Ratio	Prob>|t|
Intercept	11.592225	0.297213	39.00	<.0001*
Weather[HV]	-0.623567	0.297213	-2.10	0.0361*
Weather[LV]	0.6235669	0.297213	2.10	0.0361*
Color[Black]	0.1581871	0.594191	0.27	0.7901
Color[Orange]	-0.364214	0.595226	-0.61	0.5407
Color[Purple]	0.3701702	0.59624	0.62	0.5348
Color[White]	-0.734537	0.59124	-1.24	0.2144
Color[Yellow]	0.5703939	0.595226	0.96	0.3381
Weather[HV]*Color[Black]	-2.502536	0.594191	-4.21	<.0001*
Weather[HV]*Color[Orange]	-1.415089	0.595226	-2.38	0.0176*
Weather[HV]*Color[Purple]	-0.805032	0.59624	-1.35	0.1772
Weather[HV]*Color[White]	2.2018788	0.59124	3.72	0.0002*
Weather[HV]*Color[Yellow]	2.5207784	0.595226	4.23	<.0001*
Weather[LV]*Color[Black]	2.5025362	0.594191	4.21	<.0001*
Weather[LV]*Color[Orange]	1.4150891	0.595226	2.38	0.0176*
Weather[LV]*Color[Purple]	0.8050319	0.59624	1.35	0.1772
Weather[LV]*Color[White]	-2.201879	0.59124	-3.72	0.0002*
Weather[LV]*Color[Yellow]	-2.520778	0.595226	-4.23	<.0001*

Prediction Profiler

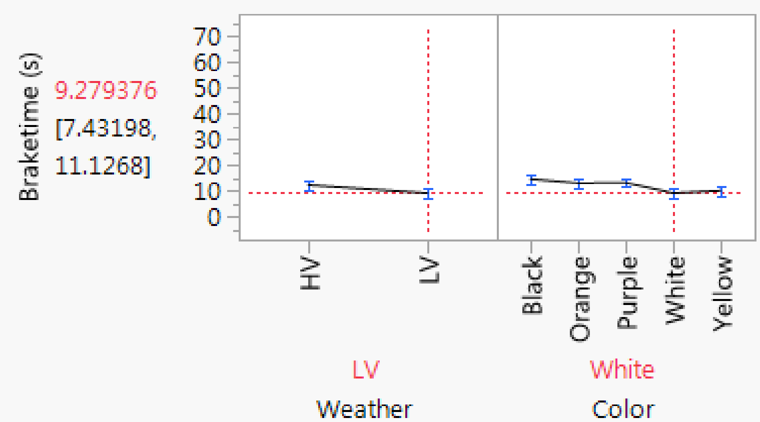

Figure 4-20: Weather and Color Effect on Brake Time

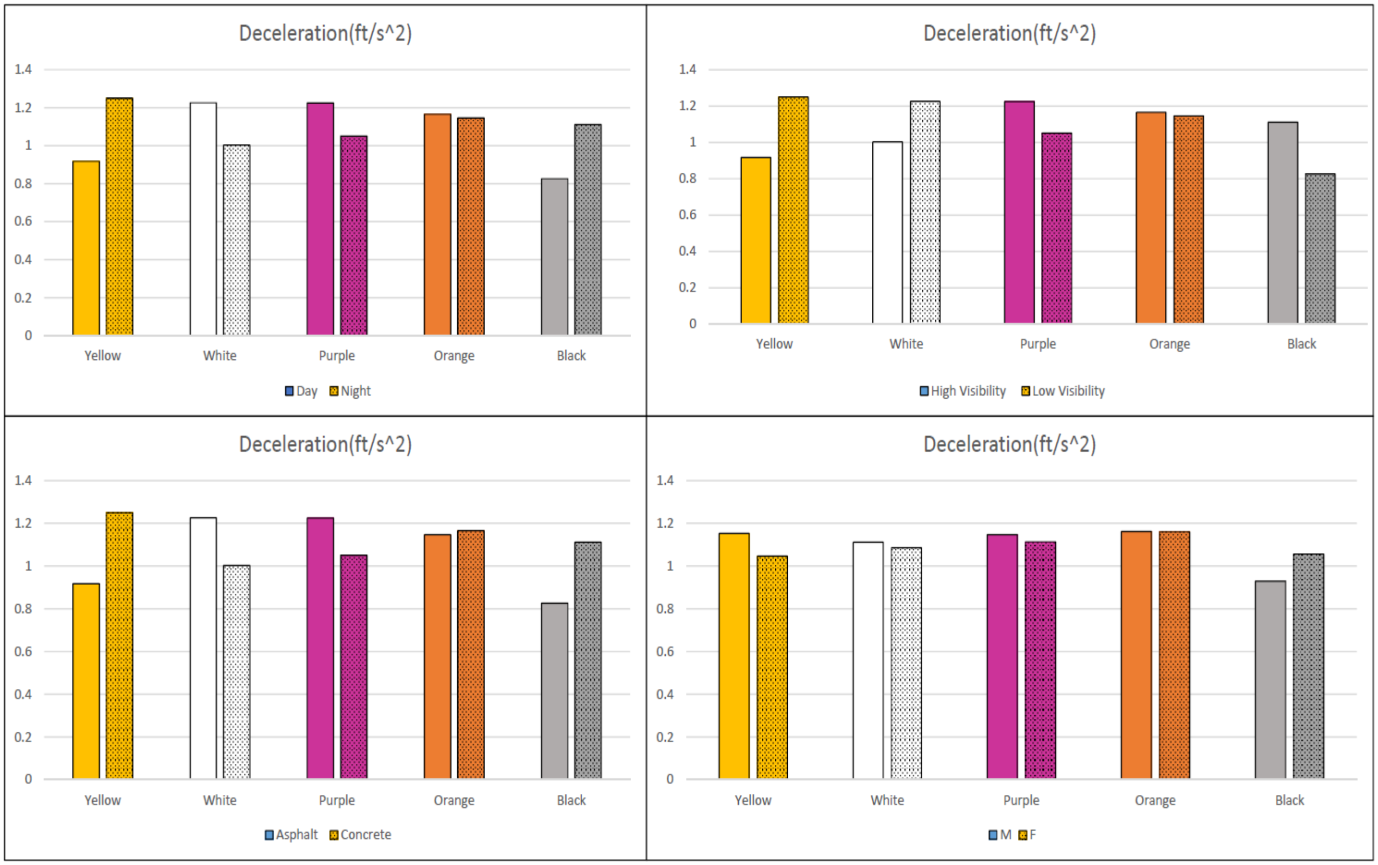

Figure 4-21: Effect of Color on Deceleration Rates in Different Driving Conditions

4.7.8 Entering Speed

The participant's speed while entering the marker areas (both straight and curved) shows the effect of the different colors on the driver behavior. As mentioned earlier, there are 4 different sections along the studies road, straight section and curved section for the one lane express lane and 2-lane ELs.

4.7.9 Straight Section

In most conditions, white marker showed higher significance when compared to the rest of the colors. As shown on Figure 4-22, the white marker is the only significant color especially in the two-way factor interaction with time of day conditions. Figures 4-23 and 4-24 summarize the effect of color on the entering speed at the straight and curved sections during different driving scenarios. The graphs show that the white marker has the most significant effect compared to the rest of the colors.

Response Velocity 1 Straight (mph)

Scaled Estimates

Term	Scaled Estimate	Std Error	t Ratio	Prob>|t|
Intercept	68.258469	0.278589	245.02	<.0001*
TOD[Day]	-1.006506	0.278589	-3.61	0.0003*
TOD[Night]	1.0065056	0.278589	3.61	0.0003*
Color[Black]	0.3731679	0.556956	0.67	0.5030
Color[Orange]	0.2450006	0.557926	0.44	0.6607
Color[Purple]	0.0161252	0.558877	0.03	0.9770
Color[White]	-0.48379	0.55419	-0.87	0.3829
Color[Yellow]	-0.150504	0.557926	-0.27	0.7874
TOD[Day]*Color[Black]	0.2792903	0.556956	0.50	0.6162
TOD[Day]*Color[Orange]	0.7659647	0.557926	1.37	0.1701
TOD[Day]*Color[Purple]	-0.00431	0.558877	-0.01	0.9938
TOD[Day]*Color[White]	-1.49621	0.55419	-2.70	0.0070*
TOD[Day]*Color[Yellow]	0.4552654	0.557926	0.82	0.4147
TOD[Night]*Color[Black]	-0.27929	0.556956	-0.50	0.6162
TOD[Night]*Color[Orange]	-0.765965	0.557926	-1.37	0.1701
TOD[Night]*Color[Purple]	0.0043101	0.558877	0.01	0.9938
TOD[Night]*Color[White]	1.4962103	0.55419	2.70	0.0070*
TOD[Night]*Color[Yellow]	-0.455265	0.557926	-0.82	0.4147

Prediction Profiler

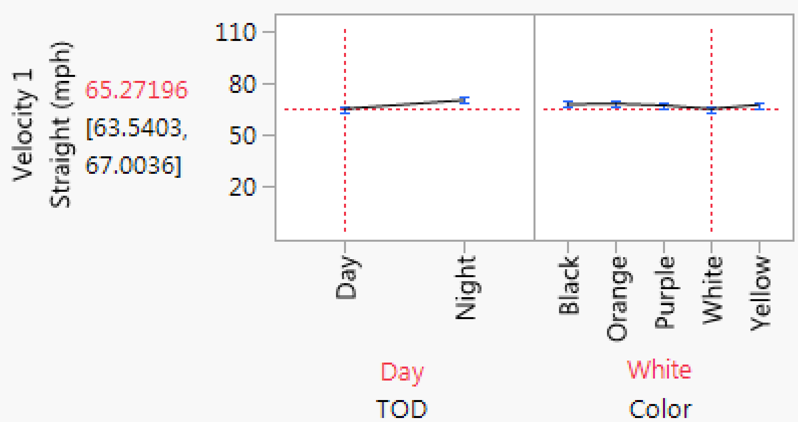

Figure 4-22: Time of Day and Color Effect on Speed at Section 1A

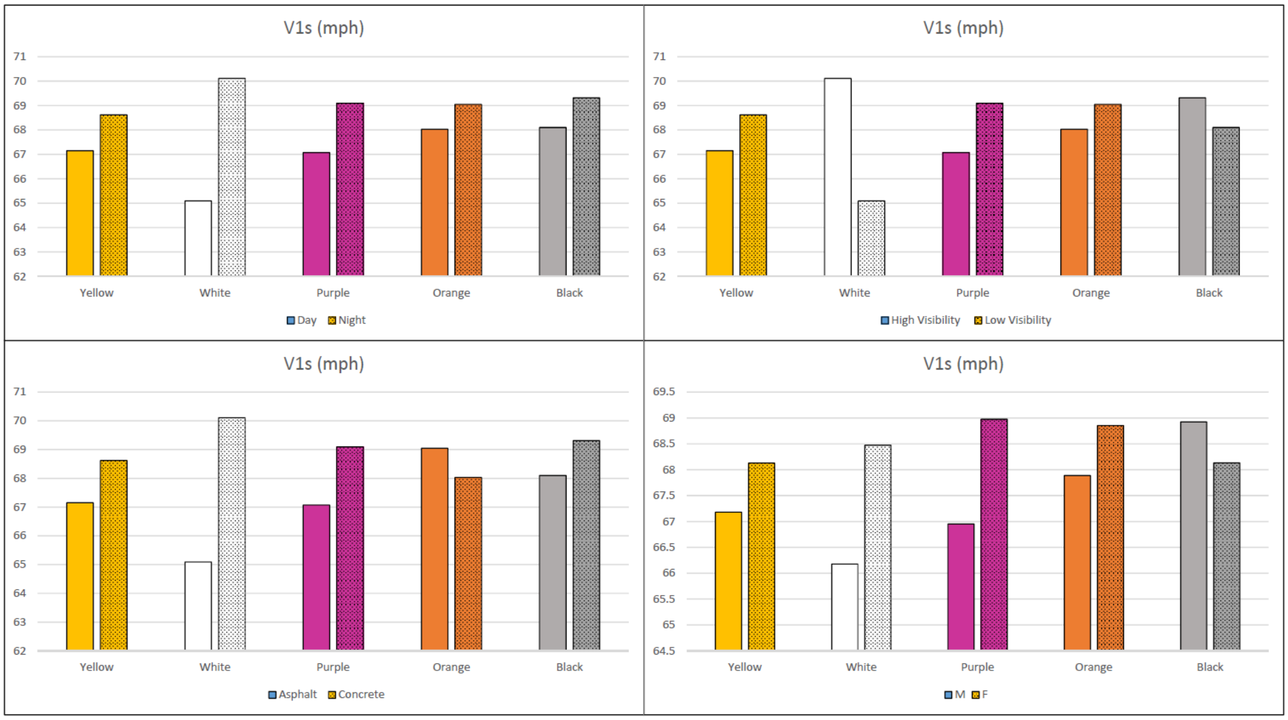

Figure 4-23: Color Effect on Speed at Section 1A in Different Driving Conditions

4.7.10 Curved Section

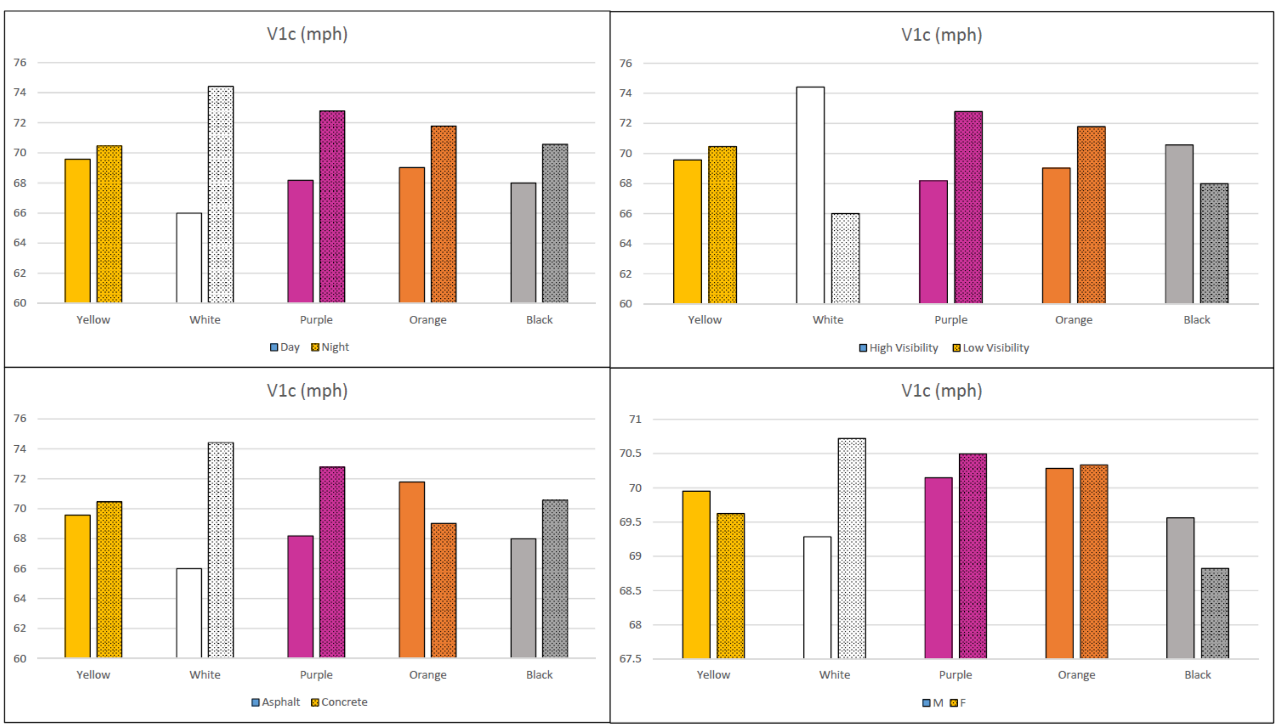

Figure 4-24: Color Effect on Speed at Section 1-24 in Different Driving Conditions

4.7.11 Lane Deviation

Lane deviation measures the vehicle position while entering the express lane whether to the left side of the markers (away) or to the right side (closer). Figure 4-25 shows the statistical results for the effect of time of day and color on lane deviation. The results show that the white and black markers are the most significant compared to the rest of the colors. However, drivers tend to align to the left side of the lane (negative value) while encountering white markers. On the other hand, Black markers show vehicle alignments that are closer to the markers in all cases especially during nighttime conditions due to the undetectable black markers.

Figure 4-26 also shows the significant effect of white marker on lane deviation at section 1A in different weather conditions especially high visibility compared to the rest of the colors.

Figures 4-27 and 4-28 summarize the effect of color on lane deviation in the straight section 1A and curved section 1-24, respectively. The results show that white marker is the most significant in the straight section, while yellow is the most significant in the curved section.

