Analysis of the Effects of Adaptive Cruise Control (ACC) on Driver Behavior and Awareness Using a Driving Simulator

By

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ABSTRACT

The thesis was aimed at determining the effects of adaptive cruise control (ACC) on driver behavior and awareness using a fixed-base driving simulator. ACC provides enhanced assistance by automatically adjusting vehicle speed according to the headway preference selected by the driver. The first step was to define the qualitative and quantitative measures of driver behavior and awareness.

A review of existing literature was carried out to determine similar studies. The literature revealed information on modeling the ACC in driving simulators and the effects of the ACC on driver behavior. Based on this, a methodology was developed consisting of six main tasks. First, participants were recruited and screened using a questionnaire. The questionnaire provided a quick way to select participants from a particular demographic and screen them for any medical conditions. The simulator was then prepared for the study by configuring the ACC, setting up the detection response task (DRT) device, configuring the distraction application, and designing events targeted to capture changes in driver behavior and awareness with and without the ACC. After configuring events, data were collected during the drive of the participants. Data were then reduced and prepared for a statistical analysis consisting of hypothesis testing and analysis of variance (ANOVA).

The statistical analysis resulted in a few significant differences between the variables collected. Participants were observed to maintain longer headways, reach lower peak velocities, and react slower in some critical events when driving with the ACC. The data from the DRT showed a significantly lower cognitive load when participants were engaged in a secondary task and driving with the ACC when compared to driving without the ACC.

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Finally, my parents, for providing me with everything I required to achieve my goals. Their selflessness and immense love got me through the most challenging moments.

ACRONYMS

ACC	Adaptive Cruise Control
ADAS	Advanced Driver Assistance Systems
ADO	Autonomous Dynamic Objects
CAN	Controller Area Network
CC	Cruise Control
CI	Confidence Interval
DDO	Deterministic Dynamic Objects
DOF	Degree of Freedom
DRT	Detection Response Task
ECG	Electrocardiogram
EEG	Electroencephalogram
FB	Fixed-Base
FHWA	Federal Highway Administration
FOV	Field of View
GPS	Global Positioning System
HD	High Definition
HR	Hit Rate
ISAT	Interactive Scenario Authoring Tool
ITS	Intelligent Transportation Systems
KU	University of Kansas
LED	Light Emitting Diode
MR	Miss Rate
NADS	National Advanced Driving Simulator
NHTSA	National Highway Traffic Safety Administration
RSME	Rating Scale Mental Effort
RT	Response Time
TLX	Task Load Index
TMT	Tile Mosaic Tool
VDS	Vehicle Dynamics
VR	Virtual Reality

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1. Problem Statement

Adaptive cruise control (ACC) systems are an increasingly common guidance feature in new vehicle models. These systems are similar to the conventional cruise control systems in terms of engaging and disengaging. However, unlike cruise control, ACC provides enhanced assistance by automatically adjusting vehicle speed according to the headway preference selected by the driver. This is done by either accelerating or decelerating based on the in-lane traffic flow detected by sensors, without constant input from the driver.

ACC systems are intended to increase roadway safety especially on highways and freeways by minimizing driver errors caused due to fatigue, poor judgement, distractions inside and outside the vehicle, lighting conditions, and weather. Although, the ACC is theoretically known to increase roadway safety, the effects of this system on actual driver behavior and awareness are unclear.

This thesis aims at determining the effects of ACC systems on driver behavior and awareness. Driver behavior and awareness includes, but is not limited to, aspects such as driver reaction times in case of sudden lane changes or crossing animals, distractions caused by cell phones or other electronic devices, adhering to speed limits, perceiving vehicles violating traffic regulations, mental workload during various aspects of driving, and overall situational awareness.

1.2. Objectives

The objectives of the thesis are as follows:

- Conduct a literature review on existing ACC systems and how they are modeled in actual vehicles versus driving simulators;
- Configure a working ACC system on the newly acquired University of Kansas (KU) driving simulator;
- Design a questionnaire to establish and screen possible test subjects;
- Design custom highway scenarios using compatible software, to test approved subjects on the effects of the ACC on driver behavior and awareness;
- Determine driver behavior and awareness based on individual reaction time, headway, cognitive workload, time to collision, acceleration, lateral position, brake pedal force, and speed in custom designed highway scenarios; and
- Perform a statistical analysis on the collected data to establish conclusions.

1.3. Thesis Outline

First, the thesis starts by briefly introducing the concept of ACC systems. It then discusses the aim and objectives. Second, a review of the literature related to the thesis is presented. This consists of the applications of ACC systems and their incorporation into driving simulators. It also consists of data collection equipment and strategies that have been previously used in similar studies.

Third, the methodology followed in the thesis is presented involving the tasks carried out. The methodology is grouped into six main tasks and they include: participant recruitment, setting up the simulator, creating distraction and measuring workload, data collection, data reduction and statistical analysis, and establishing conclusions. The methodology section also discusses possible limitations to the methodology.

After the methodology, the process of data collection is explained in detail. The process of participant recruitment, functionality of the KU driving simulator, scenario design, configuring events, measuring cognitive workload, and creating an application to simulate distraction is explained.

The results obtained from data collection are discussed in detail. Statistical significance of the variables is determined with respect to the events and variables collected. Finally, the findings of the research are stated with recommendations and scope for future research.

2. LITERATURE REVIEW

2.1. Introduction

A literature review is conducted to determine existing research related to this research topic and their findings. Several publications, theses, and books were obtained using online library databases and the University of Kansas Library resources. Online library databases such as Google Scholar, Transportation Research International Documentation (TRID), ScienceDirect, DBPIA, JSTOR, IEEE Xplore Digital Library, WorldCat, and KU Library WebRetrieve, were used.

First, a history of the ACC systems is presented. Second, a discussion of the configuration of adaptive cruise control and its mechanism is presented. Third, a detailed review of existing driving simulators is offered, including their mechanics, operation, and possible limitations. Fourth, previous algorithms used to configure ACC on driving simulators are discussed. Fifth, a series of previously conducted studies to determine the influence of ACC on driver behavior and response times are presented. Finally, a summary of all the literature reviewed is provided, highlighting the critical points discussed.

2.2. History of Adaptive Cruise Control

ACC systems were first available in high-end commercial vehicles around 1995 *(1)*. Although ACC has been available for the last 20 years, it is still being actively tested and refined in order to improve safety and efficiency.

The first car equipped with a laser-based ACC system was the Mitsubishi Diamante *(1)*. However, this system did not apply brakes but instead it adjusted speed by downshifting the gears

(1). ACC systems were then further refined by Toyota in 2000, by providing braking and low-speed tracking *(1)*.

Around the same period, Mercedes-Benz also introduced their own ACC system known as "Distronic" in the S-class Sedan. The refined "Distronic Plus" is able to bring a car to a complete stop in order to prevent a collision. Similar guidance systems are currently available with most car manufactures around the world *(1)*.

2.3. ACC in Real Life

ACC is an Advanced Driver Assistance System (ADAS) that enables vehicles to maintain appropriate speed and headway in a longitudinal trajectory *(2)*. ACC systems were developed to provide additional assistance to the driver by reducing the mental and physical workload. Users select appropriate headway based on their comfort preference while maintaining control of the steering *(4)*.

The ACC system is engaged and disengaged just like a conventional cruise control system. Figure 2-1 shows an illustration of the ACC equipped vehicle detecting a target. Although the forward vehicle is closer to the ACC equipped vehicle, it is not selected as the target vehicle because it is traveling in a different lane. However, if the forward vehicle decides to merge into the left lane, sensors detect this movement and designate it as the new target vehicle.

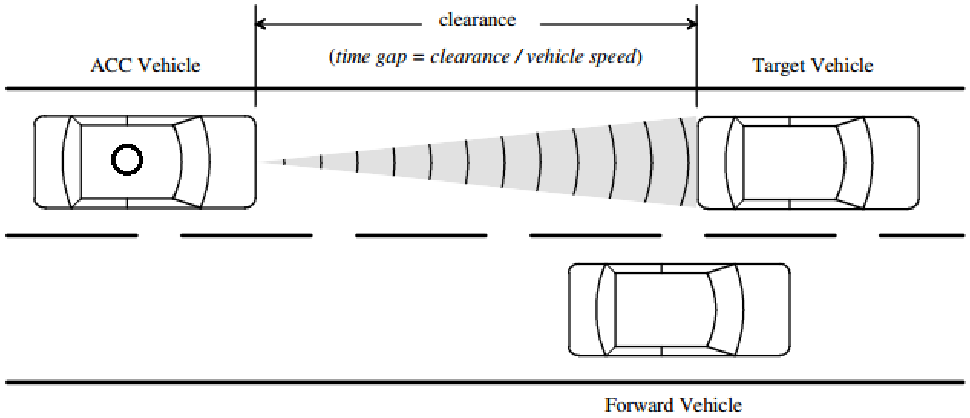


Figure 2-1: ACC vehicle detecting target vehicle *(3)*

ACC equipped vehicles consist of a network of several components and modules known as the Controller Area Network (CAN). Just as Local Area Network (LAN) enables data transmission between multiple computers, CAN enables transmission of messages between multiple modules present in the vehicle based on their priority. Three main modules are responsible for the proper functioning of the ACC system in any vehicle *(3)*. They are the ACC module, the engine control module, and the brake control module. The three modules and the instrument cluster are connected via the CAN. The layout of these modules in shown in Figure 2-2.

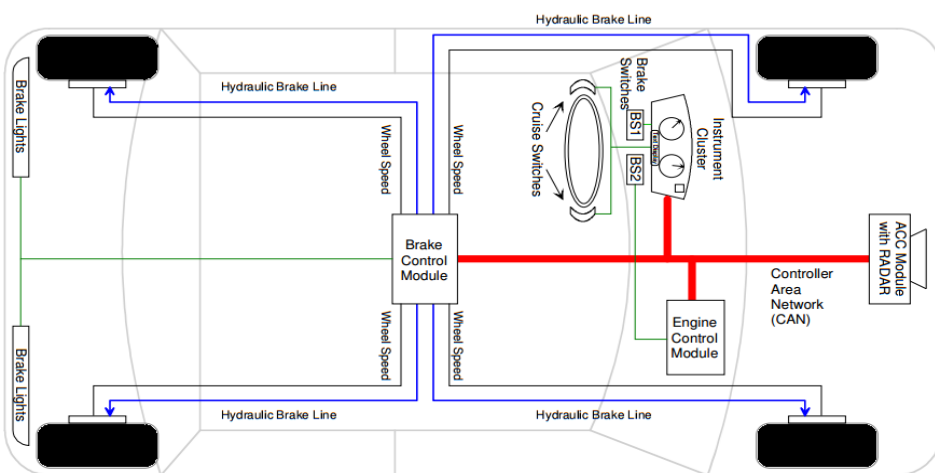


Figure 2-2: Internal layout of ACC vehicle *(3)*

The ACC interface is similar to that of the conventional cruise control system except for two additional switches that control the time gap settings *(3)*. When the cruise switches are activated, the instrument cluster processes and sends the information to the ACC and engine control module. The ACC module consists of a radar sensor that detects the presence of a forward vehicle and its speed. The main function of the ACC module is to determine if a forward vehicle exists, send information to the engine and brake control modules *(3)*.

The engine control module receives information from the ACC module and instrument cluster. Based on the information received, it regulates vehicle speed by controlling the engine's throttle *(3)*. The brake control module also receives information from the ACC module. The primary function of the brake control module is to monitor vehicle speed and apply brakes when requested by the ACC module.

ACC systems usually have two operation modes when active. They are the speed control and time gap control. The speed control mode is essentially the same as conventional cruise control and applies when no forward vehicle is detected *(3)*. The time gap control is activated if a forward vehicle is detected. The ACC system chooses to either decelerate, accelerate, or stop depending on the forward vehicle's speed and clearance.

Canceling the ACC operation selected by the user is done either manually by the driver or automatically by the system. Manual cancelation involves stepping on the brake pedal or pressing the off button. An ACC operation can also be canceled automatically if a fault is detected within the system or if the vehicle speed drops below 25 mph. In the event of ACC cancelation, a warning message is displayed on the instrument panel to alert the driver.

2.4. Mechanics of Driving Simulators

Capustiac, in 2011, defined driving simulators as a virtual representation of the dynamics of a vehicle and the surrounding environment without physically jeopardizing test subjects *(5)*. The goal of the driving simulator is to immerse drivers into a virtual environment generated by computer rendering *(5)*. While driving in a particular scenario, the virtually generated environment moves with respect to the vehicle creating a perception of motion *(6)*.

Several vehicle manufacturers and educational institutions use driving simulators to carry out research on driver behavior, body position, human-vehicle interactions, roadway geometrics, and driver assistance systems. As there is no physical threat to individuals, simulators act as an efficient platform to determine risks associated with driving.

Driving simulators are generally categorized in terms of cost and number of degrees of freedom (DOF) present. Degree of freedom (DOF) is defined as the direction in which motion is free to occur. For example, a simulator with 3 DOFs would be capable of motion in three planes (x-axis, y-axis, and z-axis). As the number of DOFs increases, the driving experience becomes more realistic but the cost also increases as seen in Figure 2-3. The three main categories of simulators are low level, mid-level, and high-level simulators *(5)*. Low-level simulators are usually fixed-based (FB) simulators *(7)*.

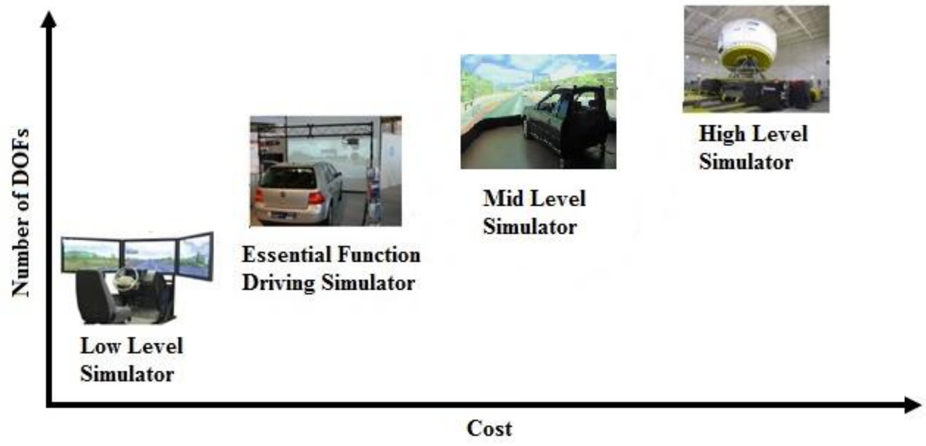


Figure 2-3: Types of simulators *[Image modified from (5)]*

Driving simulators have existed since the early 1950s. Vehicle manufacturers started designing their own simulators to test designs. In early 1970s, Volkswagen built their first driving simulator with a 3 DOF (yaw, roll, and pitch) motion system *(7)*. Mazda was the next vehicle manufacturer to develop a 4 DOF (yaw, roll, pitch, and serge) system in 1985 *(5)*. Around the same period, Daimler-Benz introduced a 6 DOF system with a 180-degree view in a hydraulic hexapod *(7)*.

Ford Motors also introduced their 6 DOF simulator called Virttex in 1994 *(7)*. Apart from yaw, roll, and pitch, the simulator was also capable of sway, heave, and surge. Renault implemented a similar system in 2004 *(7)*. Kookmin University in South Korea started the development of a 6 DOF system in a single seat simulator *(8)*. In 2001, the system was replaced with a full car chassis and a 2 DOF motion platform. The Kookmin University Simulator is capable of generating effects such as rumble strips and speed bumps *(8)*.

Bus and truck simulators are installed in driver training institutions to help improve driver skill *(7)*. TUTOR is a simulator that was commissioned in Spain around 2004 to assist in commercial driver training. The benefit of such simulators is that drivers are able to perfect various skill-demanding scenarios, allowing them to overcome similar situations when encountered in the real world.

Highly sophisticated simulators (high-level simulators) such as the Toyota Driving Simulator located at Higashifuji Technical Center in Susono City, Japan and the National Advanced Driving Simulator (NADS) located at the University of Iowa in the United States, allow for a more realistic and immersed driving experience *(5, 7)*. Both Toyota and NADS simulators have 13 DOFs supporting a fully enclosed hexapod with a 360^{o} horizontal view. Figure 2-4 shows the kinematics of the NADS-1 simulator, with lateral and longitudinal motion along the X-Y plane. The design of both simulators is similar, except that the Toyota simulator is larger *(5)*.

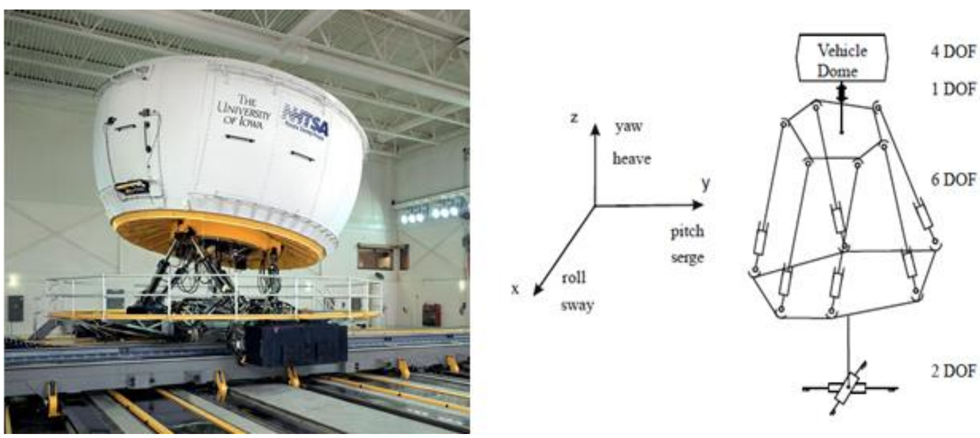


Figure 2-4: Kinematics of NADS-1 *(5)*

Although high-level simulators tend to completely immerse the drivers in a virtual environment, low-level simulators are not fully capable of delivering such realistic perception. Low-level simulators are also more prone to effects such as simulator sickness.

