**Center for Accessibility and Safety for an Aging Population**

**Florida State University**

**In Partnership with Florida A&M University and University of North Florida**

# RESEARCH FINAL REPORT

# Developing an Algorithm using the Connected Vehicles Technology to Enhance Aging Drivers' Freeway Merging Maneuver – Phase II


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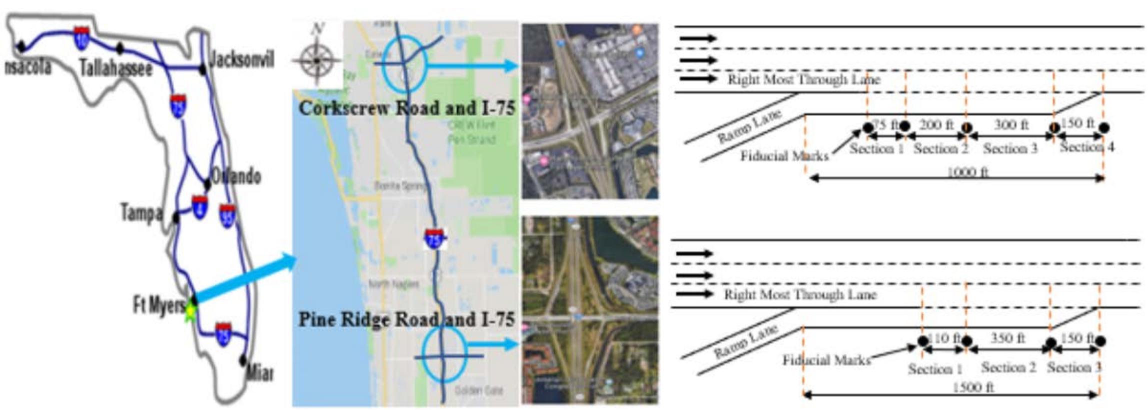


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METRIC CONVERSION FACTORS

1 ft = 0.3048

1 mph = 1.609 km/h

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# ABSTRACT

Freeway merging is one of many complex decision-making maneuvers that drivers, especially the aging population, face when driving on the freeway. Moreover, when visibility is hindered due to adverse weather conditions, merging maneuvers become even more challenging. The objective of this paper is therefore to identify factors affecting the time taken for drivers of different age groups to complete merging maneuvers on freeway-ramps under different driving, traffic and geometric conditions. A driving simulator was utilized to simulate merging scenarios in clear and foggy weather, LOS A and LOS B, and onto four-lane and six-lane freeways. Simulator data was collected from 100 participants, alongside responses to questions about participants' socio-economic characteristics, driving experience in clear and foggy weather conditions, health conditions, driving abilities, and the number of times they had driven a simulator. Using ANOVA and stepwise loglinear regression models to analyze the collected data, results confirm that there were statistically significant differences among age groups. In addition, number of lanes was the most significant predictor variable in the global model. Drivers took longer time merging onto the four-lane freeway than the six-lane freeway. However, weather (clear and fog) and traffic (LOS A and LOS B) conditions were not statistically significant. Other statistically significant variables include race, driving experience, distance driven per week, difficulty driving in foggy weather conditions, ability to see vehicles coming beside, ability to make over-the-shoulder check, ability to make quick decisions, and ability to react to horns.

**Keywords:** Freeway maneuvers, merging time, age groups, driving simulator

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# 1. INTRODUCTION

Merging is a mandatory lane changing process by which vehicles moving in the same direction in two separate streams combine to form a single stream. It is a complex decision-making process that involves driver estimation of safe gaps between merging vehicles and approaching vehicles, lane maintenance with eyes off roadway, and ability to make quick decisions under time pressure with good steering angle. Merging time or time to complete merging maneuvers on freeway ramps is known to be influenced by factors such as traffic characteristics, ramp geometrics, environmental elements and conditions, and freeway geometric characteristics (Drew et al., 1967). As a result of these factors, variations occur in merging time, leading to undesirable stop-and-go driving, recurring bottlenecks, and excessive fuel consumption (Rios-Torres & Malikopoulos, 2017).

Due to the changes that occur in cognitive and physiological abilities with age (Selander et al., 2011), it has been widely reported that older drivers process information longer (Skaar, Rizzo, & Stierman, 2005), face difficulties maintaining constant speed, and encounter problems driving in complex situations like intersections, gore areas and during festive periods requiring driving maneuvers (Chin & Zhou, 2018a). Older drivers themselves report difficulties making decisions under time pressure, and often compensate for their shortcomings by driving slowly with wider gaps, and avoid busy distracting environments (Musselwhite & Haddad, 2010). These age-related differences have prompted many researchers to study the merging behavior of older drivers in comparison with younger drivers. Hetrick, (1997) conducted a study that examined the lane change behavior of 16 drivers in the presence of an observer who gave directions. It was found that age did not significantly affect lane change duration. Though the participants were instructed to drive normally and data was collected unbeknown to them, the presence of observers could have influenced drivers' experience and their lane changing behavior. Yuan et al., (2019) also assessed the merging behavior of forty-five licensed drivers on a freeway, and observed that older drivers had longer lane changing duration than middle-aged drivers, while female drivers had less safe lane changing process with significantly shorter lane change duration, higher maximum longitudinal deceleration and larger maximum steering wheel angle than their male counterparts.

The effect of changing traffic densities on merging time have also been documented. Li & Cheng, (2019) collected data trajectories in four different ranges of traffic conditions and observed that there were statistically significant differences in merging duration between traffic densities 0-30 veh/km/ln and 30-45 veh/km/ln, and between 0-30 veh/km/ln and 45-60 veh/km/ln. Study also speculated that high relative speeds could influence merging duration after observing that the mean and median values of merging duration were smallest under the lowest traffic density and second smallest under the highest traffic density. Yuan et al., (2019) also indicated that higher traffic volume (at peak conditions) increased difficulty of lane changing process leading to longer lane merging gap and duration, lower longitudinal maximum deceleration and maximum lateral acceleration.

Visibility impairment has also been a challenge for drivers, and the Highway Capacity Manual (HCM, 2010) has shown that when visibility is less than 1 mile as a result of rain, fog, and snow, driver behavior affects general traffic flow operations. Xu et al, (2013) reported that under reduced visibility condition, the standard deviation of occupancy at downstream and the speed difference between upstream and downstream of freeway affect crash risk. In foggy weather, all drivers were likely to reduce their travelling speeds and acceleration in mixed traffic conditions (LOS C to F) than in free-flow conditions (LOS A and B), while female drivers and older drivers were likely to drive with reduced speed compared to male drivers and young drivers respectively. In the same study, it was also observed that educated drivers and married drivers drove safely and within speed limits compared to uneducated and single drivers. Hamdar et al. (2016) observed that weather-related factors affected drivers' average speed and headway. Wu et al. (2018) reported that visibility impairment reduced average traffic volume and speed on freeway, and increased crash risk near freeway ramps, innermost lane and locations with heavy traffic. Of all these studies, none considered the effect of adverse weather conditions on the time to complete merging maneuvers.

The effect of varying conditions on drivers in different age groups have been reported. Trick et al., (2009) investigated the driving performance of older and younger drivers in different visibility conditions, traffic densities, and wayfinding challenges. Utilizing hazard RT, collisions, wayfinding errors, and driving speed as driving performance indicators, it was found that older drivers performed just as good as younger drivers in the face of various challenges aside from a few wayfinding errors. Study also noted that experienced drivers reduced their speeds in the fog area, while novice drivers rarely did and drove with high risk. Though this study evaluated driver behavior in varying conditions, the effect of these conditions on the merging behavior of drivers was not considered.

Though many research works have explored the merging behavior of drivers on freeway on-ramps in various conditions. None of them have considered the effect of changing number of lanes, driver characteristics, and other self-reported driving abilities. The studies that focused on freeway merging segments did not consider weather condition, while those that investigated the effect of weather condition on driving behavior did not consider merging segments. In order to accurately model freeway merging behavior on traffic simulation tools, more investigation is needed in understanding better the merging behavior of drivers at freeway on-ramps. Thus, this study was undertaken to evaluate the effect of different weather, traffic, and geometric conditions on drivers across different age groups in the time to complete merging maneuvers on freeway ramps.

As part of a pilot study, a CDS250 driving simulator was used to develop scenarios in clear and foggy weather, LOSA and LOS B, and on four-lane and six-lane freeways. A total of 100 participants took the simulator test, all of whom filled questionnaire forms to collect information on driver socio-economic characteristics, driving experience in clear and foggy weather conditions, health conditions, driving abilities, and the number of times they had driven a simulator. Data from the simulator and questionnaire responses was analyzed using ANOVA and stepwise loglinear regression models.

### 1.2 Hypothesis

It was hypothesized that, in all scenarios, older drivers will take longer time completing merging maneuvers than younger drivers. It was also expected that, among other predictors, driving in a foggy weather condition over a clear or normal weather condition will increase the merging time for all drivers, especially older drivers.

## 2. LITERATURE REVIEW

### 2.1 Behavior of Aging Drivers

Not a few scholars have documented the changes that occur in the cognitive and physiological abilities of humans as they grow older. The results of the changes are seen not just in regular day-to-day activities like talking, eating, walking, sleeping, etc., but also in driving. These changes range from conservativeness to reduction in cognitive abilities and other health related issues.

#### 2.1.1 Cognitive Ability

79 older drivers (64 males 15 females, with mean age =77.86) were enrolled in the course in a study that was undertaken in Japan to analyze the relationship between cognitive functions and driving abilities of older drivers attending a license renewal course. After giving a questionnaire to each participant about their driving conditions, the Trail Making Test (TMT) which measures cognitive processing speed and cognitive load was also conducted. TMT-A involves joining numbers between 1 to 25 randomly printed on a sheet of paper in ascending order and as quickly and accurately as possible. Unlike TMT-A, TMT-B involved joining numbers between 1 to 13 and alternating it with the first letters of the Japanese character. The lack of significant linkage between cognitive functions and driving behaviors in the results shows a more reliable system needs to be developed to detect the sensitivity and specificity of traffic accidents and sustain the mobility of the ever-increasing aging population (Horikawa et al., 2009).

85 drivers (65-85 with mean age=72) partook in a study by Selander et al., (2011), undertaken to investigate what types of driving errors are associated with neurologically normal older drivers. The on-road assessment took about an hour on a fixed route in a suburban district, as an occupational therapist observed the driver’s ability/behavior. Findings in this study suggested that

some errors older drivers commit are not necessarily as a result of cognitive impairments but driving behaviors that have been habituated over the years of driving. Also, the average age of those who passed the test was lower than those who failed it, as lack of attention and failure to check blind spots were serious errors they often committed.

2.1.2 Crash Frequency

In the quest to determine the factors contributing to crashes in Kentucky, crash data for 1995 to 1999 were collected and analyzed (Chandraratna & Stamatiadis, 2003). In the study where 32,539 left-turn crashes, 31,256 gap acceptance crashes and 7,803 lane crashes were used, it was discovered that: left-turn crashes were 3.2 times higher for older drivers (age > 65) than crashes for younger drivers; females had a higher chance of being involved in crashes than men, and especially older women who were 1.25 times more likely than men to be involved in left-turn crashes; older drivers are 1.65 times more likely to be involved in left-turn crashes when driving at night (with no streetlights) than during the day; older drivers are 1.17 times more likely to be involved in left-turn crashes at rural areas (population <= 25,000) than urban areas (population >= 250,000); these left-turn crashes for older drivers are also 2.41 times more severe than crashes for younger ones; with a passenger in the vehicle, the chance of left-turn crashes for older drivers are 1.56 times lower. Gap acceptance crashes were also 1.87 times higher for older drivers than younger drivers. Drivers >= 85 were 3.6 times more likely to be involved in a gap acceptance crash than drivers from ages 65 to 69. Older women were also 1.2 times more likely to be in a gap acceptance crash than older male drivers. Older drivers are 1.20 times more likely to be involved in a gap acceptance crash in rural areas than urban areas. Also, the severity of gap acceptance crashes for an older driver is 1.78 times that of a younger driver. With a passenger in the vehicle, the chance of being involved in a gap acceptance crash for older drivers is 1.38 times lower. Lane change crashes were 1.46 times higher for older drivers as against younger drivers. No significant difference between the two genders, difference in location and severity.

A 3-year crash data of a total of 2567 drivers was taken in Singapore to investigate how the roadway, driver-vehicle, traffic and other factors contribute to older drivers being at-fault in crashes. Results show that, among other situations, older drivers have difficulties driving in complex situations requiring driving maneuvers, namely, at intersections, gore areas and during festive periods. These situations are those that require high mental workload as the results suggest the odds that older drivers driving at these areas will be at fault in a crash are the highest, and even increase significantly when speed limits are 60 km/hr or higher (Chin & Zhou, 2018)**.**

Also, in Australia, the crash patterns of 191,709 crashes of drivers aged 17-80+ taken during a period of 9 years was analyzed. Analyses indicate that older drivers are overrepresented in fatalities and hospitalization, and that the higher the age range of the older driver (i.e. 60-70, 70-80, 80+), the higher the at-fault for, seriousness and life-threatening nature of the crash. These crashes occurred especially at crossroads and T-intersections, but the seriousness of the crashes by the older drivers are much lower at roundabouts, interchanges and railway crossings (Rakotonirainy et al., 2012).

Study by Nishida, (2015) assessed the general assumption that most drivers improve on their past accidents caused by a particular mistake on the highway. Results obtained from drivers who had had numerous traffic accidents and violations are more likely to cause more accidents than those who have had no accident records in the past. However, this was not necessarily the case for the elderly drivers, who showed no correlation between relative accident ratio and accidents or apprehensions/violations. Also, older drivers' relative accident ratio in the 65-74 age group who had zero accidents still had higher accident ratios than the highest accident ratios in the 25-34 and 45-54 age groups. Study suggests a variety of approaches are needed to address the differing traffic characteristics by age group.

### 2.1.3 Conservativeness

To compare the conservativeness of older drivers with younger drivers, 18 participants were chosen for a test, where 10 were young drivers with a mean age of 36.4 while the mean of the remaining 8 neurologically normal older drivers were 65.75. Each participant sat in an instrumented vehicle readying to cross a 4-lane traffic-busy highway from an empty driveway. 10 times were they asked to press a button to mark the last possible moment they would cross the road. They were also given 3 chances to cross the road when the road was free for crossing. Results of the gap acceptance decisions based on TTC (time-to-contact), speed and distance show older drivers adjusted gap distance for speed as younger drivers do but allowed larger gaps and larger cushion before entering traffic (Skaar et al., 2005)

### 2.1.4 Lane Maintenance

To explore the relationship between driver cognitive decline and lane maintenance, Sun et al., (2018) investigated the lane maintenance of 50 older drivers aged 60-81 at intersections and roundabouts after taking a battery of neurological tests, serving as a window into their cognitive deficits, vision, motor skills and level of risk-taking personality. Using GNSS (Global Navigation Satellite System) vehicle movement tracking system mounted on the car roof to collect data, it was observed that lane maintenance performance was more strongly correlated with visual attention and executive function than age alone.

#### 2.1.5 Merging and Lane Change Behavior

After analyzing the different tactics of merging vehicles based on field trajectory data, study observed a high proportion of vehicles reject their original gap in congested conditions; and built a new lane-changing framework that sequentially simulated their dynamic gap-selection, merging location choice, speed-synchronization, and acceleration decision behavior. Study concludes that: speed difference between merging and main-lane vehicles affect the targeting gap selection; characteristics of the adjacent gap and features of alternative gaps influence gap selection and; merging vehicles maintain a relatively stable speed relative to the main-lane traffic when driving through a rejected gap (Wan et al., (2017)

Factors that influence driver decisions before making mandatory lane changes were noted by Nilsson et al., (2018) conducted in a simulator room to study driver actions (turning indicator activation, speed and lateral intrusion) before exiting a one-way multilane highway unto a ramp, 12 male truck drivers were subjected to 48 lane-change events, where 22 of their maneuvers were cooperative, 19 were forced and the other 7 were not performed. Results indicated that urgency of the driver and cooperation of surrounding traffic during these mandatory lane changes affected the truck-driver decisions. Speed of driver was high with low urgency, and urgency increased as drivers got close to the ramp and speed was much lower. Also, speed was higher with high traffic cooperation, and lower with low traffic cooperation. Study recommended the inclusion of turning indicator usage before lane-changing events in future traffic models, and how and when that affects or not affect the surrounding traffic cooperation.

In a study that assessed the merging behavior of forty-five licensed drivers on a freeway, three kinds of measurements were taken after test was conducted on a simulator and these observations were drawn: the length of the weaving lane significantly influenced driver decision as 600ft lane caused much shorter lane change patience and maximum steering wheel angle than 1000 ft and 1400 ft weaving lane; higher traffic volume (at peak conditions) increased difficulty of lane changing process leading to longer lane merging gap and duration, lower longitudinal maximum deceleration and maximum lateral acceleration; the driver characteristics (age and gender), as older drivers had longer lane changing duration than middle-aged drivers, while female drivers had less safer lane changing  process with significantly shorter lane change duration, higher maximum longitudinal deceleration and larger maximum steering wheel angel than their male counterparts (Yuan et al., 2019)

### 2.1.6 Visual-motor Co-ordination

The correlation between visual-motor coordination and age was studied by Sun et al., (2018) as 38 neurologically normal older drivers, aged 60-81 with mean 68.65 were recruited to drive their own cars with an eye tracker mounted on their heads for a study that sought to capture visual attention and perception of older drivers. A GNSS tracker was also installed on the car roof to synchronize and convert the eye fixations and vehicle trajectory into a visual-motor coordination (VMC) dataset in GIS. Using a DEA model, the VMC performance was able to identify under-performing, however, there was no significant correlation between a driver’s age and VMC performance.