Response Deviation 1 Straight (ft)

Scaled Estimates

Term	Scaled Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-1.298747	0.042394	-30.64	<.0001*
TOD[Day]	0.1375203	0.042394	3.24	0.0012*
TOD[Night]	-0.13752	0.042394	-3.24	0.0012*
Color[Black]	0.3306302	0.084755	3.90	0.0001*
Color[Orange]	0.0593558	0.084902	0.70	0.4846
Color[Purple]	0.0344591	0.085047	0.41	0.6854
Color[White]	-0.180807	0.084334	-2.14	0.0323*
Color[Yellow]	-0.243638	0.084902	-2.87	0.0042*
TOD[Day]*Color[Black]	-0.230002	0.084755	-2.71	0.0068*
TOD[Day]*Color[Orange]	-0.033082	0.084902	-0.39	0.6969
TOD[Day]*Color[Purple]	-0.031821	0.085047	-0.37	0.7084
TOD[Day]*Color[White]	0.2892847	0.084334	3.43	0.0006*
TOD[Day]*Color[Yellow]	0.0056201	0.084902	0.07	0.9472
TOD[Night]*Color[Black]	0.2300018	0.084755	2.71	0.0068*
TOD[Night]*Color[Orange]	0.0330816	0.084902	0.39	0.6969
TOD[Night]*Color[Purple]	0.0318214	0.085047	0.37	0.7084
TOD[Night]*Color[White]	-0.289285	0.084334	-3.43	0.0006*
TOD[Night]*Color[Yellow]	-0.00562	0.084902	-0.07	0.9472

Prediction Profiler

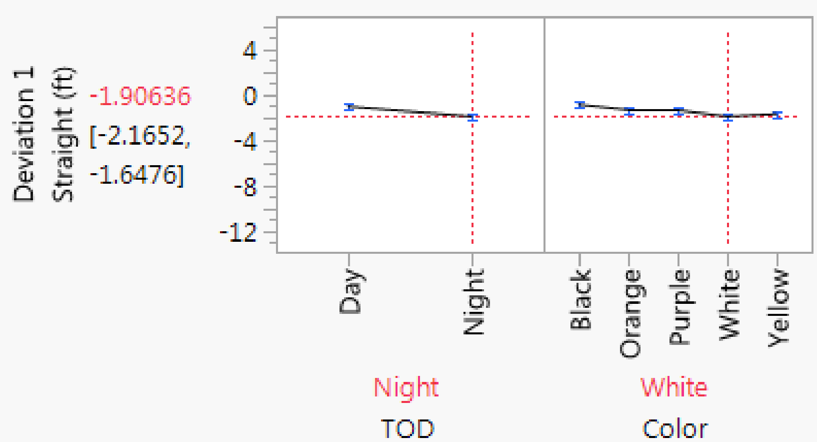

Figure 4-25: Time of Day and Color Effect on Lane Deviation at Section 1A

Response Deviation 1 Straight (ft)

Scaled Estimates

Term	Scaled Estimate	Std Error	t Ratio	Prob>|t|
Weather[HV]	0.0037909	0.042394	0.09	0.9288
Weather[LV]	-0.003791	0.042394	-0.09	0.9288
Color[Black]	0.3306302	0.084755	3.90	0.0001*
Color[Orange]	0.0593558	0.084902	0.70	0.4846
Color[Purple]	0.0344591	0.085047	0.41	0.6854
Color[White]	-0.180807	0.084334	-2.14	0.0323*
Color[Yellow]	-0.243638	0.084902	-2.87	0.0042*
Weather[HV]*Color[Black]	0.0886905	0.084755	1.05	0.2956
Weather[HV]*Color[Orange]	0.1006478	0.084902	1.19	0.2361
Weather[HV]*Color[Purple]	0.1019081	0.085047	1.20	0.2311
Weather[HV]*Color[White]	-0.430596	0.084334	-5.11	<.0001*
Weather[HV]*Color[Yellow]	0.1393495	0.084902	1.64	0.1010
Weather[LV]*Color[Black]	-0.088691	0.084755	-1.05	0.2956
Weather[LV]*Color[Orange]	-0.100648	0.084902	-1.19	0.2361
Weather[LV]*Color[Purple]	-0.101908	0.085047	-1.20	0.2311
Weather[LV]*Color[White]	0.4305959	0.084334	5.11	<.0001*
Weather[LV]*Color[Yellow]	-0.13935	0.084902	-1.64	0.1010

Prediction Profiler

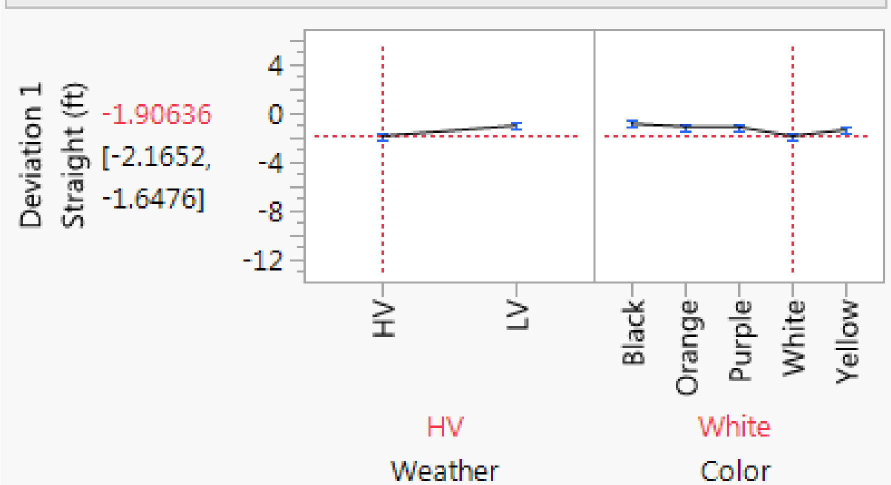

Figure 4-26: Effect of Color on Lane Deviation at Section 1A

4.7.12 Straight Section

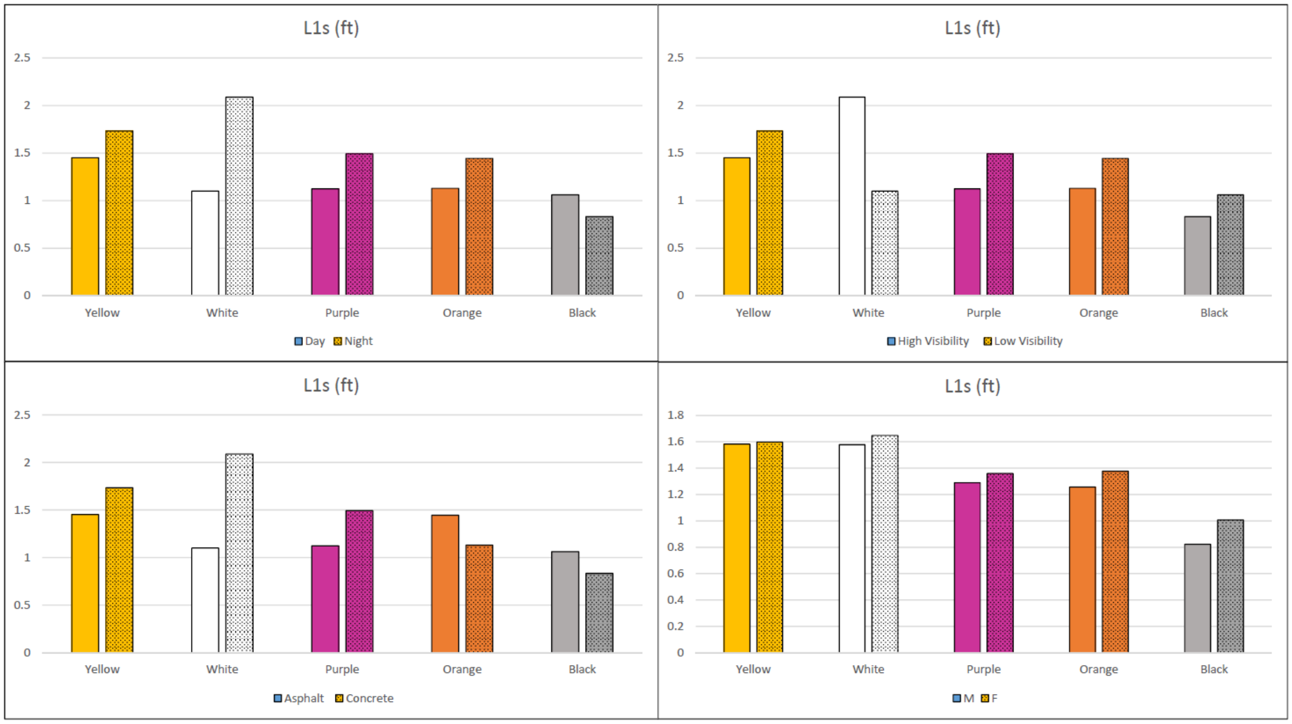

Figure 4-27: Effect of Color on Lane Deviation at 1A in Different Driving Conditions

4.7.13 Curved Section

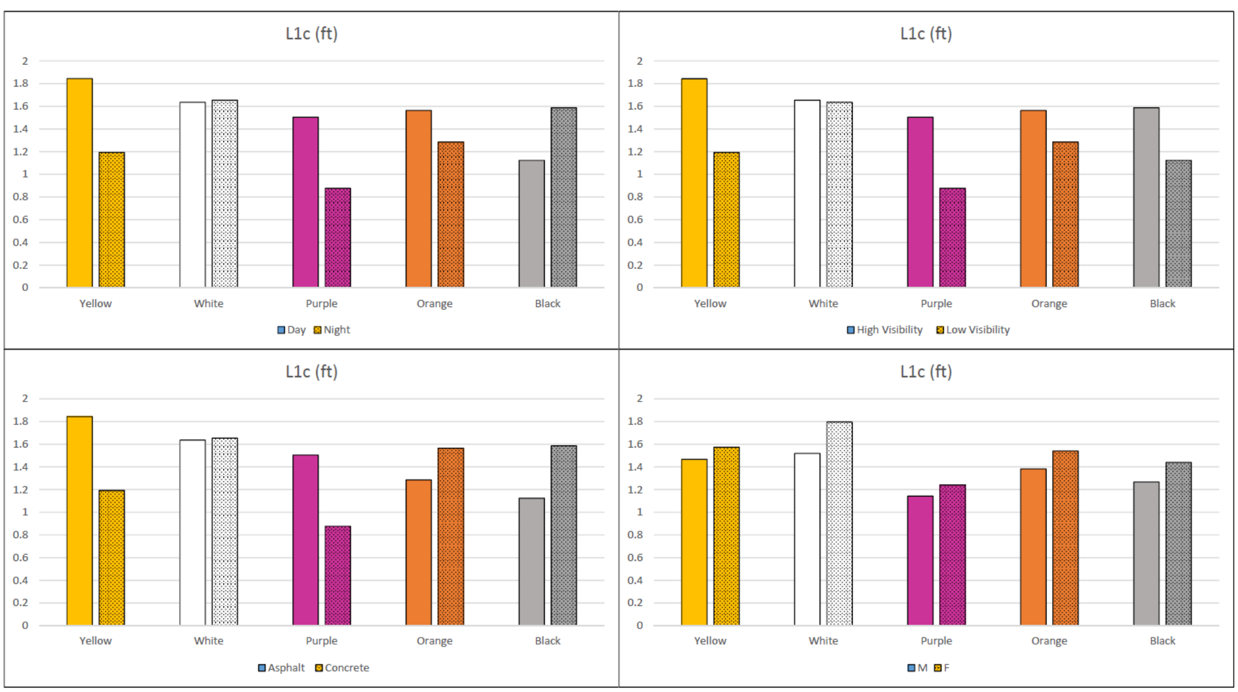

Figure 4-28: Effect of Color on Lane Deviation at 1-24 in Different Driving Conditions

4.8 Eye Tracking Data Parameters

The eye-tacking process was broken up into two components. These included the eye tracking data from the eye tracking computer itself and the video data that was analyzed frame by frame to obtain the time to first notice (TTFN).

4.8.1 Time to First Notice (TTFN) Analysis

This applied research project involves 150 degrees of visual angle which requires head movements and eye shifts across the 3 projector screens. Therefore, the raw data from the eye tracking system cannot be directly used because it does not have a reference point with regard to the visual scenes. Instead, the eye tracking data was calibrated to and superimposed upon the video feed from the head mounted camera. The person's eye position is then identified on the final output video by the crosshairs generated by the eye tracking system. A frame by frame analysis was used to identify where the participant's eyes are focused as they approached the express lane, which is indicated by the crosshairs shown on the video feed output. A specific location was marked in each of the two scenarios as the first location at which the markers can be seen. This location is approximately 2 ½ poles back from the location of the marker. Figure 4-29 shows an example of where to start the analysis for TTFN.

Figure 4-29: Starting Point for TTFN Analysis

The eye tracking video was recorded at 30 frames per second (1,800 frames per minute). For this study, 1/10 of a second was defined as a fixation. Glances less than this were regarded as brief gazes that might be accidental rather than intentional. Furthermore, a tolerance of error for the TTFN analysis was defined by drawing an imaginary circle around the center point of the crosshair as shown in Figure 4-30 below.

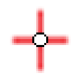

Figure 4-30: Crosshair with Circle around the Center Point

The TTFN analysis answers two questions: Did the person notice the markers before entering? (Y/N) and if yes, how long was the time to first notice (TTFN) for the markers? The time stamp for the furthest distance a person can clearly see the markers (2.5 light poles back) were recorded. In the output video, if the crosshairs from the eye tracking software crossed the markers for a minimum of 3 frames (1/10 of a second), the time stamp from the first frame was recorded. If the person did not notice the markers before entering the section, the TTFN was denoted as 0.00 seconds. If the participant missed the marker, then it's coded as -1. Table 4-12 shows an example of the TTFN data collected.

Table 4-12: TTFN Data Collection Example

Start minute	Start second	Start frame	Did they notice? (Y/N)	End Minute	End Second	End Frame
44	23	28	Y	44	25	25

The TTFN was computed by subtracting the end time from the start time (in minutes, seconds, and frames) and converted to decimal seconds and subjected to a series of statistical comparisons. The majority of the participants had 10 TTFN recordings (one for each driving run). Due to data collection issues that occurred throughout the study, some of the participants had only partial data available for TTFN analysis and this data was also included in the statistical analysis. It is assumed that since the runs were randomly performed by the participants and any equipment failures also occurred on a random basis, these failures would have no statistically significant impact on the ANOVA analysis results.

4.8.2 TTFN Statistical Results

The TTFN was also examined across the 10 driving scenarios and was analyzed by age group and gender against all driving conditions. A mixed model analysis was performed to examine within scenario differences in TTFN scores. Figure 4-31 shows that males 65+ had the shortest time to first notice the white markers among other colors especially during nighttime conditions.

Parameter Estimates - TTFN Age Group=65+, Gender=M

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	3.1937143	0.232876	13.71	<.0001*
TOD[Day]	0.0136786	0.232876	0.06	0.9533
Color[Black]	-0.438446	0.468106	-0.94	0.3524
Color[Orange]	-0.014339	0.456213	-0.03	0.9750
Color[Purple]	-0.067286	0.479704	-0.14	0.8889
Color[White]	0.2431607	0.456213	0.53	0.5958
TOD[Day]*Color[Black]	-0.172696	0.468106	-0.37	0.7134
TOD[Day]*Color[Orange]	0.1456964	0.456213	0.32	0.7505
TOD[Day]*Color[Purple]	-0.374393	0.479704	-0.78	0.4379
TOD[Day]*Color[White]	1.0444464	0.456213	2.29	0.0253*

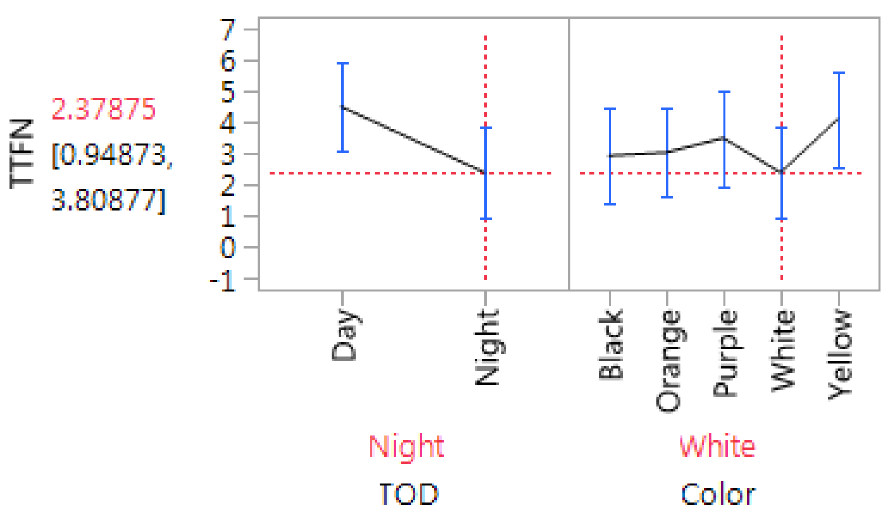

Figure 4-31: Effect of Color, Age Group, and Gender on TTFN by Time of Day

Figure 4-32 also shows that males 65+ had the shortest time to first notice the white markers among other colors especially on concrete surface conditions.

Parameter Estimates - TTFN Age Group=65+, Gender=M				
Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	3.2277208	0.189199	17.06	<.0001*
Rd Type[Asphalt]	-0.070346	0.189199	-0.37	0.7106
Color[Black]	0.1898417	0.379318	0.50	0.6175
Color[Orange]	-0.196158	0.374694	-0.52	0.6014
Color[Purple]	-0.256054	0.383886	-0.67	0.5058
Color[White]	0.0104042	0.374694	0.03	0.9779
Rd Type[Asphalt]*Color[Black]	-0.234092	0.379318	-0.62	0.5381
Rd Type[Asphalt]*Color[Orange]	-0.601217	0.374694	-1.60	0.1108
Rd Type[Asphalt]*Color[Purple]	0.3786792	0.383886	0.99	0.3256
Rd Type[Asphalt]*Color[White]	0.7865958	0.374694	2.10	0.0375*

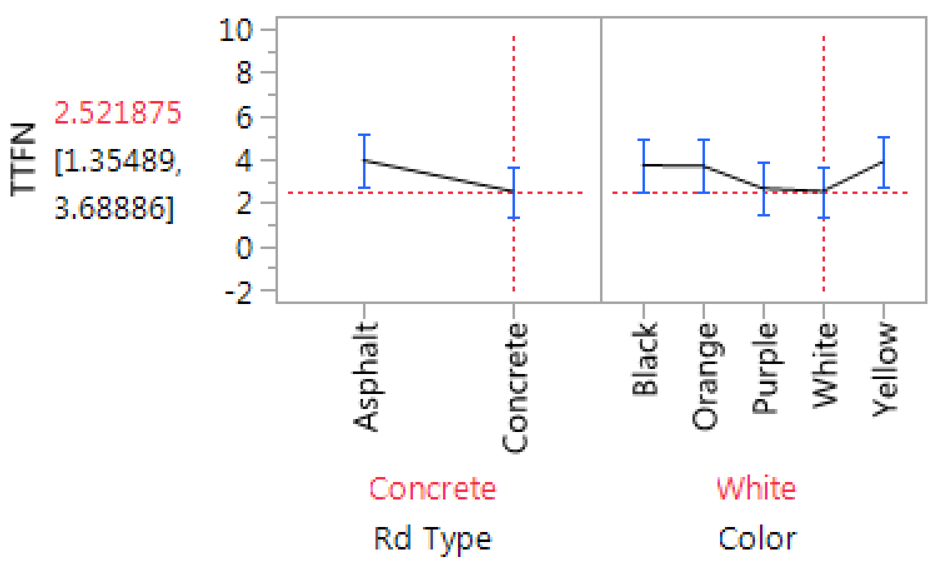

Figure 4-32: Effect of Color, Age Group, and Gender on TTFN by Road Surface Type

Figure 4-33 shows the results of the statistical analysis and demonstrates a highly significant effect of scenario presentation on TTFN scores. The results indicate that the White marker associated with scenario 3 had the shortest mean time to be noticed among the markers based on frame by frame analyses of eye-tracking data. These results also indicated that the White marker was first to be noticed among the markers under day and night time driving, concrete and asphalt roads, low and high visibility, and low- and high-density diving conditions.