Simulator sickness is usually experienced because of lacking motion cues. Humans perceive motion through skin pressure and balance organs present in the ear *(5)*. When the human body is subject to a FB simulator, the eyes register visual cues but the ears and skin do not register any movement (motion cues) leading to a lack of "perception of motion." Perception of motion can be defined as the interpretation of visual and motion cues by sensory organs to register direction of movement and velocity *(5, 10)*.

Most common symptoms experienced due to simulator sickness are nausea, headaches, vomiting, sweating, and stomach awareness. Jamson in 2000 recommended a minimum horizontal field of view (FOV) of 120° in order for drivers to accurately perceive speed with respect to moving images in a driving simulator *(12)*. In 2003, Kemey and Panerai suggested a similar concept, implying that the effects of simulator sickness could be minimized on a FB simulator by increasing the FOV as the drivers can more readily perceive speed and depth *(10)*.

2.5. Modeling ACC in Simulators

Several transportation-related studies have incorporated ACC systems to driving simulators. Each study is unique in modeling ACC.

In 2006, Guvenc and Kural proposed a nonlinear single-track model for ACC simulations *(13)*. This model was developed for cornering and straight-line cruising only. The nonlinear single-track model, also known as the bicycle model, only controls the lateral dynamics of the vehicle such as the wheel and suspension forces *(13, 14)*. However, to incorporate longitudinal dynamics such as braking, throttle, acceleration, aerodynamic drag, tire, engine, and driveline, Guvenc and Kural proposed other models *(13)*. Figure 2-5 shows a simple representation of the forces acting on a vehicle with respect to its axis.

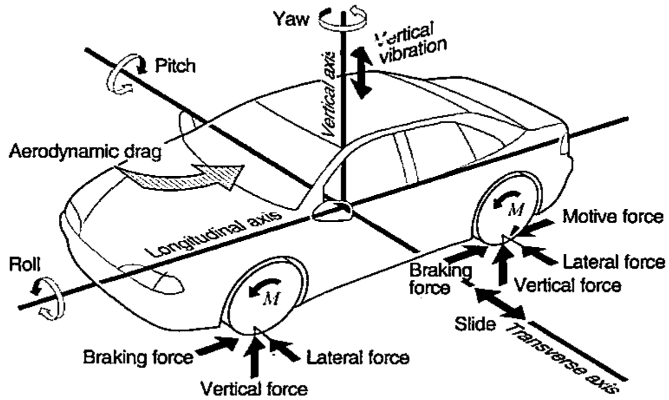


Figure 2-5: Forces acting on a vehicle *(14)*

Guvenc and Kural proposed the addition of the power-train model that consisted of the inverse engine, driveline, and Dugoff tire models to the bicycle model. This allowed the modeling of both the lateral and longitudinal components. However, the vertical components were ignored, as they were assumed insignificant.

Based on the models set to control the various lateral and longitudinal dynamics, an ACC control scheme was devised. When the ACC is engaged in an active scenario, the configured model detects the target vehicle and determines its speed and longitudinal distance. The sensors will not recognize a vehicle at a distance greater than the preset distance of 150 feet. The ACC control computer then runs the inverse engine and driveline model to maintain the desired headway between the ACC installed vehicle and target vehicle.

The configured ACC model determines the type of scenario with respect to the seven possible cases shown in Figure 2-6.

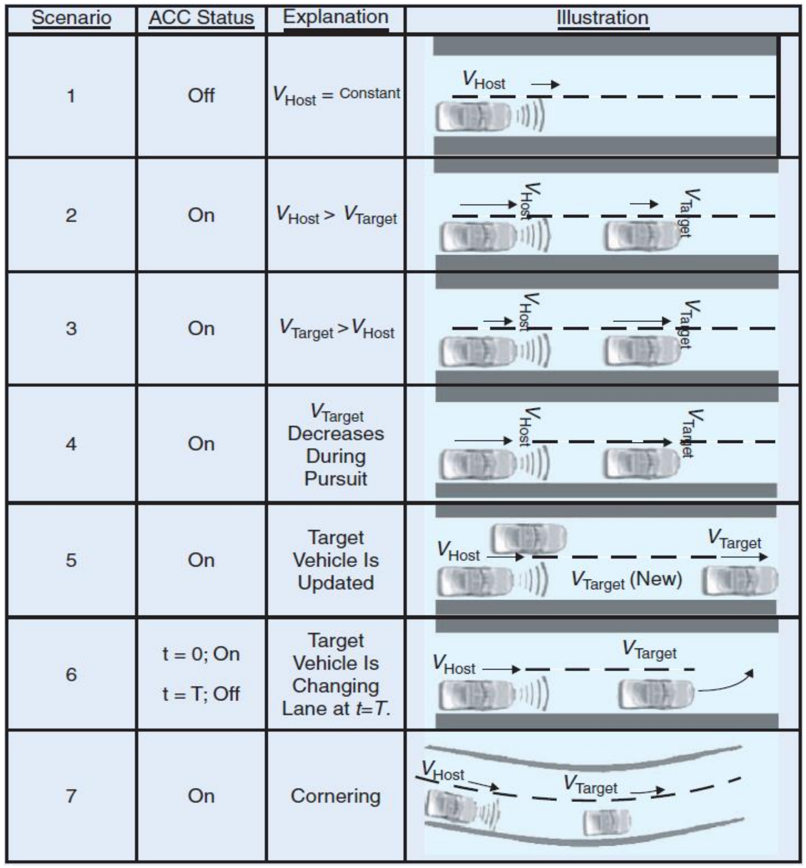


Figure 2-6: ACC scenarios *(13)*

The first scenario is based on a situation where no lead vehicle is present. The ACC system switches to conventional cruise control and proceeds with the preset driver speed. In the second and third scenario, when a target vehicle is detected, the ACC system determines its speed and position. The ACC control computer then runs the model and determines to either brake or accelerate. If the target vehicle slows down such as in scenario four, the host vehicle's speed decreases to that of the target vehicle. The fifth scenario represents a situation where a merging vehicle appears between the host and target vehicle. The ACC installed vehicle selects the merging vehicle as the new target vehicle. The sixth scenario involves the target vehicle changing lanes. If no vehicle is detected in front of the target vehicle after lane change, the ACC system switches to conventional cruise control. The most difficult maneuver for the ACC system is cornering. The seventh scenario occurs when approaching a horizontal curve, the ACC system is programmed to determine if the target vehicle is cornering or changing lanes. The model assumes a different azimuth for lane changing and cornering. This allows the two situations to be distinguished.

Moeckli et al. in 2015 modeled ACC using the NADS 1 simulator *(15)*. The ACC structure developed has two modes of operation as shown in Figure 2-7. The off-line mode and the run-time mode. The run-time mode involves processes such as running the scenario, vehicle dynamics, ACC model, sensor model, and data acquisition. The ACC model works hand in hand with the vehicle dynamics software, NADSDyna. NADSDyna only simulates the vehicle dynamics and has no knowledge of surrounding traffic in the rendered environment. The sensor model works independently, and controls lane change warning and forward collision warning systems. When ACC is activated in the cab, NADSDyna registers the input and sends information to the scenario controller. The scenario controller runs the sensor model that determines the forward vehicle speed and position. The data acquisition controller records all the necessary variables such as ACC engaging time, disengaging time, speed, and others.

The off-line mode is mainly used to analyze the recorded data. The recorded data can be analyzed by looking at a 2D representation of the simulated drive in the Interactive Scenario Authoring Tool (ISAT).

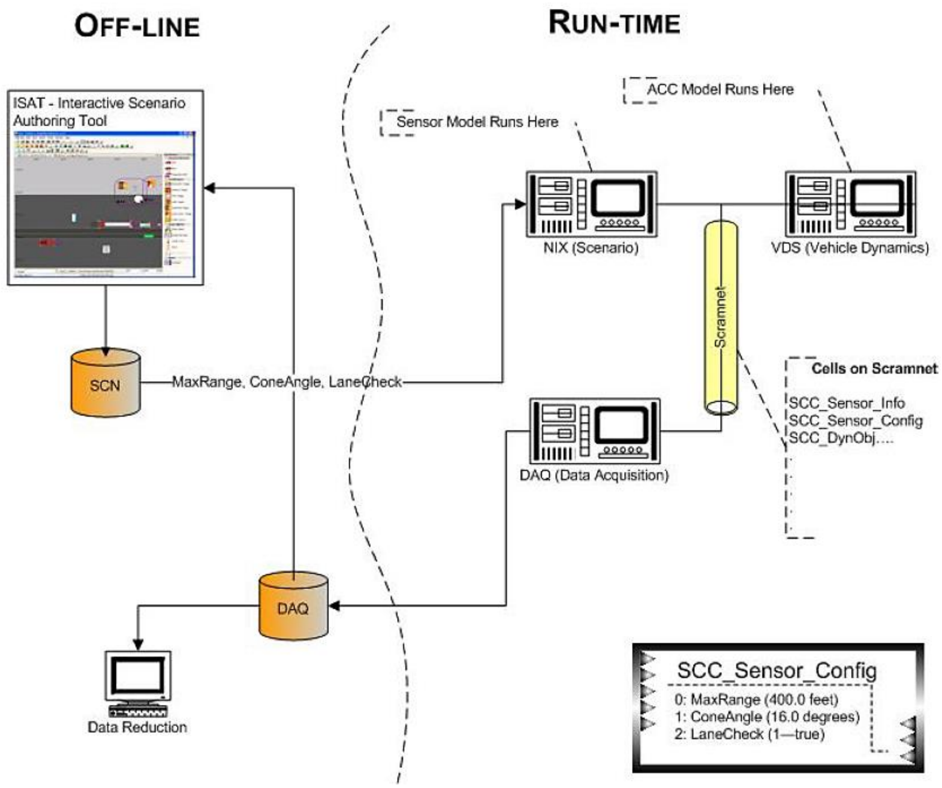


Figure 2-7: NADS ACC distributed model *(15)*

The NADS ACC algorithm can operate in either free-driving or vehicle-following mode. The conditions tested by the ACC model are as follows:

$$ACC\ Mode = \begin{cases} Free\ driving, & r > r_{max}\ or\ v + \dot{r} > v_d \\ Following, & other \end{cases}$$

Where,

r is the distance between host and target vehicle;

v is the speed of the ACC equipped vehicle;

$\dot{r}$ is the range rate; and

r_{max} is the maximum allowable distance between vehicles.

In this test condition, if the range between the vehicles exceeds the maximum range set in the algorithm, the ACC equipped vehicle switches to free driving mode. If the first condition is not met, the vehicle switches to following mode. The maximum acceleration of the vehicle also depends on the operation state. A maximum global acceleration of 0.2 g is assigned for free driving and a minimum global acceleration of 0.1 g for following.

$$a_{max} = \begin{cases} A_{max,} \, free\ driving \\ A_{min,} \quad following \end{cases}$$

Where,

a_{max} is the maximum allowed acceleration;

A_{max} is the global maximum acceleration; and

A_{min} is the global minimum acceleration.

The maximum deceleration to be applied can be calculated using three different methods *(15)*. The first method calculates using the time-to-collision (ttc) value. The second method calculates maximum deceleration using the distance to lead vehicle based on the range selected by the user. The third method uses both range rate ($\dot{r}$) and ttc. Based on the three methods shown in Figure 2-8, the worst maximum deceleration is selected.

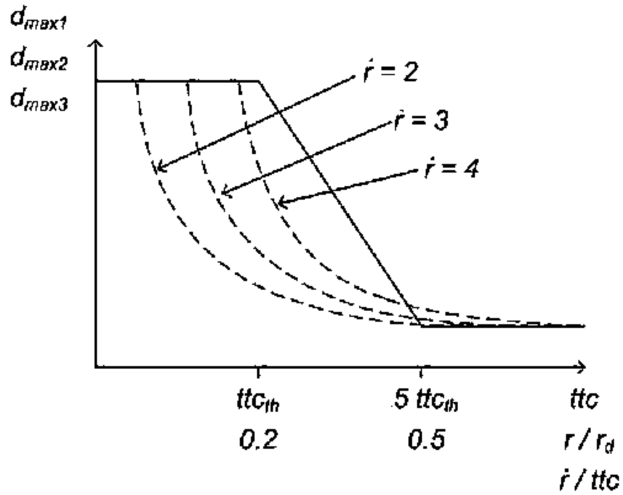


Figure 2-8: Maximum deceleration methods *(15)*

In the situation where the host vehicle is following, the desired range is determined by multiplying the headway by the velocity. Table 2-1 shows some of the parameters used to develop the ACC algorithm.

Table 2-1: ACC parameters used in the NADS model *(15)*

Parameter	Value
ACC Velocity $_{increments}$	5 mph
ttc $_{threshold}$	3 s
A_{max}	0.2 g
A_{min}	0.1 g
D_{max}	0.3 g
D_{min}	0.05 g
r_{max}	400 feet
r_{min}	16.4 feet

2.6. Influence of ACC on Driver Behavior

There have been several studies to evaluate the influence of ACC on driver behavior. Most studies involve experimentation using driving simulators.

Ohno in 2001 carried out a study on the adaptation process of driving behaviors using ACC *(16)*. The study compared behavior of drivers in manual mode versus ACC activated mode. It was determined that drivers in ACC mode kept a longer headway when compared to manual mode. The study also showed that lateral deviation was smaller for drivers in ACC mode.

Rudin-Brown and Parker, in 2004, studied the behavioral adaptation to the ACC. The study did not involve driving simulators. The participants were asked to drive a luxury sedan in a closed 6.9 km test track *(20)*. The lead vehicle used was a 1999 Toyota corolla with a polyurethane trailer attached to avoid injury to the participant in case of a crash. The collected data included braking times, lane keeping, sleepiness, trust, and subjective workload. The study concluded that ACC systems induce changes to driver behavior. It was noted that drivers reacted slowly when braking in critical situations. The study also showed reduced lane keeping ability when using ACC systems.

In 2005, Ma, and Kaber carried out a series of workload experiments using a low-cost virtual reality (VR) simulator. Eighteen participants, evenly distributed between male and female, were subject to driving with and without the ACC system. The study also collected data on changes to mental demand due to cell phone usage while driving with and without the ACC system. This study measured workload using a subjective scale, with questionnaires requesting feedback about the intensity of the task performed. The results of the study showed a reduction in overall mental demand when the ACC was active *(22).* A reduction in following speed and headway standard deviation was also observed among participants.

Cho, Nam, and Lee, in 2006, carried out a study of driver behavior with adaptive cruise control at the Kookmin University in Korea. The study consisted of forty participants with a 50-50 split of male and female subjects *(17).* The researchers recorded the headway and lateral position of participants with and without ACC. The study concluded that the preferred headway of participants with the ACC activated was 1.5 seconds. The study also showed that when using the ACC, drivers had reduced lane keeping ability. This implied that drivers were less attentive to the roadway and surroundings.

In 2011, Vollrath et al. carried out a similar study to determine the influence of cruise control (CC) and adaptive cruise control on driving behavior using a driving simulator. The study required participants to safely engage in as many secondary tasks as possible while driving a simulated scenario *(2).* The analysis revealed that drivers using the ACC and CC did not demonstrate delayed reaction times because of increased engagement in secondary tasks when intervening in critical situations. The study also found that drivers using ACC drove faster in the fog. Vollrath et al. suggested that this could be because of drivers relying on the ACC system.

Based on the findings of this section, it is noted that ACC systems lead to changes in driver behavior and awareness. Past studies showed mixed results on the effectiveness of ACC systems. Some studies demonstrated delay in braking time, reduction in mental demand, reduction in lane keeping ability, and decrease in attention towards the surrounding while others showed no significant impact on reaction times and alertness. The mixed results create an ambiguity thus justifying the need for the proposed research, aimed at establishing a more descriptive understanding of the effects of ACC on driver behavior and awareness.

2.7. Measuring Cognitive Workload

Driving is a complex task that requires utilizing several physical and mental resources. As stated in ISO 17488: 2016, resources can be categorized into three levels: sensory-actuator resources, perceptual-motor resources, and cognitive resources *(30)*. The sensory-actuator resources include physical elements used by the driver to interact with the environment such as eyes, feet, hands, ears, skin, and mouth. Perceptual-motor resources refer to brain functions that control specific activities such as hand-eye coordination, and visual perception. Cognitive resources refer to higher level brain tasks such as planning, decision making, dealing with emergency situations, and error detection.

The primary task of drivers is to safely navigate from point A to point B. However, while driving, drivers tend to engage in secondary tasks such as using their cellphones, operating the media controller, adjusting the air conditioning, and using the global positioning system (GPS). These secondary tasks can often lead to varying allocation of resources depending on the task being performed, thus competing with the primary task *(30)*.

There are several methods devised specifically to measure the cognitive resources being used during a specific task. These methods can be categorized into four main groups, namely: principal measures, subjective measures, psychological measures, and detection response tasks (DRTs). A brief description of each of these categorizes is provided below.

Principal measures of the cognitive workload involve quantifying driving abilities with respect to a secondary task assigned during the drive. The primary task of any driver is to drive safely from the origin to the destination. Secondary tasks may include phone calls, using GPS devices, texting, and using driver guidance systems. Principal measures such as lane deviations, steering position, throttle, and brake force are compared in both drives, one with primary task only and the other with both primary and secondary task. The difference in these principal measures during the two drives gives an indication of the workload experienced by the driver *(33)*. This method requires no extra equipment when used in driving simulators, as the output variables include the principal measures. The limitation to this method from previous studies is that the outputs mostly show subtle differences with contradictory results. A suggested improvement to the principal measure method is to record the reaction time to emergency events during both the drives *(33)*. However, implementing emergency events in real-life situations may lead to physical harm of the driver.

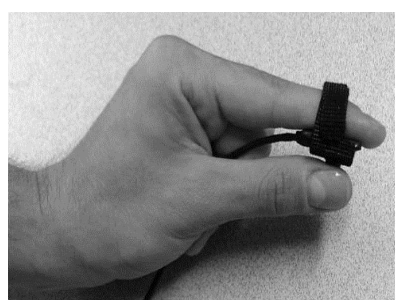
Subjective measures are usually determined by analyzing the questions answered by the participants after the completion of task/drive. The questions are aimed at establishing the difficulty of the task from the perspective of the driver. The NASA-Task Load Index (TLX) and the Rating Scale Mental Effort (RSME) are the two most commonly used subjective workload measuring questionnaires. The NASA-TLX questionnaire reports workload experienced by participants on a 21-point scale, ranging from "very low" to "very high" *(35)*. Participants respond to six questions consisting of mental demand, physical demand, temporal demand, performance, effort, and frustration experienced during the task, each on a 21-point scale. The RSME works on a similar principal, however, it consists of a nine-point scale ranging from "absolutely no effort" to "extreme effort." The main limitation of these subjective measures is that the results depend on how much the participant can remember from the event after the completion of the drive. It is also hard to judge the difficulty of a task without knowing what constitutes as extreme effort or very high workload. The advantage with the subjective measures is that they can be easily administered and require no additional equipment apart from printed questionnaires.