### 2.1.7 Freeway Crashes and Weather Conditions (Fog)

Fog affects traffic when visibility is less than 1 mile (Highway capacity manual).  It is therefore important to study the effect of fog on traffic flow. Wu, Yina Abdel-Aty, Mohamed., (2018) studied the changes in traffic flow under foggy weather conditions and normal weather conditions to identify the factors increasing crash risks during fog on roadways. Their research utilized weather and traffic data collected from the National Climate Data Center (NCDC) and detector systems respectively to conduct a binary logistic regression analysis. The results from this study show that crash risk increases near freeway ramps, innermost lane and locations with heavy traffic in fog conditions. Also, drivers are more careful while driving in fog and ultimately reducing average traffic volume and speed.

Hoogendoorn, Raymond Gerard et.al, (2010) conducted a driving simulator experiment to evaluate freeway capacity and drivers' adaptation behavior under foggy weather conditions on freeways. The drivers who participated in this study had a minimum of five years driving experience and they were between the ages 23 and 65 In this study three scenarios were created in the driving environment.: one was for the test drive while the other two were for the foggy condition and the normal(clear weather) condition. Information pertaining to speed, acceleration, deceleration and the gap between the lead and the lag vehicle were obtained from the driving simulator at a sample rate of 10 samples per second for each participant. A micro-simulation model in S-Paramics was used to estimate the effect of drivers' adaptation in actual longitudinal driving behavior in foggy weather condition on freeways. Also, Henry model and Intelligent driver model were used to determine the accuracy of the car-following models used in the study. The results from this study showed that in adverse weather condition(fog), there is a significant decrease in speed.

Xu, Chengcheng Wang, Wei, (2013) in their research tried to understand the relationship between traffic flow characteristics and crash risks on freeways under different weather condition (clear, rainy, and reduced visibility weather) by developing crash prediction models for the different weather conditions. This study used Bayesian random intercept logistic regression and ordinary logistic regression models to estimate the probability of crash occurrence under the different weather conditions considered in the study. The traffic flow characteristics that had effect on the crash risk in the various weather condition were different. The Crash risk in clear condition was affected by the upstream occupancy, speed variance at downstream detector station and the difference between the downstream and the upstream speeds. Also, under rainy weather condition, crash risk was affected by the rain intensity, upstream occupancy and the speed difference between upstream and downstream station. Under reduced visibility weather, the standard deviation of occupancy at downstream and the speed difference between upstream and downstream station affected crash risk.

In the past various researchers have studied the behavior of drivers during fog in a simulated environment. Driving in a simulated environment does not adequately represent what is obtainable in real life Thus, Anik Das et al. ,(2019) decided to study the speed selection behavior of drivers and their general performances in clear and foggy weather conditions under a naturalistic setting. The data for this study were got from the Strategic Highway Research Program (SHRP2) Naturalistic Driving Study (NDS) and Roadway Information Database (RID). This study divided traffic types into two: free-flow traffic (LOS A and B) and mixed traffic (LOS C to F). According to this study, free-flow traffic condition occurred when there is no vehicle leading the NDS driver's vehicle in any lane or there is at least one lead vehicle in one lane. However, in mixed traffic, The NDS drivers were affected by other vehicles. Results show that in foggy weather, drivers were likely to reduce their travelling speeds in mixed traffic conditions (LOS C to F) than in free-flow conditions(LOS A and B),female drivers and older drivers tend to drive with a reduced speed compared to male drivers and young drivers respectively. Furthermore, educated drivers and married drivers drove safely and within speed limits compared to uneducated and single drivers. Finally, it was found that speed distribution under foggy weather in free-flow conditions followed a Weibull distribution.

Eustace et.al., (2015) used negative binomial generalized linear model to analyze the factors affecting crash frequency in left-side and right-side diverging areas of a freeway. Some of the variables considered in this study were lighting condition, pavement condition, drivers' age and the presence of work zone. The results from this study identified the presence of left turn (diverge or merge) junction and work zone, drivers' age, lighting condition and road surface condition to be significant in affecting crash frequency at freeways. Also, crashes are 7.88 and 2.26 times more likely to occur on merging and diverging areas respectively on the left side than on the right side of the freeway. Wet and snowy road surfaces were.1.84 and 2.36 times likely to result in crash when compared with dry road surfaces while darkness and glare resulted in 2.18 and 2.69 more crashes than normal lighting conditions. Finally, Drivers whose age was between 21 and 64 had more crashes than drivers aged 65 and above.

Lerner & Neil D, (1991) offered a review of the current studies about the effects of weather characteristics on road safety. The review pointed out that there is a trend of using real-time data to conduct the traffic safety impact analysis. However, most of the previous studies focused on the effects of precipitation, snow and some other weather conditions, but few have addressed the low visibility conditions.

Rios-Torres et.al. (2017) in their research identified the reasons why older drivers (drivers aged 65+) avoid freeways as well as the problems they encounter on freeways. Some of these problems revealed from the study include the presence of large trucks on freeways, high speed, reckless driving of other drivers, inappropriate freeway signage and most importantly the merging maneuver into freeway Based on their findings, various counter measures were suggested to improve freeway safety and use among older drivers. These counter measures include lane restriction and truck separation from freeways, development of methods to reduce speed variability in traffic stream, elimination of short merge and weaving sections and improving the graphics of signs on freeways.

Ahammed M. et al., (2008) formulated and developed an online closed form solution to the problem of optimal vehicle coordination at merging roadways in terms fuel consumption given a collision avoidance constraint to improve the flow of traffic. The closed form solution was obtained from Hamiltonian analysis and was found to significantly reduce both total travel time and fuel consumption.

Calvi, Alessandro et al., (2011) studied the behavior of traffic at freeway merge areas by taking count of vehicles via video recording and collecting speed data. Results from this study show that right lane and entering traffic volume affect the right lane vehicle speed, lower merging speed are associated with high traffic volume and shorter acceleration lane, right lane speed increases as merging speed increase and right lane speed decrease with an increase in the right lane traffic volumes.

## 2.2 Statistical Models

A 5-year accident data collected between 1999 and 2003 by Caliendo et al., (2007) was used to model the frequency of accident occurrence on a four-lane median-divided rural road. In the 1916 accidents considered, 21 were fatal accidents and 594 were injury accidents, both of which were considered collectively as "severe" crashes. The Poisson, negative binomial, and negative multinomial regression models were applied separately to tangents and curves on the roadway. Variables considered include length, curvature, annul average daily traffic (AADT), sight distance, side friction coefficient, longitudinal slope, rain precipitation, and the presence of a junction. Significant variables included in the equation was detected by the Likelihood Method, and the Generalized Likelihood ratio, while the Cumulative Residuals Method was used to test the adequacy of each regression model applied throughout the range of each variable. Results show that accidents increase with length, curvature, and AADT. A wet pavement also increases the number of crashes. In contrast, accidents decrease with sight distance, pavement friction, and longitudinal slope. Length, curvature, and AADT were significant variables for all the regression models, while rain (or wet pavement) significantly increased the number of total (severe) accidents by a factor 2.32 (2.81) for tangents and 2.70 (3.26) for curves.

In another study, crash data was obtained through a 5-year period (2004 through 2008) and were classified into three categories: fatal, serious-injury, and slight injury. Statistical models were employed to explore and analyze factors affecting frequency and severity of these crashes in Riyadh city, Saudi Arabia. A multinomial logit model (MNL) and a mixed logit model were developed. Considering the underreporting problem on slight injury crashes, binary and mixed binary logistic regression models were also used. Variables considered are age, nationality, time of day, cause of crash, type of collision, location of crash, road surface condition, lighting condition, single vehicle crash, time trend, number of casualties, etc. Results from multinomial and binary response models had no significant difference. Also, random parameters model - which was determined if coefficients in the mixed logit model produced significant standard deviations – seem to be the most reasonable of the models used, as age, nationality of driver, over-speeding, wet road surface and dark lighting conditions are associated with increase in fatal crashes. Probability of having a fatal crash increases as age of driver increases, while land use in all models suggested a decrease in fatal and serious injury crashes in increased residential, transport and educational areas (Altwaijri et al., 2012)

## 3. SCENARIO DEVELOPMENT

### 3.1 Driving Simulator

The Center for Accessibility and Safety for an Aging Population (ASAP) driving simulator was used in this task. The driving simulator is located in the driving simulation laboratory at the Florida A&M University (FAMU) - Florida State University (FSU) College of Engineering and is shown in Figure 1. The ASAP on-road driving simulator is a CDS250 simulator manufactured by the Drive Safety Company (Drive Safety, 2019a) in the United States. This advanced driving simulator is a partial cabin of a Ford Focus sedan with an automatic transmission.

**Figure 1 The ASAP driving simulator.**

The apparatus is equipped with an entertainment console (a functional radio/CD and MP3 player input) and standard automotive driver controls, which include accelerator and brake pedals, steering wheel, ignition, gear select, turn signals and headlights. The simulated environment visual display is projected through three screens positioned in front of the driver, which offers a 110° field of view in the horizontal direction and a real-time rear and side view wide-angle mirrors with a high-resolution (retina-limited) visual display of 1040 x 1050 pixels. The simulator also offers a three-dimensional sound system, which produces tire and car engine noises. The driving simulator is connected to a computer, which uses the Drive Safety Hyper Drive software (Drive Safety, 2019b) to design scenarios and simulate a virtual traffic environment.

### 3.2 Description of the Developed Scenarios

The driving simulator Drive Safety Hyper Drive software (Drive Safety, 2019b) was used in this study in order to develop a set of driving simulation scenarios. The developed driving simulation scenarios will allow assessing the effects of major driver characteristics (e.g., age, gender, racial group, driving experience, marital status, health condition, etc.), freeway geometric characteristics (number of travel lanes), driving conditions (time of the day, day of the week), and traffic characteristics (space headway, time headway) on the time required to complete the freeway merging and diverging maneuvers. A total of nine driving simulation scenarios were designed in this study. A test drive scenario was developed to ensure that the participants become familiarized with the driving simulator steer and brakes. Moreover, eight other scenarios were developed by changing the traffic characteristics (level of service – LOS), freeway geometric characteristics (number of travel lanes), and driving conditions (weather conditions). The developed driving simulation scenarios include the following:

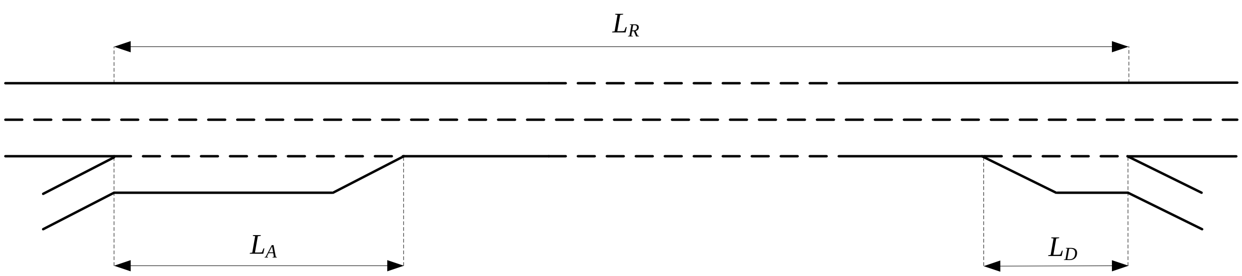
- **Scenario 0**: test drive scenario;

- **Scenario 1**: a four-lane freeway with merging and diverging segments, traffic conditions at LOS A, and normal weather conditions;
- **Scenario 2**: a four-lane freeway with merging and diverging segments, traffic conditions at LOS B, and normal weather conditions;
- **Scenario 3**: a six-lane freeway with merging and diverging segments, traffic conditions at LOS A, and normal weather conditions;
- **Scenario 4**: a six-lane freeway with merging and diverging segments, traffic conditions at LOS B, and normal weather conditions;
- **Scenario 5**: a four-lane freeway with merging and diverging segments, traffic conditions at LOS A, and foggy weather conditions;
- **Scenario 6**: a four-lane freeway with merging and diverging segments, traffic conditions at LOS B, and foggy weather conditions;
- **Scenario 7**: a six-lane freeway with merging and diverging segments, traffic conditions at LOS A, and foggy weather conditions;
- **Scenario 8**: a six-lane freeway with merging and diverging segments, traffic conditions at LOS B, and foggy weather conditions.

The roadway traffic and geometric characteristics for the developed simulation scenarios were adopted based on the recommendations of base conditions presented in the Highway Capacity Manual (HCM) 2010 and 2016 (Transportation Research Board, 2010 and 2016). A detailed description of the roadway geometric and traffic characteristics, used in the developed scenarios, is presented in the following sections of the report. Furthermore, additional triggers that were designed within the developed scenarios to model unexpected vehicle movements are described as well.

3.2.1 Roadway Geometry

Driving simulation scenarios [1]-[8] were used to collect the data, required for assessing the effects of major driver characteristics, freeway geometric characteristics, driving conditions, and traffic characteristics on the time required to complete the freeway merging/diverging maneuvers and other performance indicators. On the other hand, driving simulation scenario [0] (i.e., the test drive driving simulation scenario) was designed to familiarize each participant with the driving simulation environment and practice basic driving maneuvers under normal weather conditions (e.g., acceleration, straight driving, deceleration, complete stops, use of the available mirrors to visualize the surrounding vehicles, etc.). The duration of the test drive driving simulation scenario was approximately 5 min. After completing the test drive driving simulation scenario, the participants started driving simulation scenarios [1]-[8].




Notes: $L_A$ – acceleration lane length
$L_B$ – deceleration lane length
$L_R$ – distance between ramps

**Figure 2. The geometric characteristics of merging and diverging freeway segments.**

*Note: A set of spatial triggers were added within the Drive Safety Hyper Drive simulation environment in order to estimate the time required to complete the freeway merging and diverging maneuvers for each scenario.*

The geometric characteristics of merging and diverging freeway segments for driving simulation scenarios [1]-[8] were adopted based on chapter 13 of the Highway Capacity Manual (HCM, 2010) and are illustrated in **Error! Reference source not found.**. The major features of driving simulation scenarios [1]-[8] can be summarized as follows:

- The default values for the length of acceleration and deceleration lanes, suggested by HCM (2010), were adopted in the driving simulation scenarios: the length of acceleration lane was set to $L_A = 800$ ft, while the length of deceleration lane was set to $L_D = 400$ ft (see page 13-28 of HCM, 2010);
- The distance between ramps was assumed to be $L_R = 2$ mi (or 10,560 ft);
- One-lane merging freeway segment;
- One-lane diverging freeway segment;
- Level terrain;
- Speed of vehicles along the freeway: uniformly distributed between 60 mph and 70 mph;
- Freeway geometric characteristics (number of travel lanes): varies depending on the scenario (scenarios [1], [2], [5], and [6] have two-lane freeway, while scenarios [3], [4], [7], and [8] have three-lane freeway);
- The default value of lane width, suggested by HCM (2010), was adopted in the driving simulation scenarios for the freeway lanes, merging segment lane, and diverging segment lane: $w = 12$ ft (see page 10-11 of HCM, 2010);
- Traffic characteristics (LOS): vary depending on the scenario (scenarios [1], [3], [5], and [7] emulate traffic conditions at LOS A with density ≤ 11 pc/mi/ln, while scenarios [2], [4], [6], and [8] emulate traffic conditions at LOS B with density within the range of 11-18 pc/mi/ln);

- Driving conditions (weather conditions): vary depending on the scenario (scenarios [1], [2], [3], and [4] emulate normal weather conditions, while scenarios [5], [6], [7], and [8] emulate foggy weather conditions). For scenarios with foggy weather condition (i.e., scenarios [5], [6], [7], and [8]), the fog density was set at 50 ft.

### 3.2.2 Traffic Characteristics

A basic freeway segment can be characterized primarily by three performance measures, including the following: (a) the density of the roadway in passenger cars per mile per lane (pc/mi/ln); (b) the space mean speed in miles per hour (mi/hr); and (c) the ratio of the flow rate to capacity (v/c) (Transportation Research Board, 2010). The average speed of vehicles was set to 65 mi/hr (which was adopted as the speed limit for scenarios [1]-[8]) ± 5 mi/hr (uniformly distributed speed values). The latter assumption can be justified by the fact that it is highly impractical that all vehicles will be traveling with exactly the same speed on the roadway. In order to achieve the desired Level of Service "A" (for scenarios [1], [3], [5], and [7]) Exhibit 11-5 (Level of Service Criteria for Basic Freeway Segments) of HCM specifies that the density of the freeway segment should be less than or equal to 11 cars per mile per lane (pc/mi/ln). In order to emulate light traffic, the flow rate was set to 700 pc/hr/ln. The density of the simulated traffic stream for scenarios [1], [3], [5], and [7] was computed using Equation 11-4 of HCM 2010 as follows.

$$D = \frac{V_p}{S} = \frac{700}{65} \approx 11\, pc/mi/ln \quad (1)$$

where:

$D$ - is the traffic flow density at the freeway segment (pc/mi/ln);

$V_p$ - is the demand flow rate (pc/hr/ln);

$S$ - is the traffic mean speed (mi/hr).