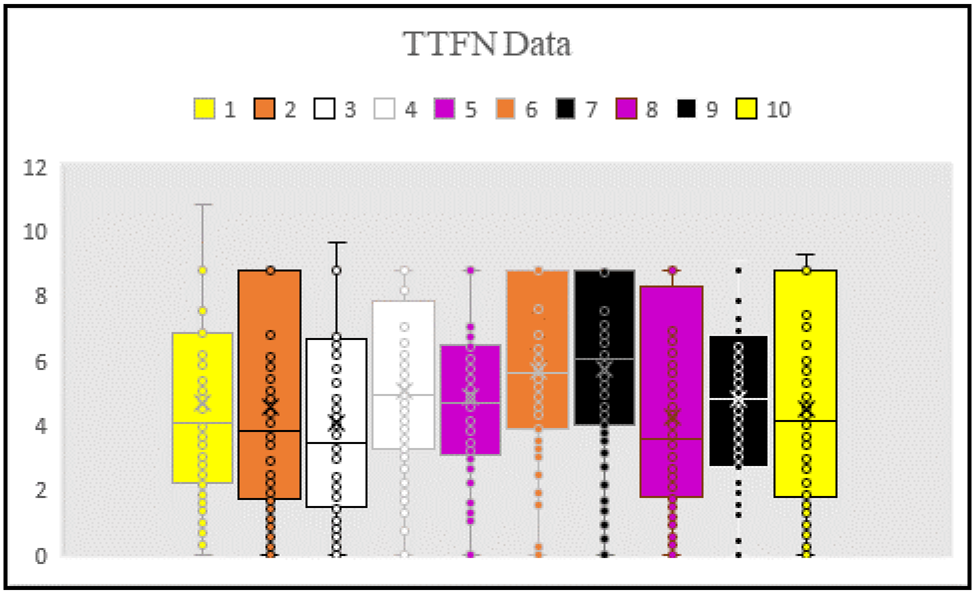

Figure 4-33: Mean TTFN by Scenario

The effect of scenario presentation was also examined across the 3 age groups. A 3x10 mixed-factorial design two-way ANOVA analysis was performed involving the three age groups as a between-subjects variable, the 10 driving scenarios as the within subject variable, and the TTFN time as the dependent variable. Again, the results showed a significant main effect especially in driving scenario 3 presentation on TTFN [$F_{(9,50)}$ =2.452, $p<.05$, η_p^2 =.06]. This indicated that these results were like the One-Way ANOVA results. However, there was a significant interaction effect between scenario presentation and age groups [η_p^2 =0.040.] especially the 40-64 age group. There were no other significant effects on TTFN scenarios [$F_{(18,50)}$=.278, $p>.05$] for the other age groups [$F_{(2,50)}$=.377, $p>.05$]. The mean scores of TTFN as a function of age group are summarized in Table 4-13 and Figure 4-34. This clearly indicates a pattern of progressive decline in TTFN scores for Scenarios 6 and 7 especially for the 18-39 age group. In general, the 18-39 age group drivers had higher TTFN scores than both the 40-64 age group and 65+ drivers, while the 40-64 drivers had lower TTFN scores than both the 18-39 age group and 65+ drivers. Similar TTFN scores patterns are also observed in Scenario 8. However, there appear to be no significant difference among the 3 age groups across the other driving scenarios as highlighted in the table and graph below.

Table 4-13: Mean TTFN as a Function of Age Group

Age Group		Scenario 1	2	3	4	5	6	7	8	9	10
18-39	mean	4.95	4.74	4.44	5.71	6.08	6.88	6.86	5.03	5.76	4.95
	SD	3.05	3.22	3.05	2.76	2.26	2.25	2.23	3.12	2.56	3.18
40-64	mean	4.70	4.50	3.78	4.61	4.37	5.28	5.44	3.79	4.77	4.34
	SD	2.61	3.21	3.09	2.19	2.40	2.60	2.89	2.62	2.12	2.75
65+	mean	4.48	4.50	4.65	5.46	4.81	5.48	6.41	4.58	5.00	5.32
	SD	2.49	2.74	3.05	2.29	2.30	1.98	2.25	2.84	2.74	2.70
All	mean	4.73	4.59	4.29	5.28	5.13	5.93	6.26	4.50	5.22	4.87
	SD	2.75	3.08	3.09	2.49	2.43	2.41	2.53	2.93	2.53	2.92

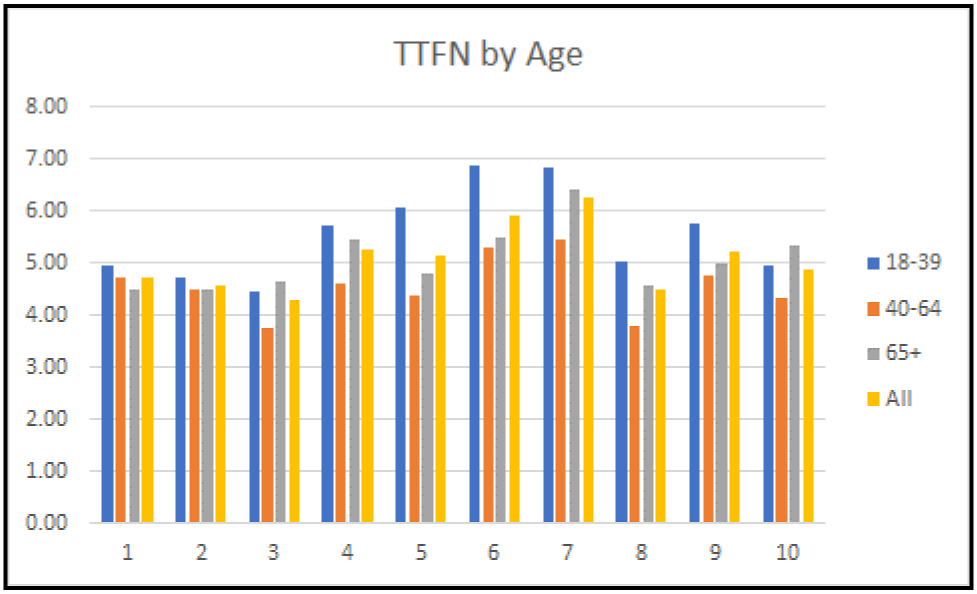

Figure 4-34: TTFN by Age

4.9 Conclusions

As of the end of the participant recruitment phase, the human factors experiment was conducted for 176 participants. The total number of participants needed was 120. Out of the 176, 134 participants were successful with useable data while the remaining 42 participants were unable to complete the experiment due to no show, motion sickness, dizziness, corrupted simulator files, simulator crashes, or inadequate vision, among other reasons. The 176 participants were recruited to participate in the study through a variety of mechanisms, which included student recruitment (UCF SONA), Learning Longevity Research Network (LLRN), Learning Institute for Elders (LIFE), social media outreach, fliers, and personal connections. Participants were required to have normal vision and be over the age of 18.

Six different datasets were examined and analyzed. They included motion sickness data, eyesight data, driving data, eye-tracking data, demographic data, and exit survey data. The statistical analysis for the driving data examined the impacts of the express lane marker color change on driver behavior among other traffic and environmental conditions at different sections along the ELs. The results showed that white and yellow markers are the most frequently identified as significant with different parameters, age group and gender. However, the "white" marker was the highest common color among the results.

The exit survey results, reflecting the participants' subjective opinion in terms of the most conspicuous color, the most noticeable by TOD, weather conditions and road surface type, were in agreement with the statistical results of the driving data. The results indicated that "white" is the optimum color for the ELs markers followed by the "yellow" marker. It should be noted that final recommendations were confirmed after analyzing the full datasets to develop an evaluation model which includes all scenario parameters by the end of the next task.

Based on the average speed parameter, most of the marker colors showed consistent speeds, close to the speed limit. However, white marker showed a much wider variability in speed based on environmental conditions. Lane deviation showed how much a driver weaves before entering the express lane. Although white and black markers showed significance in terms of lane deviation compared to the rest of the colors, drivers tend to align to the left side of the lane (away) while encountering white markers which demonstrates strong awareness of the delineated lane line while Black markers show vehicle alignments that are closer to the markers in all cases especially during nighttime conditions due to the undetectable black markers. The results also showed that the white marker was the most significant in the straight section, while yellow marker was the most significant in the curved section.

In addition, deceleration and braking time were examined; the lower the absolute deceleration, the better the color. White and yellow markers performed consistently well. Furthermore, the TTFN was also analyzed by age group and gender which showed whether people noticed the markers before entering the ELs. Based on this parameter, the results indicated that most people noticed the white marker consistently before entering the ELs. The highest miss rates were for the black markers. Based on the five parameters that were examined along with the participant's opinion, it is concluded that white is the most optimal color to be used for the express lane markers.

V. DEVELOP EVALUATION MODEL

Chapter 5 of the research provides further analysis to the different scenario parameters used in the experiment (time of day, visibility, traffic density, road surface type, color, age and gender) in order to develop an evaluation model inclusive of all the parameters. Furthermore, this data analyzed in this task encompasses the full data sets as opposed to the preliminary analysis in task 3. The previous chapter examined the effect of color change on driver behavior for each parameter individually. The current chapter develops evaluation models to test the effect of color change on driver behavior when all significant parameters are used simultaneously to predict the effectiveness of the express lane marker color. Based on the results of the evaluation models, the research team developed models and assessed the most effective color recommended for use as express lane markers. Data from the visual tests, simulator sickness, and motion sickness questionnaires were also analyzed and are discussed in the coming section.

5.1 Visual, Motion History, and Simulator Sickness Data

5.1.1 Simulator Sickness Measures

For the task 4 behavioral analysis, the full datasets for visual, motion history, and simulator sickness data were analyzed against demographics. A series of multivariate statistics were conducted to examine the effects of simulation type symptom, age group, and gender on simulation sickness. Results showed a significant effects of sickness type [$F_{(2,110)} = 90.84$, $p < .001$, $\eta^2 = .45$]. Post hoc comparisons indicated that participants' nausea scores were significantly lower (Mean = 9.98; SD = 1.12) than disorientation scores (Mean = 22.38; SD = 1.85) and were significantly higher than oculomotor scores (Mean = 3.56; SD = .57), and disorientation score were significantly higher (Mean = 22.38; SD = 1.85) than ocul0motor scores (Mean = 3.56; SD = .57). This effect is depicted in Figure 5-1.

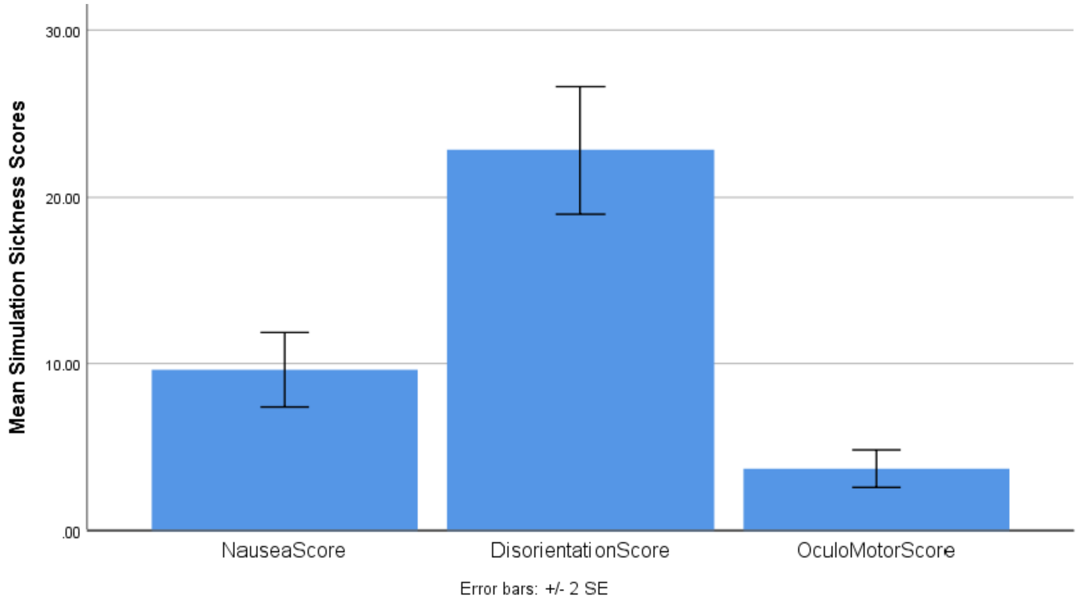

Figure 5-1: Mean Simulator Sickness Scores by Type

Additionally, our results also showed a significant effect of age group on simulation sickness symptoms [$F_{(2,110)} = 4.672$, $p < .05$, $\eta^2 = .05$]. Post hoc comparisons indicated that younger drivers reported higher levels of simulation symptoms (Mean = 14.91; SD = 1.53) than middle-aged (Mean = 7.73; SD = 1.83) drivers, and middle-aged had significantly lower (Mean = 7.73; SD = 1.83) than older drivers (Mean = 13.274; SD = 1.82). However, there was no significant difference between younger and older drivers (p>.05). Interestingly, there was a significant interaction between age group and sickness type of symptoms on participants' overall simulation sickness [$F_{(4,110)} = 3.631$, $p < .05$, $\eta^2 = .06$]. Tests of simple effects indicated that for the younger group, drivers' scores on nausea were significantly lower (Mean = 10.55; SD = 1.72) than disorientation scores (Mean = 28.95; SD = 2.83) as well as oculomotor scores (Mean = 5.23; SD = .87), and their disorientation scores were significantly higher (Mean = 28.95; SD = 2.83 than oculomotor scores (Mean = 5.23; SD = .87). For the middle-aged group, drivers' scores on nausea were significantly lower (Mean = 6.31; SD = 2.06) than disorientation scores (Mean = 15.09; SD = 3.39) as well as oculomotor scores (Mean = 1.81= 1.05), and disorientation scores were significantly higher (Mean = 15.09; SD = 3.39) than oculomotor scores (Mean = 1.81= 1.05). For the older group, drivers' scores on nausea were significantly lower (Mean = 13.07; SD = 2.04) than disorientation scores (Mean = 23.09; SD = 3.37) as well as oculomotor scores (Mean = 3.65; SD= 1.04), and disorientation scores were significantly higher (Mean = 23.09; SD

= 3.37) than oculomotor scores (Mean = 3.65; SD= 1.04. Similarly, tests of simple effects also indicated that for nausea Symptoms, there was only a significant difference between middle-aged (Mean = 6.31; SD = 2.06) and older drivers (Mean = 13.07; SD = 2.0). For disorientation symptoms, there was a significant difference between young (Mean = 28.95; SD = 2.83) and middle-aged (Mean = 15.09; SD = 3.395) drivers. For oculomotor symptoms, there was a significant difference between young (Mean = 5.23; SD = .87) and middle-aged (Mean = 1.81; SD = 1.05). None of the other post hoc comparisons were significant at 5% confidence. This interaction effect is depicted in Figure 5-2.

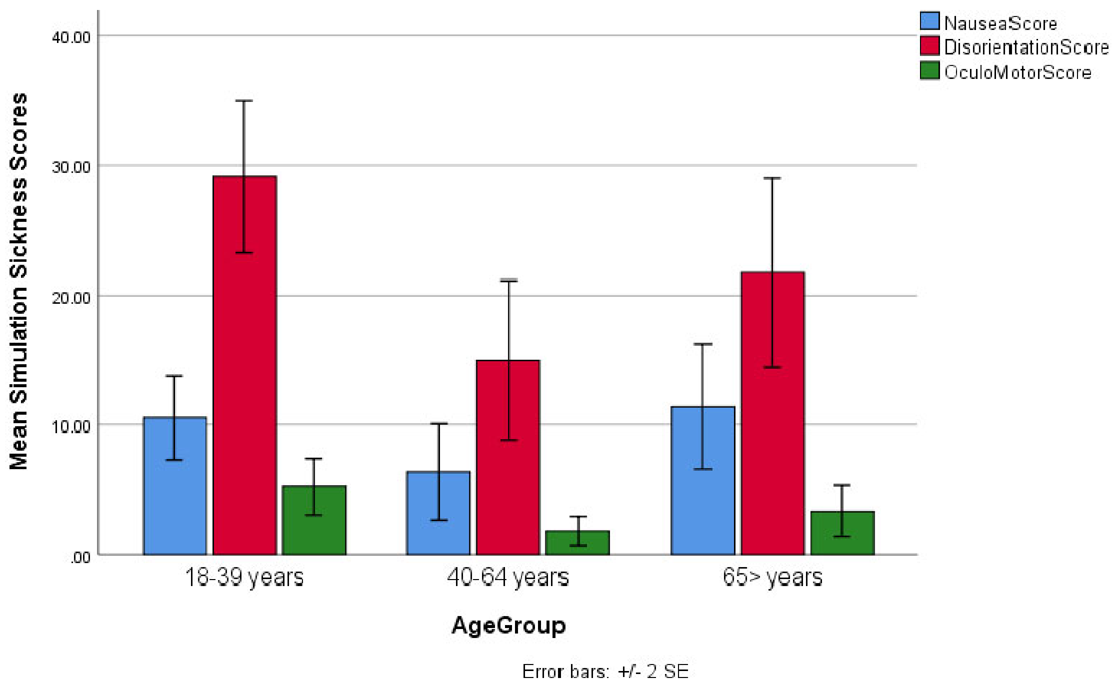

Figure 5-2: Simulator Sickness Scores by Age Group and Type

Finally, there was a significant interaction effect of between sickness type and gender group on simulation sickness symptoms [$F_{(2,110)} = 3.891$, $p < .05$, $\eta^2 = .03$]. Tests of simple effects indicated that for male drivers, nausea scores were significantly lower (Mean = 8.24; SD = 1.48) than disorientation (Mean = 17.95; SD = 2.44), but there were higher than oculomotor scores (Mean = 3.00; SD = .75), and disorientation scores (Mean = 17.95; SD = 2.44) were higher than oculomotor scores (Mean = 3.00; SD = .75). For the female drivers, nausea scores were significantly lower (Mean =11.71; SD = 1.69) than disorientation (Mean = 80; SD = 2.78), but there were higher than oculomotors scores (Mean = 4.13; SD = 1.69), and disorientation scores (Mean = 26.80 SD = 2.78) were higher than oculomotor scores (Mean = 4.13; SD = .86). This interaction effect is depicted in Figure 5-3.