Psychological measures involve determining workload by recording any changes in activity in the cardiovascular system, central nervous system, and sensory nervous system. There are several equipment that can be used to psychologically determine cognitive workload. Some of the most commonly used instruments include: electroencephalographic (EEG), electrocardiogram (ECG), and pupilometer *(35)*. EEG is commonly used in health care centers to detect abnormal electrical activity in the brain. However, it can also be used to detect changes in brain activity during driving tasks that require varying amounts of problem solving and critical reasoning. The ECG is also used in health care centers to determine abnormalities in the heart and diagnose critical heart conditions such as attacks, irregular beating, and poor blood flow. The ECG can be used to determine heart rate of participants during various events in the drive. It provides continuous data throughout the drive, accounting for any slight changes in heart rate. Another way to determine the psychological measure is by using the pupilometer, also known as the eye-tracking device. The device tracks eye movement of the driver without disrupting the primary task of driving safely *(33)*. Some advanced devices are also capable of tracking pupil dilation. The phenomenon causing changes to the pupil diameter due to varying levels of cognitive workload is known as the task-evoked pupillary response (TEPR). This can be used to assess cognitive workload at different points of a drive. The advantage of using psychological measures is that they provide continuous data without interruption during the drive. However, the equipment is very expensive and can be considered intrusive as some require electrodes to be attached to the head of the participant *(35)*.

Although the data collected is continuous, it requires extensive cleaning and sorting due to the large quantity available.

The detection response task method was mainly devised to determine the effect of a secondary task on cognitive load. The DRT equipment presents frequent artificial stimuli during a task and records participant performance in the form of response time (RT), hit rate (HR), and miss rate (MR) *(30)*. There are three types of DRT stimuli commonly used in studies. The first type is the head-mounted visual stimulus, which presents a single light-emitting diode (LED) to the participant in intervals of three to five seconds. The LED can either be red or green depending on the chosen configuration and task. The second type is the remote visual stimulus. The stimulus can be presented as an LED somewhere attached to the inside of the vehicle or as a graphic at a fixed location in a simulator scenario. The third type is a tactile stimulus, which consists of a tactor (small electrical vibrator) attached to the driver's shoulder *(30)*. The driver senses the vibration and responds accordingly. For all the different types of DRT stimuli, participants respond via a micro-switch attached to their preferred finger as shown in Figure 2-9.

(a)



(b)

Figure 2-9: Head-mount LED (a) and micro-switch (b) ***(35)***

The DRT method has been used in several studies to study the effects of secondary tasks during driving. However, there are not a lot of studies involving the use of the DRT method to measure workload while using the ACC and performing a secondary task simultaneously. In studies where participants drove with and without the ACC system while carrying out the same secondary task in both situations, significant changes in cognitive workload were observed.

In 2014, Winter et al. provided a summary of results obtained from various studies on reaction time to visual stimuli when driving with and without the ACC system. In the summarized studies, a visual stimulus was presented in the form of a red square or blue LED lamp. Participants were required to respond by either pressing the horn or steering wheel buttons. It was observed that participants had fewer misses of stimuli when driving with the ACC engaged (11.2%) than without the ACC (25.6%) *(42)*. Reaction time to the visual stimuli was also observed to be quicker, by up to 15%, for participants driving with ACC engaged. Determining the effect of the ACC on workload, based on RT, HR, and MR, will be very crucial in understanding the driver behavior and situational awareness.

The DRT method is relatively cheap and simple to implement as it only requires a visual stimulus (LED bulb or on-screen image) and a micro-switch. The data collected are easily manageable and records continuously throughout the drive. Participants also do not have to wait after every event to provide their feedback on the experienced workload. The DRT method is also less intrusive than the psychological measures previously described. The DRT method is also preferred in driving simulators as it does not significantly alter the driving experience with excessive cables or large equipment. Although the DRT method is straightforward to implement, it can easily be manipulated by participants trying to guess the intervals of the stimuli. To avoid manipulation, video data can be used to monitor and eliminate bad data. Participants should be provided with clear instructions on how to naturally respond to the stimuli.

2.8. Summary

The reviewed literature showed several important concepts with respect to ACC systems.

- ACC systems operate just like conventional cruise control systems. However, vehicles equipped with the ACC can automatically adjust speed based on a driver selected headway.

- ACC equipped vehicles contain three modules. ACC module, engine module, and brake module. The ACC module consists of sensors that allow tracking of lead vehicle speed and position.

- Several types of driving simulators exist. The number of DOFs present in a simulator is directly proportional to the realism experienced by drivers. In addition, the cost of the simulator increases significantly as the number of DOFs increase.

- Modeling an ACC system is a complicated process. It requires modeling of both longitudinal and lateral vehicle dynamics by simultaneously using several algorithms.

- Past studies showed mixed results on the effectiveness of ACC systems. Especially towards braking time, lane keeping ability, and awareness of the surroundings. Studies also showed an increase in HR and a decrease in RT for DRT tasks when the ACC was active. Some studies demonstrate negative impacts of the ACC on driver behavior and situation awareness while others show no significant impact.

- Methods to measure cognitive workload while driving can be categorized in four main groups and they include: principal measures, subjective measures, psychological measures, and DRTs. Several studies have been carried out to validate each of the measures. However, selecting the appropriate method for a study depends on several factors such as cost, timeline, accuracy, mobility and availability of the equipment. The DRT device is determined to be the least intrusive to participants while providing a continuous stream of data. Although the DRT device can be subject to manipulation by participants, following the ISO 17488: 2016, protocols while collecting video data to identify and correct manipulation, can significantly improve the quality of data obtained.

3. METHODOLOGY

This chapter presents an overview of the procedures followed during the development of the study. The first and second task were carried out simultaneously to efficiently manage time. The first task was to recruit participants. Potential participants were provided with a screening questionnaire which gathered general information pertaining to the study. The second task was to configure the simulator. The task involved setting up the ACC, designing the scenarios, and pilot testing. The process of configuring events was iterative due to visual differences between the design view and what is observed by the driver. Figure 3-1 highlights the main tasks performed in this study.

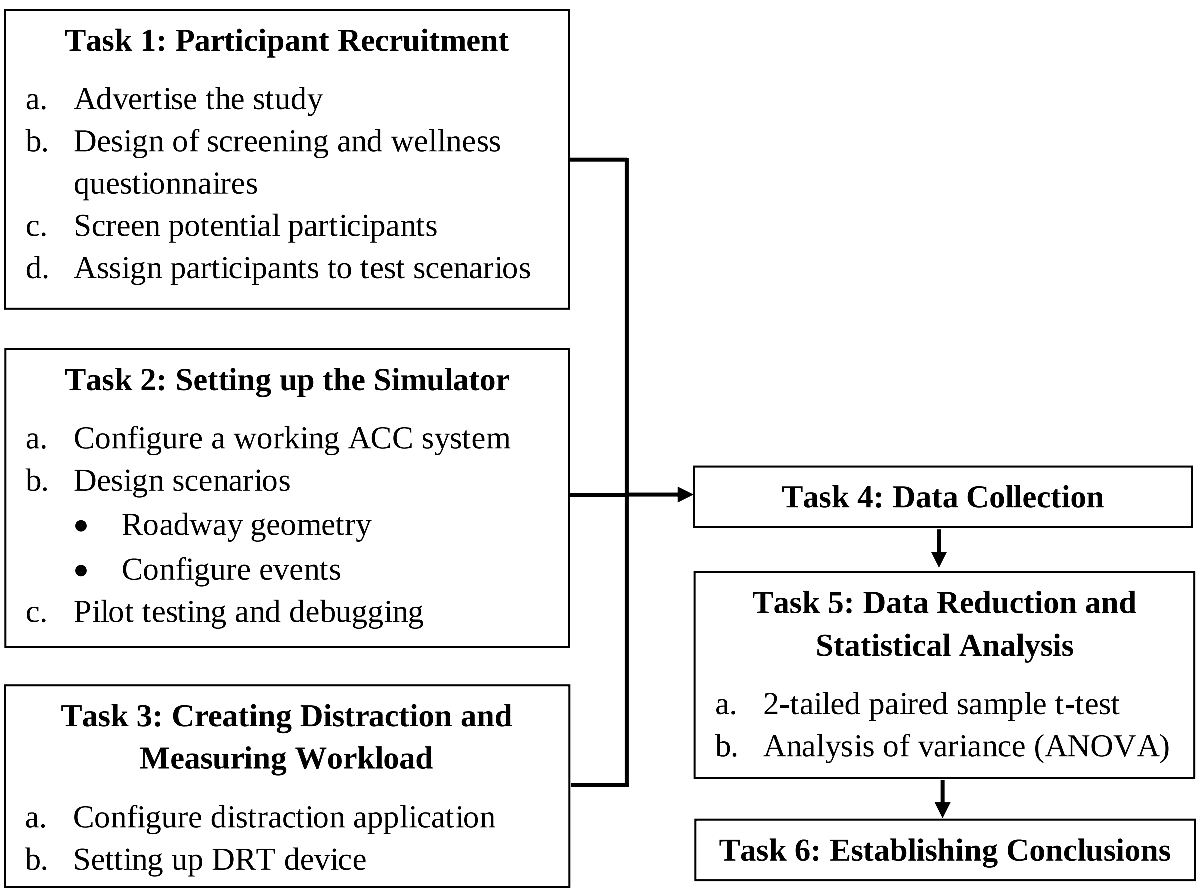


Figure 3-1: Major tasks while developing the study

After the completion of a satisfactory scenario, pilot testing was carried out to detect any discrepancies missed by the designer. Four individuals were requested to drive the scenario, providing feedback used for further debugging and a glimpse of the data output. After final debugging, participants were assigned to their respective scenarios.

The third task occurred after the first two tasks were complete. It involved programming an application to simulate distraction and to set up the DRT device. After the completion of the first three tasks, the simulator was equipped for data collection.

The fourth task was to collect data and organize them by participant ID. After data collection came data reduction and analysis. The fifth task required MATLAB *(37)* to extract the data variables of interest. The data were analyzed using the statistical package for social sciences (SPSS) software *(36).* It involved the paired t-test and the analysis of variance (ANOVA). A full description of the tasks carried out are provided in the sections that follow.

3.1. Task 1: Participant Recruitment

The study was advertised on notice boards in the University of Kansas, Lawrence public library, Department of Motor Vehicles (DMV) in Lawrence, churches, retail centers like Hy-Vee, and social media platforms. A copy of the poster is shown in Appendix A.

The survey is an important part of this thesis. It allows determining participants familiarity with ACC systems versus those who have minimal experience. The survey also provides information about the test participant such as name, contact information, age, valid driving credentials, existing health conditions, susceptibility to motion sickness, current vehicle model, and level of exposure to ACC systems.

A total of 44 participants showed interest in participating in the study. From this initial response, the selected sample size consisted of 30 participants equally split between males and females. The participants selected were equally distributed between three age groups 18-24, 5-49, and 50-65, to ensure a broader sample size and accommodate for bias caused due to age of drivers. A copy of the screening questionnaire is presented in Appendix B.

Screening was also carried out for simulator sickness, once after the completion of the first scenario and then after the completion of the second scenario. Participants with severe effects were excluded from the study. A copy of the wellness questionnaire is attached in Appendix C.

3.2. Task 2: Setting up the Simulator

3.2.1. Configuring the ACC

The system uses the NADS ACC algorithm (described in Section 2.5) and is activated using repurposed buttons present on the steering wheel. Figure 3-2 shows the modified steering wheel capable of activating the ACC system with user input. The software component had to be modified on site with the help of the NADS troubleshooting team. The process of hardware and software debugging of the ACC system required approximately three months to complete.

Figure 3-2: Steering wheel configuration

Buttons that were originally configured to increase and decrease volume were repurposed to act as the time gap increase and decrease buttons. This allowed participants to select a preferred time headway between the cab and the lead vehicle. Figure 3-3 shows a few key icons on the instrument panel such as the cruise control status, ACC time gap options, and vehicle speed, that are required by the participants when engaging the ACC.

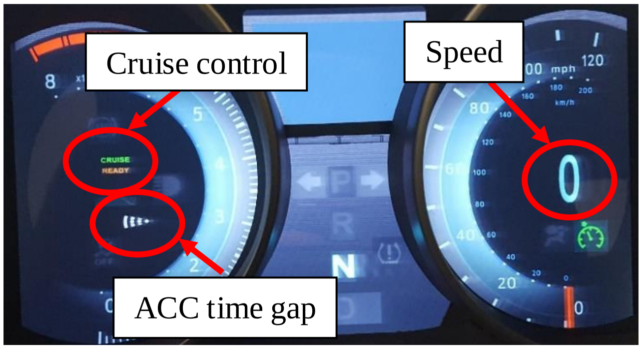
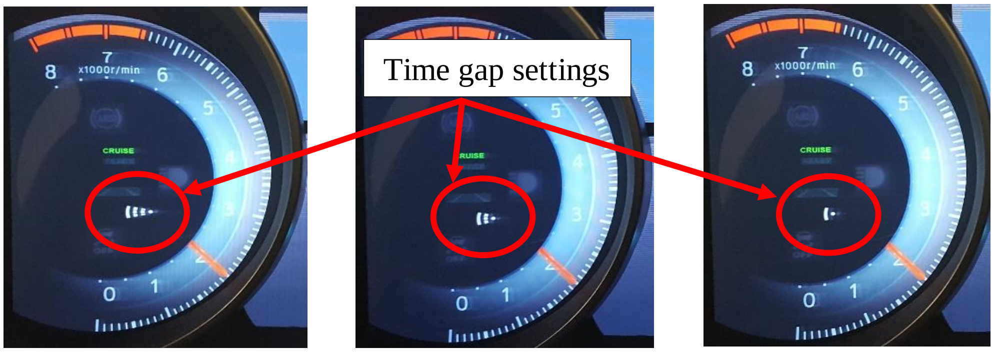


Figure 3-3: ACC activated instrument panel

For this study, three time gap settings were made available for the participants. They include 3 seconds, 2 seconds, and 1.2 seconds. These settings were modeled by NADS, based on the Toyota ACC system and were not modified for the study. Figure 3-4 shows the time gap icons on the instrument panel and how they change based on the selected gap settings. Participants were free to change the time gap to the lead vehicle at any point during the drive.



(a) (b) (c)

Figure 3-4: Possible time gap settings - 3 sec (a), 2 sec (b), and 1.2 sec (c)

The ACC system is also capable of warning drivers in instances where the system could not brake in time. The warning alert is a loud three-tone beep, that will sound only when two criteria are met simultaneously. The time to collision to the lead vehicle should to be less than three seconds and the ACC system should be braking with a maximum force of 0.3g. The beep acts as an alert to drivers, notifying them that the ACC system will not be able to brake in time to avoid the collision without external assistance.

3.2.2. Designing the Roadway Geometry

Just like conventional cruise control, ACC is also most frequently used on highways and freeways. This is because unlike smaller roadways, highways and freeways have relatively high free flow speeds with full access control. This enables drivers to use ACC without constant interaction from merging, diverging, and weaving vehicles.

The tile mosaic tool (TMT) *(39)* is used to generate the roadway alignments and render the virtual environment. The program uses square tiles in multiples of 660 feet by 660 feet, consisting of the virtual environment features such as the pavement, shoulder, vegetation, markings, and geometry. The square tiles can be combined to form a continuous roadway layout. A four-lane divided highway with a grass median is created for the study. The highway contains three clover leaf interchanges that are used exclusively for the entry or exit of interacting traffic. This allows for a smooth transition of traffic between events without visual glitches.

3.2.3. Designing the Test Scenarios

In this thesis, four major events were incorporated in the highway scenario to determine effects of ACC on driver behavior and awareness. They include:

- **Car following:** This event requires the participants to maintain a preferred headway to the lead vehicle with and without the ACC system. The lead vehicle is programmed to maintain a constant velocity of 70 mph while the drivers are expected to maintain a safe following distance;

- **Crossing animal (deer):** In this event, the participant is required to perform an evasive maneuver to avoid hitting two deer running across the roadway. The deer are programmed in such a way that the collision is unavoidable. This is done to ensure that most participants only use their brakes to avoid the deer;

- **Desk drop:** This event comprises of two sequential sub events. The participant is required to respond to a distraction, during which a desk is dropped from the lead vehicle. Participant reaction times are measured based on their ability to perform an evasive maneuver such as applying the brakes, adjusting the steering wheel angle, and speeding-up; and

- **Work zone:** In this event, the awareness of the participants is measured based on their ability to read and process traffic signs. The speed limit in the work zone is set at 55 mph while a lead vehicle is programmed to violate the set speed limit by travelling at 70 mph. Participant's ability to navigate the roadway based on the speed regulations versus lead vehicle influence is measured.

The scenario also included a few minor events such as an induced distraction in the vehicle, sudden merging vehicle, and pulled over vehicles. During these minor events, specific driver actions were monitored. For example, during the induced distraction event, the DRT response time and hit rate were recorded as well as the hit rate on the application. During sudden lane change, the driver's time to collision was recorded with respect to the braking maneuver. And, during the event involving a pulled over vehicle on the road shoulder, data on driver's ability to observe the "move over law" were collected.

3.2.4. Pilot Testing

After initial scenario design, four test participants with no prior exposure to the scenario or events were invited to drive the scenario. Based on their feedback, a few modifications were made to the events within the scenario such as changing traffic speed, adjusting distances between triggers, and fixing unnoticed graphics bugs in the simulated environment. This phase provided key insights on how actual participants would react to the study and the quality of the data to be collected.