Furthermore, in order to attain Level of Service “B” (for scenarios [2], [4], [6], and [8]) Exhibit 11-5 (Level of Service Criteria for Basic Freeway Segments) of HCM specifies that the density of the freeway segment should be within the range of 11-18 passenger cars per mile per lane (pc/mi/ln). To emulate the traffic condition for Level of Service “B”, the flow rate was set to 1,100 pc/hr/ln. The density of the simulated traffic stream for scenarios [1], [3], [5], and [7] was computed using Equation 11-4 of HCM 2010 as follows.

$$D = \frac{V_p}{S} = \frac{1{,}100}{65} \approx 17\ pc/mi/ln \qquad (2)$$

The traffic flow mix was represented by passenger cars, SUVs, buses, and trucks. The percentage of heavy hehicles in the traffic stream was was set to 5%, while the driver population factor was assumed to be 1.0. The latter assumption can be supported by the fact that for scenarios [1]-[8] each participant will be required to drive mostly on a straight freeway segment with one-lane merging and diverging segments, which should help each participant to become familiar with the surrounding environment in a short span of time.

### 3.2.3 Modeling Unexpected Vehicle Movements

A set of additional location triggers (see **Error! Reference source not found.**) were developed within driving simulation scenarios [5]-[8] to model unexpected vehicle movements. A total of four location triggers were inserted between the end of a merging segment and the beginning of the diverging segment for each scenario. Each trigger causes the vehicles in front of the participant vehicle to reduce their speeds instantaneously to 20 mph and then accelerate back to the set speed. Based on the developed triggers, some of the vehicles, surrounding the subject vehicle, were modeled to make sudden maneuvers under foggy weather conditions. Such triggers allowed assessing the ability of participants to avoid accidents under inclement weather conditions. The research team also triggered approximately 5% of vehicles to perform lane changes throughout the experiment for scenarios [1]-[8] to make the scenario more realistic.

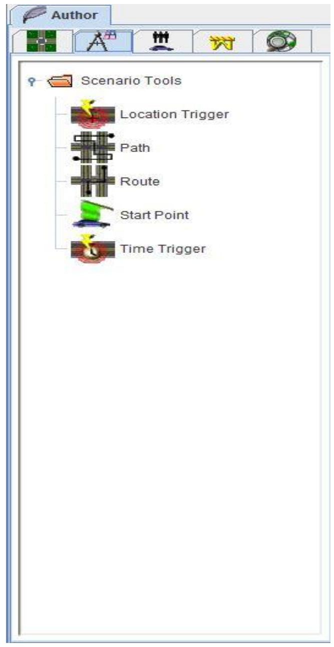



**Figure 3 Scenario tool library in the Hyperdrive Authoring Suite.**

# 4. PILOT STUDY DESCRIPTION

After the scenario development, the pilot study was organized under this project. In order to recruit participants for the pilot study, the research team developed a leaflet (a copy of the leaflet is presented in Appendix A). The leaflet highlighted the main objective of the project (i.e., identify the factors affecting the time required by individuals from different age groups to complete freeway merging and diverging maneuvers), provided details on how the experiments would be conducted, and outlined the basic expectations from the pilot study participants. The Principal Investigators (PIs) explained in the leaflet that each pilot study participant would be requested to drive the ASAP driving simulator, which was similar to a typical video game environment. The participant would be allowed to take 5 to 7-minute breaks as needed in between the experiments (i.e., a total of eight experiments and a test drive scenario) to avoid any simulation sickness, such as nausea or headaches. After the experiments were completed the participant would receive a $25 gift card as compensation. All information collected throughout the study (name, age, contact information, etc.) would be kept confidential, and participation was voluntary. The pilot study participants were informed in the leaflets that they could withdraw their scheduled appointments for the driving simulation experiments at any time. The pilot study leaflet also provided the contact information of the research team member, so the pilot study participants could schedule the driving simulation appointments. The leaflet was distributed across the FSU’s campus, FAMU’s campus, and surrounding areas such as grocery stores, coffee shops, and local shops after permission was granted. Furthermore, the leaflet was distributed among the students and faculty members of the FAMU- FSU College of Engineering.

Participants called the research team, and the following information was recorded for each participant: (1) name; (2) age; and (3) phone number. The driving simulation experiments were scheduled from 9 am to 5 pm, Monday through Friday. The duration of appointment for each participant was set to 1 hour (which was found to be adequate to complete the test drive scenario, scenarios [1]-[8], and accommodate necessary breaks between the scenarios). Throughout scheduling of participants the goal was to obtain about 25 participants for each one of the 4 age groups: (1) Group 1: 18-30 years old; (2) Group 2: 31-45 years old; (3) Group 3: 46-64 years old; and (4) Group 4: 65 years old and above. Before the start of the pilot study, the research team met to go through the whole process of how the driving simulation experiments should be conducted. Also, light snacks and drinks were provided in the simulator room to prevent any simulator sickness and to create a friendly environment.

The pilot study officially began on the 8th of April, 2019 and was completed on the 23rd of April, 2019. Upon arrival, each participant was asked to review the consent form, describing the objectives of the pilot study and expectations from the participants. A copy of the consent form is provided in Appendix B of this report. A signed consent form was scanned into a password protected computer (to ensure that the participant information will be confidential). Then, the participant was also asked to fill out the first part of the participant form, which contained the general information questions. The general information questions focused on the following participant features: age, gender, level of education, occupational status, household income, marital status, primary racial group, driving experience, average weekly driving frequency and distance, driving frequency and experience under inclement weather conditions, health-related questions, and driving ability questions. A copy of the participant form is provided in Appendix C of this report.

After completing the consent and participant data forms each participant was requested to seat in the driving simulator, and the research team member showed the participant the driving simulator features (i.e., the gearshift, pedals, turn signals, all mirrors, and the speedometer on the screen). Each participant was told that the first simulation scenario would be a test drive, so the participant could become aware of the level of sensitivity of driving simulator steers and brakes. The test drive scenario lasted between 3-5 minutes and comprised of straight urban roadway segments with two-left turns. Each participant was instructed to drive between 30-35 miles per hour and to obey any stop signs or lights on the route. Upon completion of the test drive scenario, the research team member asked if the participant was feeling okay. After that, each participant was requested to drive through scenarios [1]-[8]. Each scenario lasted 3-4 minutes per scenario.

The research team members randomly selected the order of scenarios to be completed by the participants. Such alteration of scenarios would allow eliminating the bias in the data collection and analysis. They were told that the speed limit was 65 miles per hour and that they were allowed to switch lanes after completing the merging maneuver. Moreover, speed limits signs showing "65 mph" were visible in the simulated environment. The participants were also informed to take the first exit from the freeway segment in order to complete each scenario. Moreover, the participants were reminded to tell the research team member if they felt too much discomfort during the simulation so that the research team would be able to stop the experiment. After the driving simulation experiments, the participants were requested to complete a set of Quick Simulator Sickness Assessment (QSSA) questions (see Appendix C) to rate how they were feeling in terms of discomfort in their head, stomach, or in any other part of their body. Also, the participants were asked a number of questions using the NASA TLX chart (2019) (see Appendix C) to assess their mental demand, physical demand, effort, frustration, and how well they believe they performed.

Once the participants completed all the driving simulation experiments and answered the questions following the experiment, they were given a $25 gift card and were thanked for their participation. Participants who became nauseous and couldn't complete the experiments were also given the $25 gift card and thanked for their time. After a given participant left the driving simulator room, the research team estimated additional driving performance indicators for scenarios [1]-[8] for that participant based on the data, collected during the corresponding experiments from the driving simulator along with QSSA and NASA TLX performance indicators. The driving performance indicators that were estimated for each participant and each scenario include the following (see **Error! Reference source not found.**): (1) total travel time (sec); (2) time to complete merging maneuver (sec); (3) time to complete diverging maneuver (sec); (4) lane deviation (ft); (5) crash frequency (number of crashes); (6) collision speed (mph); (7) average space headway (ft); (8) average time headway (sec); (9) minimum space headway (ft); (10) minimum time headway (sec); (11) maximum space headway (ft); (12) maximum time headway (sec); (13) average travel speed (mph); (14) travel speed standard deviation (mph); (15) average acceleration pedal pressure (from 0 to 1); and (16) average braking pedal pressure (from 0 to 1). The values of driving performance indicators were recorded for each participant in the participant form.

**Table 1 Estimated driving performance indicators.**

**To be completed by the research team members**

| a/a | Performance indicator | Data |
|---|---|---|
| 1 | Duration of the experiment, i.e. total travel time (sec) | |
| 2 | Time to complete merging maneuver (sec) | |
| 3 | Time to complete diverging maneuver (sec) | |
| 4 | Lane deviation (standard deviation of the lane position) | |
| 5 | Crash frequency (how many times the driver hit the other cars during the experiment) | |
| 6 | Collision speed (mph) | |
| 7 | Average space headway (ft) | |
| 8 | Average time headway (sec) | |
| 9 | Minimum space headway (ft) | |
| 10 | Minimum time headway (sec) | |
| 11 | Maximum space headway (ft) | |
| 12 | Maximum time headway (sec) | |
| 13 | Average travel speed (mph) | |

| | |
|---|---|
| 14 | Travel speed standard deviation (mph) |
| 15 | Average acceleration pedal pressure (from 0 to 1) |
| 16 | Average braking pedal pressure (from 0 to 1) |

The data collected throughout the pilot study, including the driver characteristics (e.g., age, gender, income, marital status, driving experience under normal and inclement weather conditions, health-related questions, and others) and driving performance indicators (e.g., total travel time, time to complete merging and diverging maneuver, mental demand, physical demand, effort, crash frequency, average travel speed, travel speed standard deviation, and others), will be used for the development of the statistical models under this project.

# 5. DISTRIBUTION OF COLLECTED DATA

A total of 100 subjects participated in the pilot study. Before starting the driving simulation experiment each participant was requested to answer a number of questions that were listed in the participant form. The questions, posed in the participant form, were related to the following aspects: (1) general participant information (such as age, gender, racial group, marital status, level of education, occupational status, and income); (2) driving experience under normal conditions (such as number of years of driving experience, average number of times driven per week, and average distance driven per week); (3) driving experience under foggy/adverse weather conditions; (4) health-related questions; (5) driving ability-related questions; and (6) experience driving the simulator (such as number of times driven a simulator before participating in the present driving simulation study). The options provided for each question were numbered starting from 1 based on the number of choices. This approach allowed the research team to enter the data in the database easily using the number assigned to the options. The response of each pilot study participant was entered into a Microsoft Excel sheet, and a database was created. A password-protected computer was used to store the information, which was gathered from the pilot study participants. The following sections of the report present a detailed analysis of the information gathered from the participants for each category of questions.

## 5.1 General Information

The first category of questions in the participant form aimed to gather the general information related to age, gender, level of education, occupational status, annual household income, marital status, and the race of the pilot study participants were captured in this section. Results of the statistical analysis of the collected data are reported in sections 0-0 of this report.

5.1.1 Distribution of participants by age

A total of 100 participants with ages ranging from 18 to 79 (M = 42.69 years, SD = 17.68 years)[1] participated in the pilot study. To obtain a proper distribution, the participants were classified into 4 age categories: (1) 18-30 years old; (2) 31-45 years old; (3) 46-64 years old; and (4) ≥65 years old. The distribution of the pilot study participants based on their age group is presented in **Error! Reference source not found.**. The analysis reveals that 32 participants were in the age group 1, 31 participants were in the age group 2, 16 participants were in the age group 3, while 21 participants were aged 65 and above. The distribution of pilot study participants based on their age group shows a relatively uniform spread.

5.1.2 Distribution of participants by gender

All the participants were requested to indicate their gender in the participant form. The distribution of the participants by gender is presented in **Error! Reference source not found.**. From the results, 51 participants (or 51%) were females, while 49 participants (or 49%) were males.

[1] M – is the notation used for "mean"; SD – is the notation used for "standard deviation".

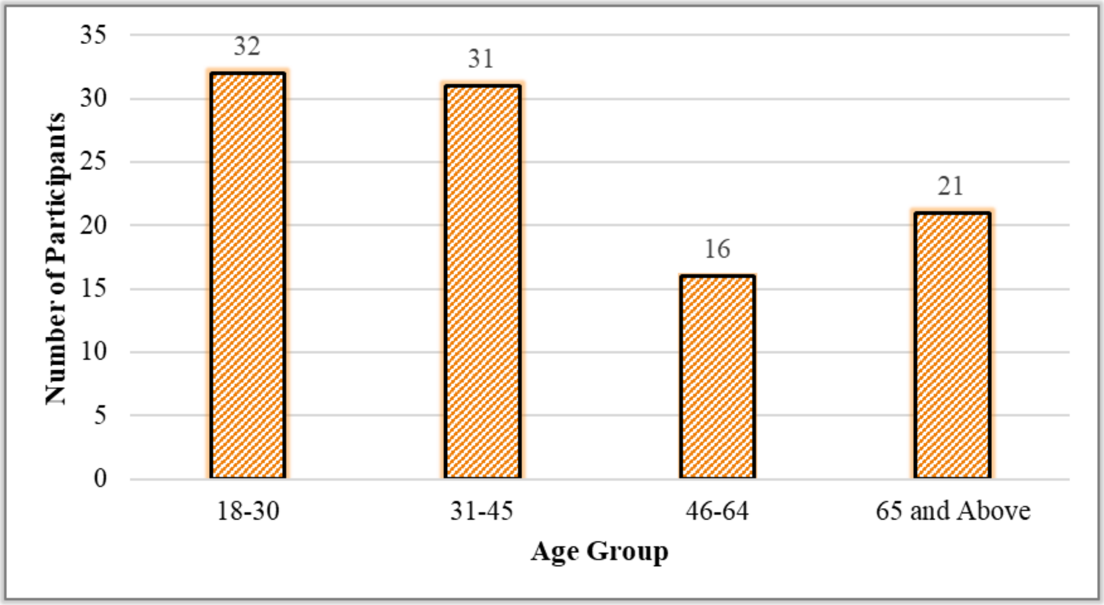



**Figure 4 Distribution of participants by age.**

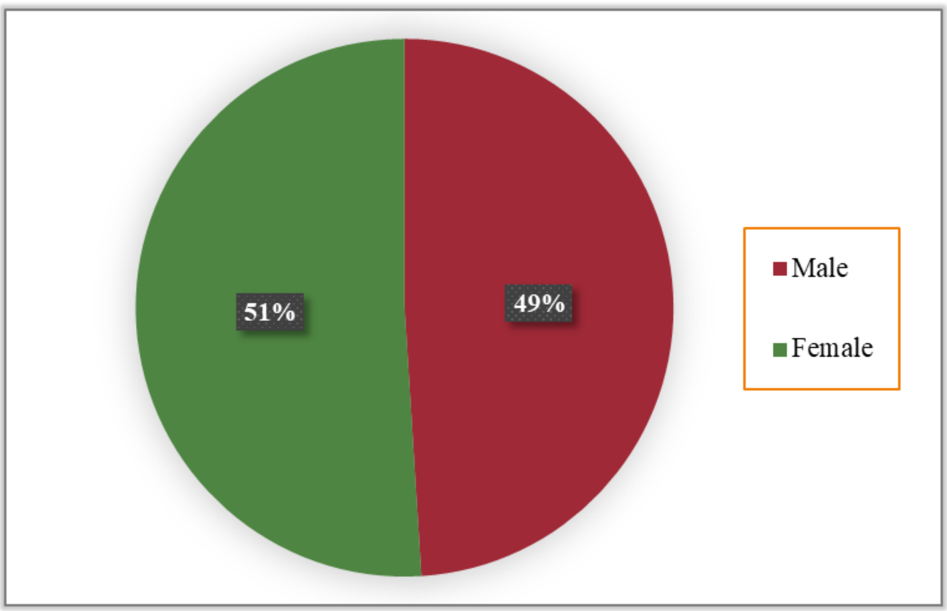



**Figure 5 Distribution of participants by gender.**

5.1.3 Distribution of participants by level of education

All the participants were requested to indicate their level of education in the participant form. The participants had to choose between options which include: 1) No formal education; 2) Less than high school graduate; 3) High school graduate/GED; 4) Vocational training; 5) Some college/Associate's degree; 6) Bachelor's degree (B.A., B.S.); 7) Master's degree (or other post-graduate training); and 8) Doctoral degree (Ph.D., M.D., Ed.D., D.D.S., J.D., etc.). All participants responded to this question by picking one of the options provided. From the analysis of the responses, it was found that most of the participants had a master's degree (32 participants or 32%), a bachelor's degree (23 participants or 23%), and an associate degree (16 participants or 16%). Also, 14 participants (or 14%) were high school graduates, 12 participants (or 12%) had a doctoral degree, and 2 participants (or 2%) took a vocational training. Only 1 participant did not graduate from a high school. The distribution of the participants by education level is presented in **Error! Reference source not found.**.