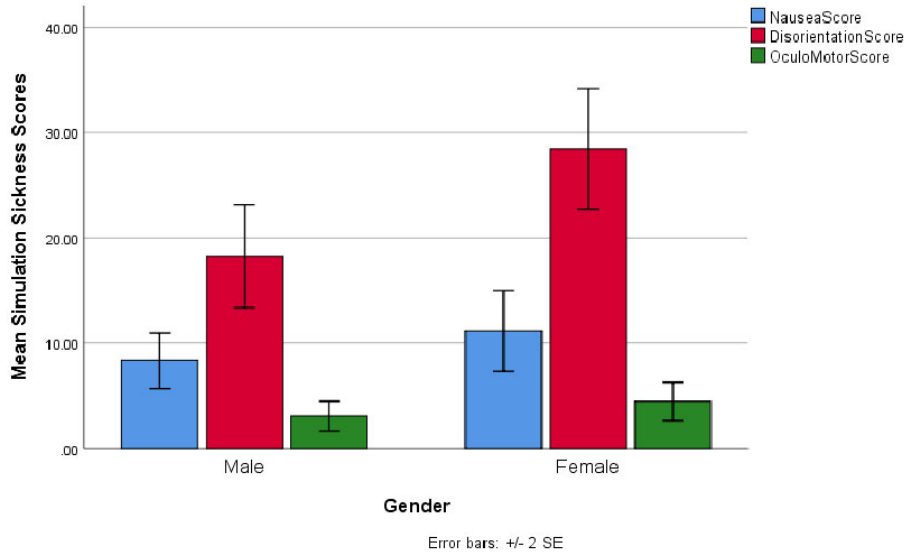

Figure 5-3: Simulator Sickness Scores by Gender and Type

Furthermore, there was a marginally significant interaction between Sickness type, Age, and gender on simulation sickness [$F_{(4,110)} = 2.269$, p =.08, $\eta^2 = .04$]. Figure 5-4 highlights the pattern of simulation sickness symptom for both male and female drivers across the three age groups.

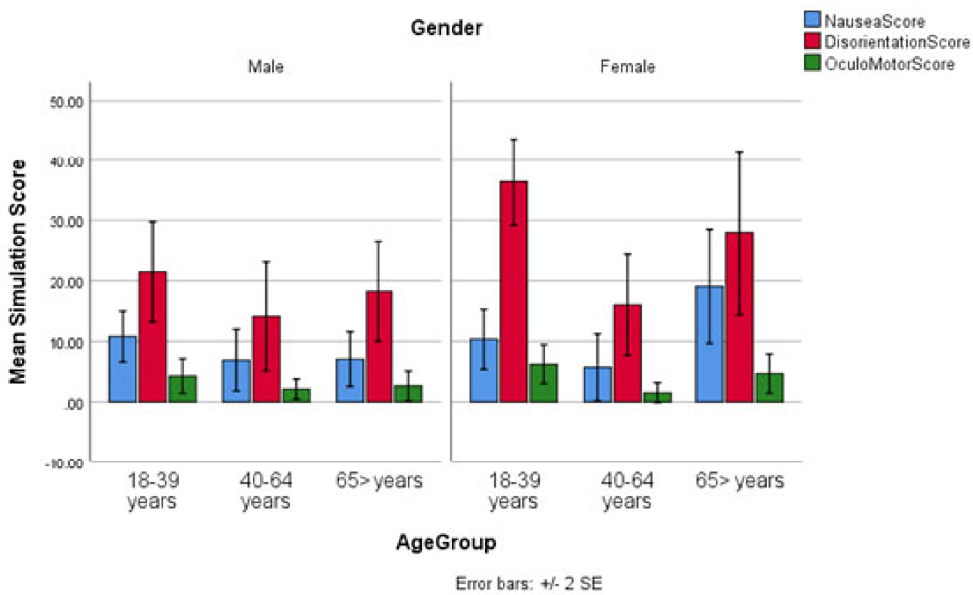

Figure 5-4: Simulator Sickness Scores by Gender, Age Group, and Type

5.2 Visual Sensory Processing Tests

5.2.1 Contrast Sensitivity Measures

A series of multivariate statistics were conducted to examine the effects of visual sensory processing tests as a function of age group. Results showed a significant main effect of contrast sensitivity level [$F_{(4,110)} = 183.64$, $p < .001$, $\eta^2 = .63$] on visual functioning. Post-Hoc comparisons indicated that participants' scores on contrast sensitivity A was significantly higher (Mean=5.79; SD=1.39) than sensitivity score E (Mean-2.53; SD=1.81), and contrast sensitivity B scores were significantly higher (Mean=5.46; SD=1.35) than contrast sensitivity E (Mean-2.53; SD=1.81). Contrast sensitivity C scores were significantly higher (Mean=5.86; SD=1.65) than contrast sensitivity D (Mean-4.47; SD=1.80), and contrast sensitivity C scores were significantly higher (Mean=5.86; SD=1.65) than contrast sensitivity E (Mean-2.53; SD=1.81). Contrast sensitivity C scores were significantly higher (Mean=5.86; SD=1.65) than contrast sensitivity E (Mean-2.53; SD=1.81), and contrast sensitivity D scores were significantly higher (Mean=4.47; SD=1.80) than contrast sensitivity E (Mean-2.53; SD=1.81). None of the other post-hoc comparisons were significant at p=.05. This effect is depicted in Figure 5-5.

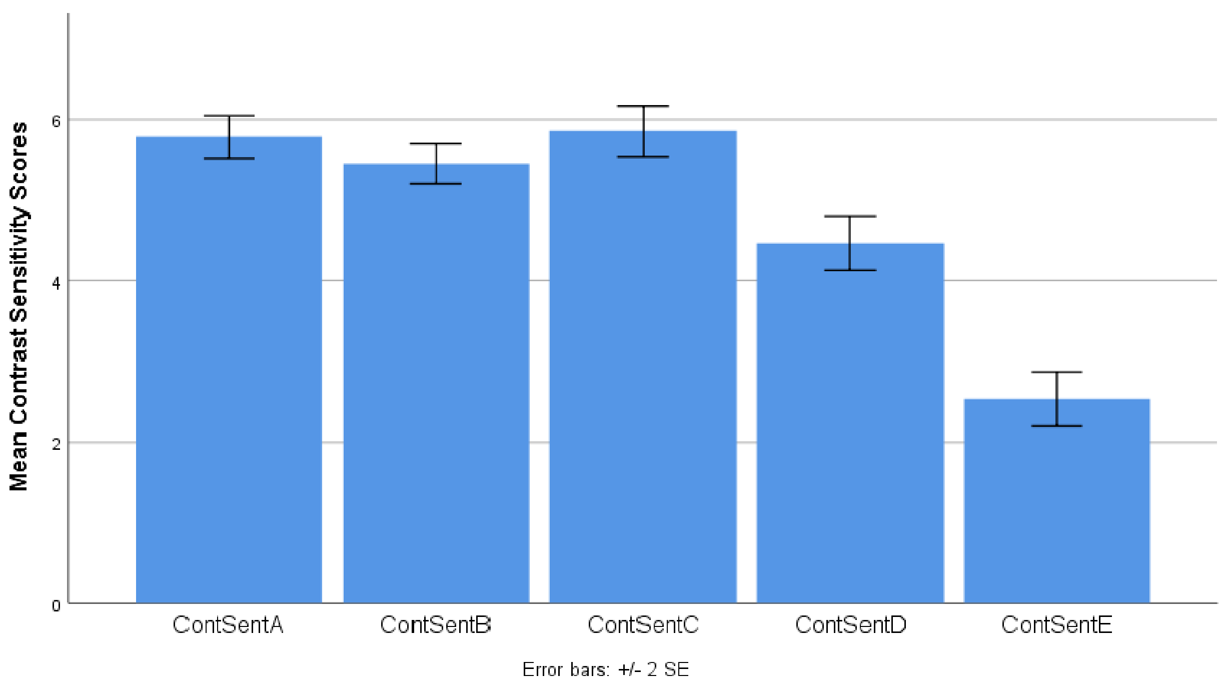

Figure 5-5: Mean Contrast Sensitivity Scores by Difficulty Level

In addition, there was a significant effect of age group on contrast sensitivity measure “C “scores [$F_{(2,110)} = 3.98$, $p < .05$, $\eta^2 = .06$]. This indicated that the younger drivers (Mean= 6.26; SD=1.59) performed significantly better one this test than the older drivers (Mean= 5.25; SD=1.59). However, there was no significant difference between the younger and middle-aged and between the middle-aged and older drivers. See Figure 5-6.

Furthermore, there was a significant effect of age group on contrast sensitivity measure “D “scores [$F_{(2,110)} = 4.96$, $p < .01$, $\eta^2 = .08$]. This indicated that the younger (Mean= 5.05; SD=1.43) performed significantly better one this test than the middle-aged older drivers (Mean= 3.69; SD=2.05). However, there were no significant differences between the younger and older, and the middle and older drivers (p>.05). Similarly, there was a significant effect of age group on contrast sensitivity measure “E “scores [$F_{(2,110)} = 8.30$, $p < .01$, $\eta^2 = .13$]. This indicated that the younger (Mean= 3.26; SD=1.60) performed significantly better one this test than the middle-aged older drivers (Mean= 2.43; SD=1.60). However, there were no other significant differences between the other pairwise comparisons (p>.05). This effect is depicted in Figure 5-8. Finally, there was a significant interaction of age group and overall contrast sensitivity level [$F_{(8,110)} = 3.808$, $p < .05$, $\eta^2 = .06$] on visual functioning. These effects are depicted in Figure 5-6.

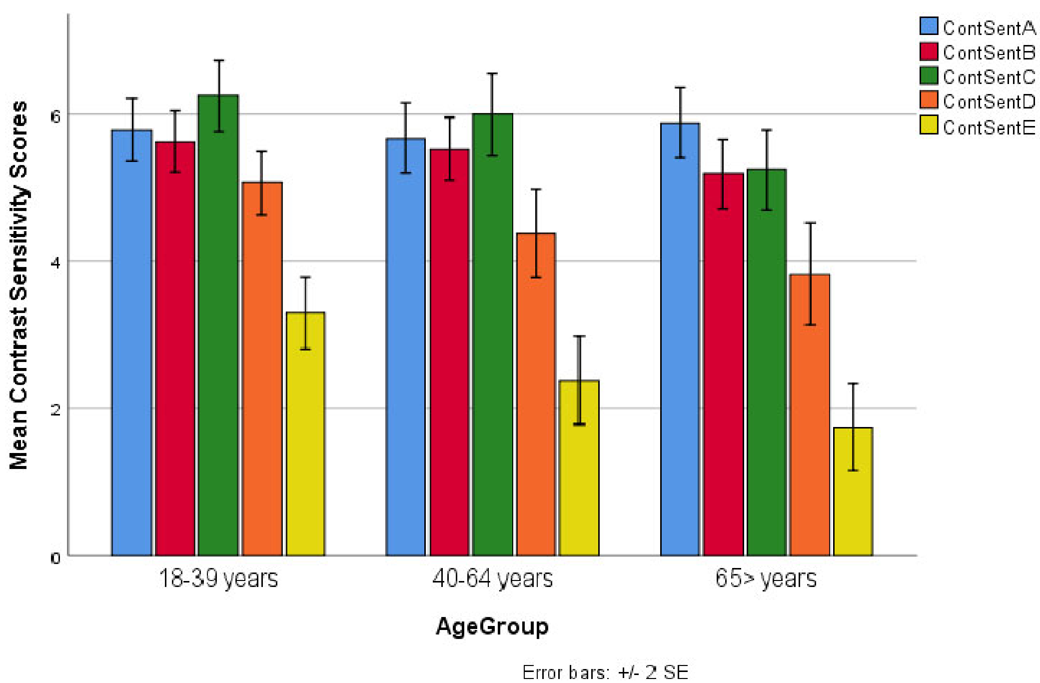

Figure 5-6: Contrast Sensitivity Scores by Age Group and Difficulty Level

5.3 Phoria (Lateral and Vertical) Measures

In addition, measures of Phoria were also collected to examine the degree of participants' eye sways both laterally and vertically. This measure tests for any deficiency in visual processing caused by eye sway or stigmatism. To this end, our sample of participants passed this test and qualified for participation in this study.

5.3.1 Lateral Phoria

A series of multivariate statistics were conducted on the lateral phoria scores to further examine the effects of age group on visual sensory processing. Results showed a significant effect of age group on Lateral Phoria scores [$F_{(2,110)} = 5.06$, $p < .005$, $\eta^2 = .09$]. Post Hoc Comparisons (Tukey Test) indicated that the younger drivers had significantly higher (Mean= 10.02; SD=11.99) Lateral Phoria Scores than the older (Mean= 8.44; SD=2.51) drivers, and middle-aged had significantly higher scores (Mean=9.82; SD=1.91) than older (Mean= 8.44; SD=2.51) drivers. However, there was no significant difference in lateral Phoria scores between the younger and middle-aged drivers (p>.05). These effects are depicted in Figure 5-7.

5.3.2 Vertical Phoria

A series of multivariate statistics were also conducted on the vertical phoria scores to further examine the effects of age group on visual sensory processing. As depicted by Figure 5-7 below, the differences in vertical phoria scores between age groups was found to be negligible.

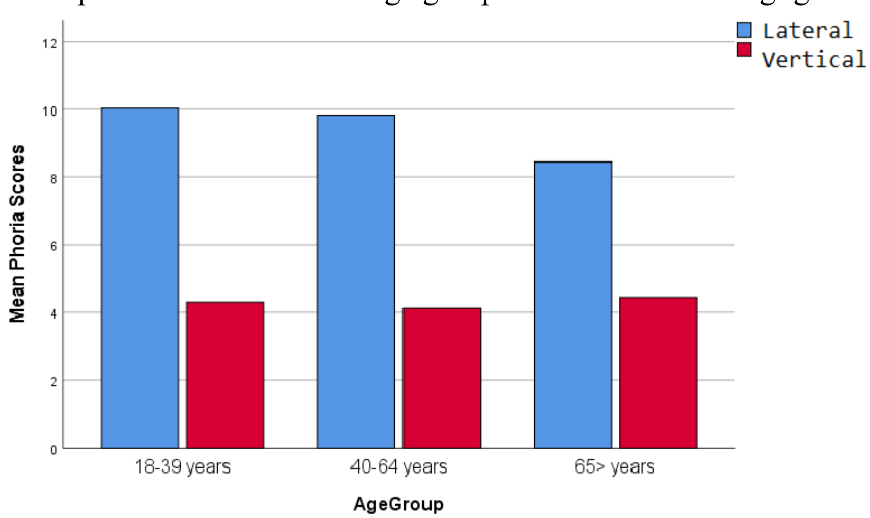

Figure 5-7: Lateral and Vertical Phoria by Age Group

5.4 Depth Perception Measure

A One-Way Between-subjects ANOVA was conducted on the participants' depth perception scores. Results showed a marginally significant effect of age on depth perception [$F_{(2,110)} = 2.70$, $p < .08$, $\eta^2 = .04$]. Post hoc-comparisons indicated that younger drivers had significantly better depth perception (Mean=6.66; SD=) than older (Mean=5.32; SD=) drivers. However, there were no significant differences in depth perception between the younger and middle-aged and between the middle-aged and older drivers. This effect is depicted in figure 5-8.

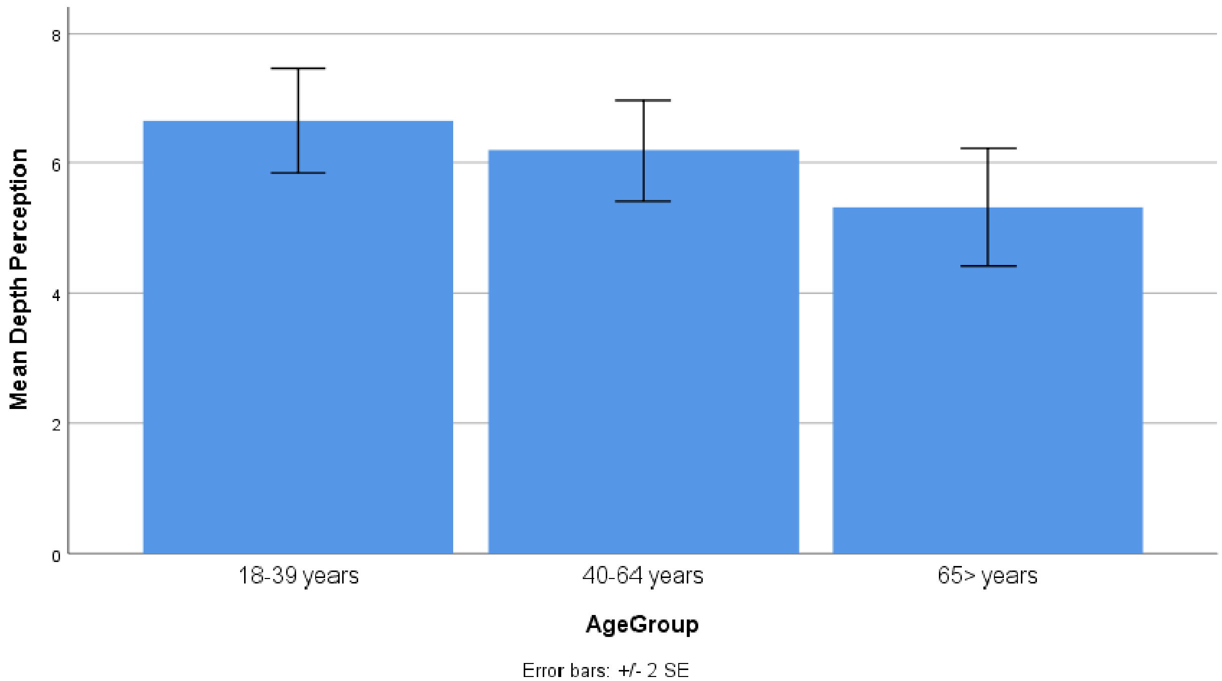

Figure 5-8: Depth Perception Scores by Age Group

As is evident by the significant differences among demographics, visual ability and, therefore, driving ability are likely have significant impacts on driving performance in the context of color noticeability. The following sections seek to model the effects on driving performance in terms of delineator color, environmental factors, and demographic characteristics. Models are developed with the aim of capturing the significant effects in regression functions to determine how driving performance factors are impacted.