3.3. Task 3: Creating Distraction and Measuring Workload

To simulate distractions in the vehicle, a Microsoft Windows based application was designed using VB.NET. The application was modeled to simulate in-vehicle distractions caused when using devices such as the media controller, climate controller, GPS device, and cell phone. The application was installed on a 10-inch Windows touch screen tablet. The layout of the application is shown in section 4.5.

For this study, a head-mount DRT device with a micro switch was used. The equipment was borrowed from the Department of Psychology at KU. The DRT stimuli were presented in accordance with the ISO 17488: 2016. A red LED was presented in intervals ranging between three to five seconds with a duration of one second. The response time (RT) was collected in micro seconds and only responses that occurred between 100ms to 2500ms were considered as hits. Anything earlier than 100ms was regarded as a premature hit while anything greater than 2500ms was regarded as a miss. Any responses that never occurred were also recorded as misses. Figure 3-5 shows a participant driving the simulator during the study.

Figure 3-5: Participant wearing a head-mount during the drive

The drive of each participant was recorded as a means of correcting ambiguities in the collected data and synchronizing the DRT output. The video cameras in the simulator were adjusted to focus on the areas of interest such as the left hand with the micro switch, application to simulate distraction (also known as the GPS device), accelerator pedal, brake pedal, and an overview of the virtual driving environment. Figure 3-6 shows a screenshot of the video output with the areas of focus highlighted in red.

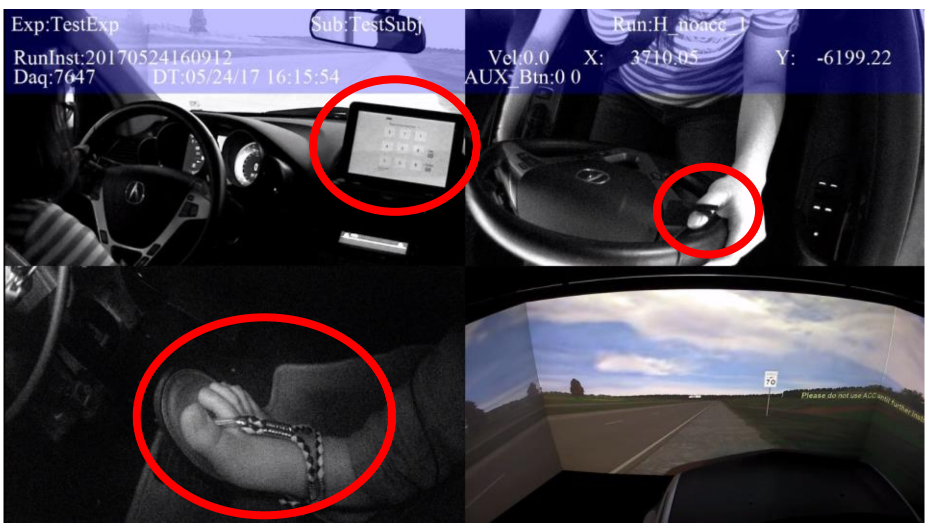


Figure 3-6: Areas of focus during video data collection

The frame rate of the video data is synchronized with the data acquisition tool, making discovery of ambiguities in the quantitative data less complicated.

3.4. Task 4: Data Collection

The scenarios are run using the NADS MiniSim software *(38)*. The software directly links to the hardware inputs such as steering wheel, accelerator pedal, brake pedal, and gear selector. When a participant drives the scenario, all the data outputs are stored in a data acquisition file, accessible through MATLAB.

The filtered and sorted data included variables such as vehicle speed, lateral position, distance to lead vehicle, driver selected time-gap, ACC disengaging time, braking force, ACC warnings, steering wheel position, deceleration rate, and video data. Video data are mainly used for DRT equipment calibration and identification of ambiguities during data reduction. Section 4 discusses the data collection task in grave detail.

3.5. Task 5: Data Reduction and Statistical Analysis

The thesis was aimed at determining changes in situational awareness of drivers, when exposed to ACC systems. The proposed null hypothesis is that there is no significant difference between driver behavior and awareness of individuals driving with the ACC and without the ACC. This is tested by carrying out the 2-tailed paired sample t-test at a confidence level of 95%. An ANOVA is also carried out where a significant difference in data variables between the age groups or genders is observed.

$$H_0: \mu_1 - \mu_2 = 0$$

$$H_a: \mu_1 - \mu_2 \neq 0$$

Where,

μ_1 represents the mean of the data variable collected during the scenario without the ACC; and

μ_2 represents the mean of the data variable collected during the scenario with the ACC active.

SPSS was used to perform the statistical analysis on the sorted data. The obtained significance tables and charts are shown in the Chapter 5.

3.6. Limitations

Driving simulators are not fully capable of reproducing real world details and motion cues. However, it is necessary to immerse drivers into the task of driving in order to obtain significant data. Although it is necessary to immerse drivers, some limitations exist.

Simulator sickness is a possibility and necessary precautions were taken to warn participants in advance. Participants were required to drive a tutorial scenario for 5 to 20 minutes depending on how comfortable they were with the ACC system and to eliminate severe cases of simulator sickness. During this study, two participants reported severe simulator sickness during the tutorial phase and could not continue. However, because it was detected early, other participants were recruited to complete the study.

Attracting older age group participants was another significant challenge faced during this study. Most businesses considered advertising in their premises soliciting and therefore declined to assist with the study. However, with the assistance from Mr. Len Andyshak and the International Students Services (ISS) at KU, willing older age group participants were recruited.

4. DATA COLLECTION

The process of data collection took approximately 50 days to complete. It required careful planning and coordination especially with the participants in the older age group. The routine followed during data collection is described below.

First, participants were given a brief tour of the equipment and what was expected during the drive. Then they were given a few minutes to read and sign the consent form which elaborated on the recorded data and how it would be used in the thesis. A copy of the consent form is attached in Appendix D.

Second, participants were given a tutorial scenario to complete. This tutorial scenario allows participants to get familiar with the ACC system, DRT device, touch screen GPS device, feel of driving, voice commands, ACC warning sounds, and time headway to lead vehicle. More detailed information on the tutorial scenario is given in Section 4.4.

After the tutorial scenario was completed and participants demonstrated a good command of using the ACC system, the actual scenario was started. Participants first drove the cab without using the ACC. Then, the participants drove the cab with the ACC system. This allowed for the comparison of the various parameters in both drives as the only difference was the use of the ACC system. The following sections provide more details on the procedure followed during data collection.

4.1. Sample Population

The initial proposal and methodology of the study was submitted to the Human Subjects Committee – Lawrence (HSCL) for approval. A copy of the approval letter is shown in Appendix D. The sample population consisted of 30 participants equally split between males and females. Participants were required to have a valid U.S. driver's license with a minimum of one-year driving experience. This was done to weed out less experienced drivers and those without a legal driving status. Participants were also offered $20 upon the successful completion of both scenarios. For this study, none of the selected participants reported any previous experience driving with ACC systems.

Participants were categorized in three age groups 18-24 years, 25-49 years, and 50-65 years, with each age group consisting of 10 participants. The youngest participant was aged 20 years while the oldest was 65 years. Figure 4-1 shows the age and gender of the selected participants with respect to assigned identification numbers and study group.

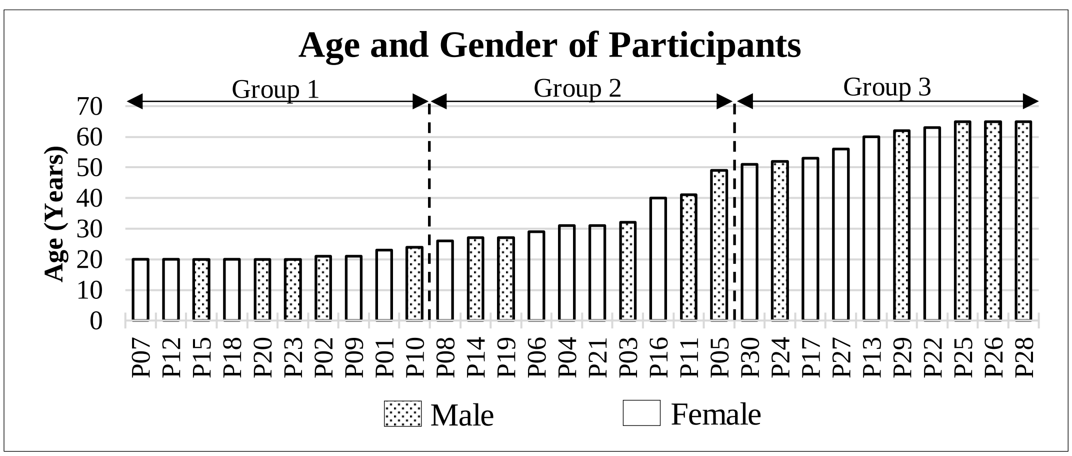


Figure 4-1: Age and gender of selected participants

4.1.1. Information from Screening Questionnaires

The screening questionnaire provided key insights into the participant's experience as a driver, medical condition, and willingness to participate in the study. Participants fill out the questionnaire with information pertaining to contact information, age, gender, possession of a valid U.S. driver's license, model/year of current vehicle, experience with ACC systems, estimate of a safe car following distance, existing medical conditions, willingness to use ACC systems, willingness to participate in a simulator based study, and history of motion sickness. A copy of the screening questionnaire is shown in Appendix B of this thesis.

For participants to be approved for the study, some criteria had to be met such as no heart conditions, no history of severe motion sickness (greater than 3 on a scale of 1 to 5), and no history of seizures. Participants were also required to have responded with a safe following distance between 2 seconds and 5 seconds, to be qualified for the study. This is because applicants who preferred any shorter or longer distances than those mentioned were not considered as average drivers. They might also affect the performance of other vehicles in the simulated scenarios, thus resulting in data collection errors. Table 4-1 shows the responses received from participants during the screening phase.

Table 4-1: Responses from the screening questionnaire

ID	Question Number							
	1	2	3	4	5	6	7	8
P01	Yes	Very Willing	F	23	Kia 2007	No	4 Seconds	No
P02	Yes	Very Willing	M	21	2000 Honda CR-V	No	2 Seconds	No
P03	Yes	Very Willing	M	32	Toyota Corolla	No	3 Seconds	No
P04	Yes	Very Willing	F	31	Toyota Corolla	No	4 Seconds	No
P05	Yes	Very Willing	M	49	Volvo S80-2001	No	5 Seconds	No
P06	Yes	Very Willing	F	29	Volkswagen Golf 2002	No	3 Seconds	No
P07	Yes	Very Willing	F	20	Toyota 2001	No	2 Seconds	No
P08	Yes	Very Willing	F	26	Honda Accord 2010	No	2 or more	No
P09	Yes	Very Willing	F	21	2007 Toyota Camry	No	2-3 Seconds	No
P10	Yes	Very Willing	M	24	Toyota Matrix '06	No	2 Seconds	No
P11	Yes	Very Willing	M	41	Plymouth Voyager 1996	No	3 Seconds	No
P12	Yes	Very Willing	F	20	Toyota Camry 2016	No	4 Seconds	No
P13	Yes	Willing	F	60	Chevy Trax 2015	No	3 Seconds	No
P14	Yes	Very Willing	M	27	Volvo S60R 2004	No	3 Seconds	No
P15	Yes	Very Willing	M	20	2015 Toyota Tundra	No	3 Seconds	No
P16	Yes	Very Willing	F	40	Toyota Matrix 2005	No	2 Seconds	No
P17	Yes	Very Willing	F	53	2009 Mazda Touring	No	1 car length	Not Sure
P18	Yes	Willing	F	20	Ford Taurus 2003	Yes	5 Seconds	No
P19	Yes	Very Willing	M	27	Hyundai Sonata 2015	No	3 Seconds	No
P20	Yes	Very Willing	M	20	Mazda 3 2012	No	2 or more	No
P21	Yes	Willing	F	31	2003 Chevy Tracker	No	2 Seconds	No
P22	Yes	Willing	F	63	2010 Lexus	No	3-4 Seconds	No
P23	Yes	Very Willing	M	20	2004 Highlander	No	2 Seconds	No
P24	Yes	Willing	M	52	2008 Ford F150	No	2 Seconds	No
P25	Yes	Very Willing	M	65	Honda Pilot 2013	No	1 car length	No
P26	Yes	Willing	M	65	2011 Subaru Forester	No	5 Seconds	Not Sure
P27	Yes	Very Willing	F	56	2014 Toyota Rav 4	No	3 Seconds	No
P28	Yes	Very Willing	M	65	2014 Toyota Rav 4	No	3 Seconds	No
P29	Yes	Very Willing	M	62	2014 Toyota Camry	No	2-3 Seconds	No
P30	Yes	Blank	F	51	Toyota Camry 2008	No	3 Seconds	Not Sure

Legend-Questions 1 to 8			
1	Do you have a valid United States driver's license?	**5**	What vehicle do you own/drive (make & year)?
2	How willing are you to participate in a driving simulator study?	**6**	Have you ever used ACC in any vehicle?
3	What is your gender?	**7**	What is a safe car following distance in seconds?
4	What is your age?	**8**	Is your current vehicle equipped with ACC?

Table 4-1: Continued

ID	Question Number							
	9	10	11	12	13	14	15	16
P01	N/A	Very Willing	Blank	No	No	No	1	1
P02	N/A	Very Willing	Blank	Blank	Blank	Blank	0	0
P03	N/A	N/A	Blank	Blank	Blank	Blank	0	0
P04	N/A	N/A	Blank	Blank	Blank	Blank	0	0
P05	N/A	Very Willing	None	No	Blank	No	0	0
P06	N/A	Very Willing	None	None	None	No	2	0
P07	N/A	Very Willing	N/A	N/A	N/A	N/A	0	0
P08	N/A	Very Willing	Hypothyroidism	No	No	No	0	0
P09	N/A	Very Willing	No	No	No	No	Bus 2, Car 1	1
P10	Blank	Very Willing	Blank	No	No	No	0	0
P11	N/A	Very Willing	No	No	No	No	0	0
P12	N/A	Very Willing	Asthma	No	No	No	1	1
P13	N/A	Willing	Rheumatoid Arthritis	No	No	No	0	0
P14	N/A	Very Willing	No	No	No	No	0	0
P15	N/A	Very Willing	None	No	No	No	0	0
P16	N/A	Very Willing	Blank	Blank	No	Blank	3-Back seat	3
P17	N/A	Very Willing	Not aware of any	No	Hearing Aid	No	0	0
P18	N/A	N/A	Blank	Blank	Blank	Blank	3-Riding in cars	3
P19	Blank	Very Willing	Blank	No	No	No	0	0
P20	N/A	Very Willing	None	No	No	No	0	N/A
P21	Blank	N/A	Blank	Blank	Blank	Blank	Car 3	3
P22	Blank	Willing	Blank	No	No	No	0	0
P23	N/A	Very Willing	N/A	N/A	N/A	N/A	N/A	N/A
P24	N/A	Willing	Not aware of any	No	No	No	Boat-2	2
P25	Blank	Willing	Blank	Yes 1981	No	No	0	0
P26	N/A	Willing	Blank	No	No	No	0	0
P27	Blank	Very Willing	No	No	No	No	0	Blank
P28	Blank	Very Willing	No	No	No	No	0	Blank
P29	N/A	Blank	Blank	No	No	No	Car 1	0
P30	N/A	Very Willing	N/A	No	No	No	0	0

Legend-Questions 9 to 16			
9	If YES, how often do you use ACC in your commute?	**13**	Have you experienced problems with hearing or ear?
10	If No, how willing are you to try using ACC?	**14**	Do you suffer from a heart condition?
11	Do you suffer from any health conditions?	**15**	Do you experience motion sickness? Scale 0-5
12	Have you ever experienced seizures?	**16**	Please state the intensity of your motion sickness? Scale 0-5

4.1.2. Assigning Participants to Scenarios

After the participants for the study were finalized, a distribution chart was developed to assign participants to the different versions of the scenarios. This was done to prevent errors resulting from all participants being exposed to the same sequence of events. Table 4-2 shows the distribution of participants in the three versions of the scenario without ACC. Each age group sums up to ten participants of which five are male and five are female.

Table 4-2: Participant distribution in scenarios without the ACC

<table>
<tr><th>Age</th><th>Scenario 1</th><th>Scenario 2</th><th>Scenario 3</th><th colspan="2">Total</th></tr>
<tr><td>18-24</td><td>1M 2F</td><td>2M 1F</td><td>2M 2F</td><td>5M 5F</td><td>10</td></tr>
<tr><td>25-49</td><td>1F 2M</td><td>2M 2F</td><td>2F 1M</td><td>5M 5F</td><td>10</td></tr>
<tr><td>50-65</td><td>2M 2F</td><td>1M 2F</td><td>1F 2M</td><td>5M 5F</td><td>10</td></tr>
<tr><td rowspan="2">Total</td><td>5M 5F</td><td>5M 5F</td><td>5M 5F</td><td rowspan="2" colspan="2">30</td></tr>
<tr><td>10</td><td>10</td><td>10</td></tr>
</table>

After distributing to the scenarios without ACC, participants in each age group and scenario were further distributed into two scenarios with ACC. For example, the age group between 18-24 years in scenario 1 without ACC contained one male and two female participants. During the ACC scenario, the one male and one female participant were assigned to scenario 2 while the one female participant was assigned to scenario 3, to ensure that male and female participants in the same age group were exposed to different sequence of events. However, not all scenarios were able to fill both the male and female slots due to a small sample size. Table 4-3 shows how participants were assigned to their respective ACC scenarios.

Table 4-3: Assigning participants to respective scenarios with the ACC

NO ACC	Scenario 1		Scenario 2		Scenario 3		Total	
ACC	Scenario 2	Scenario 3	Scenario 1	Scenario 3	Scenario 1	Scenario 2		
18-24	1M 1F	1F	1M	1M 1F	1M 1F	1M 1F	5M 5F	10
25-49	1M	1M 1F	1M 1F	1M 1F	1M 1F	1F	5M 5F	10
50-65	1M 1F	1M 1F	1M 1F	1F	1M	1M 1F	5M 5F	10
Total	3M 2F	2M 3F	3M 2F	2M 3F	3M 2F	2M 3F	30	
	5	5	5	5	5	5		

4.2. The KU driving simulator

The KU driving simulator is a FB simulator with both the Acura MDX vehicle chassis and the display screens mounted to the ground. Because the vehicle is mounted to the ground, the simulator does not provide any motion cues.