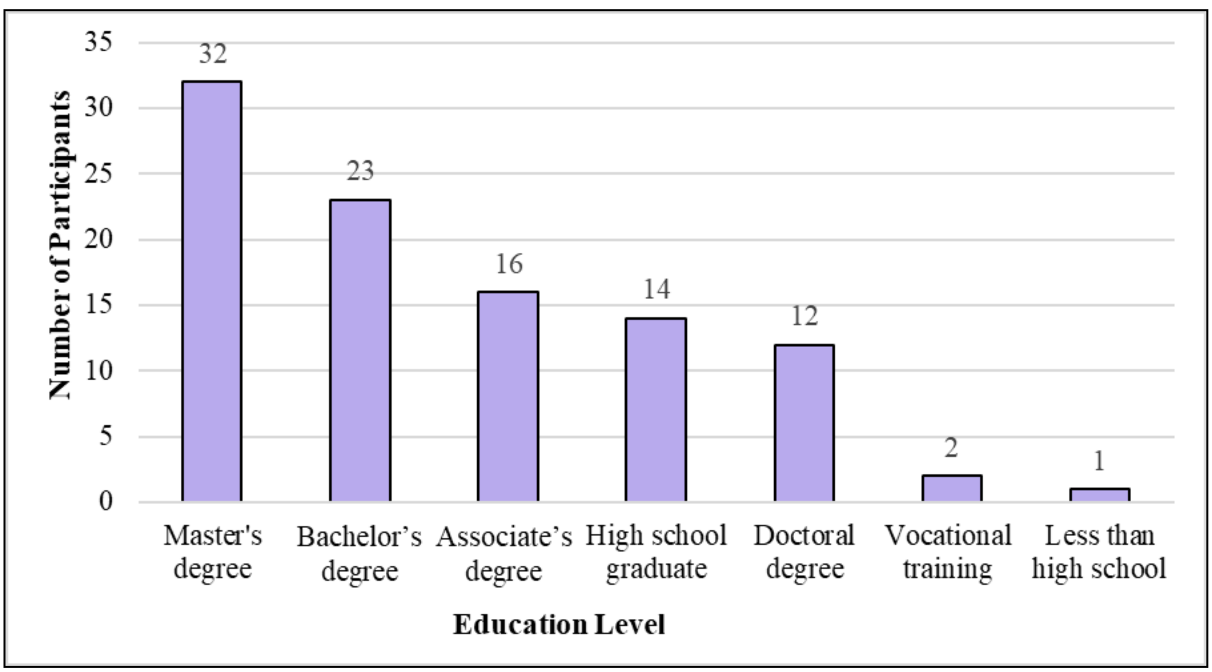



**Figure 6 Distribution of participants by level of education.**

5.1.4 Distribution of participants by primary occupational status

All the participants were requested to indicate their primary occupational status in the participant form. The following options were provided in the participant form: 1) Work Full-time; 2) Work Part-time; 3) Student; 4) Homemaker; 5) Retired; 6) Volunteer worker; 7) Seeking employment, laid off, etc. and 8) Other (participants were asked to specify). **Error! Reference source not found.** illustrates the distribution of the participants by occupational status. The analysis of responses to this question reveals that 39 participants (or 39%) were students, 30 participants (or 30%) were working full-time, 16 participants (or 16%) were retired, and 8 participants (or 8%) worked part-time. Moreover, 4 participants (or 4%) specified their job as other, and 2 participants (or 2%) were seeking employment. Only one participant was a homemaker.

5.1.5 Distribution of participants by yearly household income

All the participants were requested to indicate their annual household income in the participant form. The options started with "<$10,000" up to ">$80,000". The participants were also requested to indicate if they "do not know for certain" or if they "do not wish to answer". Distribution of the participants by yearly household income is presented in Table 2. Results show that 25 participants (or 25%) earn between $20,000 and $39,000, 20 participants (or 20%) earn between $40,000 and $59,000, 16 participants (or 16%) earn $80,000 or more, and 13 participants (or 13%) earn between $10,000 and $19,000. Also, 7 participants (or 7%) earn less than $10,000, and 4 participants (or 4%) earn between $60,000 and $79,000. Moreover, 10 participants (or 10%) said they do not wish to answer, while 5 participants (or 5%) did not know for certain what their annual household income was.

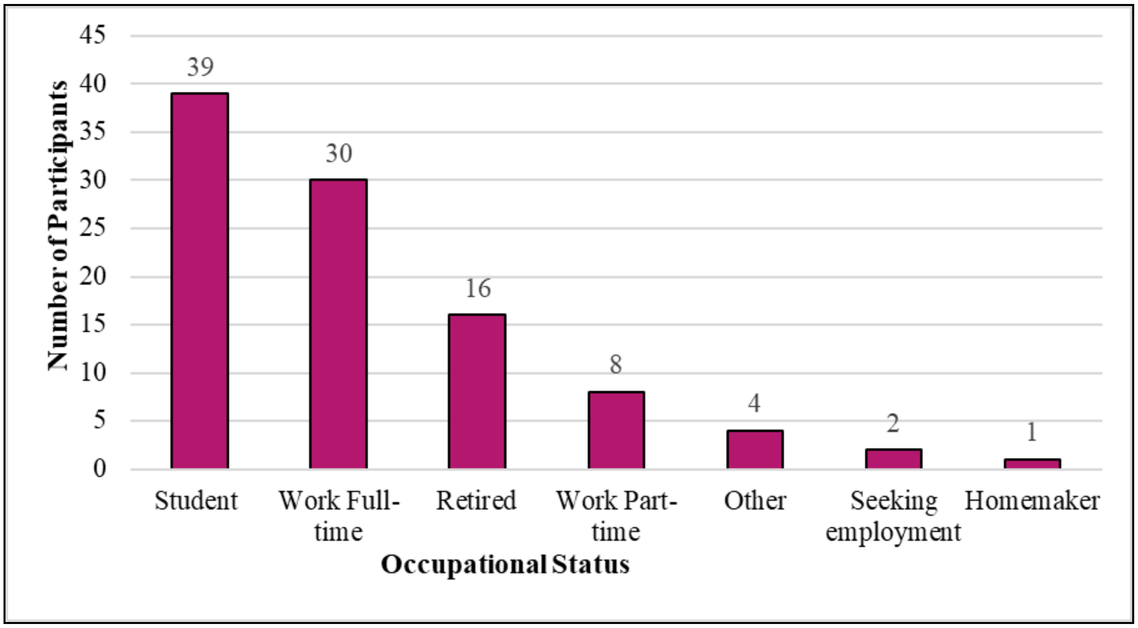



**Figure 7 Distribution of participants by primary occupational status.**

**Table 2 Distribution of participant by their yearly household income.**

| a/a | Household Income | No. of Participants | % Participants |
|---|---|---|---|
| 1 | Less than $10,000 | 7 | 7% |
| 2 | $10,000 - $19,999 | 13 | 13% |
| 3 | $20,000 - $39,999 | 25 | 25% |
| 4 | $40,000 - $59,999 | 20 | 20% |
| 5 | $60,000 - $79,999 | 4 | 4% |
| 6 | $80,000 or more | 16 | 16% |

| | | | |
|---|---|---|---|
| 7 | Do not know for certain | 5 | 5% |
| 8 | Do not wish to answer | 10 | 10% |

5.1.6 Distribution of participants by marital status

The participants were asked to indicate their marital status as either being single, married, separated, divorced, or widowed. A blank space was provided for any participant who did not belong to any of the marital status groups listed. Based on the study results, all the participants selected one of the options provided. The distribution of participants by marital status is presented in **Error! Reference source not found.**. It was found that 49 participants (or 49%) were married, 46 participants (or 46%) were single, 3 participants (or 3%) were separated, while 2 participants or (2%) were divorced. None of the participants were widowed.

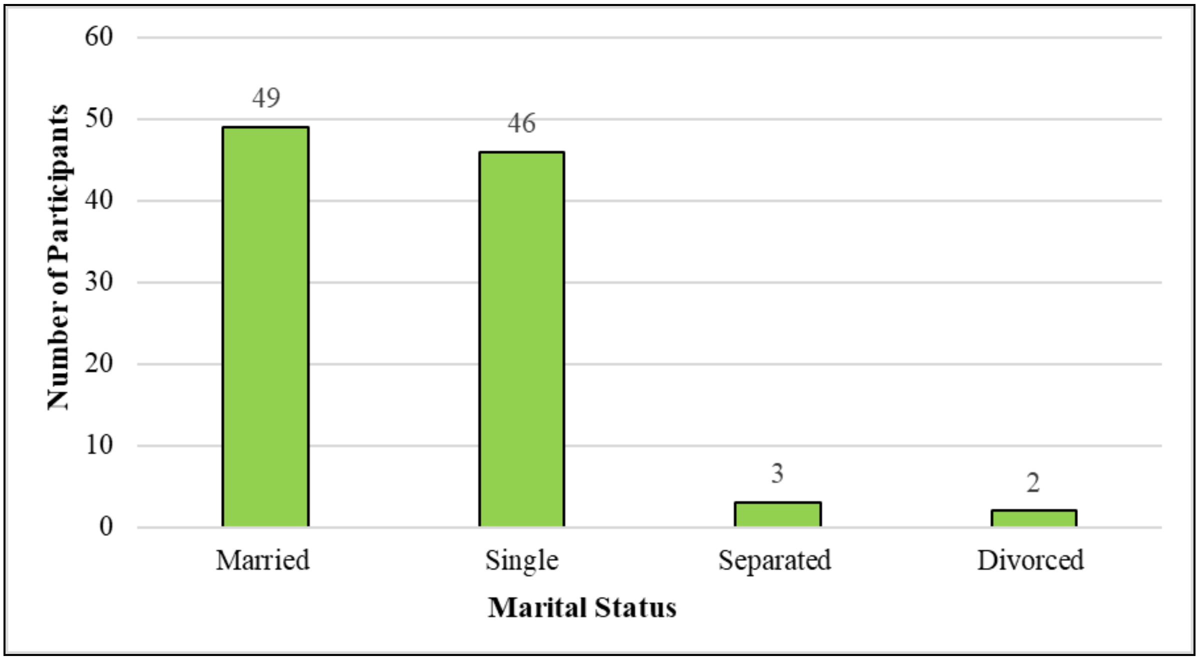



**Figure 8 Distribution of participants by marital status.**

5.1.7 Distribution of participants by primary racial group

All the participants were requested to indicate their primary racial group in the participant form. The list of options provided include: 1) No primary group; 2) White/Caucasian; 3) Black/African American; 4) Hispanic/Latino; 5) Asian; 6) American Indian/Alaska Native; 7) Native Hawaiian/Pacific Islander; and 8) Multi-racial. A blank space was provided for participants whose racial group was not on the list provided. Distribution of the participants by race is shown in Table 3. Results of the analysis show that all the participants indicated their racial group. Moreover, 38 participants (or 38%) were Black/African American, 33 participants (or 33%) were White/Caucasian, 13 participants (or 13%) were Asian, and 5 participants (or 5%) were Hispanic/Latino. Also, 2 participants (or 2%) multi-racial, 2 participants (or 2%) had no primary racial group, and one participant was an American Indian/Alaska Native. A total of 6 participants (or 6%) indicated that they belong to other racial groups.

**Table 3 Distribution of participants by primary racial group.**

| a/a | Racial Group | No. of Participants | % Participants |
|---|---|---|---|
| 1 | Black/African American | 38 | 38% |
| 2 | White/Caucasian | 33 | 33% |
| 3 | Asian | 13 | 13% |
| 4 | Hispanic/Latino | 5 | 5% |
| 5 | No Primary Group | 2 | 2% |
| 6 | Multi-racial | 2 | 2% |
| 7 | American Indian/Alaska Native | 1 | 1% |
| 8 | Other (please specify) | 6 | 6% |

## 5.2 Driving Experience

The second category of questions in the participant form aimed to gather the information related to the driving experience of participants. The information regarding the number of years the participants have been driving, an average mile driven per week, as well as the frequency of driving was collected. Results of the analysis performed are presented in sections 0-0 of this report.

### 5.2.1 Distribution of participants by driving experience

The participants were asked how long they had been driving, and they all reported the number of years driving, which ranged from 0 to 62 years (M = 20.80 years, SD = 18.64 years). To get a proper distribution, the data were sorted into classes of 10 years. **Error! Reference source not found.** shows the distribution of the participants by the number of years they have been driving. Results of the analysis show that 42 participants (or 42%), 17 participants (or 17%), and 12 participants (or 12%) had about 0-9 years, 20-29 years, and 10-19 years of driving experience, respectively. A high variation in the years of driving experience among participants can be explained by a significant difference in age of participants.

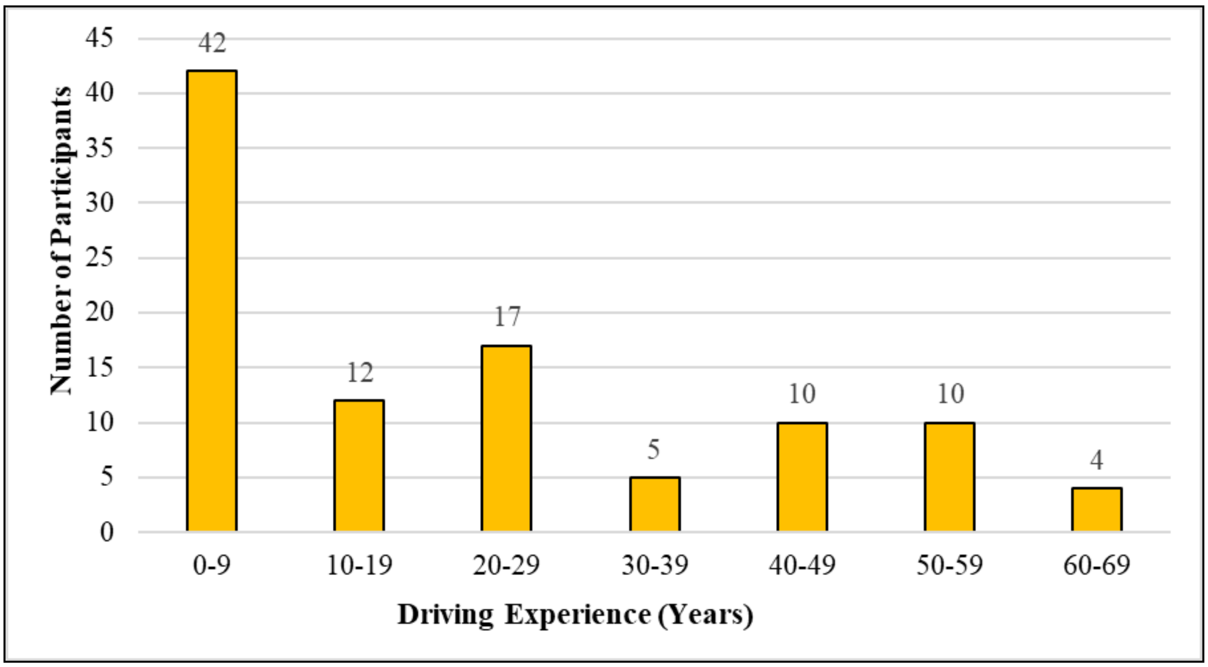



**Figure 9 Distribution of participants by driving experience.**

5.2.2 Distribution of participants by driving frequency

The participants were asked how often they drive per week. The following options were provided: (1) one time a week; (2) 2-4 times a week; (3) 5-10 times a week; and (4) 11+ times a week. The distribution of participants by driving frequency is presented in **Error! Reference source not found.**. Based on the analysis of responses, it was found that 43 participants (or 43%) drive at least 11 times a week, and 42 participants (or 42%) drive between 5-10 times per week. Also, 8 participants (or 8%), and 7 participants (or 7%) drive 2-4 times a week and once a week, respectively. Therefore, most of the participants of the pilot study are active drivers.

5.2.3 Distribution of participants by average distance they drive per week

All the participants were requested to indicate the average distance they drive per week. The following options were provided: (1) 0-2 miles; (2) 2-6 miles; (3) 6-10 miles; (4) 10-30 miles; (5) and 30+ miles. Results from the analysis of the collected data show that 38 participants (or 38%) drive 30 miles or more per week, and 35 participants (or 35%) drive between 10 and 30 miles per week. Also, 20 participants (or 20%) drive between 6 to 10 miles per week, 4 participants (or 4%) drive less than 3 miles per week, and 3 participants (or 3%) drive 2 to 6 miles per week. **Error! Reference source not found.** illustrates the distribution of participants by the average distance they drive per week.