5.5 Statistical Models of Driving Performance

Statistical analysis was first conducted for 92 participants which had full data sets (without any missing datasets from the six collected per participant) and then for the 134 participants, including the 42 incomplete data sets (all simulator scenarios are useable) using JMP and a forward stepwise regression approach with all main effects and interactions as candidate effects according to the effect hierarchy principle. It was found that adding in participants with incomplete data sets to the analysis did not change the model significant effects at all, with all models showing the very similar results. In most cases, the relevant effects increased in significance with the addition of the incomplete sets due to the increase in sample size, implying the models were accurate to predicting driver behavior.

Rather than using a basic linear regression model for all effects, linear mixed models (also called multilevel models) were also used to account for both fixed and random effects. These models are useful in determining fixed effects when there are multiple observations (scenarios) per subject, including random effects to account for differences among group (of scenarios) means. In general, ANOVA is a more popular statistical model for analyzing differences among group means. However, multiple measurements per subject generally result in correlated errors that are explicitly forbidden by the assumptions of ANOVA and regression models. Mixed models can handle these correlated errors by adding the fixed effects and random effects. In addition, ANOVA cannot be used when any subject has missing values, while the mixed model allows the missing values in the dataset. Therefore, the mixed model was used to analyze the relationship between independent and dependent variables in this study.

5.5.1 Analysis of Driving Performance Factors

Each of the performance measures was tabulated and analyzed to develop models for estimating the impacts of different driving scenario conditions on driver performance. The figures in the following sections depict the variable distributions and the fixed effect impacts of the significant scenario conditions on each performance factor. Five scenario factors and two main driver characteristics were chosen as the independent variables. The scenario factors included the marker's color (white, yellow, orange, purple, and black), traffic density (high and low), visibility (high and low), time of day (day and night), and surface type (asphalt and concrete). The driver characteristics included gender and age group (18-39, 40-64, and 65+). It should be noted that marker color was the main target to examine its significant effect for all performance factors across all models.

5.5.2 Distributions of Performance Factors

Figure 5-9 describes the distribution of the performance factors across all driving scenarios after filtering for outliers. Performance factors included deceleration, brake time, speed and lane deviation at the two straight and curved sections along the road. The main cause of outliers in most cases were due to drivers that took some time to get used to the driving performance of the simulator. For example, in some cases, drivers would be moving far too quickly as they were not paying attention to the speedometer, or they were not paying attention to the road and would swerve into the shoulder upon entry of the express lane. Other outliers included a handful of brake time measurements which were extremely short, only capturing a single time step (1/60 s) and resulting in deceleration measurements that were not accurate to reflecting braking behavior.

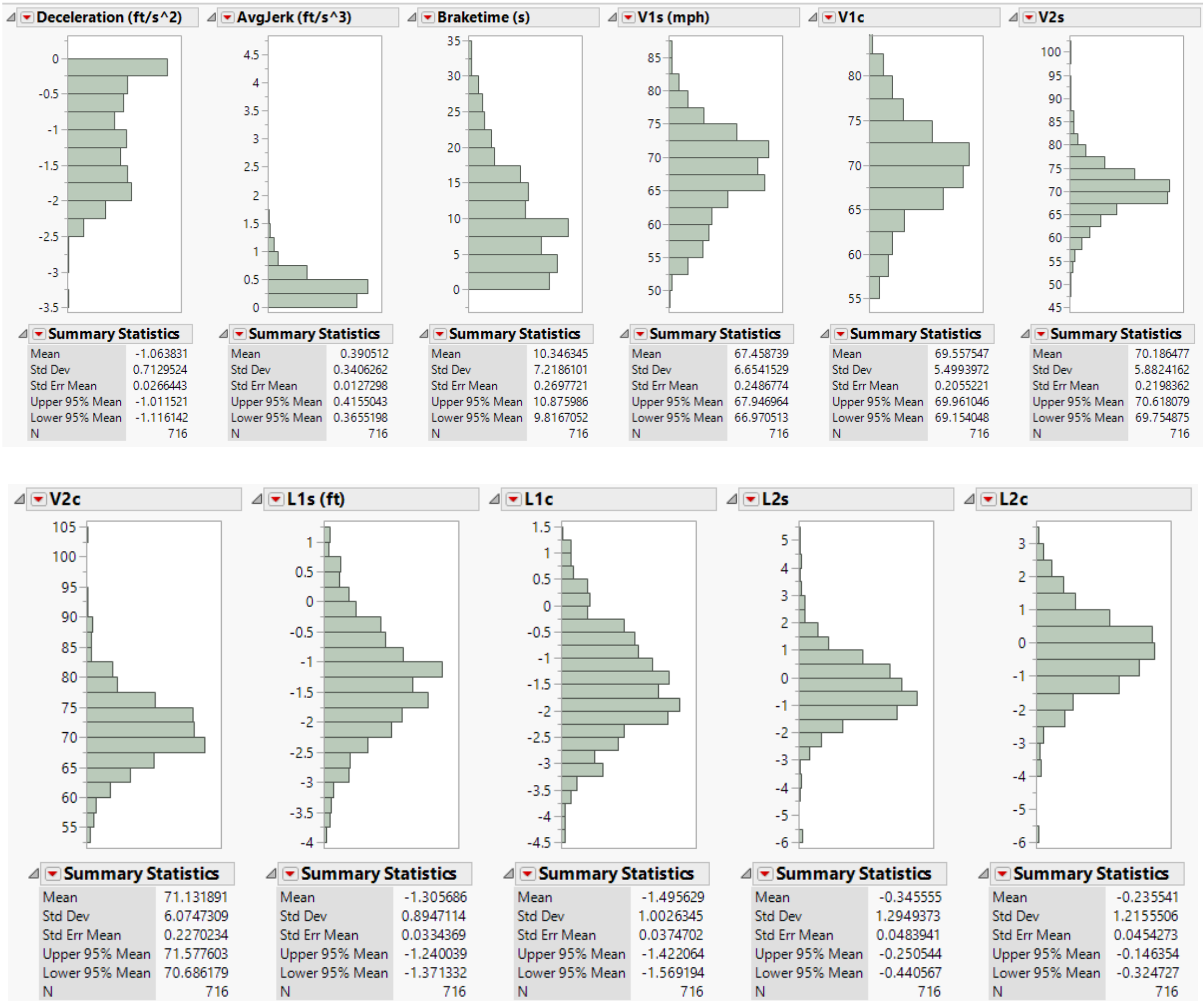

Figure 5-9: Distributions and Descriptive Statistics of Driving Performance Factors

Several expected conclusions were drawn from the distributions, particularly for velocity and lane deviation. Despite the 70-mph speed limit, the means for the velocity measurements in the first 1-lane section were below 70, while the means in the 2-lane section were slightly higher. This followed basic transportation engineering principles as a larger ‘sense of space’ influences drivers to go faster. Despite the express lane designation, both means were still very close to the speed limit. Comparing between the straight and curved entries for both sections found that drivers were willing to accelerate after they have entered the express lane and acclimated to the markers. For higher throughput, 2-lane configurations were ideal. With regards to lane deviation, the impact of ‘sense of space’ was also apparent with drivers tending roughly one foot to the left more in the 1-lane configuration. While the difference wasn't very significant, the 2-lane configuration showed that drivers stayed closer to the markers. For brake-time, deceleration and average jerk, the distributions were found to be highly variable, suggesting that braking behavior varied significantly across scenarios and participants. This was also expected due to the differences in braking performance, possibly due to individual and environmental factors, such as age, gender, traffic conditions, vehicle type, and visibility.

5.6 JMP Statistical Analysis and Model Development

As mentioned in the previous section, JMP was used to analyze and model the effects of the environmental and driver characteristics on driving performance. For the majority of analyses, the mixed model was found to be ideal to account for individual effects. To account for these effects, a random variable is introduced to the mixed model (in this case, the participant number was used). Otherwise, typical linear regression models were used. Contrary to the preliminary analysis, no significant two-way factor interactions were found for the majority of tested models following the addition of the final recruited participants' data.

5.6.1 Deceleration – Mixed Model

Figures 5-10 and 5-11 show the parameter effects and profiler results for deceleration. The profiler depicts the differences in means for deceleration relative to the significant factors. The analysis found that the only factors to impact deceleration are color and traffic density. It was found that the only color with a major effect was black, showing a lower average deceleration. This was attributed to the comparatively low visibility of the black markers despite the reflective strip that covered the top part of all marker colors. This was indicative that low visibility markers resulted in failure to notice and therefore failure to react in the appropriate time, which agreed with the subjective results of the survey, as well as the experience of the researcher, in which many of the participants failed to notice the black markers outright. The remaining colors all depicted very similar mean decelerations, signifying that individual colors might not have a significant influence on the actual magnitude of braking, but simply whether or not the driver noticed and hit the brakes. The results from traffic density were expected as more cars in the road meant more distractions and lower mean velocity, therefore putting drivers on higher alert and more likely to brake in response to other drivers. This resulted in a higher deceleration rate as seen in Figure 5-11 (note the deceleration is negative in this analysis: a higher value translates to a lower braking effect and vice versa).

It should be noted that when interpreting the model outputs, there will be one level missing from each category. The yellow marker and low-density effects are missing from the parameter estimates for deceleration. This is because the JMP model uses the deceleration estimate for the yellow and low-density combination as a baseline (intercept) for calculating the impacts of the remaining effects. As the purpose of the model is to compare between the colors, it is necessary to choose a color as a reference to compare the rest with. Furthermore, the model profiler displays all the parameter levels and shows which level was different from the reference category. The following is a general guide for interpretation of all the models. For example, consider Figure 5-10 which highlights the effects of the two most significant parameter values: Color [Black] and Traffic Density [High Density]. As seen on the profiler in Figure 5-11, this combination gives a deceleration estimate of **negative 1.09295 ft/s^2**. This is computed as follows:

Intercept = E(Deceleration; Yellow, Low Density) = -1.053847

E(Deceleration; Black, High Density) = Intercept + Color[Black] + Traffic Density[High Density]

E(Deceleration; Black, High Density) = -1.053847 + (0.1032078) + (-0.142316) = **-1.09295**

Fixed Effects Parameter Estimates

Term	Estimate	Std Error	DFDen	t Ratio	Prob>|t|	95% Lower	95% Upper
Intercept	-1.053847	0.0411795	88.6	-25.59	<.0001*	-1.135675	-0.972019
Color[Orange]	-0.041242	0.0473234	627.3	-0.87	0.3838	-0.134173	0.0516898
Color[Purple]	-0.0243	0.0470607	631.1	-0.52	0.6058	-0.116715	0.0681141
Color[White]	-0.027545	0.0478293	631.3	-0.58	0.5649	-0.121469	0.0663789
Color[Black]	0.1032078	0.0471829	634.4	2.19	0.0291*	0.0105543	0.1958613
Traffic Density[High Density]	-0.142316	0.0237593	629.5	-5.99	<.0001*	-0.188973	-0.095659

Figure 5-10: Mixed Model Effects on Deceleration

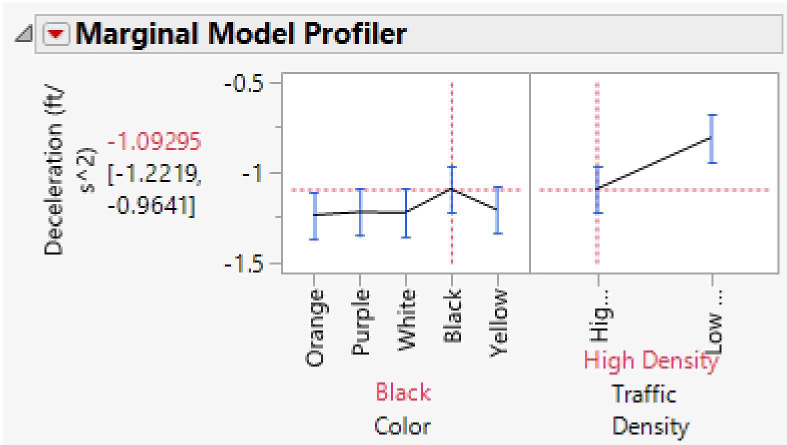

Figure 5-11: Profiler Results for Deceleration

5.6.2 Brake Time – Mixed Model and Ordinal Logistic Regression

The analysis for brake time found more significant factors in the mixed model (age, density, color, and surface type) and an ordinal logistic regression (age, density, color, and two-way interaction between age and color). In general, brake-time and deceleration were correlated and should both be considered when interpreting results when possible. For instance, a high mean brake time in combination with a low deceleration indicated a smooth braking experience that was less disruptive to the traffic flow, while a low brake time with a high deceleration indicated a surprised, more erratic brake pattern.

The previous mixed model results (with regards to deceleration) found overlapping significance with color and traffic density. While the white markers did show a lower mean brake time, the mean deceleration was on par with the other colors, excluding black, as previously mentioned. This suggested that drivers in the scenarios with white markers weren't surprised and were able to adjust their speed at a slower pace, which was ideal for smoother traffic flow. Black, on the other hand, also influenced a lower brake time. At first glance, this appeared to be a positive effect; however, when considering the lower deceleration as well, the more apparent interpretation was that black was more likely to go unnoticed, with the remaining colors showing no significant effect on both performance factors. Other than color, the factors that influenced brake time were age group, traffic density, and surface type. Notably, age group showed a significant impact on brake time with the 18-39 age group showing the lowest brake times. The main findings were demonstrated in Figures 5-12 to 5-15. An Ordinal Logistic Regression model was also analyzed for brake time and found similar results.

Fixed Effects Parameter Estimates

Term	Estimate	Std Error	DFDen	t Ratio	Prob>|t|	95% Lower	95% Upper
Intercept	10.787078	0.3478858	85.3	31.01	<.0001*	10.095422	11.478734
Age Group[18-39]	-1.922571	0.4644724	83.1	-4.14	<.0001*	-2.846374	-0.998768
Age Group[40-64]	1.2934223	0.5026441	83.2	2.57	0.0118*	0.2937168	2.2931278
Traffic Density[High Density]	-1.081038	0.2547474	635.8	-4.24	<.0001*	-1.581286	-0.58079
Surface[Asphalt]	0.67964	0.2549632	638.4	2.67	0.0079*	0.1789721	1.1803079
Color[Orange]	1.0481873	0.4957083	631.2	2.11	0.0349*	0.0747504	2.0216243
Color[Purple]	0.4663674	0.4936717	635.4	0.94	0.3452	-0.503058	1.4357926
Color[White]	-1.715122	0.5016655	635.8	-3.42	0.0007*	-2.700244	-0.730001
Color[Black]	-0.151549	0.494455	639.8	-0.31	0.7593	-1.1225	0.8194016