The scenarios are displayed onto the screens using overhead projectors. The three front screens provide a 120^{o} horizontal field of view (FOV) as seen in Figure 4-2 and Figure 4-3. A rear screen (Screen 4) is also available to further increase realism by rendering display in the rear-view mirror and side mirrors. This allows the simulator to deliver an all-round display, providing a more immersed driving experience. As shown in Figure 4-2, the cab also contains a digital instrument panel that is activated when a scenario starts. This panel displays the speed, turn signals, cruise control notifications, gear selector display, and other vehicle related messages.

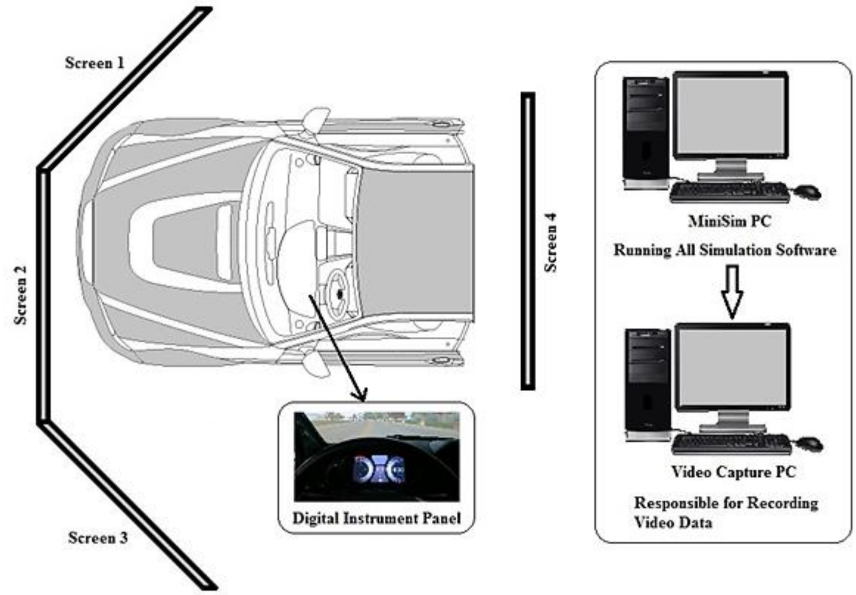


Figure 4-2: Configuration and layout of the KU driving simulator

The MiniSim PC controls the scenario simulation while the Video Capture PC is responsible for video data collection. The cab is mounted with four high definition (HD) cameras that record braking activity, facial cues, scenario position, and steering wheel activity. During this thesis, the MiniSim PC was also used to run the DRT software and record the output data.

Figure 4-3: KU driving simulator in action

4.3. Designing an Application to Simulate Distraction

The application layout consists of nine tiles with numbers varying between zero and eight as seen in Figure 4-4. The numbers are coded to rearrange randomly to prevent drivers from easily remembering the layout and not actually taking their eyes off the road.

Participants were required to match the number in the yellow box to the number on the square tiles. The application records the number of correct responses and the total number of attempts carried out by each person. However, in this study we are only interested in the total number of attempts during a given task as they were also required to respond to the DRT stimuli during the task. Participants were asked to simultaneously drive and use the application during the in-vehicle distraction task.

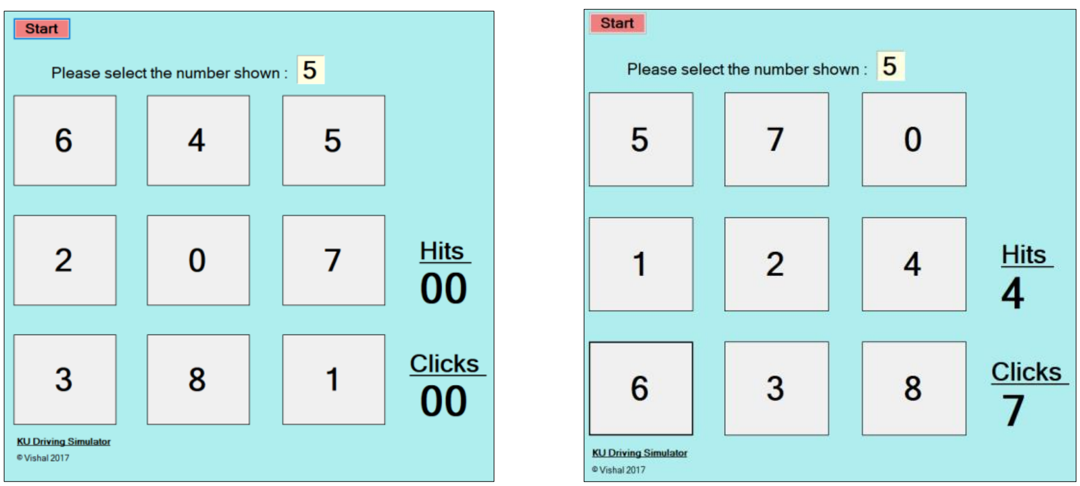


Figure 4-4: Interface of the application to simulate distraction

Participants practiced and got accustomed to the touch screen interface during the tutorial scenario. Participants were also familiarized with the voice commands that trigger the use of the application. The interface including the touch screen tablet was referred to as the GPS for this study. Although it did not function as the GPS, participants were trained to respond to voice commands that contained the word “GPS.” When the “start using the GPS now” phrase was heard, participants were required to hit the application as accurately as possible, until the phrase “stop using the GPS” was heard.

4.4. Configuring Events in the Driving Simulator

The Interactive Scenario Authoring Tool (ISAT) *(40)* is used to add roadway traffic and safety infrastructure to the scenario. Roadway traffic includes objects such as the autonomous dynamic object (ADO), deterministic dynamic object (DDO), stationary objects, and dependent DDO. The paths of the roadway traffic can be altered using the different triggers. Triggers can be activated by pads on the road (when any vehicle drives over the road pad), global time in the scenario, and other traversing vehicles. These triggers control visual aspects such as indicators, lane changes, vehicle dynamics, and vehicle condition.

The ADO can be visually represented as any type of vehicle (passenger car, bike, truck) available in the ISAT database. The ADO follows a defined path and adheres by all the traffic regulations just like a human driver. Although ADOs have a certain level of independent driving capabilities, their path can be altered using triggers. For example, a lane change at a desired point can be triggered when the desired vehicle drives over a road pad.

The DDO can also be represented as any type of vehicle. However, it can also be represented as an animal or object. Unlike the ADO, the DDO does not adhere to any traffic regulations, it blindly follows the path set in the scenario. The dependent DDO is almost the same as the DDO but with a capability of arriving at a point based on another vehicle/object in the scenario. The dependent DDO is used in the deer scenario as the deer was intended to reach the center of the road when the external driver is 40 feet away. In this way, the deer is always at the exact same location and distance for every participant in the study. The events are discussed at length in Section 4.5.

Six highway scenarios were created, three intended for driving without the ACC and three with the ACC system. The total length of the highway was 12 miles and took approximately 13 to 16 minutes depending on driver actions. The three variations of the highway scenario were created to prevent participants from predicting the sequence of events thus causing a bias in the data. Figure 4-5 shows the arrangement of events in the designed scenario.

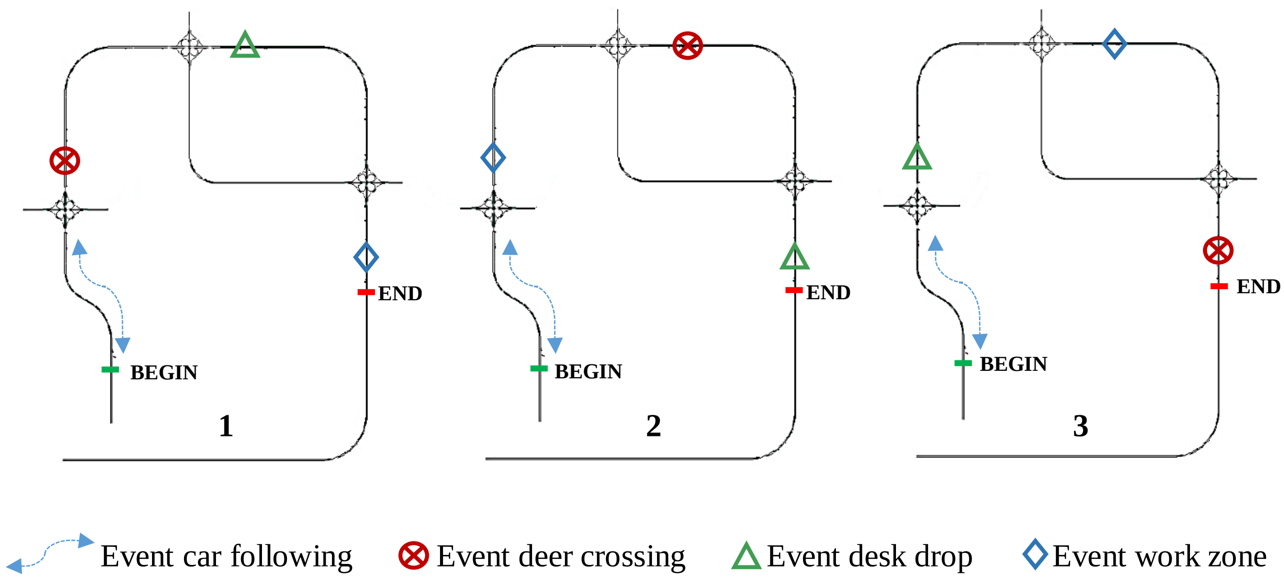


Figure 4-5: Layout of scenarios showing varying event locations

Voice commands set up within the scenarios, using a female computer-generated voice with a United States accent, were used to guide participants. The voice instructions were short and precise to avoid confusion or delays during the drive.

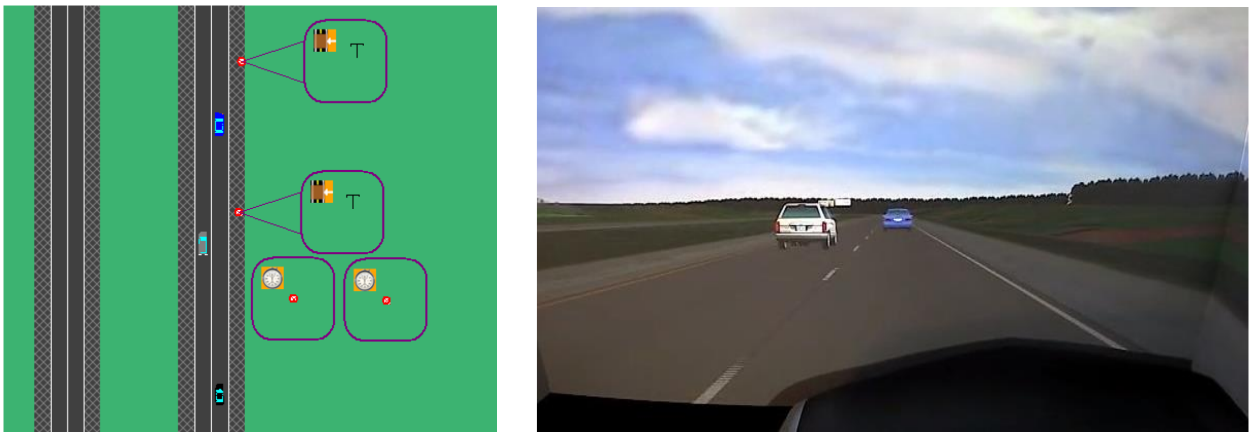
Participants were only allowed to proceed to the actual scenario if they showed proper understanding of the use of ACC system, especially with respect to warning alerts, engaging, disengaging, and time-gap adjustment. This Process of familiarizing participants with the ACC system took anywhere between 5 to 20 minutes. During the tutorial scenario, participants were also familiarized with the DRT equipment, GPS device, and in-vehicle systems such as air conditioning, instrument panel, ignition, indicators, side mirror adjustment buttons, and seat adjustment buttons.

The tutorial scenario was designed as a two-lane undivided highway. The goal of the scenario was to get participants accustomed to the following distances in the driving simulator, as they would differ slightly from real driving. Participants were asked to follow a lead vehicle (ambulance) while trying to maintain a safe following distance. Within the scenario, participants were also instructed to reach a velocity of 65 mph and activate the ACC system. However, the lead ambulance was designed to travel at a speed of 55 mph, allowing participants to adjust the time gap settings while observing the braking and acceleration capabilities of the ACC system. While driving the tutorial scenario, participants were monitored for simulator sickness. In cases where simulator sickness was detected, depending on how they felt, participants were given the option to continue or quit the study.

The actual scenario has two phases. The first phase where the participants drive without the ACC system and the second phase where they drive while engaging the ACC system at their discretion. Each phase has the same number of major and minor events occurring in a different sequence based on the participant allocation chart, shown in Table 4-3.The scenarios were designed as a grass median divided four-lane highway. The total length of the highway was 12 miles and consisted of four major events and three minor events. To keep participants engaged, simulated traffic was present in both directions of the highway. The design of each event with respect to the resulting data variables are described in detail below.

4.4.1. Car Following

This event was the first to occur in all scenarios. The posted speed limit for this section of the drive was 70 mph. It consisted of two lead vehicles, one in the left lane and the other in the right lane as seen in Figure 4-6. The driver is expected to follow either vehicles at a headway that he/she is comfortable maintaining. This event did not require the drivers to perform an emergency maneuver as it designed to establish their normal driving preferences of headway, lane position, and speed on a divided highway.



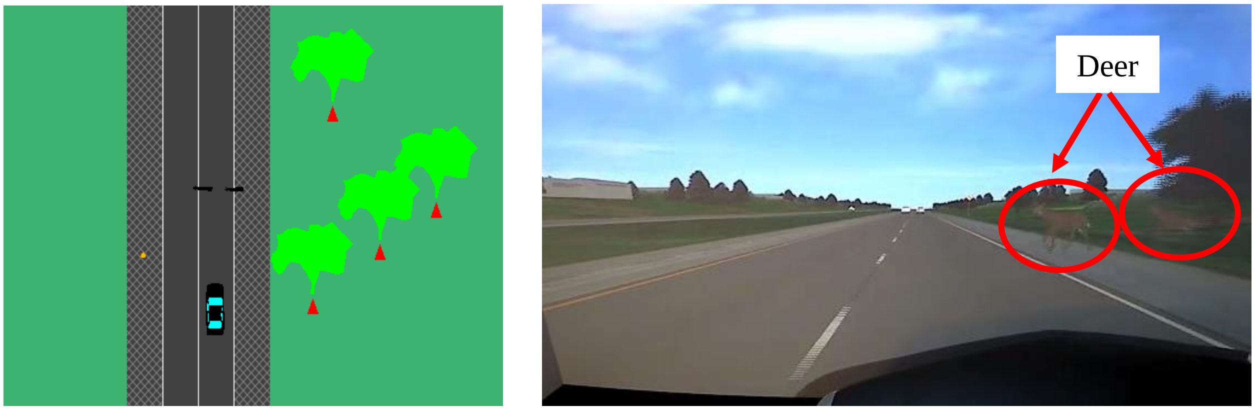
(a) (b)

Figure 4-6: Car following event - design view (a) and driver view (b)

The two lead vehicles are designed to travel at a constant velocity of 70 mph. The drivers have the opportunity to maintain a safe headway while keeping close to the speed limit.

4.4.2. Deer Crossing

During this event, participants were required to perform some sort of evasive maneuver such as applying the brakes, accelerating, and rotating the steering wheel. Based on these actions, time to collision with the deer at the instance when the evasive maneuver was performed can be determined. Time to collision will be used as a measure of the driver's reaction time. Figure 4-7 shows the design and driver view of the deer scenario.



(a) (b)

Figure 4-7: Deer crossing event - design view (a) and driver view (b)

The deer in the event were configured to reach a designated point when the participants reach the target zone. The distance between the deer and the target zone is 40 feet. This was done to induce an emergency evasive maneuver to avoid the deer. In order to provide a clue to participants, animal crossing traffic signs were placed at three locations. However, the event only occurred at one of the three locations. The mechanics of the event are shown in Figure 4-8. When the participant's vehicle arrives at the target points/zones, D1 (deer 1) arrives at location P1 and D2 (deer 2) arrives at location P2. The lane chosen by the driver does not influence the distance to the deer.

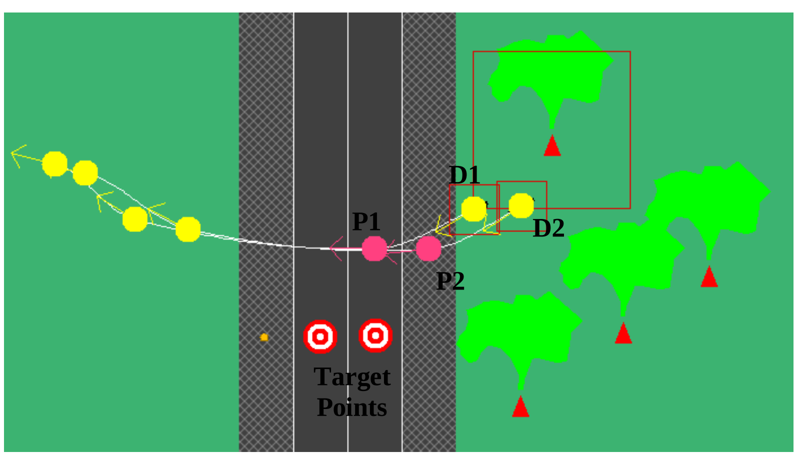
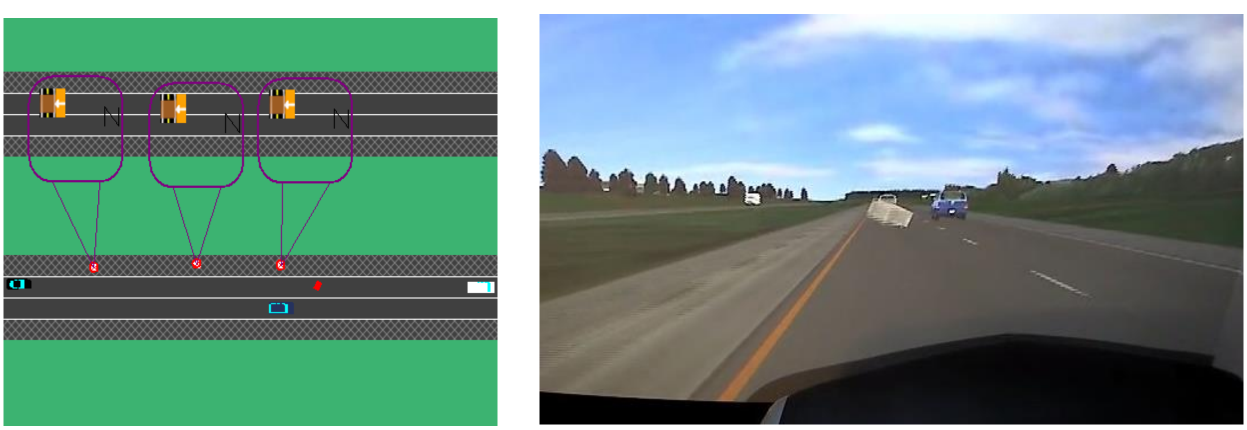


Figure 4-8: Path followed by the deer

4.4.3. Desk Drop

The desk drop event was the most challenging to design and execute. This is because it consisted of an overlapping path between an object (desk) and the transport vehicle (van). The van transporting the desk is only activated when the driver is within 800 feet of the creation point. The 800 feet does not provide any significance to the event as it is the distance required by the van, from the creation point, to get ahead of the driver with a 70 mph velocity. The desk is designed to slide out of the transporting van with a velocity of 15 mph, towards the direction of the participant's vehicle. At the time of the desk drop, participants were instructed to use the GPS device through voice commands. This induced distraction by forcing participants to take their eyes off the roadway, thus creating an event that required an emergency evasive action.