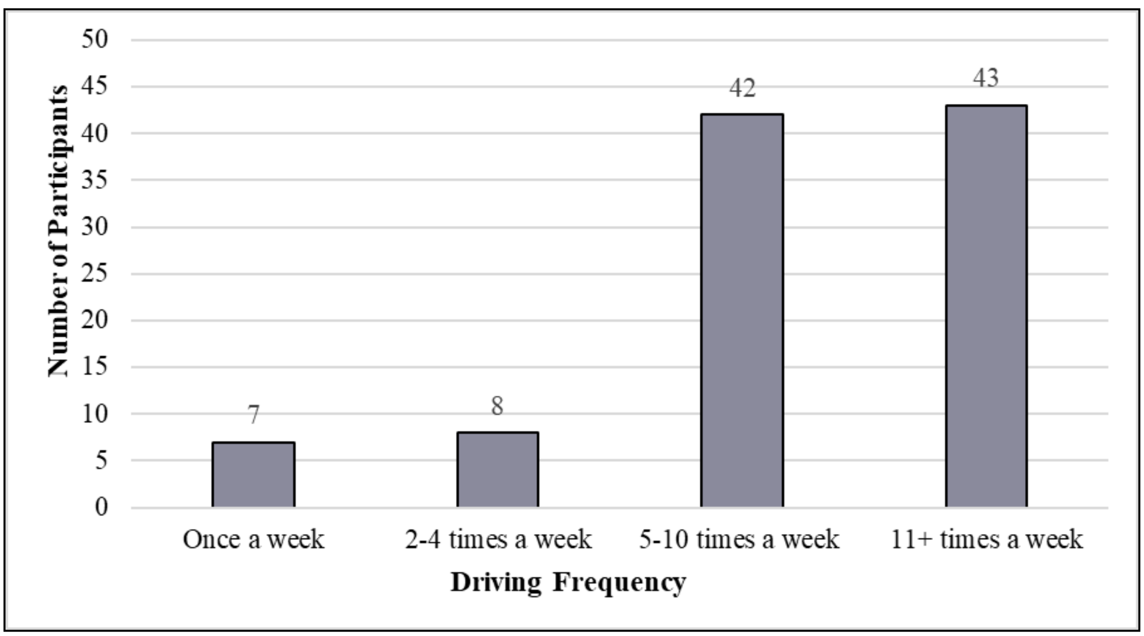



**Figure 10 Distribution of participants by driving frequency.**

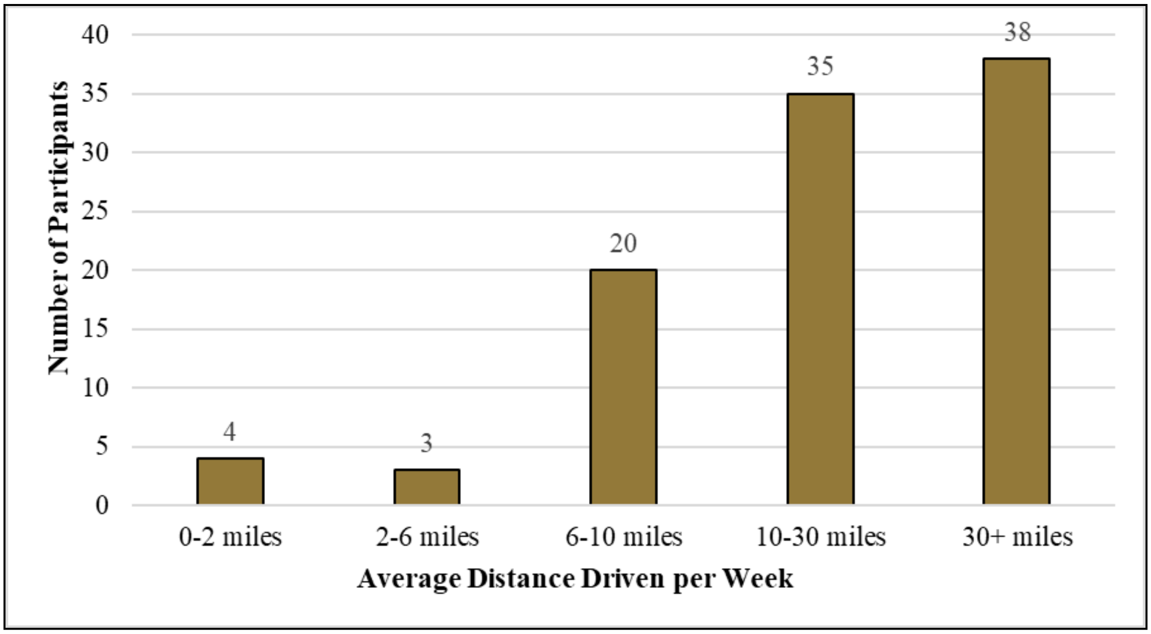



**Figure 11 Distribution of participants by average distance they drive per week.**

5.3 Driving Experience under Inclement Weather Condition

The third category of questions in the participant form aimed to gather the information related to the driving experience of participants under inclement weather condition. The participants were asked how often they drive under inclement weather condition. The following options were provided: (1) once in two weeks; (2) once a week; (3) two times a week; and (4) more than two times a week. The distribution of participants by their driving frequency under inclement weather condition is presented in **Error! Reference source not found.**. Based on the analysis of responses, it was found that 46 participants (or 46%) drive under inclement weather condition once every two weeks, and 25 participants (or 25%) drive under inclement weather condition once a week. Also, 15 participants (or 15%) and 14 participants (or 14%) drive under inclement weather condition two times a week and more than twice a week, respectively. Therefore, all the participants have experience driving under inclement weather conditions. The distribution of participants by the number of times they drive under inclement weather condition is presented in **Error! Reference source not found.**.

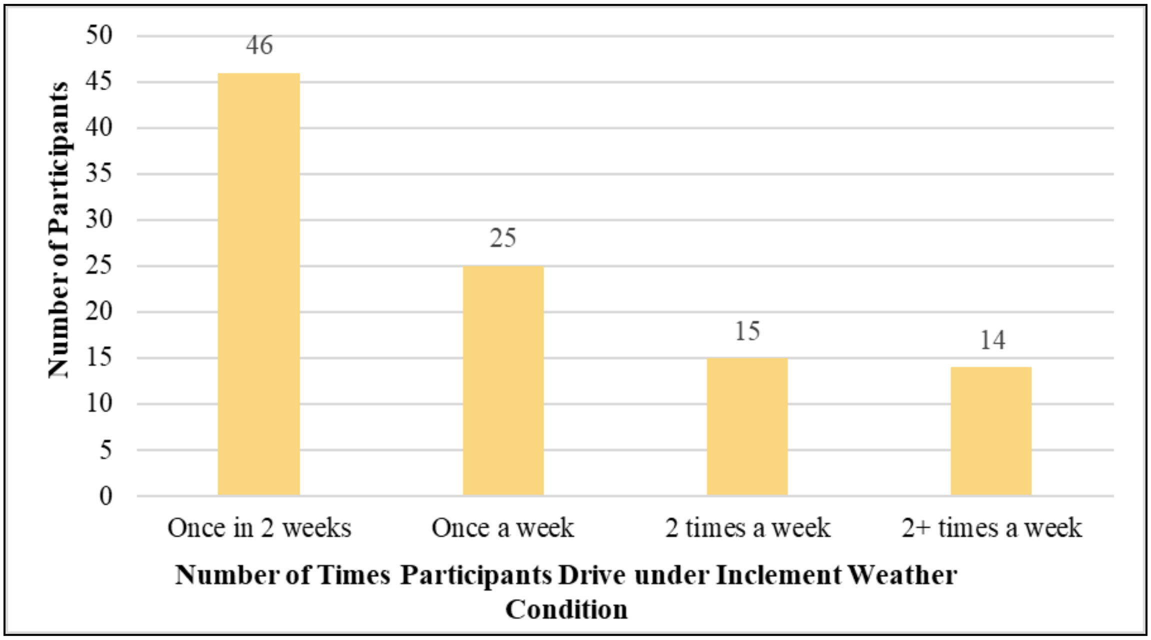



**Figure 12 Distribution of participants by driving frequency under inclement weather condition.**

The participants were asked to indicate how often they drive under foggy weather condition. The analysis of the collected data reveals that 47 participants (or 47%) drive under a foggy weather condition less than one time in two months, 25 participants (or 25%) drive under a foggy weather condition once in two months, and 17 participants (or 17%) drive under a foggy weather condition once a month. A total of 11 participants (or 11%) drive under a foggy weather condition at least two times a month. The distribution of participants by driving experience under foggy weather condition is presented in **Error! Reference source not found.**. Also, the participants were asked if they had ever experienced any difficulty while driving during under an inclement weather condition. It was found that 48 participants (or 48%) had difficulties driving during an inclement weather condition, while the other 52 participants (or 52%) did not experience any difficulties.

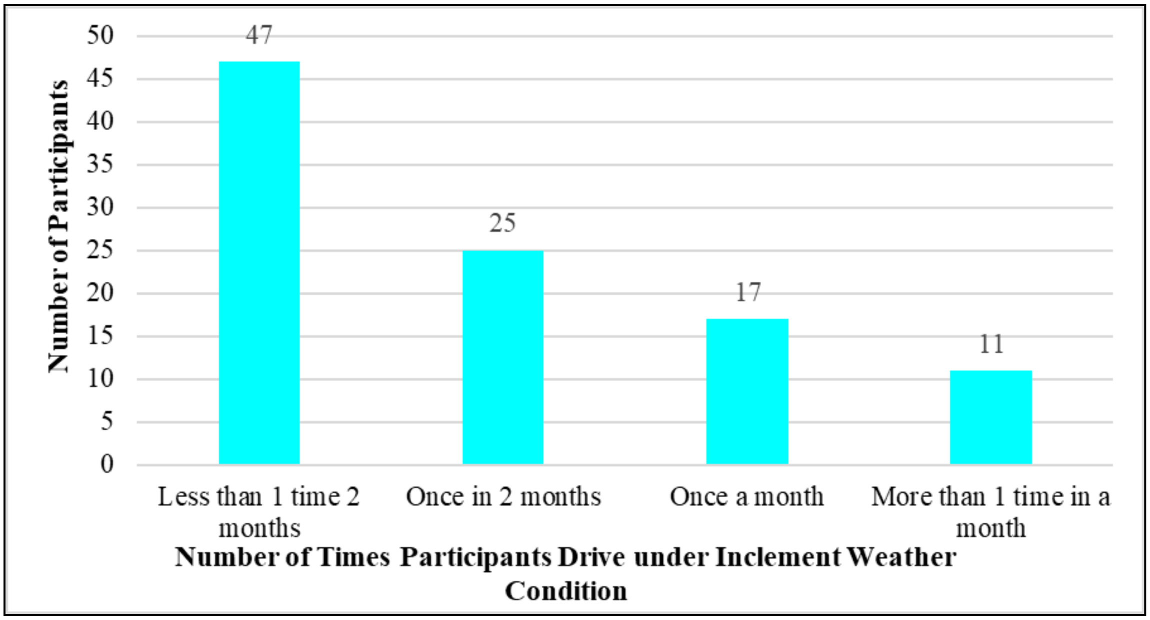



**Figure 13 Distribution of participants by driving frequency under foggy weather condition.**

5.4 Health-Related Questions

The fourth category of questions in the participant form aimed to gather the information related to the health condition of the participants. First, the pilot study participants were requested to rate their health, compared to others of their age based on their individual perception. **Error! Reference source not found.** shows the distribution of participants by the self-reported health condition. Results from the analysis of the collected responses reveal that 29 participants (or 29%) rated their health as "excellent", 34 participants (or 34%) said that their health was "very good", and 31 participants (or 31%) reported their health status as "good". Also, 6 participants (or 6%) said that their health was "fair", and none of the participants reported that their health was "poor" compared to others of their age. Furthermore, a total of 21 participants (or 21%) confirmed that they had visual disorders, while the rest of participants did not report any visual disorders. A total of 7 participants (or 7%) indicated that they had a chronic disease (e.g., cancer, dementia, diabetes, heart disease), while 93 participants (or 93%) said that they did not have any chronic diseases.

Second, the participants were asked to rate their vision compared to others of their age group. **Error! Reference source not found.** illustrates the distribution of participants by vision rating. The analysis of the collected data reveals that 21 participants (or 21%), 29 participants (or 29%), and 38 participants (or 38%) reported that they had “excellent” vision, “very good” vision, and “good” vision, respectively. Also, 10 participants (or 10%) said that they had a “fair” vision, and 2 participants (or 2%) reported their vision as “poor” compared to others of their age.

Third, the participants were asked to rate their hearing compared to others of their age. The distribution of participants based on hearing ratings is presented in **Error! Reference source not found.**. Results from the analysis of the collected data demonstrate that 27 participants (or 27%) reported that they had an “excellent” hearing, while 37 participants (or 37%) had a “very good” hearing. A total of 32 participants (or 32%) indicated that they had a “good” hearing. Also, 4 participants (or 4%) said that they had a “fair” hearing ability, and none of the participants reported their hearing as “poor” compared to others of their age.

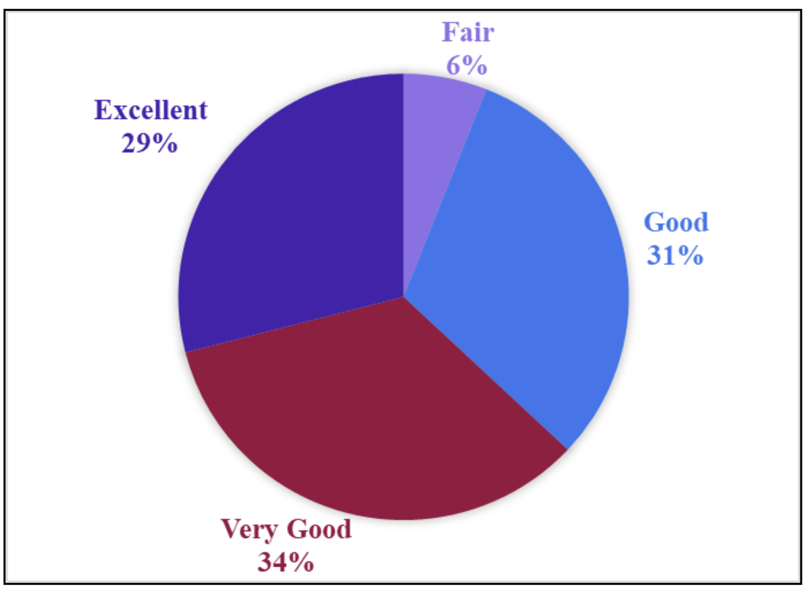



**Figure 14 Distribution of participants by self-reported medical condition.**

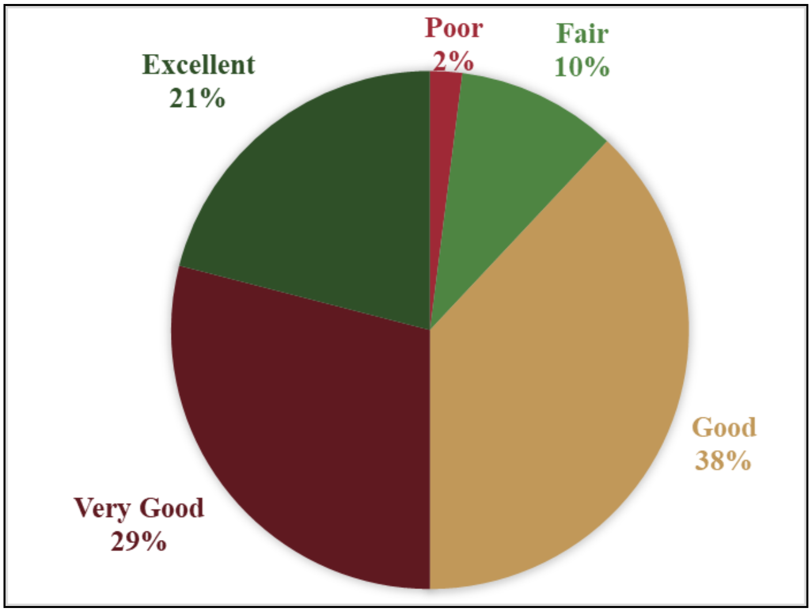



**Figure 15 Distribution of participants by vision rating.**

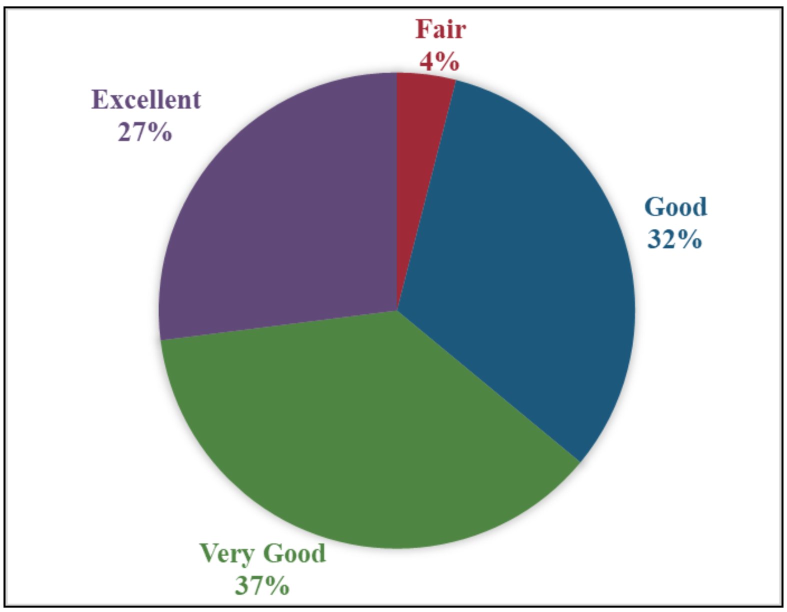



**Figure 16 Distribution of participants by hearing rating.**

### 5.5 Driving Ability

The fifth category of questions in the participant form aimed to gather the information related the driving ability of the pilot study participants. First, the participant were asked to rate their ability to see road signs at a distance. A total of 40 participants reported “very good”, while 45 participants indicated “good”. Moreover, 14 participants rated their ability to see road signs at a distance as “fair”, while one participant reported “poor”. Second, the participants were requested to rate their ability to see the speedometer and controls. A total of 91 participants rated their ability to see the speedometer and controls as “very good” or “good”, and 9 participants reported “fair”. Third, the participants were asked to rate their ability to avoid hitting curbs and medians. A total of 44 participants reported “very good”, 43 participants stated “good”, 12 participants indicated “fair”, and one participant reported “poor”. Fourth, the participants were requested to rate their ability to see an upcoming vehicle beside them. The analysis of the collected responses indicates that 89 participants rated their ability to see an upcoming vehicle beside them as “very good” or “good”, and 11 participants reported “fair”.

Fifth, the participants were asked to rate their ability to move their foot quickly from the gas pedal to the brake pedal. Results from the analysis reveal that 90 participants rated their ability to move their foot quickly from the gas pedal to the brake pedal as “good” or “very good”, 9 participants responded “fair”, and one participant indicated “poor”. Sixth, the participants were requested to rate their ability to make over-the-shoulder check. It was found that 82 participants rated their ability to make over-the-shoulder check as “good” or “very good”, while 16 other participants reported “fair”. A total of 2 participants rated their ability to make over-the-shoulder check as “poor”. Seventh, the participants were asked to rate their ability to make quick driving decisions. The analysis of the collected data indicates that 88 participants rated their ability to make quick driving decisions as “good” or “very good”, while 12 participants reported “fair”. Eighth, the participants were requested to rate their ability to drive safely (avoid accidents). Results showed that 47 participants rated their ability to drive safely as “very good”, 44 participants indicated “good”, and 8 participants reported “fair”. Only one participant rated their ability to drive safely as “poor”.  Ninth, the participants were asked to rate their ability to react to a blowing horn from an approaching car. A total of 86 participants rated their ability to react to a blowing horn from an approaching car as “good” and “very good”, 13 participants responded “fair”, while one participant indicated “poor”.