Figure 5-12: Mixed Model Effects on Brake Time

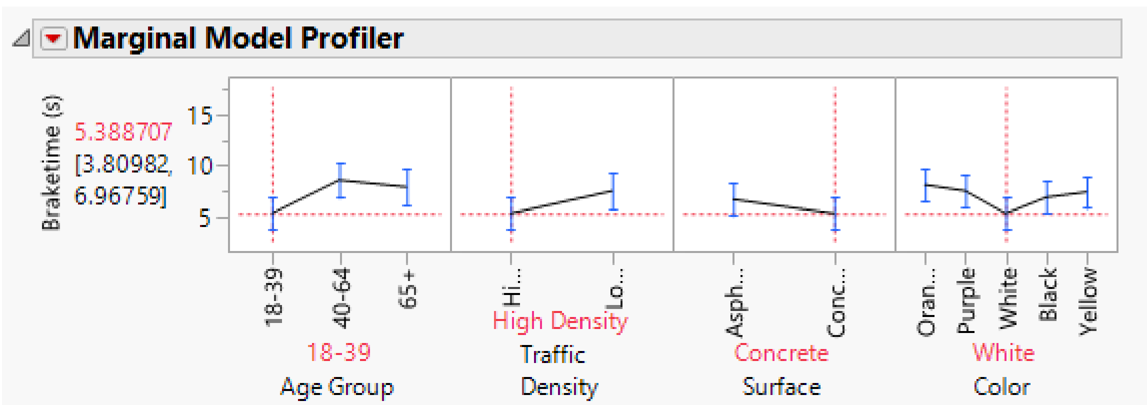

Figure 5-13: Profiler Results for Brake Time

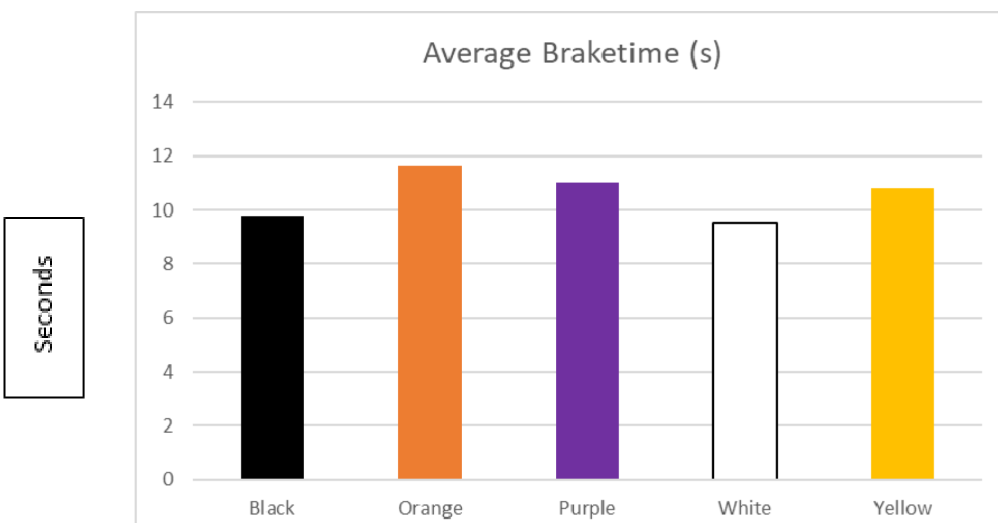

Figure 5-14: Average Brake Time by Color

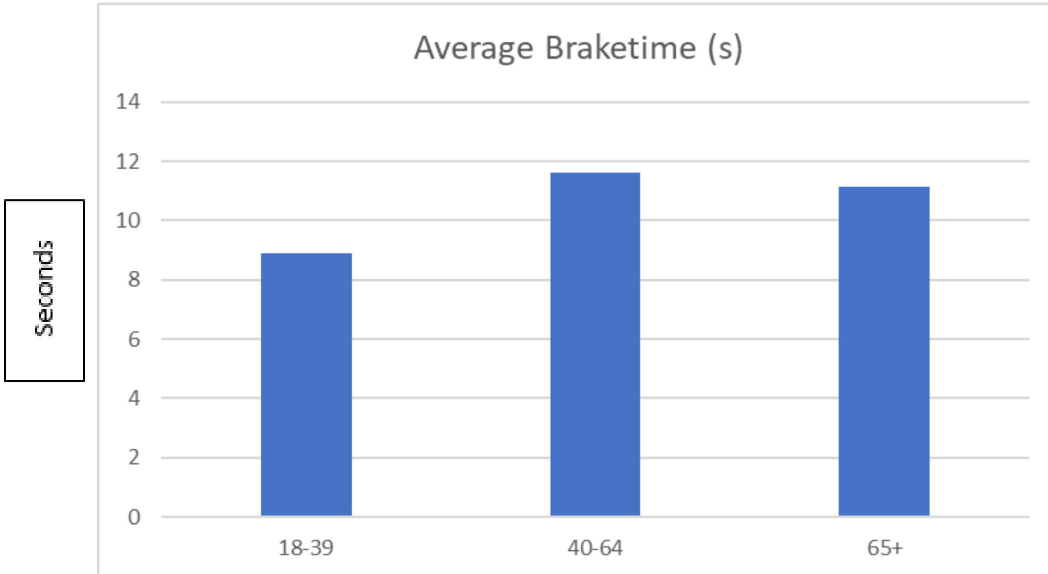

Figure 5-15: Average Brake Time by Age Group

5.6.3 Velocity (section 1) Straight and Curved– Mixed Models

The findings for velocity continued to demonstrate the disparity between the black and white markers. As with the deceleration and brake time analysis, black markers showed a higher entering speed which again hinted towards non-notice of the markers, with drivers showing the most caution towards the white and yellow markers. So far, the pattern showed the most notable impacts to driving performance come as a result of whether the selected color was visible enough to notice, with white as the most noticeable color in most of the analyses. Furthermore, the TOD (time-of-day) also showed a noticeable effect on entering velocity, also suggesting that higher visibility led to a more cautious entry. The only group that fell out of the ideal 65-75 mph range were the 65+ age group, and only under conditions of highest visibility (daytime and white). The findings are demonstrated in Figures 5-16 to 5-19.

Analysis of V1c (curved section entry) found similar results with significant two-way factor interaction, with the white-daytime combination coming up with the highest impact on a lower velocity. While the orange marker showed some significance, it reflected the highest entering speed which did not reflect optimum safety conditions through the curve. Although other colors showed a decreasing velocity effect, this was attributed to over-correction of speed after the driver has entered the express lane. This is expressed in Figures 5-20 and 5-21.

Fixed Effects Parameter Estimates

Term	Estimate	Std Error	DFDen	t Ratio	Prob>|t|	95% Lower	95% Upper
Intercept	67.191991	0.4978646	86.8	134.96	<.0001*	66.202397	68.181585
Color[Orange]	0.5561452	0.391309	620.1	1.42	0.1557	-0.212306	1.3245966
Color[Purple]	-0.038672	0.3900816	622.4	-0.10	0.9211	-0.804707	0.7273637
Color[White]	-0.897327	0.3964093	622.5	-2.26	0.0239*	-1.675788	-0.118865
Color[Black]	0.9664753	0.3929573	624.4	2.46	0.0142*	0.1947975	1.7381532
TOD[Day]	-0.703205	0.1969132	622.7	-3.57	0.0004*	-1.089899	-0.316511

Figure 5-16: Mixed Model Effects on Entering Velocity

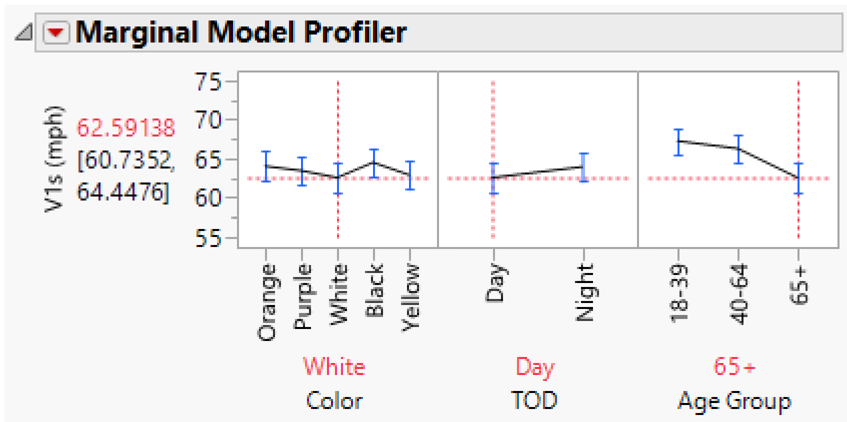

Figure 5-17: Profiler Results for Entering Velocity

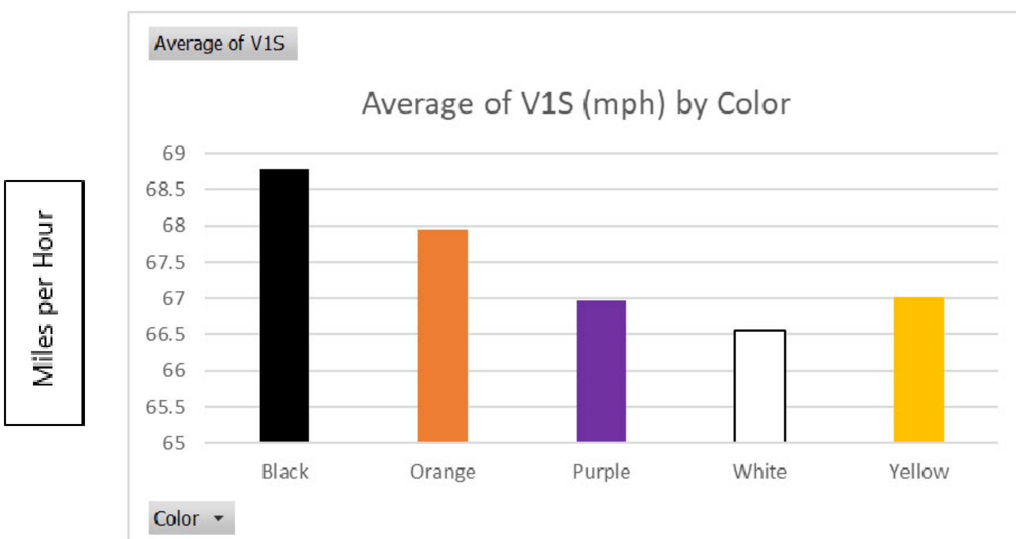

Figure 5-18: Impact of Color on Entering Velocity

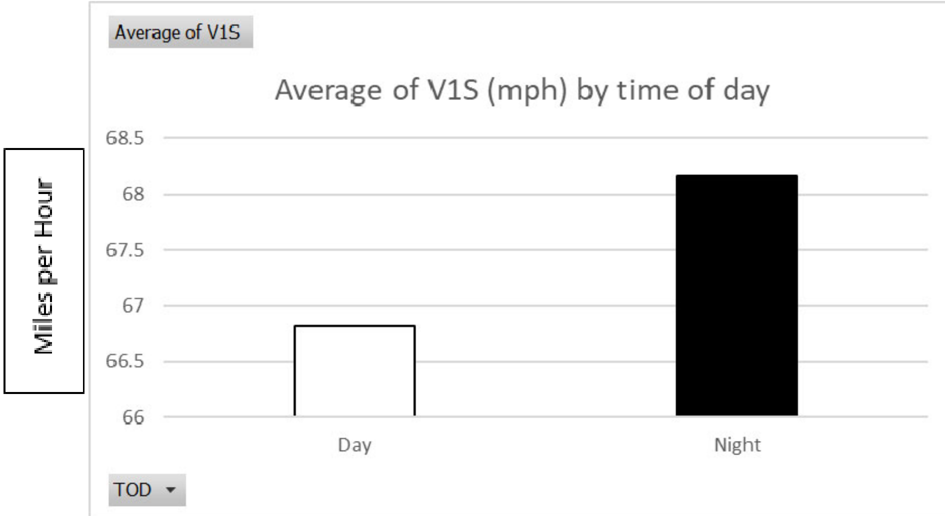

Figure 5-19: Impact of TOD on Entering Velocity

Fixed Effects Parameter Estimates

Term	Estimate	Std Error	DFDen	t Ratio	Prob>|t|	95% Lower	95% Upper
Intercept	69.686262	0.3933361	84.5	177.17	<.0001*	68.904144	70.46838
Color[Orange]	0.7266382	0.3292151	614.6	2.21	0.0277*	0.0801154	1.373161
Color[Purple]	0.4046919	0.3300692	617.0	1.23	0.2206	-0.243503	1.0528871
Color[White]	-0.415677	0.3353627	617.4	-1.24	0.2156	-1.074267	0.2429124
Color[Black]	-0.570262	0.3308064	619.4	-1.72	0.0852	-1.2199	0.0793759
TOD[Day]	-1.53034	0.164707	616.8	-9.29	<.0001*	-1.853795	-1.206886
TOD[Day]*Color[Orange]	0.2964301	0.331242	619.7	0.89	0.3712	-0.354063	0.946923
TOD[Day]*Color[Purple]	-0.118723	0.3297103	616.2	-0.36	0.7189	-0.766215	0.5287695
TOD[Day]*Color[White]	-0.760852	0.3348629	616.5	-2.27	0.0234*	-1.418462	-0.103242
TOD[Day]*Color[Black]	0.1093884	0.329009	616.2	0.33	0.7396	-0.536727	0.7555033

Figure 5-20: Mixed Model Effects on V1C

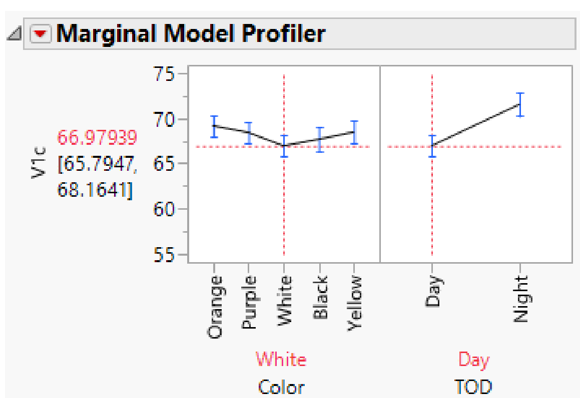

Figure 5-21: Profiler Results for Curved Section Velocity

5.6.4 Speed Differential (change in mph [V1C-V1S]) – Mixed Model

To better understand the relationship between V1c and V1s, speed differential was also analyzed. As one of the express lane's most important functions, speed differential is important to analyze to make sure the express lane operated as intended for different marker colors. Stepwise regression found that the differences in speed were only affected by color. Across most colors, we see, on average, an increase in speed signifying that the lane functions properly. However, the analysis also found that drivers tend to overcorrect their speeds especially with the black markers, showing the lowest speed differential, strengthening the argument that overall visibility was one of the most important factors in color selection. This is expressed in the profiler results in Figures 5-22 and 5-23.

Fixed Effects Parameter Estimates

Term	Estimate	Std Error	DFDen	t Ratio	Prob>|t|	95% Lower	95% Upper
Intercept	2.2481031	0.3453402	78.9	6.51	<.0001*	1.5607077	2.9354984
Color[Orange]	0.1773926	0.5046543	626.5	0.35	0.7253	-0.813626	1.1684114
Color[Purple]	0.3851744	0.5013304	631.2	0.77	0.4426	-0.599303	1.3696517
Color[White]	0.2717595	0.5095767	632.0	0.53	0.5940	-0.728909	1.272428
Color[Black]	-1.362238	0.5023542	637.0	-2.71	0.0069*	-2.348709	-0.375768

Figure 5-22: Mixed Model Effects on Speed Differential

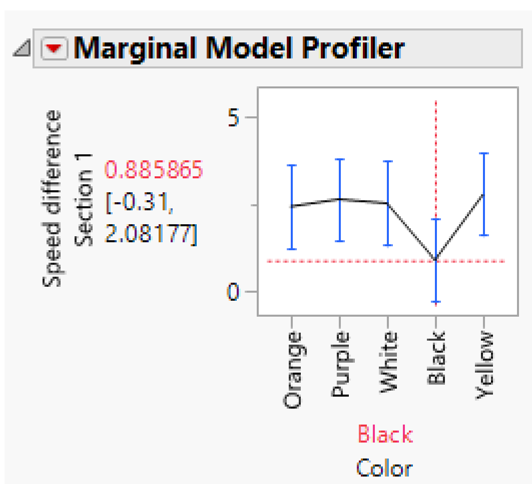

Figure 5-23: Profiler Results for Speed Differential

5.6.5 Lane Deviation 1 Straight and Curved Sections – Mixed model

Lane deviation measured the vehicle position while entering the express lane whether to the left side of the lane center (further from the markers) or to the right side (closer). Figures 5-24 and 5-25 show the statistical results for the effects on lane deviation. The most prominent effects were found due to the colors, with lesser impacts due to age, surface type, and traffic density. Remarkably, the 18-39 age group tends to align closer to the center of lane across all conditions. The results show that the white, yellow, and black markers were the most significant compared to the rest of the colors. Drivers tend to align more to the left side of the lane (negative value) while encountering white or yellow markers, suggesting a higher awareness of the markers. On the other hand, black markers showed vehicle alignments that were closer to the markers. This is demonstrated in Figure 5-26. Analysis on the curved section found that drivers inclined furthest from the markers with the white and yellow markers.

Fixed Effects Parameter Estimates

Term	Estimate	Std Error	DFDen	t Ratio	Prob>|t|	95% Lower	95% Upper
Intercept	-1.341413	0.0582274	87.5	-23.04	<.0001*	-1.457137	-1.225688
Color[Orange]	0.0739869	0.056023	624.0	1.32	0.1871	-0.03603	0.1840033
Color[Purple]	-0.013036	0.0558552	626.7	-0.23	0.8155	-0.122722	0.0966499
Color[White]	-0.143049	0.0567622	626.8	-2.52	0.0120*	-0.254517	-0.031582
Color[Black]	0.3030099	0.0560008	628.9	5.41	<.0001*	0.1930386	0.4129812
Age Group[18-39]	0.1561481	0.0780572	86.2	2.00	0.0486*	0.00098	0.3113163
Age Group[40-64]	-0.060433	0.0844261	86.5	-0.72	0.4760	-0.228253	0.1073877
Traffic Density[High Density]	0.0635681	0.0288238	626.8	2.21	0.0278*	0.0069652	0.1201711
Surface[Asphalt]	0.0846154	0.0288701	628.6	2.93	0.0035*	0.027922	0.1413089

Figure 5-24: Mixed Model Effects on Lane Deviation (Section 1 Straight)

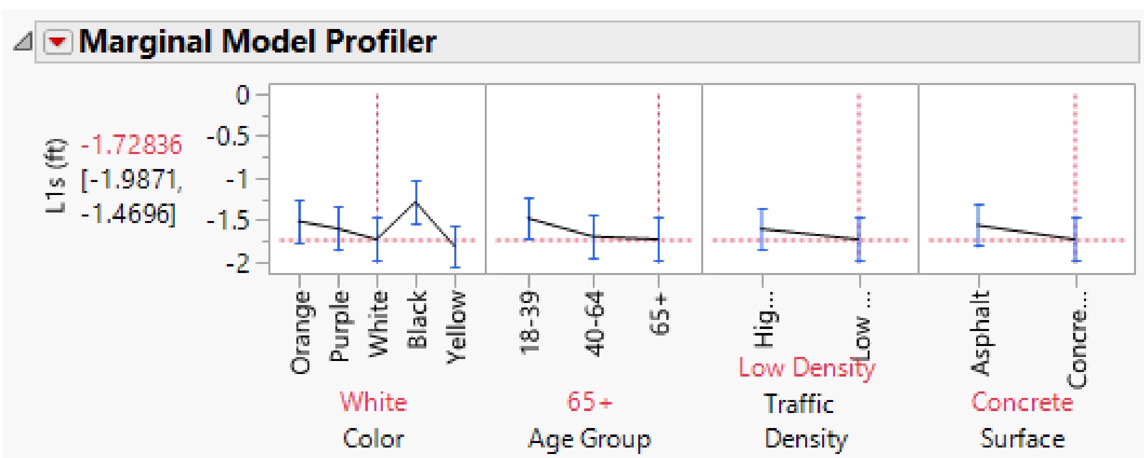

Figure 5-25: Profiler Results for Lane Deviation

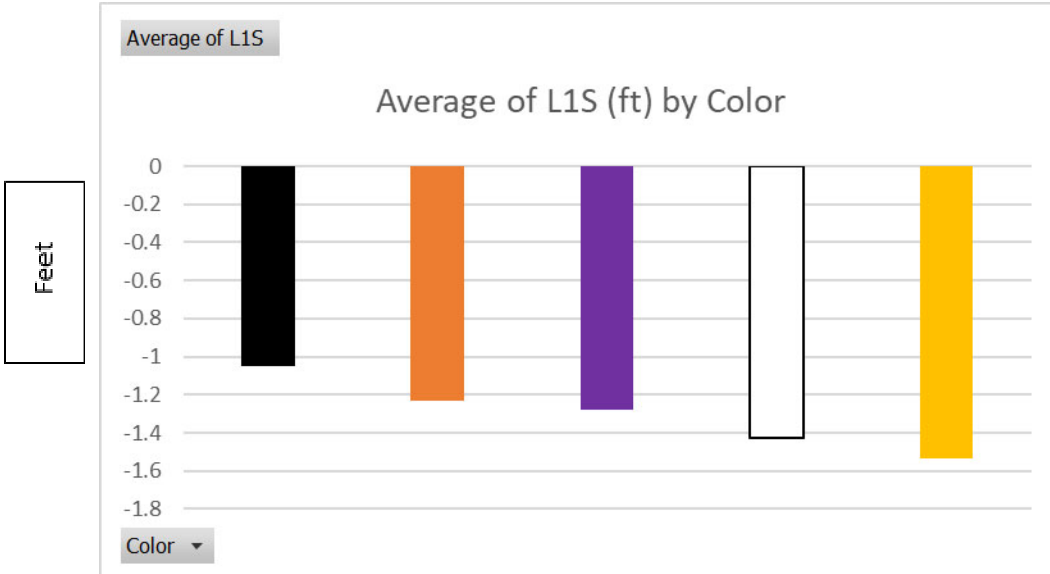

Figure 5-26: Average of Lane Deviation by Color

5.6.6 TTFN Statistical Results – Mixed Model Analysis of Log (TTFN)

Analysis of the logarithm of TTFN found that the main significant factors are time of day, color, and traffic density. Similarly with the driving factors analysis, it was found that the black marker took the longest to notice, further strengthening the argument that visibility of color was the most important factor in color selection. There was little significance across the remaining colors with very similar average values for notice of the markers. Furthermore, it was found that drivers notice the markers more quickly in low density scenarios, likely due to fewer distractions making the markers stand out more. Drivers also noticed the markers more quickly in night-time conditions, which was likely due to the reflective sheets on the markers catching drivers' eyes as they approach the express lane. Among all colors, white markers were the quickest to notice on average. However, orange and yellow markers showed very close results as well. This is suggestive that orange, yellow, and white all succeed at grabbing drivers' attention especially during nighttime, likely due to the brightness of these colors compared to purple and black. These findings are illustrated in Figures 5-27 to 5-29.