The location of the desk drop during the event, in any scenario, is the same. However, participant's distance relative to the location of the desk drop depends on the traveling speed, and chosen time gap setting. Also, to make sure that the participants do not easily recognize the van that drops the desk, the same vehicle was used as roadway traffic during other events in the scenario. Figure 4-9 shows the desk drop event from the perspective of the designer and the participant in the study.



(a) (b)

Figure 4-9: Desk drop event - design view (a) and driver view (b)

The desk is represented as a red rectangle in the design view. However, during the simulated event, it is represented as a wooden desk as shown in Figure 4-9 (b). During this event, three variables were collected. They include: distance headway to the lead vehicle, vehicle speed, and time to collision with the desk at the instance of evasive maneuver.

4.4.4. Work Zone

The work zone event was located on a straight one-and-one-half mile section of highway. During the event, the left lane on the roadway was closed with traffic channelizers and road work machinery. Warning signs were placed at intervals of 500 feet for one-half mile, ahead of the work zone. This permitted sufficient time for participants to observe and process information on the warning signs such as left lane closed ahead, speed limit 55 mph, and road work ahead.

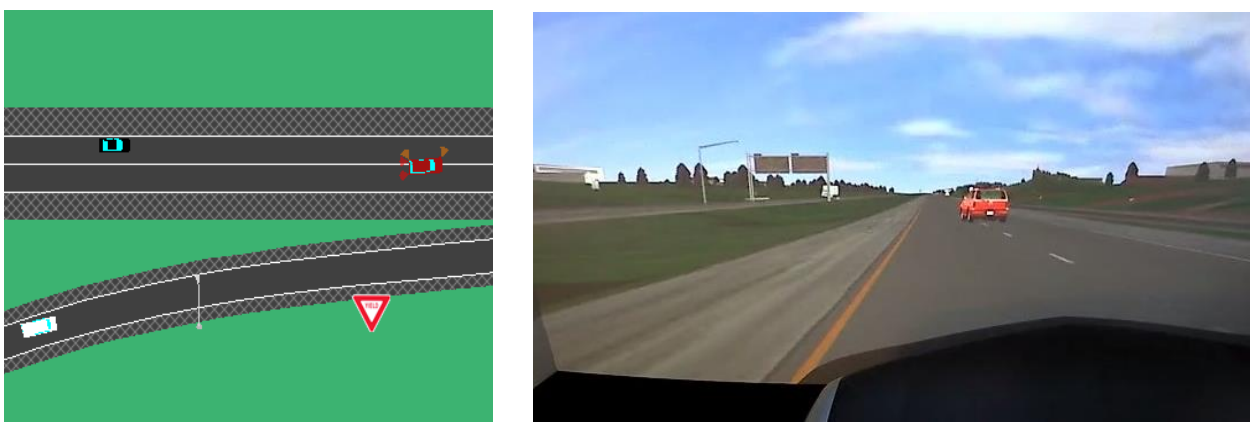
In this event, each participant's ability to follow traffic regulations based on the roadway signs and surrounding environment was measured. The lead vehicles in the event were configured to travel at 70 mph, violating the 55 mph speed limit. Participant's ability not to blindly follow the lead vehicle violating the traffic speed regulations is monitored. An average speed above 65 mph in the work zone event is considered as a violation. This is because drivers usually take time to slow down from the previous speed limit of 70 mph and speed up towards the end of the work zone.

(a) (b)

Figure 4-10: Work zone event - design view (a) and driver view (b)

4.4.5. Sudden Merging Vehicle

As the name suggests, this event involves a vehicle merging suddenly into the left lane with a lower speed (60 mph) than the posted speed limit of 70 mph. Participants were required to react to the sudden merging by applying brakes. This event captures variables such as brake pedal force, deceleration rate, and time to collision at the instance of braking. Figure 4-11 shows the instance when the lead vehicle suddenly merges into the left lane.



(a) (b)

Figure 4-11: Sudden merging vehicle event - design view (a) and driver view (b)

Participants were forced to only apply their brakes as there was another vehicle configured to merge into the right lane from the on-ramp at that instance, shown in Figure 4-11 (a). This narrowed down the choices of evasive maneuvers to one, applying brakes. As a result, data variables that were not available during other events were recorded and analyzed.

4.4.6. Move Over Law

The “move over or slow down” law applies to most roadways in the United States. As the name suggests, it requires drivers to move over to the left lane or slow down when vehicles are seen stationary alongside the shoulders or curbs. This is done mostly to avoid pedestrian fatalities especially during entry and exit into the stationary vehicle or during roadway construction works.

During this event, participants ability to successfully move over during a stationary vehicle scenario was analyzed. Every variation of the scenario was incorporated with three move over events. They include: stationary passenger car, stationary construction truck, and passenger car pulled over by the police. When a participant successfully obeyed the move over law by switching lanes or slowing down, a value of one was recorded in the data sheet. However, if the participant did not observe the law, a value of zero was recorded for that event. Figure 4-12 shows an example of the move over event where a passenger car has been pulled over by the police. The police vehicle is configured to have its warning lights active during the event. A maximum total of three can be recorded in each scenario, if participant observed the law. Driver’s ability to demonstrate situational awareness was determined by comparing the total number of successfully observed move over law events, with and without using the ACC system.

(a) (b)

Figure 4-12: Move over event - design view (a) and driver view (b)

4.4.7. Distraction in the Vehicle

During this event, participants were required to drive the vehicle while using the GPS device designed to simulate in-vehicle distractions as shown in Figure 4-13. The GPS device was a 10-inch touch screen tablet with a custom application, capable of shuffling numbers between 0 to 8 randomly as described in Section 4.3. Three distraction events were present in every scenario of the drive, each lasting between 10 and 15 seconds depending on the speed of the driver. All distraction events occurred on straight segments of the roadway with no traffic interference.

Figure 4-13: Simulated distraction while driving

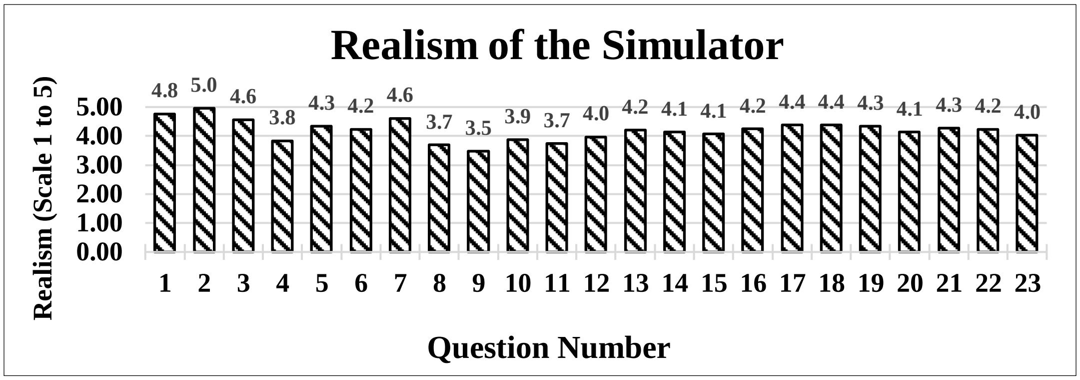
The main variable recorded during the event was the number of hit attempts on the touch screen interface. Hit attempts were analyzed together with the DRT data collected during the event, to determine whether the reduction of mental workload as a result of using the ACC system significantly altered the number of hit attempts recorded on the application.

4.5. After the Drive

After successful completion of both phases of the drive, participants were requested to fill a realism questionnaire about their driving experience in the simulator. A copy of the realism questionnaire is attached in Appendix E.

Figure 4-14 shows the average data obtained from the responses of the participants regarding the comparison of the driving simulator to actual driving. Based on the data, it can be determined that the overall experience was similar to driving. However, some aspects such as the feel of brakes, response of brake pedal, and sensation of acceleration received less positive feedback. The less positive feedback was anticipated as the simulator has a fixed-base and does not provide any significant motion cues to the drivers. Overall, the driving experience and the ease of engaging the ACC received positive feedback.

Participants were kept engaged after the drive, between 5-10 minutes, by asking a few questions about their personal life such as work, education, and sports interest, to ensure full physical and mental presence before leaving the test site. After, participants were issued a $20 gift card for their contribution to the study.



Legend			
1	Car external appearance	**13**	Driving along curves
2	Car interior	**14**	Feel of cars passing by
3	Startup sounds	**15**	Sensation of speed at 20 mph
4	Response of speedometer	**16**	Sensation of speed at 40 mph
5	Appearance of vehicles in rear view mirror	**17**	Sensation of speed at 55 mph
6	Appearance of vehicles in side mirrors	**18**	Sensation of speed at 65 mph
7	Response of gear shift	**19**	Sensation of speed at 75 mph
8	Response of the brake pedal	**20**	ACC engaging
9	Feel when brakes are applied	**21**	ACC alerts
10	Response of the accelerator pedal	**22**	Overall appearance of driving scenarios
11	Sensation of acceleration	**23**	Similarity to actual driving
12	Sensitivity of steering wheel		

Figure 4-14: Participants responses on the realism of the driving simulator

4.6. Data Extraction and Sorting

The first step after collecting the data was to extract it in its raw form. This was done using MATLAB and Microsoft excel. The data acquisition file, which recorded each participant's drive is only accessible through MATLAB. A MATLAB plugin known as the data acquisition viewer, provided by NADS, was used to select the required data variables from each scenario.

After extracting the required variables, data were exported to excel for further sorting. This process was time consuming as it required data to be sorted by individual events. Each event was uniquely numbered in ISAT between 1 and 20, allowing easy identification during sorting. Data variables were then summarized by participant ID and study group.

DRT data also required extensive filtering. This is because the data collected first needed to be synchronized with the MiniSim frame rate. The DRT device used for this study was not provided by NADS and hence required manual synchronization using video recordings. However, both the DRT device and MiniSim data acquisition had a frame rate of 60Hz, making the synchronization process easier. After synchronization, RT data had to be cleaned to weed out misses and guess work. Non-responses to stimuli were recorded as misses. Only responses between 100ms and 2500ms were considered as hits. Any responses less than 100ms were considered as premature responses, while responses that took longer than 2500ms were considered as unrequested responses. Both premature hits and unrequested responses were excluded from the analysis, as recommended in the ISO 17488: 2016.

4.7. Data Collection Summary

This section of the thesis elaborated on the process followed during data collection. Details such as the process of participant recruitment, scenario assignment, configuration of events, recorded data variables, and data sorting were discussed in length.

Participants were first assigned a unique identification number to avoid disclosing personal information. Then, they were distributed to specific scenarios with the ACC and without the ACC. This allowed each participant to be exposed to a different sequence of events in both phases of the drive.

Participants were then familiarized with the simulator using the help of a tutorial scenario. This exposed participants to the ACC system and its various time gap settings. After demonstrating proper understanding of the ACC system, thr DRT process, and the use of the simulator functions, successful participants proceeded to drive the actual scenario in two phases, without the ACC system and with the ACC system. Each scenario consisted of four major events and three minor events, each aimed at collecting a particular set of data variables. After collection, the data needed to be sorted and summarized using MATLAB and Microsoft excel. The results obtained are discussed in the next section of this thesis.

5. RESULTS

This section presents the results obtained from the data collection phase. The SPSS software was used for the statistical analysis that involved the 2-tailed paired t-test and the analysis of variance (ANOVA). The data used for the statistical analysis are shown in Appendix G and Appendix H.

5.1. Whole Drive

Every instance involving a contact between the driver and another vehicle or object was recorded as a collision during the drive. A minimum of one collision was possible during the drive. This is because the event involving the crossing deer was designed to be unavoidable. However, the event involving a desk drop could be avoided by performing an evasive maneuver. Determining differences in collision count between the two drives can be crucial in establishing whether participants showed a significant change when exposed to the ACC system. Figure 5-1 shows the number of collisions with respect to each participant.

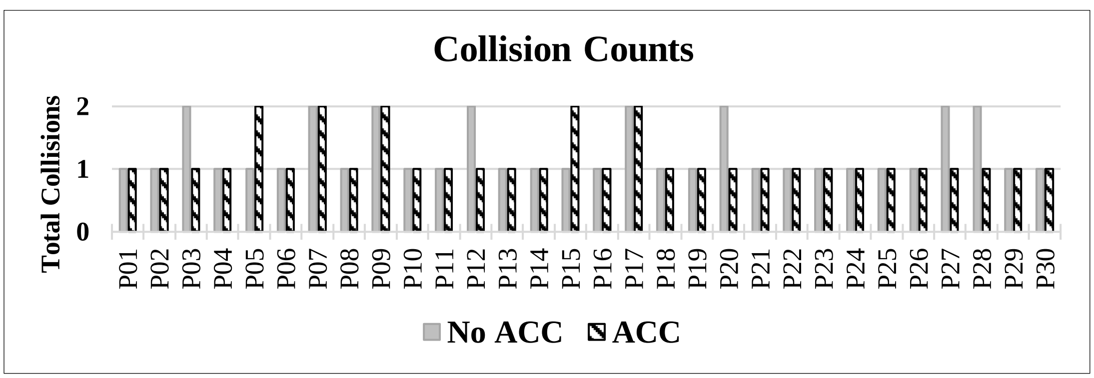


Figure 5-1: Collision counts for the entire drive

Just by looking at Figure 5-1, there does not seem to be an increase or decrease in the total number of collisions in the drive without ACC and with the ACC. A paired t-test was carried out and the results are shown in Table 5-1. The paired t-test resulted in a p-value of 0.264 which is greater than 0.025, indicating no significant difference between the means of the collision counts during the two phases of the drive. Thus, failing to reject the null hypothesis. The ANOVA, comprising of Tukey's and Bonferroni's multiple comparisons, was also carried out to determine any significant differences in collision counts resulting from the age group and gender of the participants. However, no significant results were observed.

Table 5-1: Paired sample t-statistic for collisions during the drive

		Mean	N	Std. Deviation	Std. Error Mean
Collision Counts	No ACC	1.27	30	.450	.082
	ACC	1.17	30	.379	.069

			Std. Error	95% CI of the Difference				
	Mean	Std. Dev	Mean	Lower	Upper	t	df	Sig. (2-tailed)
No ACC - ACC	.100	.481	.088	-.079	.279	1.140	29	.264

Maximum recorded speed during the whole drive was recorded as one of the variables. It helps to understand how the ACC system affects the speed of drivers on a highway with a speed limit of 70 mph. Figure 5-2 shows the maximum speeds recorded by each participant during the two phases of the drive.

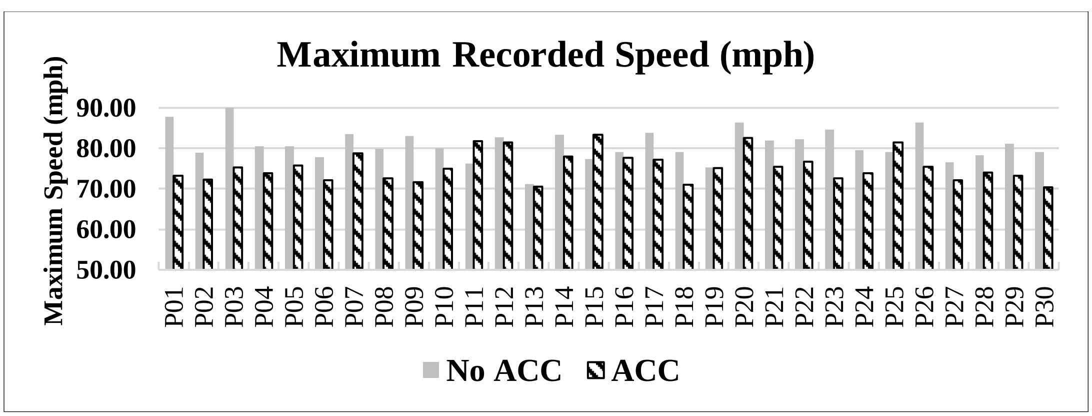


Figure 5-2: Maximum speed recorded during the drive

Most participants recorded higher maximum speeds during their drive without the ACC than with the ACC. During the phase with the ACC, participants were observed to record a maximum velocity 6.7% smaller than those without the ACC. The resulting p-value of the two-tailed t-test is less than 0.001, indicating a significant difference between the means of the two samples. Table 5-2 shows the results obtained from the SPSS analysis.