5.6 Experience Driving in a Simulator

All participants were requested to indicate the number of times they had driven a simulator before they took the pilot study experiments. **Error! Reference source not found.** shows the distribution of the participants by the number of times they have driven a simulator. All of the participants responded to this question, and the analysis of their responses shows that 50 participants (or 50%) have driven a simulator once or twice, while 43 participants (or 43%) have never driven a simulator before the pilot study. Also, 6 participants (or 6%) have driven a simulator about three to five times, and only 1 participants (or 1%) have driven the simulator more than ten times.

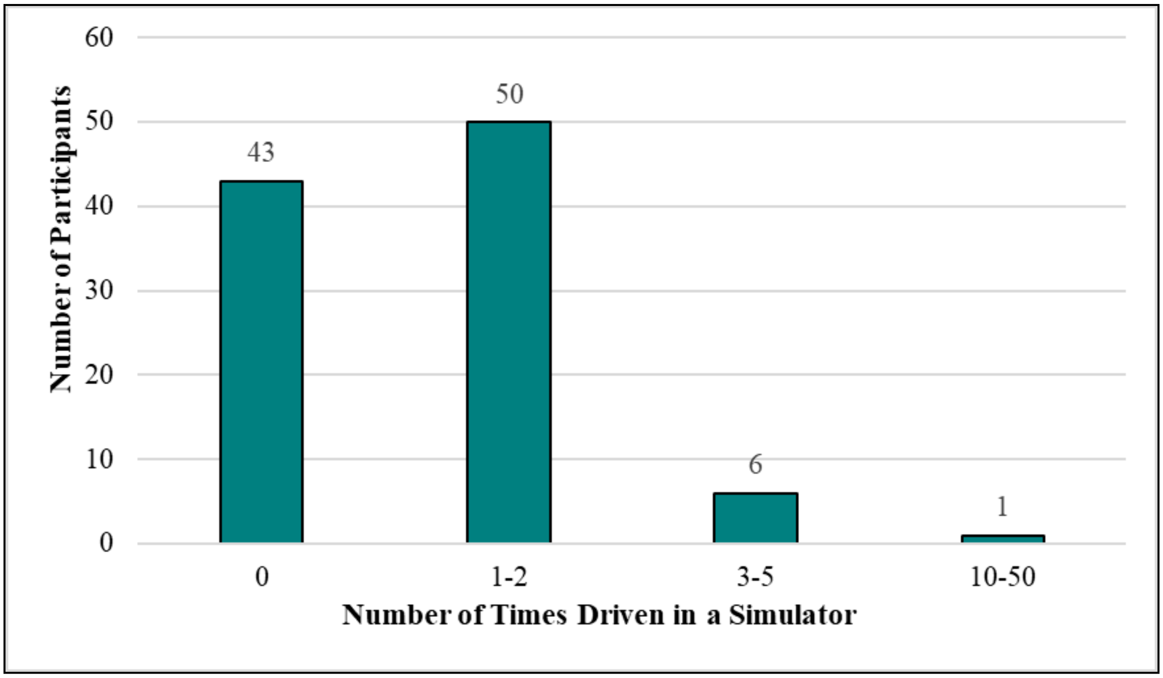



**Figure 17 Distribution of participants by number of times they have driven a simulator.**

# 6. STATISTICAL ANALYSIS AND RESULTS

## 6.1 Descriptive Statistics of Response Variables for Each Scenario

This section shows in tables the descriptive statistic (mean, variance, standard deviation, median, maximum and minimum) of the response or independent variables for each scenario

Table 4 Four-lane freeway, LOS A in clear weather

| *Response Variable* | *Mean* | *Var* | *Std* | *Median* | *Max* | *Min* |
|---|---|---|---|---|---|---|
| *Duration of experiment (sec)* | 166.516 | 641.847 | 25.335 | 164.120 | 271.122 | 117.486 |
| *Time to complete diverging Maneuver (sec)* | 2.843 | 1.049 | 1.024 | 2.670 | 7.530 | 1.160 |
| *Time to complete Merging Maneuver (sec)* | 9.608 | 5.159 | 2.271 | 9.630 | 15.630 | 2.300 |
| *Lane Deviation* | 0.505 | 0.009 | 0.097 | 0.502 | 0.852 | 0.313 |
| *Crash Frequency* | 0.021 | 0.020 | 0.143 | 0.000 | 1.000 | 0.000 |
| *Collision Speed (mph)* | 0.721 | 24.969 | 4.997 | 0.000 | 36.431 | 0.000 |
| *Average Acceleration Pedal Pressure from 0 to 1* | 0.270 | 0.010 | 0.099 | 0.247 | 0.709 | 0.123 |
| *Average Braking Pedal Pressure from 0 to 1* | 0.047 | 0.001 | 0.027 | 0.039 | 0.168 | 0.012 |

Table 5 Four-lane freeway, LOS A in foggy weather

| *Response Variable* | *Mean* | *Var* | *Std* | *Median* | *Max* | *Min* |
|---|---|---|---|---|---|---|
| *Duration of experiment (sec)* | 180.717 | 714.684 | 26.734 | 173.903 | 275.289 | 121.486 |
| *Time to complete diverging Maneuver (sec)* | 2.693 | 2.072 | 1.439 | 2.370 | 11.930 | 1.030 |
| *Time to complete Merging Maneuver (sec)* | 10.308 | 7.539 | 2.746 | 10.230 | 19.800 | 2.700 |
| *Lane Deviation* | 0.481 | 0.011 | 0.105 | 0.464 | 0.893 | 0.314 |
| *Crash Frequency* | 0.198 | 0.181 | 0.426 | 0.000 | 2.000 | 0.000 |
| *Collision Speed (mph)* | 7.165 | 228.826 | 15.127 | 0.000 | 46.592 | 0.000 |
| *Average Acceleration Pedal Pressure from 0 to 1* | 0.252 | 0.010 | 0.100 | 0.223 | 0.572 | 0.099 |
| *Average Braking Pedal Pressure from 0 to 1* | 0.047 | 0.000 | 0.021 | 0.044 | 0.119 | 0.009 |

Table 6 Four-lane freeway, LOS B in clear weather

| *Response Variable* | *Mean* | *Var* | *Std* | *Median* | *Max* | *Min* |
|---|---|---|---|---|---|---|
| *Duration of experiment (sec)* | 161.113 | 387.481 | 19.685 | 157.036 | 263.289 | 123.686 |
| *Time to complete diverging Maneuver (sec)* | 2.724 | 0.820 | 0.905 | 2.530 | 5.840 | 1.130 |
| *Time to complete Merging Maneuver (sec)* | 9.791 | 4.892 | 2.212 | 9.465 | 15.800 | 4.330 |
| *Lane Deviation* | 0.505 | 0.012 | 0.108 | 0.491 | 0.854 | 0.288 |
| *Crash Frequency* | 0.010 | 0.010 | 0.102 | 0.000 | 1.000 | 0.000 |
| *Collision Speed (mph)* | 0.482 | 22.320 | 4.724 | 0.000 | 46.290 | 0.000 |
| *Average Acceleration Pedal Pressure from 0 to 1* | 0.271 | 0.008 | 0.089 | 0.254 | 0.634 | 0.103 |
| *Average Braking Pedal Pressure from 0 to 1* | 0.044 | 0.000 | 0.016 | 0.042 | 0.085 | 0.010 |

Table 7 Four-lane freeway, LOS B in foggy weather

| *Response Variable* | *Mean* | *Var* | *Std* | *Median* | *Max* | *Min* |
|---|---|---|---|---|---|---|
| *Duration of experiment (sec)* | 177.584 | 356.285 | 18.876 | 173.170 | 248.655 | 131.653 |
| *Time to complete diverging Maneuver (sec)* | 2.619 | 0.670 | 0.819 | 2.485 | 5.260 | 1.060 |
| *Time to complete Merging Maneuver (sec)* | 10.555 | 9.735 | 3.120 | 10.460 | 25.360 | 2.600 |
| *Lane Deviation* | 0.457 | 0.010 | 0.102 | 0.439 | 0.796 | 0.248 |
| *Crash Frequency* | 0.229 | 0.263 | 0.513 | 0.000 | 2.000 | 0.000 |
| *Collision Speed (mph)* | 5.918 | 172.795 | 13.145 | 0.000 | 43.019 | 0.000 |
| *Average Acceleration Pedal Pressure from 0 to 1* | 0.259 | 0.009 | 0.094 | 0.237 | 0.660 | 0.108 |
| *Average Braking Pedal Pressure from 0 to 1* | 0.049 | 0.000 | 0.020 | 0.045 | 0.118 | 0.019 |

Table 8 Six-lane freeway, LOS A in clear weather

| *Response Variable* | *Mean* | *Var* | *Std* | *Median* | *Max* | *Min* |
|---|---|---|---|---|---|---|
| *Duration of experiment (sec)* | 188.796 | 707.598 | 26.601 | 187.420 | 299.623 | 133.319 |
| *Time to complete diverging Maneuver (sec)* | 4.306 | 25.318 | 5.032 | 3.560 | 52.530 | 1.900 |
| *Time to complete Merging Maneuver (sec)* | 7.350 | 9.332 | 3.055 | 6.530 | 19.630 | 3.360 |
| *Lane Deviation* | 0.738 | 0.009 | 0.096 | 0.728 | 0.953 | 0.538 |
| *Crash Frequency* | 0.041 | 0.040 | 0.200 | 0.000 | 1.000 | 0.000 |
| *Collision Speed (mph)* | 1.257 | 41.285 | 6.425 | 0.000 | 46.921 | 0.000 |
| *Average Acceleration Pedal Pressure from 0 to 1* | 0.259 | 0.006 | 0.074 | 0.244 | 0.605 | 0.105 |
| *Average Braking Pedal Pressure from 0 to 1* | 0.047 | 0.001 | 0.026 | 0.039 | 0.138 | 0.010 |

Table 9 Six-lane freeway, LOS A in foggy weather

| *Response Variables* | *Mean* | *Var* | *Std* | *Median* | *Max* | *Min* |
|---|---|---|---|---|---|---|
| *Duration of experiment (sec)* | 201.714 | 948.197 | 30.793 | 195.621 | 341.223 | 144.686 |
| *Time to complete diverging Maneuver (sec)* | 4.044 | 1.614 | 1.270 | 4.060 | 7.300 | 1.060 |
| *Time to complete Merging Maneuver (sec)* | 7.103 | 7.623 | 2.761 | 6.430 | 17.130 | 2.210 |
| *Lane Deviation* | 0.680 | 0.189 | 0.435 | 0.626 | 4.820 | 0.444 |
| *Crash Frequency* | 0.299 | 0.358 | 0.598 | 0.000 | 3.000 | 0.000 |
| *Collision Speed (mph)* | 8.597 | 263.207 | 16.224 | 0.000 | 53.656 | 0.000 |
| *Average Acceleration Pedal Pressure from 0 to 1* | 0.244 | 0.005 | 0.072 | 0.234 | 0.533 | 0.087 |
| *Average Braking Pedal Pressure from 0 to 1* | 0.046 | 0.000 | 0.021 | 0.044 | 0.112 | 0.005 |

Table 10 Six-lane freeway, LOS B in clear weather

| *Response Variable* | *Mean* | *Var* | *Std* | *Median* | *Max* | *Min* |
|---|---|---|---|---|---|---|
| *Duration of experiment (sec)* | 176.073 | 483.751 | 21.994 | 171.337 | 301.023 | 127.319 |
| *Time to complete diverging Maneuver (sec)* | 3.775 | 0.971 | 0.985 | 3.485 | 6.630 | 1.230 |
| *Time to complete Merging Maneuver (sec)* | 7.071 | 8.690 | 2.948 | 6.300 | 25.200 | 3.370 |
| *Lane Deviation* | 0.689 | 0.010 | 0.101 | 0.668 | 0.911 | 0.478 |
| *Crash Frequency* | 0.052 | 0.050 | 0.223 | 0.000 | 1.000 | 0.000 |
| *Collision Speed (mph)* | 1.751 | 60.071 | 7.751 | 0.000 | 49.425 | 0.000 |
| *Average Acceleration Pedal Pressure from 0 to 1* | 0.280 | 0.008 | 0.090 | 0.259 | 0.682 | 0.101 |
| *Average Braking Pedal Pressure from 0 to 1* | 0.041 | 0.000 | 0.017 | 0.036 | 0.106 | 0.010 |

Table 11 Six-lane freeway, LOS B in foggy weather

| *Response Variable* | *Mean* | *Var* | *Std* | *Median* | *Max* | *Min* |
|---|---|---|---|---|---|---|
| *Duration of experiment (sec)* | 195.162 | 621.966 | 24.939 | 189.854 | 301.989 | 140.153 |
| *Time to complete diverging Maneuver (sec)* | 4.036 | 1.582 | 1.258 | 3.830 | 9.560 | 1.400 |
| *Time to complete Merging Maneuver (sec)* | 7.220 | 6.408 | 2.531 | 6.600 | 17.100 | 3.670 |
| *Lane Deviation* | 0.608 | 0.007 | 0.084 | 0.600 | 0.886 | 0.465 |
| *Crash Frequency* | 0.330 | 0.473 | 0.688 | 0.000 | 4.000 | 0.000 |
| *Collision Speed (mph)* | 8.456 | 237.507 | 15.411 | 0.000 | 50.612 | 0.000 |
| *Average Acceleration Pedal Pressure from 0 to 1* | 0.263 | 0.007 | 0.084 | 0.256 | 0.545 | 0.101 |
| *Average Braking Pedal Pressure from 0 to 1* | 0.048 | 0.000 | 0.021 | 0.047 | 0.115 | 0.004 |

## 6.2 Statistical Analysis

This section assesses the variances and means of the age groups in their times to complete merging maneuvers (or merging time) using Analysis of variance. Also, statistical models were developed to evaluate the significance of all other predictor variables in completing merging maneuvers. A log linear regression model was adopted for this analysis because the logarithm of the response variable (Time to complete merging maneuver) was found to be normally distributed.

6.2.1 Analysis of Variance (ANOVA) among Age Groups

The null hypothesis for this analysis was that the age group into which participants fall in does not affect their merging time and if the age group affected travel time then the question is where do the differences lie? The analysis in this section was developed to answer these questions - using a one-way ANOVA and a resulting post hoc analysis.

Normality: Before using the ANOVA, a test for normality was performed to make sure the response variable followed a normal or near normal distribution. The residuals for the merging time deviated slightly from a normal distribution; therefore, a log-normal distribution was used. Figure 18 shows the response variable before and after normalization.

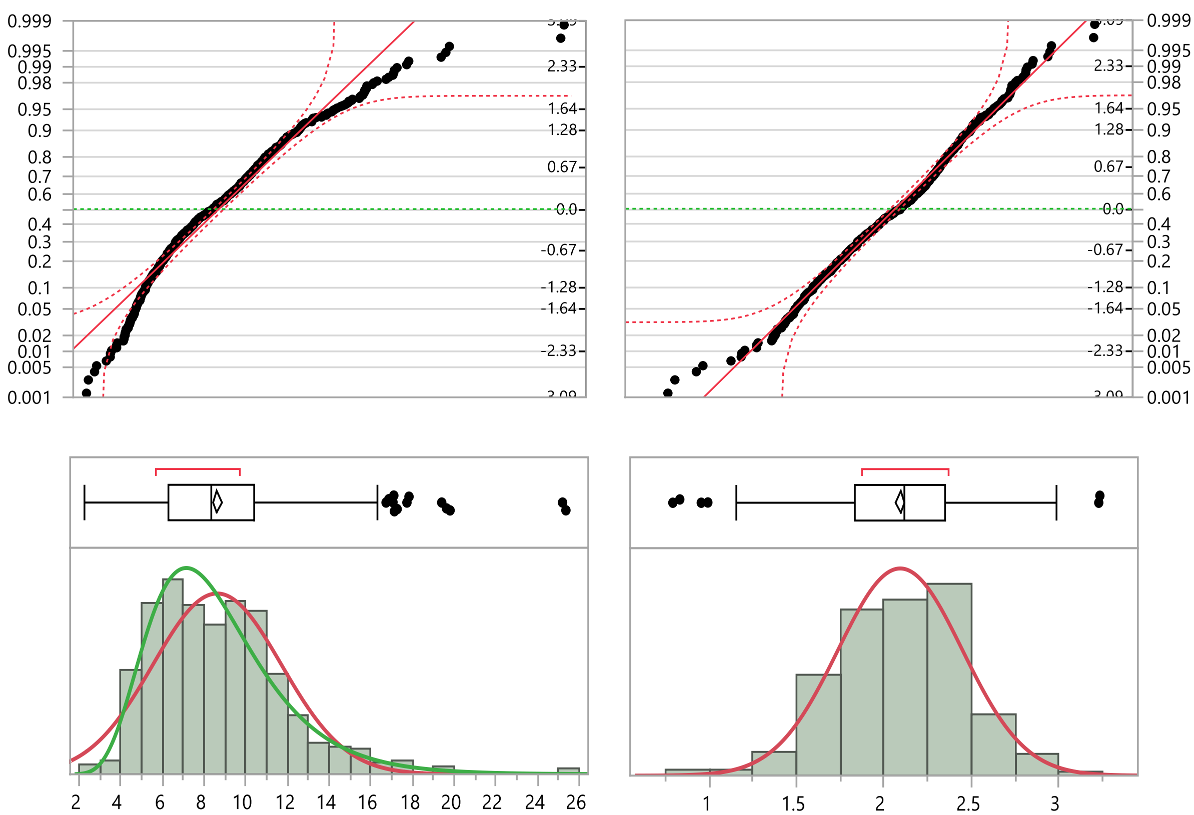


**Figure 18 Plots of response variable before and after normalization.**

Independence: The Chi-Square test was done to test for non-independence among age groups. With a null hypothesis of independence among the age groups, the p-Value for the Chi-Square approximation resulted to 0.0014, rejecting the null hypothesis. Therefore, there was non-independence of residuals among the age groups.