Fixed Effects Parameter Estimates

Term	Estimate	Std Error	DFDen	t Ratio	Prob>|t|	95% Lower	95% Upper
Intercept	0.4650093	0.0269889	85.0	17.23	<.0001*	0.4113486	0.51867
Color[Orange]	-0.031578	0.0253724	436.6	-1.24	0.2139	-0.081446	0.0182888
Color[Purple]	-0.00536	0.0244253	438.8	-0.22	0.8264	-0.053365	0.042645
Color[White]	-0.03985	0.0243968	436.2	-1.63	0.1031	-0.0878	0.0080997
Color[Black]	0.1028583	0.0257581	437.9	3.99	<.0001*	0.0522335	0.1534832
Traffic Density[High Density]	0.0513424	0.0126292	435.1	4.07	<.0001*	0.0265206	0.0761643
TOD[Day]	0.0687996	0.0126749	439.7	5.43	<.0001*	0.0438886	0.0937106

Figure 5-27: Mixed Model Effects on Log (TTFN)

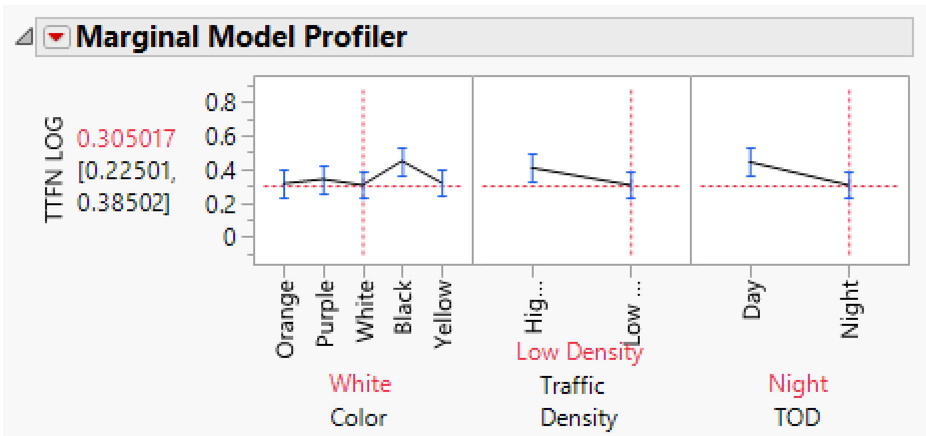

Figure 5-28: Profiler Results for Log (TTFN)

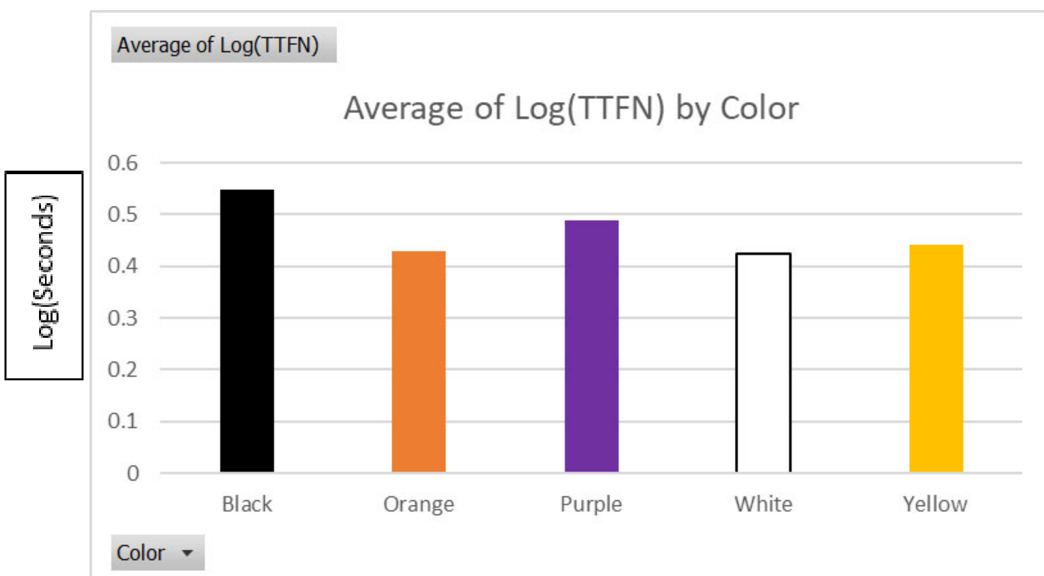

Figure 5-29: Average of Log (TTFN) by Color

5.6.7 Frequency Analysis of Delineator Hits

One of the major benefits to this research is the reduction in drivers striking the delineators as a result of increased visibility. As shown in the previous models, the delineator color that consistently shows high significance and optimal performance responses is white. As it is the most likely candidate for color selection as a result of this research, white was compared against the current standard for delineator color, orange. The comparison sought to test the differences in delineator strikes at the beginning of the curved and straight sections for both the one-lane and two-lane segments. Hits were determined by processing the lane deviation data such that a hit is coded as a lane deviation of greater than positive three feet (to the right). As the lanes are 12 feet wide, and the car is six feet wide, any deviation greater than three feet indicates the right side of the car shifting out of lane and striking a delineator.

The following table 5-1 describes the number of hits and hit rate at each measurement point in the driving track. Figure 5-30 depicts the overall reduction in hit rate between the orange and white delineators. As mentioned in the literature review, delineators require frequent replacement due to damage from unaware drivers. The comparison finds that the orange delineators have a hit rate roughly one and a half times the hit rate of white delineators. As such, the benefits of enhanced visibility may result in significant savings as delineators will require fewer replacements. It is also important to note the height difference between the delineators. Table 5-1 shows that in general, the delineators at the start of the curved sections suffer significantly more hits than those at the start of the straight sections. The two main effects that can account for this are the beginning of the curve and the lowered height of the delineators (from 36 to 24 inches). As these changes occur simultaneously, it cannot be stated for certain which of the effects is correlated to the increase in delineator strikes, only that they both correlate to the effect.

Table 5-1: Delineator Hits and Hit Rates by Location and Color

Color	White				Orange			
Location	L1S	L1C	L2S	L2C	L1S	L1C	L2S	L2C
Hits	5	6	1	4	3	11	2	6
Hit-Rate (%)	1.90	2.28	0.38	1.52	1.15	4.21	0.77	2.30
Green is less hits, red is more hits								

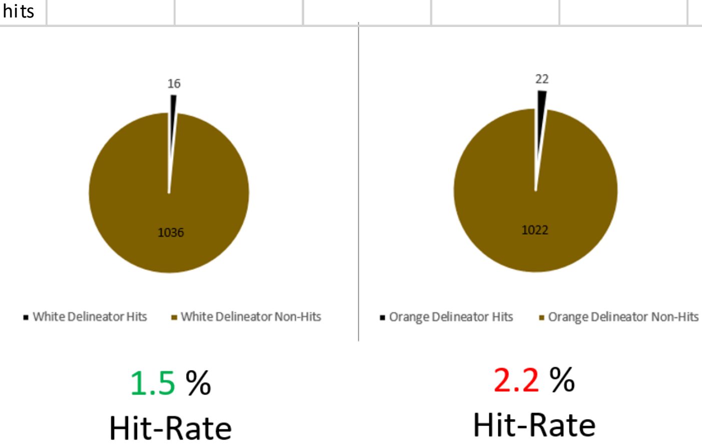

Figure 5-30: Delineator Hits and Hit Rates between Orange and White

VI. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The use of express lanes (ELs) in freeway traffic management has seen growing popularity across the United States that aims at making the most efficient transportation system management and operations (TSM&O) tool where lanes that are physically separated from existing general use or general toll lanes use vehicle eligibility, access control, and dynamic tolling to provide a more reliable trip. The current standards for colors of express lane markers, according to the 2009 Manual of Uniform Traffic Control Devices (MUTCD), Section 3H.01, is orange or the same color as the pavement marking that they supplement. However, the upcoming changes of the MUTCD seek to limit the colors only to match those of the pavement markings. Due to the state-wide impact on current and future ELs, it was important to understand the impacts to driver perception and performance in response to the color of the EL markers. It was also valuable to understand the differences between demographics in responding to markers under different driving conditions. The driving simulator in the Intelligent Transport Systems (ITS) lab at UCF was used to test the responses of several demographic groups to changes in marker color and driving conditions.

The total number of participants needed across the three age groups (18-39, 40-64 and 65+) was 120. However, the study required roughly 50% more recruits in order to meet the 120-participant target due to technical issues, ranging from eye-tracking calibration errors, corrupt video files, and corrupt simulator output files. The 176 participants were recruited to participate in the study through a variety of mechanisms, which included student recruitment (UCF SONA), Learning Longevity Research Network (LLRN), Learning Institute for Elders (LIFE), social media outreach, fliers, and personal connections. Participants were required to have driver license with normal vision and be over the age of 18. Out of the 176, 134 participants were successful with useable data while the remaining 42 participants across all age groups were unable to complete the experiment due to no show, motion sickness, dizziness, or inadequate vision, among other reasons.

Six different datasets were examined and analyzed. They include motion sickness data, eyesight data, driving data, eye tracking data, demographic data, and exit survey data. The statistical analysis for the driving data examined the impacts of the express lane marker color change on driver behavior among other traffic and environmental conditions at different sections along the ELs.

Chapter 5 of the research provided further analysis to the different scenario parameters used in the experiment (time of day, visibility, traffic density, road surface type, color, TTFN, age and gender) in order to develop an evaluation model inclusive of all the parameters. Chapter 4 examined the effect of color change on driver behavior but for each parameter individually. However, the evaluation models determined the optimal settings of all the significant parameters simultaneously to predict the effectiveness of the marker's color in relation to driver performance.

Statistical analysis was first conducted for 92 participants which had full data sets (without any missing data) and then for the 134 participants, including the 42 incomplete data sets. The incomplete data included driving datasets that were missing scenarios due to participant motion sickness, corrupted DAQ files, or equipment error. In some cases, participants were able to complete most of the scenarios but had to quit near the end due to motion sickness. Other examples were cases in which the equipment was found to have been miscalibrated upon video analysis, and cases in which the participant carried out all the scenarios, but due to equipment error, a few of the DAQ files were corrupted such that they would cause MATLAB to crash during the data extraction. Therefore, 42 of the participants' objective datasets were labelled incomplete due to some missing scenarios. To ensure the integrity of the analysis, it was conducted first using only the full objective datasets, then including the datasets with a few missing scenarios. The results remained the same for every model with increased significance due to the increased sample size, suggesting that the models are accurate in determining the significant effects.

Rather than using a basic linear regression model for all effects, linear mixed models (also called multilevel models) were used to account for both fixed and random effects. These models were useful in determining fixed effects when there are multiple observations (scenarios) per subject, including random effects to account for differences among group (of scenarios) means. The following points summarize the results of the evaluation models on the performance factors:

- **Deceleration:** The analysis of deceleration found that most colors exhibited similar results, with the exception of black which indicated lower average decelerations. This was attributed to failure to notice and react, which agreed with the results of the analysis of other performance factors. Furthermore, it was found that drivers were more alert in high density conditions with higher deceleration rates. (Optimal colors: White, Yellow, Orange, Purple)

- **Brake time:** White markers correlated to less erratic brake patterns as drivers were more able to notice. It was also found that 65+ drivers brake the longest and were slower in general, while the 18-39 age group brake the least. When considering the low deceleration, black markers exhibited patterns that imply failure to notice. (Optimal colors: [From more optimal to less optimal] White, Yellow)

- **Velocity:** It was found that white markers were the most noticeable as drivers enter the express lane at lower speeds, indicating a more cautious behavior. Also, it was found that 65+ drivers had the slowest entering speeds on average. (Optimal colors: [From more optimal to less optimal] White, Yellow)

- **Speed differential:** Black was found to be the least desirable as they worked against the function of the express lane, showing failure in maintaining driving speeds indicating disruptive behavior especially in the curved section when compared to the other colors. (Optimal colors: [From more optimal to less optimal] Yellow, White, Purple)

- **Deviation:** White and yellow markers exhibited deviations such that drivers were furthest from the markers, indicating a raised awareness when compared to the other colors. Also, the 18-39 age group was found to tend closest to the center of lane. (Optimal colors: [From more optimal to less optimal] Yellow, White)

- **Time-To-First-Notice:** It was found that white, orange, and yellow were the quickest to notice while black was the longest. Furthermore, it was found that in low density situations markers were more easily noticeable, which reflected lack of distraction. Surprisingly, night-time conditions exhibited lower TTFN values, likely due to the retroreflective sheets which were able to catch drivers' attention. (Optimal colors: [From more optimal to less optimal] White, Yellow, Orange)

The above results agree that the ideal color for influencing driving performance across several measures, from objective and subjective standpoints, was the **White** marker, followed by the

Yellow marker. The results revealed that Black marker consistently showed high significance but low optimality. White and Yellow consistently showed high significance and high optimality among all the models, with white always outperforming yellow except in the case of lane deviation. Purple and Orange markers only appeared to be effective occasionally. Combining these results with the results of the subjective data analysis confirmed White as the most effective color recommended for use for the express lane markers followed by the Yellow marker. Also important to note is the use of retroreflective sheets on the markers resulting in improved performance at nighttime when compared to daytime.

6.2 Future Recommendations

With regards to future technological implementations, it may also be useful to investigate the impacts of color on perception for artificial intelligence and sensor applications. While these results are conclusive in their relevance to human perception, machine perception of channelizing devices is an area that will need further research to quell uncertainties and ensure the safest, most efficient rollout of driverless technologies. For instance, some of the earliest applications of self-driving vehicles relied on embedded magnets in the asphalt to guide the navigation systems at high speeds, while many of the more current applications rely on Light Detection and Ranging (LIDAR), video-feed technology or dedicated short range communications (UC Berkeley, 2019). However, several of the newer detection technologies may suffer shortcomings with regards to cost of implementation and safety, when compared to the older infrastructure-based detection methods. For instance, Tesla's autopilot systems have been proven to be fallible, even to the point where hackers can trick these systems using stickers that are barely visible on the road (Vaas, 2019). Furthermore, LIDAR and video-feed detection systems that focus on the road markings have also proven to be unreliable depending on the quality of some of those roads (Sage, 2016).

The use of specifically purposed markers, such as the embedded magnets, is a concept that has been around since the earliest tests on driverless systems. While this may come off as a relatively simplistic application when compared to fully driverless systems (minimal reliance on infrastructure), the fallibility of current technology causes a significant delay in the rollout of automated systems. Local and state governments have an important role to play in gradually introducing these technologies in the safest manner possible, and lane markers for purposed express lanes provide an opportunity to safely speed up the process (Isaac, 2016; Winston and Mannering, 2014). Combining detection systems from fully automated vehicles with more robust freeway infrastructure (as opposed to systems unassisted by infrastructure) such as lane markers, may offer an effective compromise to streamlining automated freeway travel in the safest and most cost-effective way possible.

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APPENDIX

APPENDIX A – IRB APPROVALS AND PROJECT EXTENSION

IRB Approval Letter – March 2018

University of Central Florida

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: **Hatem Abou-Senna, Ahmed E Radwan, Mustapha Mouloua, PhD**

Date: **March 27, 2018**

Dear Researcher:

On 03/27/2018 the IRB approved the following modifications / human participant research until 03/26/2019 inclusive:

Type of Review:	UCF Initial Review Submission Form Expedited Review Categories # 6 and #7 Driving Simulation; n=120
Project Title:	Human Factors Study on the Use of Colors for Express Lane Delineators
Investigator:	Hatem Abou-Senna
IRB Number:	SBE-17-13707
Funding Agency:	FL Department of Transportation
Grant Title:	
Research ID:	1063391

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 03/26/2019, 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 and flyer 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 signed and dated 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

Page 1 of 2

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.