Table 5-2: Paired sample t-statistic for maximum speed during the drive

		Mean	N	Std. Deviation	Std. Error Mean
Max Speed	No ACC	80.9	30	4.02	.734
	ACC	75.5	30	3.73	.680

			Std. Error	95% CI of the Difference				
	Mean	Std. Dev	Mean	Lower	Upper	t	df	Sig. (2-tailed)
No ACC - ACC	5.40	5.02	.916	3.529	7.275	5.899	29	.000

The ANOVA was also carried out to determine any significant differences in maximum speeds resulting from the age group and gender of the participants. However, no significant results were observed.

5.2. Major Events

5.2.1. Car Following

During the car following event, data on preferred headway (distance in feet) to the lead vehicle were recorded. This variable was collected every 60 HZ (1/60 seconds). Section 4.3.1 contains a detailed description of the event. The average headway value from the beginning to the end of the car following event was calculated for each participant. Figure 5-3 shows the average headway for all participants in both phases of the drive.

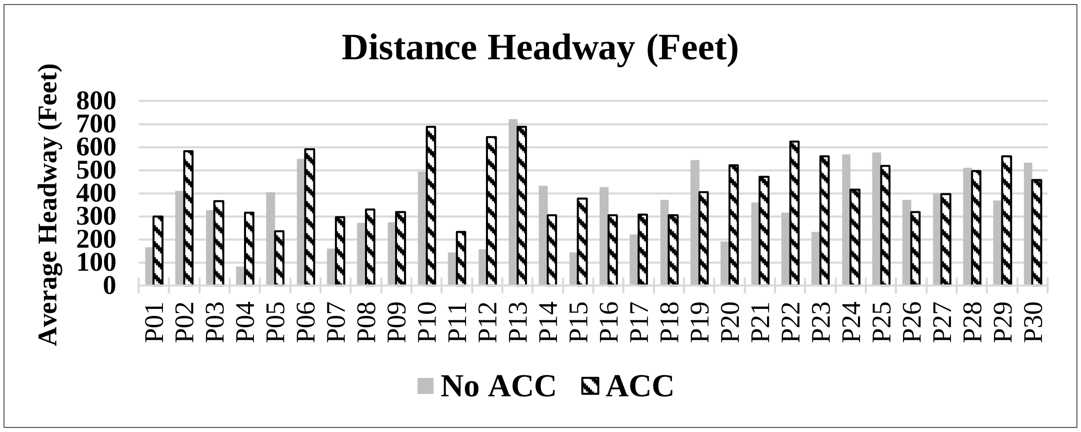


Figure 5-3: Average headway during the car following event

Preferred headway distance provides an insight into risky driver behavior. Drivers who tend to maintain shorter headways are less likely to perform a successful evasive maneuver in an emergency due to a shorter time to collision with the lead vehicle. However, when using the ACC, it was noticed that most drivers opted for longer headways. On average, participants observed 20.5% longer headways when using the ACC. This could be a result of the selected time gap setting during the drive or due to the compensation effect of being unfamiliar with the ACC system. Studies have shown that drivers tend to be more cautious when using new driver assistance systems to compensate for their unfamiliarity *(8, 41)*.

The SPSS analysis shown in Table 5-3, resulted in a p-value of 0.022 which is less than 0.025 (two-tailed test at 95% confidence level). This indicates a significant difference in the means of the two phases of the drive, based on the headway data collected from this sample of participants.

Table 5-3: Paired sample t-statistic for headway during the car following event

		Mean	N	Std. Deviation	Std. Error Mean
Headway	No ACC	357.3	30	160.6	29.3
	ACC	430.6	30	138.1	25.2

	Mean	Std. Dev	Std. Error Mean	95% CI of the Difference		t	df	Sig. (2-tailed)
				Lower	Upper			
No ACC - ACC	-73.2	165.4	30.198	-135.0	-11.48	-2.425	29	.022

Data on Maximum speed were also recorded during the event. Similar data, as seen during the whole drive, were observed. Maximum speeds were higher during the no ACC phase with a mean velocity of 77.3 mph, than those recorded in the ACC phase with a mean velocity of 73.3 mph (on average 5.2% reduction in maximum speed with the ACC active). Figure 5-4 and Table 5-4 show the resulting values of the statistical analysis. The observed p-value was less than 0.001, indicating a significant difference between the two means. This also indicated that when using the ACC, participants were closer to the posted speed limit than when not using the ACC.

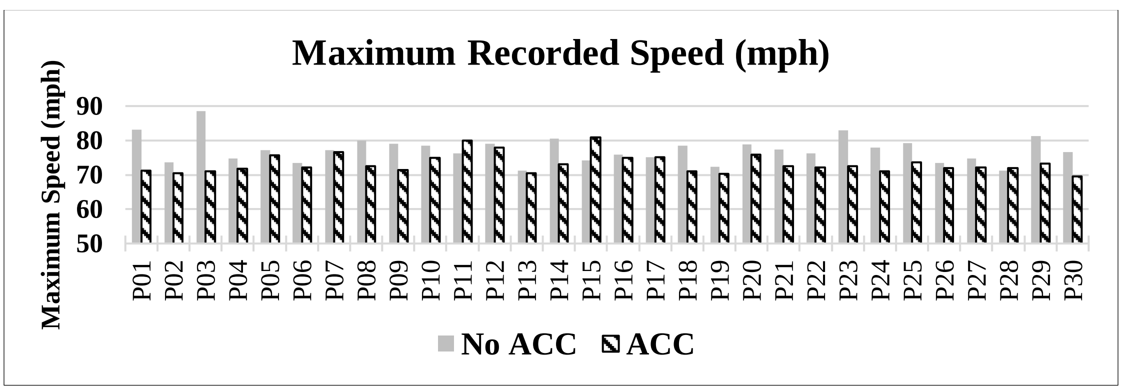


Figure 5-4: Maximum speed recorded during the car following event

Table 5-4: Paired sample t-statistic for maximum speed during the car following event

		Mean	N	Std. Deviation	Std. Error Mean
Max Speed	No ACC	77.3	30	3.789	.692
	ACC	73.3	30	2.831	.517

	Mean	Std. Dev	Std. Error Mean	95% CI of the Difference Lower	Upper	t	df	Sig. (2-tailed)
No ACC - ACC	3.990	4.76	.869	2.215	5.772	4.593	29	.000

The average speed variable is similar to the maximum speed variable. However, it is calculated by averaging the point speed, recorded at a frequency of 60 HZ. Figure 5-5 shows the average speeds during the car following event. The average speeds of both phases of the drive are similar. This could be because the high and low values are averaged out over the span of the event.

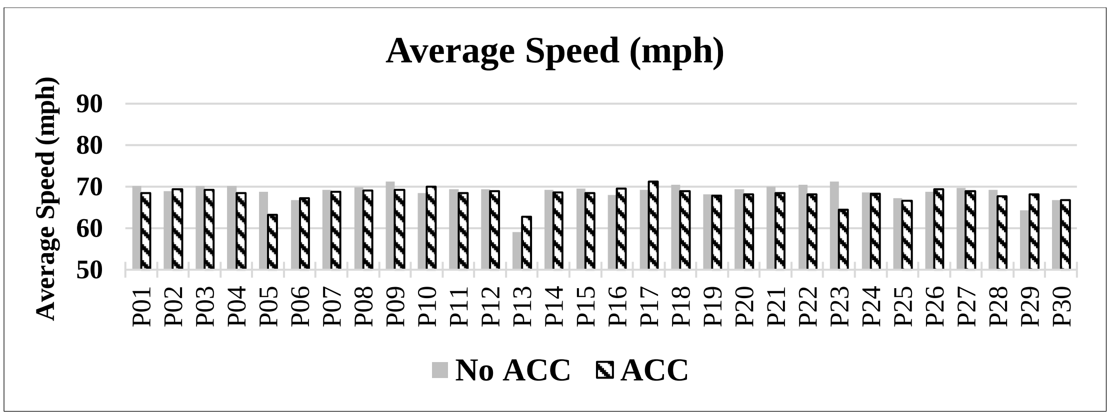


Figure 5-5: Average speed during the car following event

The comparison of the means in the paired t-test resulted in a p-value of 0.128 (Table 5-5), indicating no significant difference. The t-test failed to successfully reject the null hypothesis.

Table 5-5: Paired sample t-statistic for average speed during the car following event

		Mean	N	Std. Deviation	Std. Error Mean
Average Speed	No ACC	68.7	30	2.323	.424
	ACC	68.1	30	1.823	.333

	Mean	Std. Dev	Std. Error Mean	95% CI of the Difference Lower	95% CI of the Difference Upper	t	df	Sig. (2-tailed)
No ACC - ACC	.613	2.144	.392	-.187	1.414	1.566	29	.128

The speed standard deviation of each participant was calculated to determine the consistency of the traveling speed during the event. The plots for the standard deviations are shown in Figure 5-6. A paired t-test was also performed to determine any difference in the deviations between the two phases of the drive. The test resulted in a p-value of 0.462 (Table 5-6), suggesting no significant difference between the means. No sufficient evidence was present to reject the null hypothesis, indicating similar speed deviations in both phases of the drive.

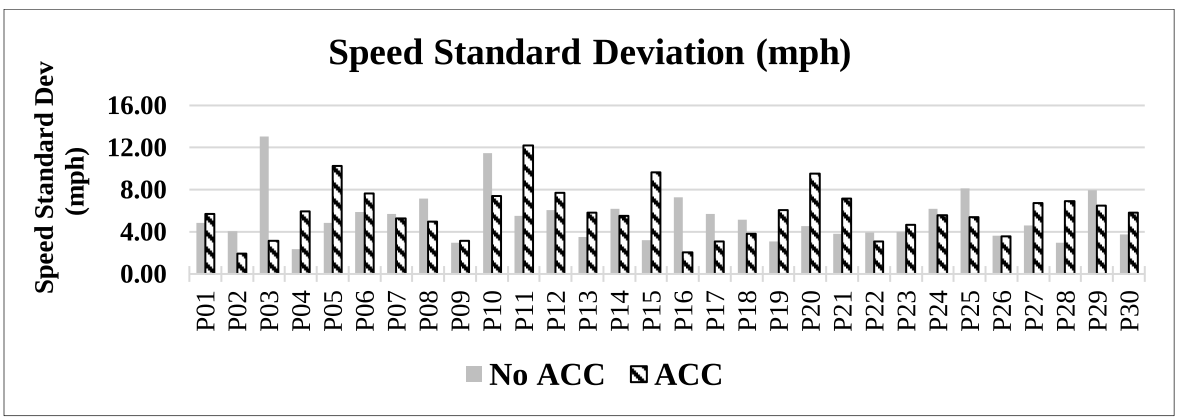


Figure 5-6: Standard deviation of speed during the car following event

Table 5-6: Paired sample t-statistic for speed deviation during the car following event

		Mean	N	Std. Deviation	Std. Error Mean
Speed	No ACC	5.387	30	2.419	.4416
Std. Dev	ACC	5.877	30	2.441	.4456

	Mean	Std. Dev	Std. Error Mean	95% CI of the Difference Lower	Upper	t	df	Sig. (2-tailed)
No ACC - ACC	-.490	3.601	.6575	-1.8347	.8549	-.745	29	.462

Figure 5-7 shows an amalgamation of Figure 5-5 and Figure 5-6. The error bars represent the speed deviations of drivers. The red error bars represent the drive without the ACC, while the black error bars represent the drive with the ACC system. Apart from a few extreme values of speed deviations seen in participants P03, P05, P11, P15, and P16, the rest seem consistent during both phases of the drive.

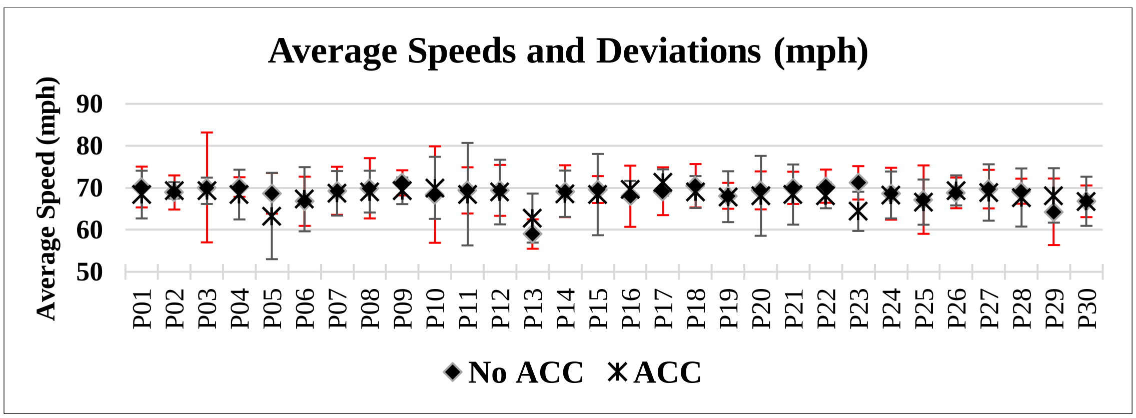


Figure 5-7: Combined average speeds and standard deviations

Another variable collected during this event was the lane position deviation. As drivers are engaged in different tasks, their ability to maintain a constant offset from the centerline of their lane varies. Large deviations indicate inconsistent driving with poor lane keeping abilities while small deviations indicate consistent driving with good lane keeping abilities. Figure 5-8 shows lane deviations of each participant during the car following event. Based on the paired t-test carried out on the study sample, a p-value of 0.049 (greater than 0.025) shown in Table 5-7 was obtained, indicating no significant difference between the means of the two phases of the drive.

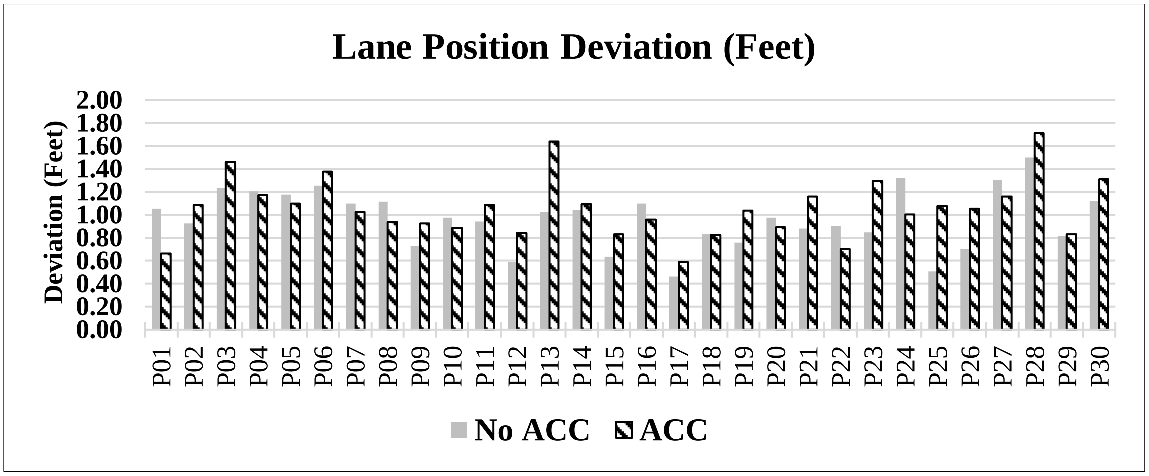


Figure 5-8: Lane deviation from centerline during the car following event

Table 5-7: Paired sample t-statistic for lane deviation during the car following event

		Mean	N	Std. Deviation	Std. Error Mean
Lane Pos Std. Dev	No ACC	.968	30	.2514	.04591
	ACC	1.059	30	.2620	.04783

	Mean	Std. Dev	Std. Error Mean	95% CI of the Difference Lower	95% CI of the Difference Upper	t	df	Sig. (2-tailed)
No ACC - ACC	-.0905	.2408	.04397	-.1804	-.00053	-2.057	29	.049

The ANOVA, comprising of Tukey’s and Bonferroni’s multiple comparisons, was carried out for all the variables in the car following variables (headway, maximum speed, average speed, speed deviation, and lane deviation). However, no significant differences between participants of different age groups or gender were observed.

5.2.2. Crossing Animal (Deer)

This event recorded four variables and they include: distance headway, time to collision, maximum speed, and lane position standard deviation. The event was mainly aimed at determining driver reaction time to the crossing deer. Time to collision was selected as a suitable variable to describe reaction time, as it considers both the speed of the driver and the distance to the deer. The time to collision variable recorded the instance at which an evasive maneuver was performed by the participant to avoid crashing into the deer in seconds. A large time to collision indicated that the participant perceived and reacted to the deer faster. However, a small time to collision indicated a slower perception and reaction to the event.

As described in section 4.3.2, the event design consists of two lead vehicles in both the left and right lanes of the roadway. It is designed to let participants maintain a safe headway to either lead vehicles, without anticipating a crossing deer. Figure 5-9 shows the recorded headways in feet of the 27 participants. Headway data for three participants were not included as the results for this variable were unavailable due to errors resulting from not maintaining the posted highway speed limit. The SPSS analysis on the headway data resulted in a p-value of 0.217, indicating no significant difference in between the means of the drive without the ACC and with the ACC. Participants tended to maintain 11% larger headways while using the ACC system than without the ACC.

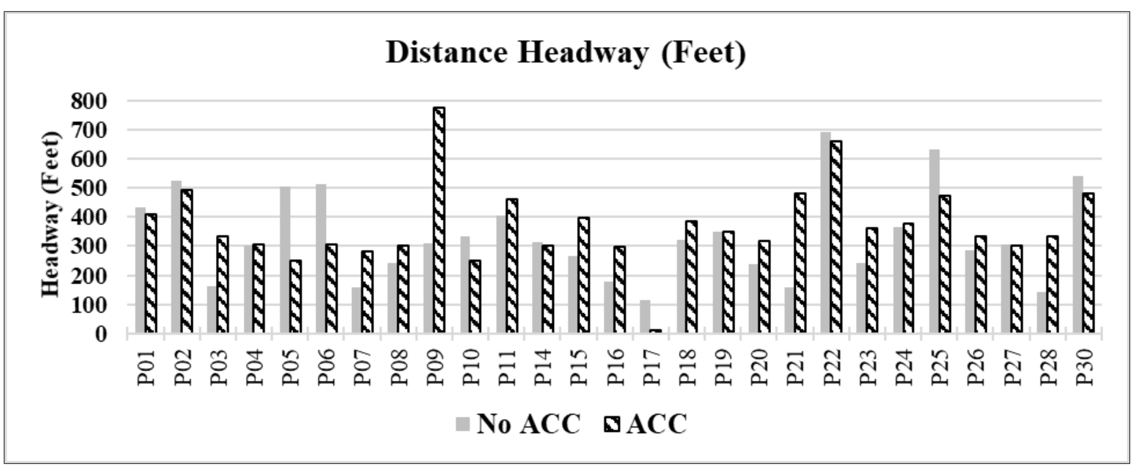


Figure 5-9: Average headway during the crossing animal event

The paired t-test for time to collision resulted in a p-value of 0.002 (Table 5-8), indicating a significant difference between the means of the two phases of the drive. Figure 5-10 shows the time to collision to the deer before an evasive maneuver was performed. It was observed that participants took 0.111 seconds (30%) longer to react with the ACC system engaged than without the ACC. This could be as a result of reduced mental workload when using the ACC system. It could also be because of an increased level of comfort when using the ACC system, thus increasing the reaction time when required. For example, participants were observed to take their feet off the brakes after engaging the ACC, resulting in a longer distance to cover to reach the brake pedal in turn increasing the reaction time.