Homoscedasticity: Figure 19 shows that the age groups have unequal sample sizes and variances. To determine if the differences among the heterogenous group samples are statistically significant, the Welch test was used to compare the means of the groups. The null hypothesis of equal means (allowing unequal standard deviations) among the age groups for the Welch test was also rejected with a p-value of 0.0009. This is much less than the 0.05 threshold, indicating significant differences among the means of the age groups.

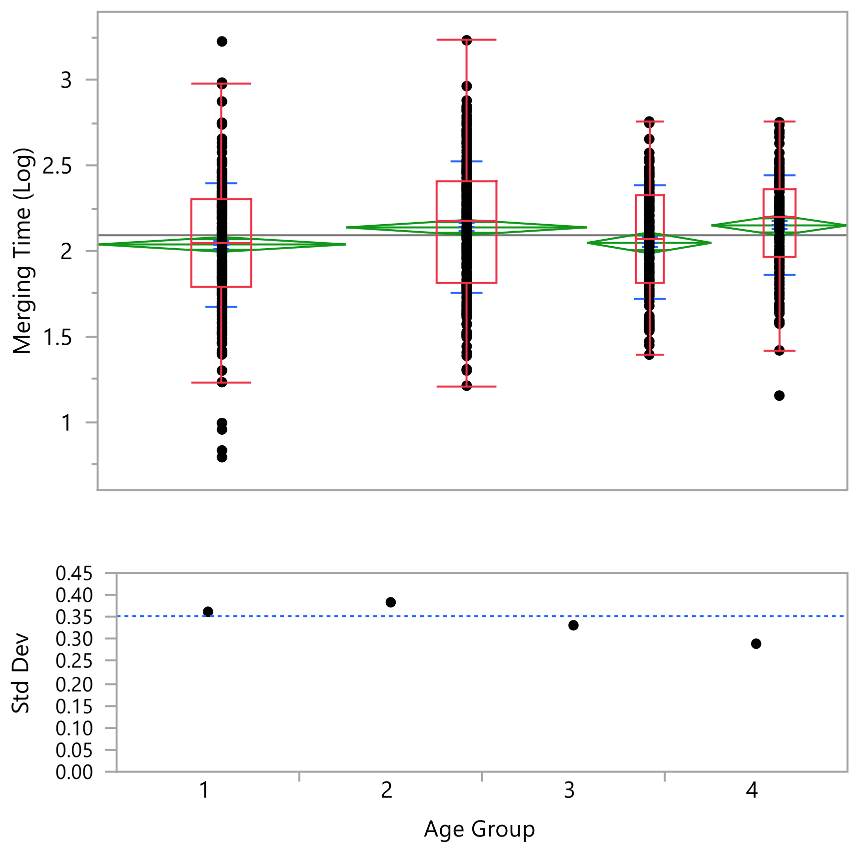



**Figure 19 Unequal variance and standard deviation among age groups.**

Post-hoc Analysis: A post-hoc analysis was further done to detect where the differences among the age groups lie. Using Wilcoxon method for nonparametric samples, comparisons were done in pairs to see the pairs with the most significant differences, as presented in Table 12.

The score mean difference is computed using the equations below:

$$Positive\ Score\ Mean\ Difference = \frac{RankSum1 - 0.5}{N1} - \frac{RankSum2 + 0.5}{N2}$$

$$Negative\ Score\ Mean\ Difference = \frac{RankSum1 + 0.5}{N1} - \frac{RankSum2 - 0.5}{N2}$$

where:

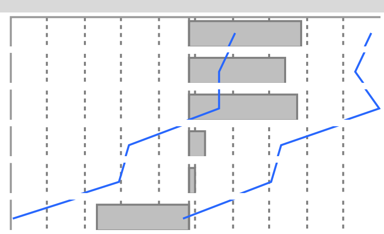
$RankSum1$ - sum of the ranks for group 1;

$Ranksum2$ - sum of the ranks for group 2;

$N1$ - sample size of group 1;

$N2$ - sample size of group 2.

Table 12 Nonparametric comparisons among age groups

| Group | - Group | Score Mean Diff | Std Err Diff | Z Score | p-Value | Difference Plot |
|---|---|---|---|---|---|---|
| 4 | 1 | 38.661 | 12.031 | 3.213 | 0.0013* |  |
| 2 | 1 | 35.719 | 12.976 | 2.753 | 0.0059* | |
| 4 | 3 | 24.818 | 9.479 | 2.618 | 0.0088* | |
| 4 | 2 | 4.559 | 11.855 | 0.385 | 0.7005 | |
| 3 | 1 | 1.154 | 12.015 | 0.096 | 0.9235 | |
| 3 | 2 | -25.336 | 11.829 | -2.142 | 0.0322* | |

*Group *p*-value < 0.005.

The rank mean of the merging time of drivers in group 4 is higher than that of group 1 and group 3 with a p-Value of 0.0013 and 0.0059 respectively. However, there was no statistically significant difference between group 4 and group 2, indicated by a p-Value of 0.7005. Statistical insignificance is also shown between groups 3 and 1 by a p-Value of 0.9235. The negative score mean difference indicates that the mean of group 2 is higher than that of group 3. Note that the “std err diff” is the standard error difference of the score mean difference. The “difference plot” depicts graphically the differences in the group means among the group pairs.

### 6.2.2 Development of Statistical Models

This section is targeted towards analyzing the effects of selected responses on the time taken for drivers to complete merging maneuvers among different age groups under different traffic, weather and geometric conditions. To achieve this objective, a stepwise log-linear regression model was used. This model takes the form:

$$\log(y) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \cdots \beta_n x_n + e$$

Where y is the response variable, $x_1$ to $x_n$ are the predictors, $\beta_0$ is the interception term, $\beta_1$to $\beta_n$ are the parameter estimates, and $e$ is the error term.

Response Variable

Merging time: This is the time taken for drivers to merge onto the freeway from the point of entry onto the freeway on-ramp.

Predictor Variables

a) Driver characteristics

- Socio-economic characteristics: age, gender, level of education, occupational status, marital status, income, and race;
- Driving experience under clear weather conditions: driving experience in years, driving frequency per week, and distance driven per week;

- Driving experience under inclement weather conditions: driving frequency under inclement weather conditions, driving frequency under foggy weather conditions, and difficulty driving in fog;
- Health-related characteristics: health rating, vision rating, hearing rating, presence of visual disorders, presence of chronic diseases;
- Driving ability: ability to see vehicle coming up beside, ability to brake, ability to make over the shoulder check, ability to drive safely, and ability to react to horns;
- Simulator experience: number of times driven in a simulator.

Note that among the predictor variables for the driving ability, "ability to see road signs at a distance", "ability to see speedometer and controls", "ability to avoid hitting curbs and medians" were removed from the model because of their irrelevance to predicting merging time of drivers. Ability to see road signs, speedometer/controls, and avoid hitting curbs are relevant only on the main freeway after the completion of merging maneuvers. Removing irrelevant variables from the model may help to deal with problems of overfitting.

b) Driving, traffic and geometric conditions

- Weather conditions: clear weather condition, foggy weather condition;
- Levels of Service (LOS): LOS A, and LOS B;
- Number of lanes: four-lane freeway, and six-lane freeway.

Stepwise Log-linear Regression Models

The statistical software used to analyze the data was JMP 2014 developed by SAS institute. Backward elimination method, a commonly used method for continuous variables (Dulebenets et al., 2019), was used to analyze the data in this study. Backward elimination regression model enters all the variables in the original linear regression model and removes variables that are insignificant at 95% confidence level one after the other to obtain the best model that explains the data. Predictor variables were analyzed in subsets and combinations, which include:

- Socio-economic characteristics;
- Driving experience under clear weather condition;
- Driving experience under inclement weather condition;
- Health-related characteristics;
- Driving ability;
- Simulator experience;
- Driving-traffic-geometric conditions;
- All combined predictor variables.

6.3. Model Results

Table 13 Parameter estimates for socio-economic characteristics only

| **Term** | **Estimate** | **Std Error** | **t Ratio** | **Prob>\|t\|** |
|---|---|---|---|---|
| Intercept | 1.9175452 | 0.041873 | 45.79 | <.0001* |
| Age Groups | 0.0383603 | 0.012033 | 3.19 | 0.0015* |
| Race | 0.0260972 | 0.006875 | 3.80 | 0.0002* |

From Table 13, merging time was found to be significantly affected with age groups and race at 95% confidence level. Age groups and race have a positive effect on merging times of drivers on freeway. Older individuals take more time to merge than their younger counterparts on freeways. Generally, longer merging time was recorded for higher age groups. The race into which participants fell also influenced their merging time.

Table 14 Parameter estimates for driving experience

| Term | Estimate | Std Error | t Ratio | Prob>\|t\| |
|---|---|---|---|---|
| Intercept | 2.1910114 | 0.05063 | 43.28 | <.0001* |
| Distance driven per week | -0.024844 | 0.012329 | -2.02 | 0.0442* |

Merging time was significantly affected by the distance participants drove per week. Results from Table 14 suggests that the longer the distances driven in a week by participants, the shorter their merging time which implies that drivers who drive more often in a week have more experience than drivers who drive only a few times during the week. Their experience improved merging abilities and thus they spend less time merging.

Table 15 Parameter estimates for driving experience under inclement weather

| Term | Estimate | Std Error | t Ratio | Prob>\|t\| |
|---|---|---|---|---|
| Intercept | 1.9933388 | 0.040868 | 48.77 | <.0001* |
| Difficulty driving under fog | 0.0650062 | 0.025512 | 2.55 | 0.0110* |

Merging time was significantly affected by difficulty driving in foggy weather conditions, as shown in Table 15. Increased difficulty driving in foggy weather conditions is linked with higher merging time.

Table 16 Parameter estimates for driving ability only

| Term | Estimate | Std Error | t Ratio | Prob>\|t\| |
|---|---|---|---|---|
| Intercept | 2.2526126 | 0.074851 | 30.09 | <.0001* |
| Ability to see vehicles coming beside | -0.084997 | 0.028107 | -3.02 | 0.0026* |
| Ability to make over-the-shoulder check | 0.0827606 | 0.027221 | 3.04 | 0.0024* |
| Ability to make quick decisions | -0.110022 | 0.030371 | -3.62 | 0.0003* |
| Ability to react to horns | 0.0657409 | 0.025258 | 2.60 | 0.0094* |

From Table 16, merging time was found to be significantly affected by ability to see vehicles coming from beside, ability to make over-the-shoulder check, ability to make quick decisions, and ability to react to horns. Increase in merging time is linked with increase in the ability to make over-the-shoulder check and ability to react to horns. Lower merging time is linked with high ability to see vehicles coming beside and ability to make quick decisions.

Table 17 Parameter estimates for driving-traffic-geometric conditions

| Term | Estimate | Std Error | t Ratio | Prob>\|t\| |
|---|---|---|---|---|
| Intercept | 2.0927477 | 0.011017 | 189.95 | <.0001* |
| No of Lanes [4L] | 0.1806672 | 0.011017 | 16.40 | <.0001* |

From Table 17, number of lanes driven was the only variable that is statistically significant at 95% confidence interval. The number of lanes have a positive effect on merging time. The lesser the number of lanes the more time it takes to merge. In this case, drivers took longer time to merge on to the 4-lane freeway than the 6-lane freeway segment. However, weather and the level of service did not affect the merging time of drivers.

Table 18 Parameter estimates for all combined variables

| Term | Estimate | Std Error | t Ratio | Prob>\|t\| |
|---|---|---|---|---|
| Intercept | 1.9691965 | 0.079614 | 24.73 | <.0001* |
| Age Group | 0.0737123 | 0.018972 | 3.89 | 0.0001* |
| Race | 0.0269432 | 0.005922 | 4.55 | <.0001* |
| Driving experience in years | -0.002911 | 0.001151 | -2.53 | 0.0116* |
| Difficulty driving under fog | 0.0567541 | 0.022382 | 2.54 | 0.0114* |
| Ability to see vehicles coming beside | -0.094864 | 0.024154 | -3.93 | <.0001* |
| Ability to make over-the-shoulder check | 0.0827149 | 0.023635 | 3.50 | 0.0005* |
| Ability to make quick decisions | -0.117433 | 0.025368 | -4.63 | <.0001* |
| Ability to react to horns | 0.0828853 | 0.021427 | 3.87 | 0.0001* |
| No of Lanes [4L] | 0.1809368 | 0.010504 | 17.23 | <.0001* |

From Table 18, age group, race, driving experience, difficulty driving in foggy weather conditions, ability to see vehicles coming beside, ability to make over-the-shoulder check, ability to make quick decisions, ability to react to horns, and number of lanes are all significant (< 0.005) in the global model. Note that though the level of significance of each significant variable in the global model slightly changed, all the significant variables in the subset models are also significant in the global model.

Table 19 Parameter estimates for interactions between age groups and driving-traffic-geometric conditions

| **Term** | **Estimate** | **Std Error** | **t Ratio** | **Prob>\|t\|** |
|---|---|---|---|---|
| Intercept | 2.0329299 | 0.024722 | 82.23 | <.0001* |
| Age Groups | 0.0272285 | 0.010084 | 2.70 | 0.0071* |
| No of Lanes [4L] | 0.1807943 | 0.010973 | 16.48 | <.0001* |

From Table 19, the interactions between varying driving, traffic and geometric conditions did not influence merging time of drivers.

Figure 20 below shows the difference in the merging times of all age groups under clear and foggy weather conditions, in 4-lane and 6-lane freeway segments, and on LOS A and LOS B.

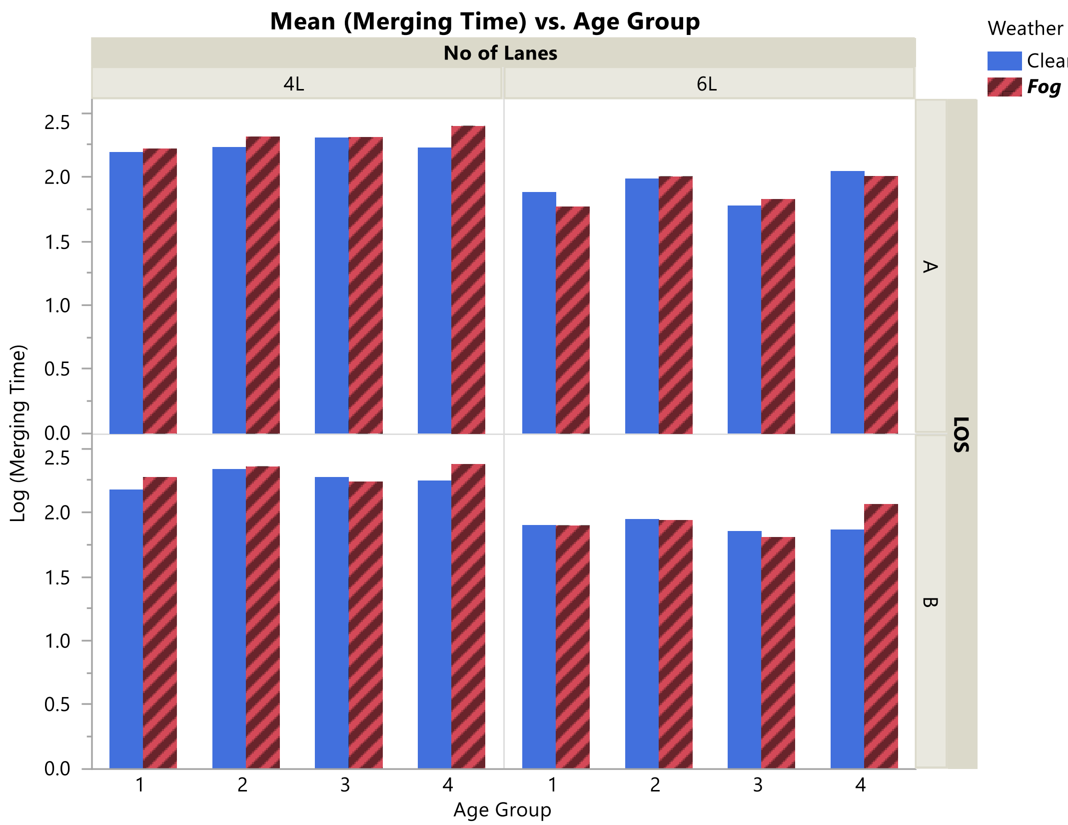



**Figure 20 Merging time of age groups in driving-traffic-geometric conditions**

# 7. DISCUSSION

## 7.1. Age group

There was significant difference among age groups in their time taken to complete merging maneuvers. These differences are not by chance as results show with high statistical significance that older drivers in group 4 took longer to complete merging maneuvers than the younger drivers in age groups 1 and 3. There was no significant difference when comparing older drivers with group 2 in completing merging time.

The observation that older drivers take longer time in completing merging maneuvers is in tandem with the conclusion of (Yuan et al., 2019) as study noted that older drivers had longer lane changing duration than middle-aged drivers. Also, the conservativeness of older drivers and the decline in their cognitive ability may be the reason for their merging behavior.