This letter is signed by:

Signature applied by Jennifer Neal-Jimenez on 03/27/2018 11:43:44 AM EDT

Designated Reviewer

Page 2 of 2

IRB Addendum Approval – August 2018

University of Central Florida

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: **Hatem Abou-Senna** and Co-PIs: **Ahmed E. Radwan, Mustapha Mouloua**

Date: **August 09, 2018**

Dear Researcher:

On 08/09/2018 the IRB approved the following modifications to human participant research until 03/26/2019 inclusive:

Type of Review:	IRB Addendum and Modification Request Form Expedited Review
Modification Type:	Updated study personnel, additional questionnaires, changes to the flyer, protocol, and consent.
Project Title:	Human Factors Study on the Use of Colors for Express Lane Delineators
Investigator:	Hatem Abou-Senna
IRB Number:	SBE-17-13707
Funding Agency:	FL Department of Transportation
Grant Title:	
Research ID:	1063391

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 03/26/2019, 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.

Page 1 of 2

No-Cost Time Extension

DocuSign Envelope ID: 141C0A06-E20C-4623-9763-04D34799E24D

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION

TASK WORK ORDER FOR MASTER UNIVERSITY AGREEMENT AMENDMENT

375-040-81
PROCUREMENT
OGC - 11/12

Master Agreement #: BDV24	Cost Center # - Task Work Order #: 977 - 26	Amendment #: 1

University:
University of Central Florida

Task Work Order Description:
Human Factors Study on the Use of Colors for Express Lane Delineators

The effective date of this amendment is the date the Department signs the amendment, unless otherwise stated within the amendment.

Check all applicable terms

- [x] The time for completion of services for the subject task work order is extended thru 9/30/2019.
- [ ] The subject task work order is hereby canceled (no work has been performed and no payment is due).
- [ ] The total amount for services performed under this task work order is increased by $________. The additional funds will be allocated as defined in the attached revised Exhibit B, Method of Compensation.
- [ ] The total amount for services performed under this task work order is decreased by $________. The decrease in funds will be allocated as defined in the attached revised Exhibit B, Method of Compensation.
- [ ] There is no increase/decrease in the task work order amount. Funds are only redistributed between compensation elements as defined in the attached revised Exhibit B, Method of Compensation.
- [ ] The Scope of Service is hereby amended, attached hereto, and incorporated herein.
- [ ] Other:

Department Contact:

Name: Patti Brannon Phone: 850-414-4616

Office: Research Center Email: patti.brannon@dot.state.fl.us

Departmental Approval:

J. Darryll Dockstader	Manager, Research Center	DocuSigned by: J. Darryll Dockstader	10/4/2018 | 4:28 PM
(Name)	(Title)	(Signature)	(Date)

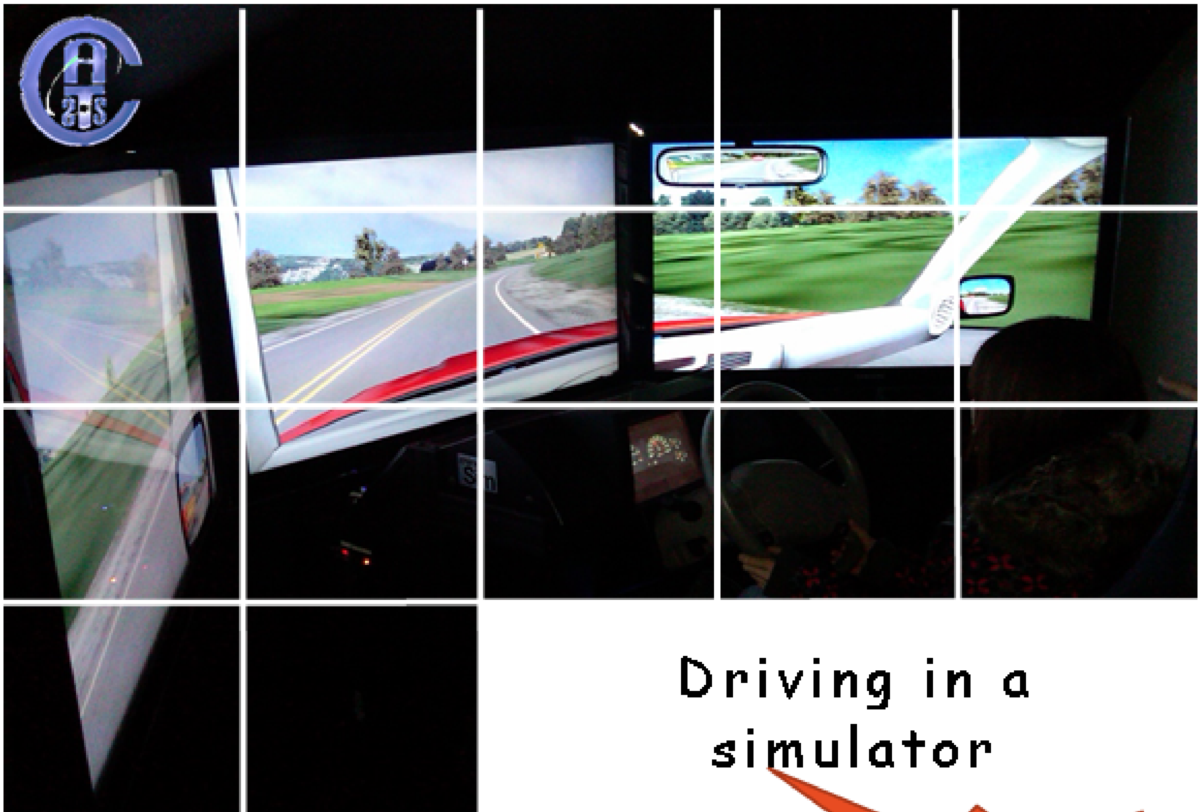
University Acceptance:

Mindy Solivan	Assistant Director	Mindy Solivan Signed: Wednesday, October 3, 2018	
(Name)	(Title)	(Signature)	(Date)

Legal Review:

DocuSigned by:
Larry Ringers

APPENDIX B – ADVERTISEMENT FLYER



Driving in a simulator

$25 or Course Credits!

Bored by driving in the real world?

Try to drive in a virtual environment & Earn $25!

You may be qualified to help in our transportation research study

Only takes 1.5 hours of your time!

Reserved parking and light refreshments provided !!!

Requirements: You must have normal vision and a valid driver's license. You cannot be prone to extreme motion sickness. **Age must be over 18**.

Please contact the research assistants to schedule an appointment
Dr. Jiawei Wu: Jiawei.Wu@ucf.edu, or Jessica Michaelis: Jmichaelis@knights.ucf.edu

Location: Transportation Lab room 325
Engineering Building II
University of Central Florida
12800 Pegasus Drive, Orlando, FL 32816

University of Central Florida

Principal Investigator: Dr. Hatem Abou-Senna, P.E. **The research study has been approved by UCF IRB.**

APPENDIX C – DEMOGRAPHICS QUESTIONNAIRE

1. How long have you had a Florida driver's license?
   a. Less than 5 years
   b. 5-10 years
   c. 11-15 years
   d. 16-20 years
   e. 21+
2. How old are you?
   a. 18-24
   b. 25-40
   c. 40-64
   d. 65+
3. How far do you typically drive in one year?
   a. 0-5000 miles
   b. 5,000-10,000 miles
   c. 10,000-15,000 miles
   d. 15,000-20,000 miles
   e. 20,000 miles+
4. What is your highest level of education?
   a. High school
   b. College
   c. Bachelor's Degree
   d. Graduate School
5. What is your range of income?
   a. 0-10,000
   b. 10,000-25000
   c. 25,000-40,000
   d. 40,000-55,000
   e. 55,000-70,000
   f. 70,000+

6. Have you been in any accidents that involved pedestrian(s) in the last 3 years?
   a. Yes
   b. No

If so, how many pedestrians were involved? Where did the crash occur (e.g., intersection, highway, freeway, mid-block, etc.)?

7. 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
8. Are you a professional driver, like taxi driver, truck driver?
   a. Yes
   b. No
9. Do you have a history of severe motion sickness or seizures?
   a. Yes
   b. No
10. Do you have an experience about virtual reality games (such as simulator)?
    a. Yes
    b. No

APPENDIX D – MOTION HISTORY QUESTIONNAIRE

Developed by Robert S. Kennedy & colleagues under various projects. For additional information contact:

Robert S. Kennedy, RSK Assessments, Inc., 1040 Woodcock Road, Suite 227, Orlando, FL 32803 (407) 894-5090

Subject Number: _____________ **Date:** ________________

1. Approximately how many total flight hours do you have? ____ hours

2. How often would you say you get airsick?

   Always____ Frequently____ Sometimes____ Rarely____ Never________

3. a) How many total flight simulator hours? _____ Hours

   b) How often have you been in a virtual reality device? _____ Times _____ Hours

4. How much experience have you had at sea aboard ships or boats?

   Much ____ Some ____ Very Little ____ None _______

5. From your experience at sea, how often would you say you get seasick?

   Always ___ Frequently____ Sometimes____ Rarely____ Never________

6. Have you ever been motion sick under any conditions other than the ones listed so far?

   No____ Yes____ If so, under what conditions?

7. In general, how susceptible to motion sickness are you?

   Extremely___Very___Moderately___Minimally___Not at all__________

8. Have you been nauseated FOR ANY REASON during the past eight weeks?

   No ___ Yes ___ If yes, explain

9. When you were nauseated for any reason (including flu, alcohol, etc.), did you vomit?

   Easily ___ Only with difficulty ___ Retch and finally vomited with great difficulty _____

10. If you vomited while experiencing motion sickness, did you:

    a) Feel better and remain so?

    b) Feel better temporarily, then vomit again?

    c) Feel no better, but not vomit again?

    d) Other - specify

11. If you were in an experiment where 50% of the subjects get sick, what do you think your chances of getting sick would be?

    Almost certainly would ____ Probably would ____ Almost Probably would not ____ Certainly would not _________

12. Would you volunteer for an experiment where you knew that: (Please answer all three)

a) 50% of the subjects did get motion sick? Yes ___ No ______

b) 75% of the subjects did get motion sick? Yes ___ No ______

c) 85% of the subjects did get motion sick? Yes ___ No ______

13. Most people experience slight dizziness (not a result of motion) three to five times a year. The past year you have been dizzy:

More than this ___ The same as ___ Less than ___ Never dizzy ______

14. Have you ever had an ear illness or injury which was accompanied by dizziness and/or nausea? Yes No ____

15. Listed below are a number of situations in which some people have reported motion sickness symptoms. In the space provided, check (a) your PREFERENCE for each activity (that is, how much you like to engage in that activity), and (b) any SYMPTOM(s) you may have experienced at any time, past or present.

SITUATIONS	PREFERENCE			SYMPTOMS												
	LIKE	NEUTRAL	DISLIKE	VOMITED	NAUSEA	STOMACH AWARENESS*	INCREASED SALIVATION	DIZZINESS	DROWSINESS	SWEATING	PALLOR	VERTIGO**	AWARENESS OF BREATHING	HEADACHE	OTHER SYMTPOMS	NONE
Aircraft																
Flight simulator																
Roller Coaster																
Merry-Go-Round																
Other carnival devices																
Automobiles																
Long train or bus trips																
Swings																
Hammocks																
Gymnastic Apparatus																
Roller / Ice Skating																
Elevators																
Cinerama or Wide-Screen Movies																
Motorcycles																

**Stomach awareness refers to a feeling of discomfort that is preliminary to nausea.*

***Vertigo is experienced as loss of orientation with respect to vertical upright.*

END OF MOTION HISTORY QUESTIONNAIRE

APPENDIX E – SIMULATOR SICKNESS QUESTIONNAIRE

Developed by Robert S. Kennedy & colleagues under various projects. For additional information contact:

Robert S. Kennedy, RSK Assessments, Inc., 1040 Woodcock Road, Suite 227, Orlando, FL 32803 (407) 894-5090

Subject Number: __________ Date: _____________

PRE-EXPOSURE BACKGROUND INFORMATION

1. How long has it been since your last exposure in a simulator? _______ days

   How long has it been since your last flight in an aircraft? _______ days

   How long has it been since your last voyage at sea? _______ days

   How long has it been since your last exposure in a virtual environment? _______ days

2. What other experience have you had recently in a device with unusual motion?

PRE-EXPOSURE PHYSIOLOGICAL STATUS INFORMATION

3. Are you in your usual state of fitness? (Circle one) YES NO

   If not, please indicate the reason:

4. Have you been ill in the past week? (Circle one) YES NO

   If "Yes", please indicate:

   a) The nature of the illness (flu, cold, etc.):

   b) Severity of the illness: Very _________________Very

      Mild Severe

   c) Length of illness: _________________ Hours / Days

   d) Major symptoms:

   e) Are you fully recovered? YES NO

5. How much alcohol have you consumed during the past 24 hours?

   ____ 12 oz. cans/bottles of beer ____ ounces wine ____ ounces hard liquor

6. Please indicate <u>all</u> medication you have used in the past 24 hours. If none, check the first line:

   a) NONE b) Sedatives or tranquilizers c) Aspirin, Tylenol, other analgesics

   d) Anti-histamines e) Decongestants f) Other (specify):

7. a) How many hours of sleep did you get last night? _____ hours

   b) Was this amount sufficient? (Circle one) YES NO

8. Please list any other comments regarding your present physical state which might affect your performance on our test battery.

Baseline (Pre) Exposure Symptom Checklist

Instructions: Please fill this out BEFORE you go into the virtual environment. Circle how much each symptom below is affecting you right now.

#	Symptom	Severity			
1.	General discomfort	None	Slight	Moderate	Severe
2.	Fatigue	None	Slight	Moderate	Severe
3.	Boredom	None	Slight	Moderate	Severe
4.	Drowsiness	None	Slight	Moderate	Severe
5.	Headache	None	Slight	Moderate	Severe
6.	Eye strain	None	Slight	Moderate	Severe
7.	Difficulty focusing	None	Slight	Moderate	Severe
8a.	Salivation increased	None	Slight	Moderate	Severe
8b.	Salivation decreased	None	Slight	Moderate	Severe
9.	Sweating	None	Slight	Moderate	Severe
10.	Nausea	None	Slight	Moderate	Severe
11.	Difficulty concentrating	None	Slight	Moderate	Severe
12.	Mental depression	None	Slight	Moderate	Severe
13.	"Fullness of the head"	None	Slight	Moderate	Severe
14.	Blurred Vision	None	Slight	Moderate	Severe
15a.	Dizziness with eyes open	None	Slight	Moderate	Severe
15b.	Dizziness with eyes closed	None	Slight	Moderate	Severe
16.	*Vertigo	None	Slight	Moderate	Severe
17.	**Visual flashbacks	None	Slight	Moderate	Severe
18.	Faintness	None	Slight	Moderate	Severe
19.	Aware of breathing	None	Slight	Moderate	Severe
20.	***Stomach awareness	None	Slight	Moderate	Severe
21.	Loss of appetite	None	Slight	Moderate	Severe
22.	Increased appetite	None	Slight	Moderate	Severe
23.	Desire to move bowels	None	Slight	Moderate	Severe
24.	Confusion	None	Slight	Moderate	Severe
25.	Burping	None	Slight	Moderate	Severe
26.	Vomiting	None	Slight	Moderate	Severe
27.	Other				

* Vertigo is experienced as loss of orientation with respect to vertical upright.

** Visual illusion of movement or false sensations of movement, when not in the simulator, car, or aircraft.

*** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

STOP HERE! The test director will tell you when to continue.

POST 00 Minutes Exposure Symptom Checklist

Instructions: Circle how much each symptom below is affecting you <u>right now</u>.

#	Symptom	Severity			
1.	General discomfort	None	Slight	Moderate	Severe
2.	Fatigue	None	Slight	Moderate	Severe
3.	Boredom	None	Slight	Moderate	Severe
4.	Drowsiness	None	Slight	Moderate	Severe
5.	Headache	None	Slight	Moderate	Severe
6.	Eye strain	None	Slight	Moderate	Severe
7.	Difficulty focusing	None	Slight	Moderate	Severe
8a.	Salivation increased	None	Slight	Moderate	Severe
8b.	Salivation decreased	None	Slight	Moderate	Severe
9.	Sweating	None	Slight	Moderate	Severe
10.	Nausea	None	Slight	Moderate	Severe
11.	Difficulty concentrating	None	Slight	Moderate	Severe
12.	Mental depression	None	Slight	Moderate	Severe
13.	"Fullness of the head"	None	Slight	Moderate	Severe
14.	Blurred Vision	None	Slight	Moderate	Severe
15a.	Dizziness with eyes open	None	Slight	Moderate	Severe
15b.	Dizziness with eyes closed	None	Slight	Moderate	Severe
16.	*Vertigo	None	Slight	Moderate	Severe
17.	**Visual flashbacks	None	Slight	Moderate	Severe
18.	Faintness	None	Slight	Moderate	Severe
19.	Aware of breathing	None	Slight	Moderate	Severe
20.	***Stomach awareness	None	Slight	Moderate	Severe
21.	Loss of appetite	None	Slight	Moderate	Severe
22.	Increased appetite	None	Slight	Moderate	Severe
23.	Desire to move bowels	None	Slight	Moderate	Severe
24.	Confusion	None	Slight	Moderate	Severe
25.	Burping	None	Slight	Moderate	Severe
26.	Vomiting	None	Slight	Moderate	Severe
27.	Other				

* Vertigo is experienced as loss of orientation with respect to vertical upright.
** Visual illusion of movement or false sensations of movement, when <u>not</u> in the simulator, car or aircraft.
*** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

POST-EXPOSURE INFORMATION

1. While in the virtual environment, did you get the feeling of motion (i.e., did you experience a compelling sensation of self motion as though you were actually moving)? *(Circle one)*

   YES NO SOMEWHAT

2. On a scale of 1 (POOR) to 10 (EXCELLENT) rate your performance in the virtual environment:

3. a. Did any unusual events occur during your exposure? *(Circle one)* YES NO

   b. If YES, please describe

APPENDIX F – EXIT SURVEY

1. Did you notice the change of the delineator's colors?

   a. Yes b. No

   If yes, which color attracted you the most or the conspicuous (noticeable) color.

   a. orange b. white c. purple d. black e. yellow

2. Which color was more noticeable in the night?

   a. orange b. white c. purple d. black e. yellow

3. Which color was more noticeable in the low visibility scenarios?

   a. orange b. white c. purple d. black e. yellow

4. Which color was more noticeable under asphalt roadway surface?

   a. orange b. white c. purple d. black e. yellow

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

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

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