## 7.2. Driver characteristics

Among socio-economic characteristics of drivers, age group, as discussed above, was a statistically significant factor in predicting time to complete merging maneuvers. Race of drivers was also found to be a predictor of time to complete the merging maneuvers.

The distance driven per week was found to be an important factor influencing the time to complete merging maneuvers on freeways. Participants who indicated driving for longer distances in a week had shorter time in completing merging maneuvers than those who drove for shorter distances in a week. It may be said that drivers who drove for longer distances in a week are those who loved driving and have perfected their merging processes; or are required to drive long distance due to the nature of their work or other necessities. Although this does not suggest better decisions, it indicates faster merging maneuvers.

Higher merging time was recorded for drivers with more difficulty driving in foggy weather conditions. Since all drivers drove in both clear and foggy weather conditions, and there was no correlation between vision rating or visual disorders and difficulty driving in foggy weather conditions, it is not clear how this difficulty can be linked with time to complete merging maneuvers. If this difficulty is linked to the fog itself, then "weather" would have been a significant factor in predicting time to complete merging maneuvers. It could be surmised that such self-reported rating of the difficulty driving in a foggy weather conditions is far from actuality when compared with other participants.

Among self-reported ratings of participants' driving abilities, the ability to see vehicles coming from beside, ability to make over-the-shoulder check, ability to make quick decisions, and ability to react to horns were all significant with the time to complete merging maneuvers. Higher ratings of participants' ability to make over-the-shoulder check and ability to react to horns were recorded for longer time to complete merging maneuvers. However, higher ratings of participants' ability to see vehicles coming beside and ability to make quick decisions were recorded for shorter time to complete merging maneuvers.

## 7.3. Driving, traffic and geometric conditions

Contrary to the hypothesis that driving in a foggy weather condition would increase drivers' time to complete merging maneuvers, findings show that driving in either normal or foggy weather conditions did not affect merging time. In fact, the number of lanes participants merged unto is the most significant predictor of time to complete merging maneuvers in the model. Regardless of age group, the time it took participants to complete merging maneuvers unto the four-lane freeways was significantly higher than the time it took them on six-lane freeways. Even the interactions of the levels of service, weather conditions, and age group did not yield any significance in the model.

Literature indicates that high density traffic strongly affects driver behavior, which includes the difficulty experienced in merging and the time it takes in completing merging maneuvers. The insignificance of the LOS A and LOS B in affecting time to complete merging maneuvers could be due to the slight or, perhaps, inconsequential difference between the densities of the two levels.

# 8. CONCUSIONS AND FUTURE RESEARCH

This study investigated the time it took older drivers in comparison with other younger drivers to complete merging maneuvers on freeways under different driving, traffic and geometric conditions in a driving simulator. The effect of socio-economic characteristics, driving abilities, driving experience under clear and foggy weather conditions, difficulty under foggy weather conditions, health ratings, and the simulator experience of drivers on the time to complete merging maneuvers were also considered. It was hypothesized that older drivers, due to their conservative driving behavior, would generally take longer time completing merging maneuvers. Also, driving in inclement weather conditions was expected to affect drivers' merging time, especially older drivers.

Using analysis of variance and stepwise regression models in analyzing the data, results show that there are statistically significant differences among groups, with older drivers (age group 4) completing merging maneuvers longer than younger drivers in age group 1 and 3. The difference between driving on a four-lane freeway and on a six-lane lane freeway was shown to be the most significant factor affecting drivers' time to complete merging maneuvers. Drivers completed merging maneuvers longer on the four-lane freeways than on the six-lane freeways. Also, driving in different weather conditions (clear and foggy weather), and in different levels of service (LOS A and LOS B) were not significant in predicting the time taken for drivers to complete merging maneuvers. Other self-reported driver characteristics, such as race, driving experience in years, distance driven per week, difficulty driving in foggy weather conditions, ability to see vehicles coming beside, ability to make over-the-shoulder check, ability to make quick decisions, and ability to react to horns all significantly affected the time taken to complete merging maneuvers in the driving simulator.

The findings in this research can be helpful in prioritizing the problems of the interference of traffic flow and traffic congestion at merging segments on the freeways. New intelligent transportation technologies should be developed to consider the delay older drivers cause in completing merging maneuvers. Future research should consider crash occurrences at merging segments, driving on different types of ramps and higher levels of service. More questions can be used to collect driver characteristics, comparing subjective self-reported ratings of drivers' abilities with their objective abilities.

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**APPENDICES**

Appendix A. Leaflet for Recruiting the Pilot Study Participants

**LEAFLET**

**ATTN: Potential Pilot Study Participant**

**Subject:** Participation in the pilot study for the project "**Developing an Algorithm Using the Connected Vehicles Technology to Enhance Aging Drivers' Freeway Merging Maneuver**"

Greetings,

Currently, we are involved in the project sponsored by the U.S. Department of Transportation and Center for Accessibility and Safety for an Aging Population (ASAP), located at FAMU-FSU College of Engineering. The **objective of the project** is to identify the factors influencing driving ability of different population groups (with various socio-demographic characteristics) on freeway merging and diverging segments under normal and inclement weather conditions. The findings will be further used within the existing microsimulation software packages (e.g., VISSSIM, PARAMICS, CUBE) to model traffic flow along freeways that is composed of conventional vehicles, autonomous vehicles, or combination of conventional and autonomous vehicles. As a part of the project, a pilot study will be conducted. Each participant of the pilot study will be requested to drive the ASAP driving simulator for **25-30 min** to collect the necessary data. Location of the Driving Simulation Laboratory is **2525 Pottsdamer Street, Building B, Suite B307, Tallahassee, FL 32310-6046, USA**. Each pilot study participant must be **18 years of age or older**. The ASAP driving simulator environment is similar to a typical video game environment. Before the actual experiment begins, each pilot study participant will be given a thorough instruction on how to use the driving simulator. Each pilot study participant will be allowed to take additional **5-7 min breaks** as needed to ensure that the participant will not become nauseous. The pilot study participant will not be required to complete the driving experiment, if s/he becomes nauseous. Additional refreshments (e.g., soda, water, light snacks) will be provided for the pilot study participants. Furthermore, once the driving experiment is completed, each participant will receive a **$25 gift card**. Your personal information (e.g., name, address, contact information) **will be kept confidential**. The data will be stored and secured on a **password protected computer**. In the event of any publication or presentation resulting from this research, **no personally identifiable information will be disclosed**. Note that the study results (including development and analysis of new models based on the collected data) will not be shared with the pilot study participants. The **participation** in this study **is voluntary**, and the **participant may withdraw** his/her participation at any time. Furthermore, participants can **decline to answer specific**

**questions**, which may be asked by the research team members. If you are interested to participate in this pilot study, please make a call to Mr. Jason Owens at (404)-626-0744 (9:30 am – 4:30 pm) after March 18th, 2019 to schedule an appropriate date and time for the driving experiment.

Thank you for your time and participation. Please do not hesitate to contact us if you have any questions.

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Principal Investigators:

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**Doreen Kobelo, Ph.D.** (Florida A&M University)

**Thobias Sando, Ph.D., P.E., PTOE** (University of North Florida)

Appendix B. Consent Form for the Pilot Study

Participant's ID: ________________ (to be filled by the research team members)
Project **"Developing an Algorithm using the Connected Vehicles Technology to Enhance Aging Drivers' Freeway Merging Maneuver"**

**Principal Investigator:**
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**Florida Agricultural and Mechanical University Institutional Review Board (IRB)**
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**Study Description**
This study is a part of the project, entitled as "Developing an Algorithm using the Connected Vehicles Technology to Enhance Aging Drivers' Freeway Merging Maneuver", which is sponsored by the Center for Accessibility and Safety for an Aging Population (ASAP), located at FAMU-FSU College of Engineering. The **objective of the project** to give an extensive study on driving behavior under adverse conditions to assist in better design of vehicles and roadway features for efficient and safe mobility. The findings will be further used within the existing microsimulation software packages (e.g., VISSSIM, PARAMICS, CUBE) to model traffic flow along freeways that is composed of conventional vehicles, autonomous vehicles, or combination of conventional and autonomous vehicles. Each participant of the study will be requested to drive the ASAP driving simulator for **25-30 min** to collect the necessary data. Each pilot study participant must be **18 years of age or older**. The ASAP driving simulator environment is similar to a typical video game environment. Before the actual experiment begins, each pilot study participant will be given a thorough instruction on how to use the driving simulator. Each pilot study participant will be allowed to take additional **5-7 min breaks** as needed to ensure that the participant will not become nauseous. The pilot study participant will not be required to complete the driving experiment, if s/he becomes nauseous.

Additional refreshments (e.g., soda, water, light snacks) will be provided for the pilot study participants. Furthermore, once the driving experiment is completed, each participant will receive a **$25 gift card**. Your personal information (e.g., name, address, contact information) **will be kept confidential**. The data will be stored and secured on a **password protected computer**. In the event of any publication or presentation resulting from this research, **no personally identifiable information will be disclosed**. Note that the study results (including development and analysis of new models based on the collected data) will not be shared with the pilot study participants. The **participation** in this study **is voluntary**, and the **participant may withdraw** his/her participation at any time. Furthermore, participants can **decline to answer specific questions**, which may be asked by research team members.

Thank you for your time and participation.

Please contact Dr. Maxim Dulebenets at +1(850)-410-6621 with questions, complaints or concerns about this research study.

Participant's Signature: _________________________________ Date: ______________

Research Team Member's Signature: ______________________ Date: ______________

Appendix C. Participant Form for the Pilot Study
Project "**Developing an Algorithm using the Connected Vehicles Technology to Enhance Aging Drivers' Freeway Merging Maneuver**".

Participant's ID: ________________ (to be filled by the research team members)

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**Questions to the Pilot Study Participant BEFORE THE EXPERIMENT**

**General Information**

1) Please indicate your age

| |
|---|
| |

2) Please indicate your gender
☐ male

☐ female

3) What is your highest level of education?
☐ No formal education
☐ Less than high school graduate
☐ High school graduate/GED
☐ Vocational training
☐ Some college/Associate's degree
☐ Bachelor's degree (BA, BS)
☐ Master's degree (or other post-graduate training)
☐ Doctoral degree (PhD, MD, EdD, DDS, JD, etc.)

4) What is your primary occupational status? (Check one)
☐ Work Full-time
☐ Work Part-time
☐ Student
☐ Homemaker
☐ Retired
☐ Volunteer worker
☐ Seeking employment, laid off, etc.
☐ Other (please specify) ____________________________________

5) Which category best describes your yearly household income. Do not give the dollar amount, just check the category

☐ Less than $10,000
☐ $10,000 - $19,999
☐ $20,000 - $39,999
☐ $40,000 - $59,999
☐ $60,000 - $79,999
☐ $80,000 or more
☐ Do not know for certain
☐ Do not wish to answer

6) Current marital status (check one)

☐ Single
☐ Married
☐ Separated
☐ Divorced
☐ Widowed
☐ Other (please specify) ___________________

7) How would you describe your primary racial group?

☐ No Primary Group
☐ White/Caucasian
☐ Black/African American
☐ Hispanic/Latino
☐ Asian
☐ American Indian/Alaska Native
☐ Native Hawaiian/Pacific Islander
☐ Multi-racial
☐ Other (please specify) _________________________

**Driving Experience**

8) How long have you been driving?

| |
|---|
| __________ years |

9) How often do you drive in a week?

☐ 1 time a week
☐ 2-4 times a week

☐ 5-10 times a week
☐ 11+ times a week

10) On average, how far do you drive in a week?
☐ 0-2 miles
☐ 2-6 miles
☐ 6-10 miles
☐ 10-30 miles
☐ 30+ miles

**Driving Experience under Inclement Weather Conditions**

11) How often do you drive under inclement weather conditions (on average)?
☐ 1 time in 2 weeks
☐ 1 time in a week
☐ 2 times in a week
☐ 2+ times in a week

12) How often do you drive under foggy weather conditions (on average)?
☐ less than 1 time in 2 months
☐ 1 time in 2 months
☐ 1 time in a month
☐ more than 1 time in a month

13) Have you experienced any difficulties while driving under inclement weather conditions (e.g., unexpected maneuvers from other drivers, accidents, vehicle malfunctioning)?

| |
|---|
| |

**Health-Related Questions**

14) How would you rate your own **health**, compared to others of your age?
☐ Poor
☐ Fair
☐ Good
☐ Very Good
☐ Excellent

15) How would you rate your own **vision**, compared to others of your age?

☐ Poor
☐ Fair
☐ Good
☐ Very Good
☐ Excellent

16) How would you rate your own **hearing**, compared to others of your age?
☐ Poor
☐ Fair
☐ Good
☐ Very Good
☐ Excellent

17) Do you have any **visual disorders**?

| |
|---|
| |

18) Do you have any **chronic diseases** (e.g., cancer, heart disease, dementia, diabetes)?

| |
|---|
| |

**Driving Ability**

19) How would you rate your current ability to see road signs at a distance?
☐ Poor
☐ Fair
☐ Good
☐ Very Good

20) How would you rate your current ability to see the speedometer and controls?
☐ Poor
☐ Fair
☐ Good
☐ Very Good

21) How would you rate your current ability to avoid hitting curbs and medians?
☐ Poor
☐ Fair
☐ Good
☐ Very Good

22) How would you rate your current ability to see vehicles coming up beside you?
☐ Poor
☐ Fair

☐ Good
☐ Very Good

23) How would you rate your current ability to move your foot quickly from the gas to the brake pedal?
☐ Poor
☐ Fair
☐ Good
☐ Very Good
24) How would you rate your current ability to make an over-the-shoulder check?
☐ Poor
☐ Fair
☐ Good
☐ Very Good

25) How would you rate your current ability to make quick driving decisions?
☐ Poor
☐ Fair
☐ Good
☐ Very Good

26) How would you rate your current ability to drive safely (avoid accidents)?
☐ Poor
☐ Fair
☐ Good
☐ Very Good

27) How would you rate your current ability to react to a blowing horn from an approaching car?
☐ Poor
☐ Fair
☐ Good
☐ Very Good

**Experience Driving in a Simulator**

28) How many times, if any, have you driven in a simulator before today?

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**Quick Simulator Sickness Assessment – Introduction and Baseline (AFTER THE EXPERIMENTS)**

(Experimenter instructions: Repeated questions about symptoms of sickness can sometimes provoke sickness if countermeasures are not taken. To prevent this, please be sure to read the introduction word for word to each participant before collecting their baseline responses.)

**Introduction:**

One more thing before we get started – you know how some people tend to get carsick? In the same way, some people can experience discomfort in the simulator. Most people are fine, but all the same, I'm going to check in with you every few minutes by asking you three short questions about any discomfort, and we'll do it once right now.

**Baseline QSSA**
On a scale of 1 to 20, where 1 means no discomfort and 20 means you need to stop the experiment immediately:

1) How would you rate any discomfort in your head, including your eyes?

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2) On that same scale, how about any stomach discomfort?

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3) And any discomfort anyplace else, from 1 to 20?

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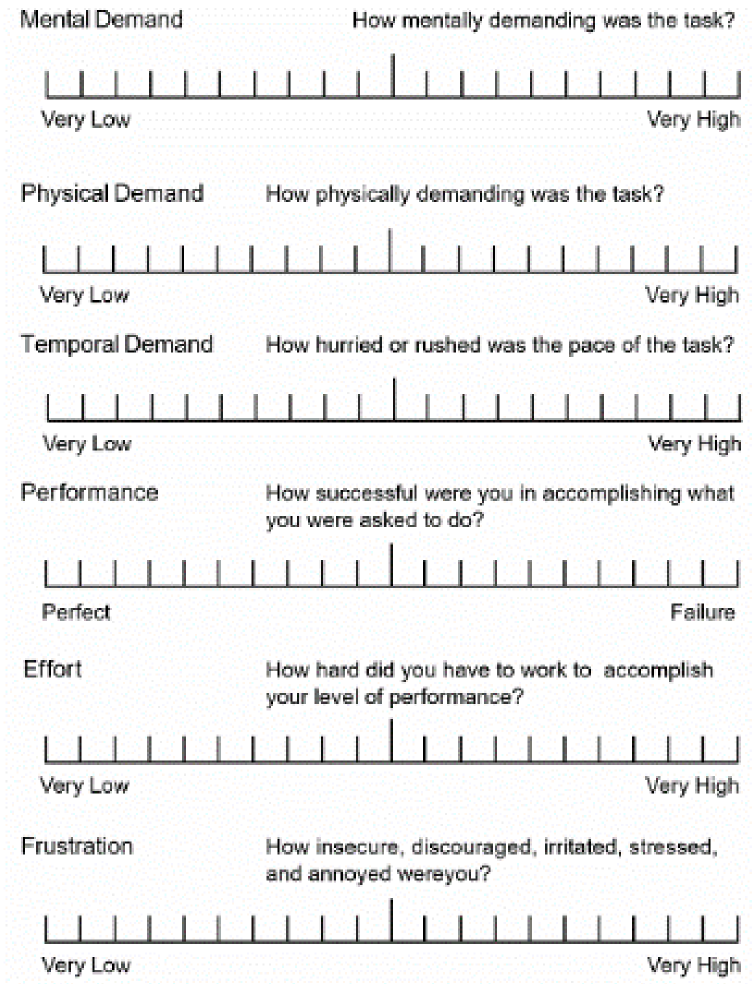
|---|
| |

Time at baseline QSSA: ____________________

**Questions to the Pilot Study Participant (AFTER THE EXPERIMENTS)**




NASA TLX chart

*Source: NASA (2019).*