Table 5-8: Paired sample t-statistics for the crossing animal event

		Mean	N	Std. Deviation	Std. Error Mean
Headway	No ACC	334.72	27	152.96	29.44
	ACC	371.37	27	139.79	26.90
ttc	No ACC	.370	30	.178	.033
	ACC	.259	30	.190	.035
Max Speed	No ACC	73.4	30	3.614	.660
	ACC	70.6	30	1.896	.346
Lane Pos Std Deviation	No ACC	.872	30	.779	.142
	ACC	.835	30	.606	.111

		Mean	Std. Dev	Std. Error Mean	95% CI of the Difference Lower	95% CI of the Difference Upper	t	df	Sig. (2-tailed)
Hd way	No ACC - ACC	-36.65	150.54	28.97	-96.20	22.90	-1.265	26	.217
ttc	No ACC - ACC	.111	.182	.033	.043	.179	3.356	29	.002
Mx spd	No ACC - ACC	2.843	3.307	.604	1.609	4.078	4.710	29	.000
Ln dev	No ACC - ACC	.037	1.061	.194	-.360	.4338	0.189	29	.852

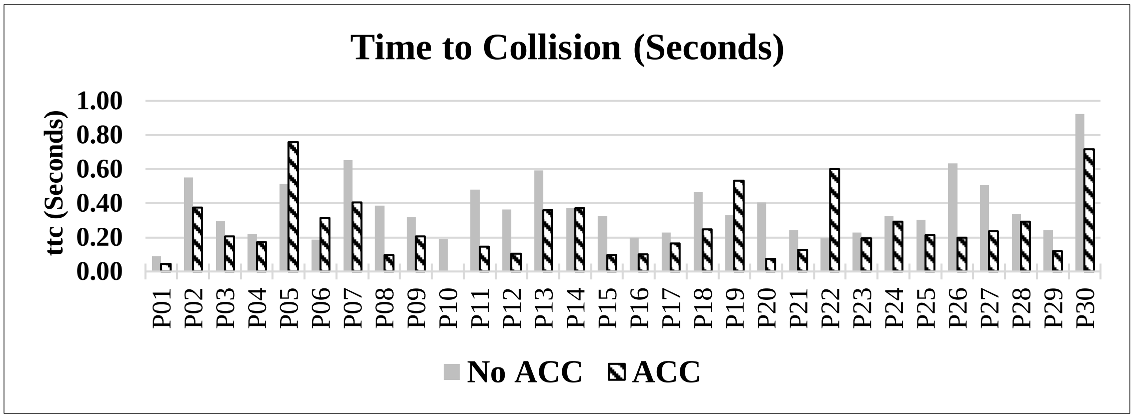


Figure 5-10: Time to collision to the deer

The maximum speed is also recorded during the event. A p-value of less than 0.001 was obtained from the SPSS analysis shown in Table 5-8. As seen from previous events, similar results were recorded with participants achieving a higher overall speed without the ACC than with the ACC. The obtained p-value indicated a significant difference between the means of the two phases of the drive. Figure 5-11 shows the maximum speed recorded per test subject during the crossing animal event.

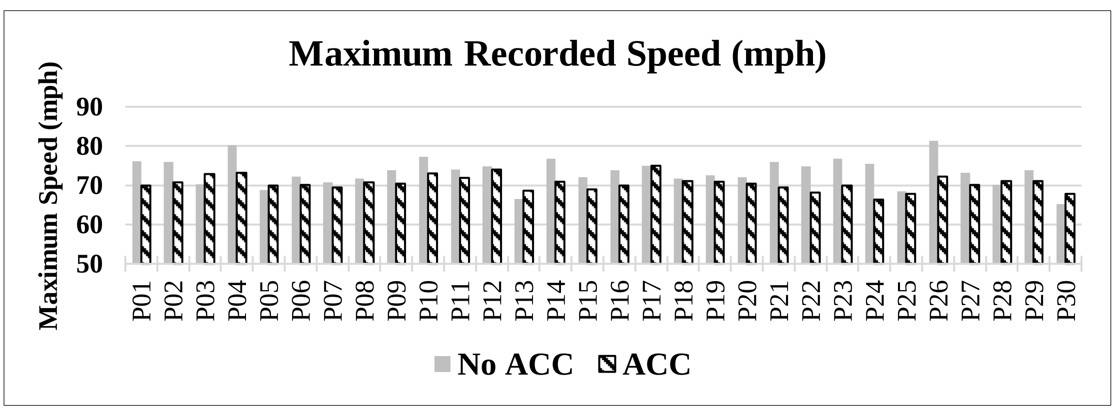


Figure 5-11: Maximum speed recorded during the crossing animal event

The SPSS analysis of the lane position deviation resulted in a p-value of 0.852, showing no significant difference between the means of the drive without the ACC and the drive with the

ACC. However, few participants such as P12, P14, P17, P25, P28, and P29, demonstrated large lane position deviations between their drives.

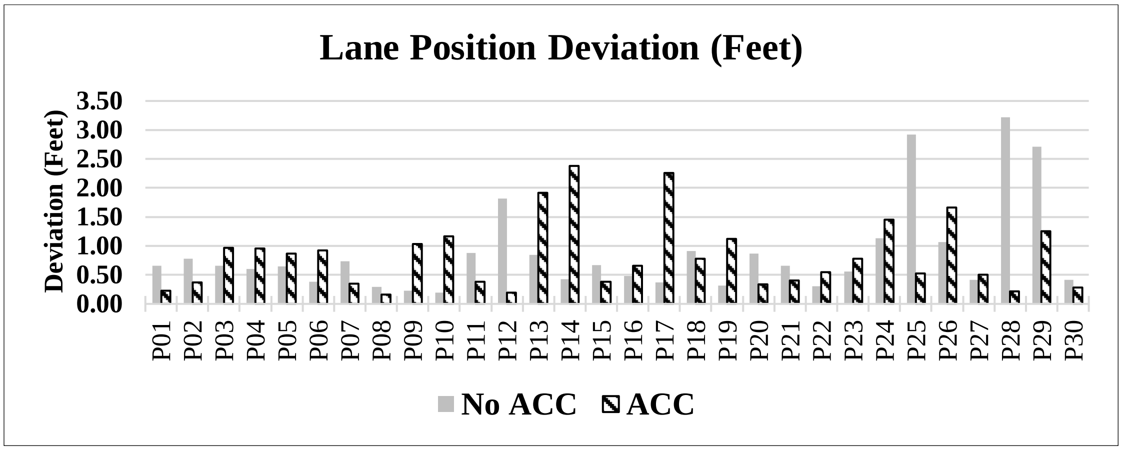


Figure 5-12: Deviation of lane position during the crossing animal event

The ANOVA was also carried out for the four variables in this event. However, no significant differences in the variables were observed because of the gender and age of participants.

5.2.3. Desk Drop

The desk drop event is similar to the crossing animal event in that they both require participants to perform an evasive maneuver to avoid collision. However, during the instance of the drop, participants were simultaneously engaged in a distraction task as described in Section 4.3.3. Three variables were obtained from this event and they include: headway, time to collision at the instance an evasive maneuver was performed to avoid the dropped desk, and deviation of lane position.

The average headway of the event is recorded per participant and is shown in Figure 5-13. It was observed that participants driving with the ACC preferred maintaining longer headways than those without the ACC, by up to 29.6%. The SPSS paired t-test analysis shown in Table 5-9 resulted in a p-value of 0.016 for the difference between the means of the headways. This indicated a significant difference between the means of the average headways of the two phases of the drive.

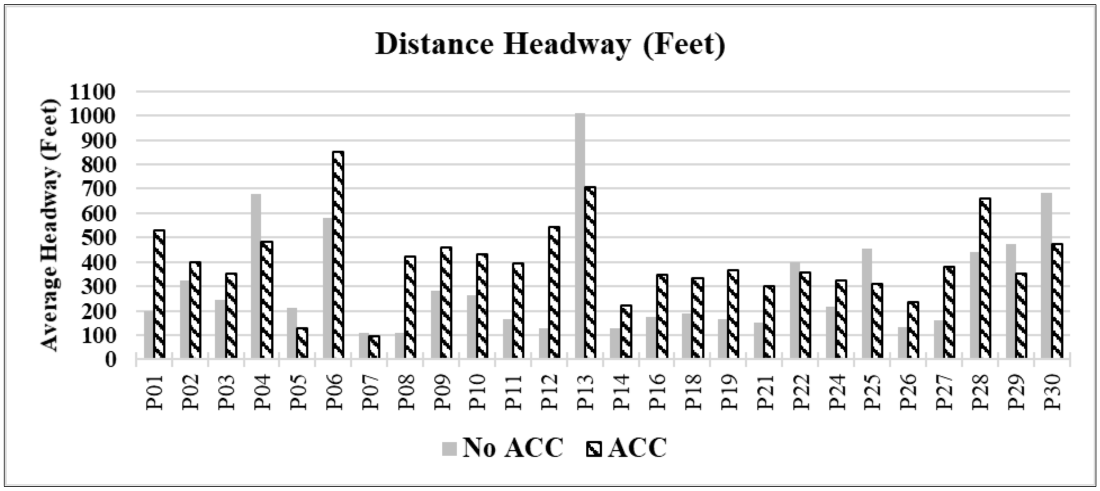


Figure 5-13: Average headway during the desk drop event

Time to collision is recorded in a similar manner to that of the crossing animal event. Only data collected from 24 drivers were used for the SPSS analysis of this variable, as some participants failed to react to the desk due to the distraction task. A p-value of 0.404 resulted from the SPSS paired t-test analysis as shown in Table 5-9. This indicated no significance difference between the means of the drives without the ACC and with the ACC. The obtained data failed to reject the null hypothesis for this variable.

Table 5-9: Paired sample t-statistics for the desk drop event

		Mean	N	Std. Deviation	Std. Error Mean
Headway	No ACC	310.47	26	223.536	43.840
	ACC	402.25	26	165.582	32.473
ttc	No ACC	2.089	24	1.401	.286
	ACC	2.371	24	1.243	.254
Lane Pos Std. Dev	No ACC	1.228	29	.665	.123
	ACC	1.342	29	.731	.136

				Std. Error	95% CI of the Difference				
		Mean	Std. Dev	Mean	Lower	Upper	t	df	Sig. (2-tailed)
Hd way	No ACC - ACC	-91.78	181.55	35.611	-165.11	-18.449	-2.578	25	.016
ttc	No ACC - ACC	-.281	1.620	.331	-.966	.403	-.851	23	.404
Ln dev	No ACC - ACC	-.113	.609	.113	-.345	.118	-1.003	28	.324

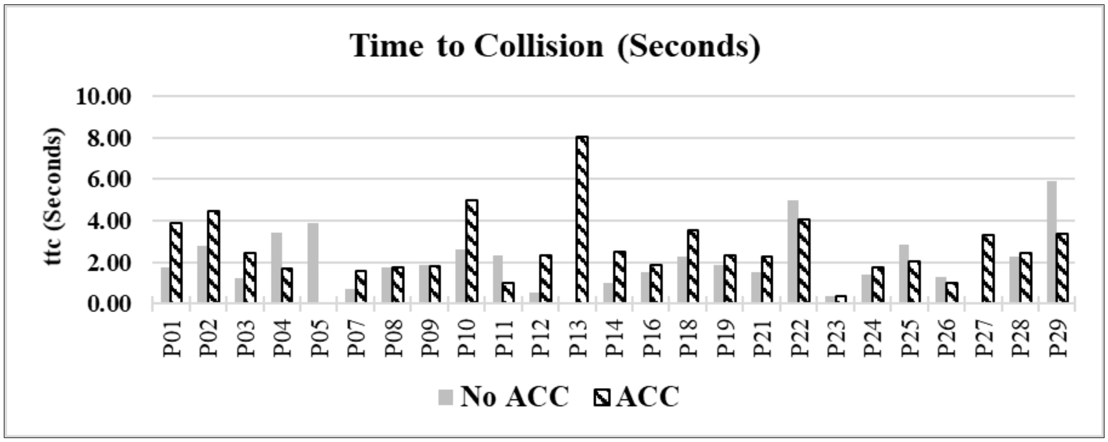


Figure 5-14: Time to collision to the desk

Figure 5-15 shows the recorded deviation of lane position during this event. Two participants, P07 and P25, experienced large deviations of lane position between the two phases of their drive. However, a paired t-test resulted in a p-value of 0.324, indicating no significant difference between the means of the two phases (without the ACC and with the ACC).

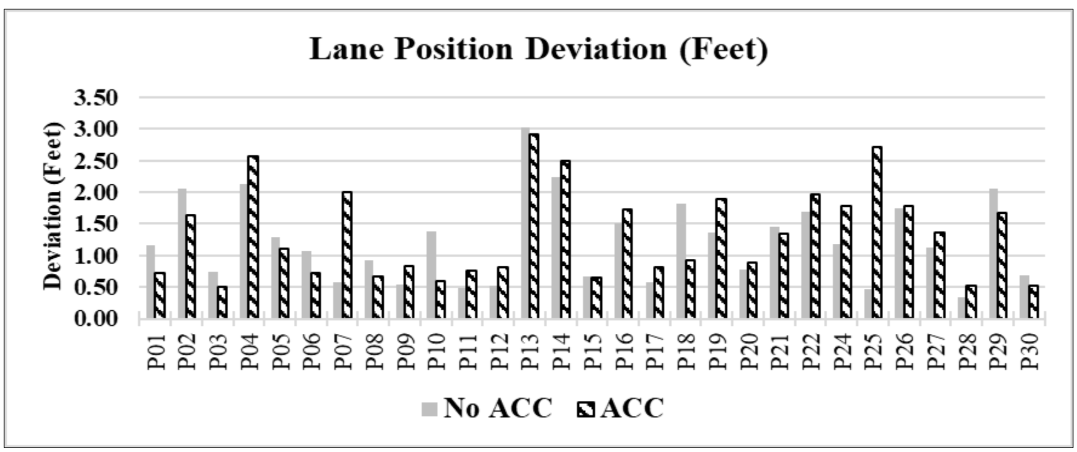


Figure 5-15: Deviation of lane position during the desk drop event

The ANOVA was carried out for the three variables (headway, ttc, and lane deviation). The results showed no significant difference in the variables resulting from age and gender.

5.2.4. Work Zone

The work zone event was designed to determine situational awareness of participants. The event consisted of two lead vehicles, travelling at 70 mph, while violating the posted work zone speed limit of 55 mph. Driver's ability to pay attention to the traffic signs and adjust the speed accordingly, without instinctively following the lead vehicles especially while using the ACC was monitored.

The average speed during the event is analyzed to determine any posted speed limit violations. A violation is recorded if the average speed of the participant is greater than 10 mph of the posted speed limit of 55 mph. A total of seven violations were observed during the drive without the ACC and seven violations were also observed during the drive with the ACC. Figure 5-16 shows the average speeds recording during both phases of the drive.

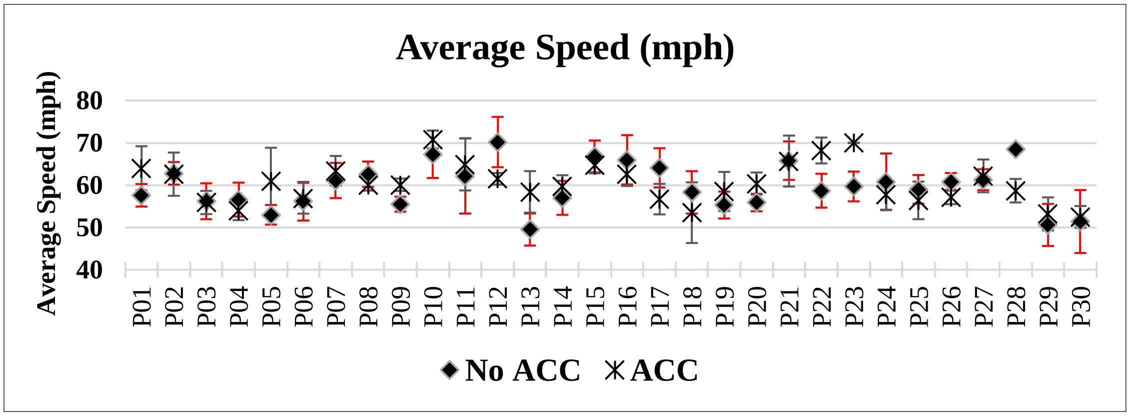


Figure 5-16: Average speed with standard deviations during the work zone event

A SPSS analysis was not carried out for this variable as the total number of violations in both phases of the drive among the participants were the same. There was no difference between the means of the two drives. The ANOVA also resulted in no significant difference in the average speeds of participants with respect to age or gender.

5.3. Minor Events

5.3.1. Sudden Merging Vehicle

In this event, participants are required to avoid collision with a vehicle suddenly merging from the right to the left lane. The sudden merging event is unlike the other events in that only one evasive maneuver, applying brakes, can be carried out to avoid the collision. This event allows for data variables such as braking force, deceleration rate, and time to collision at the instance when brakes were applied, to be recorded.

Figure 5-17 shows the time to collision to the merging vehicle at the instance brakes were first applied. Data from 28 participants were used to carry out the statistical analysis as the output file of the remaining two participants showed missing data during this event.

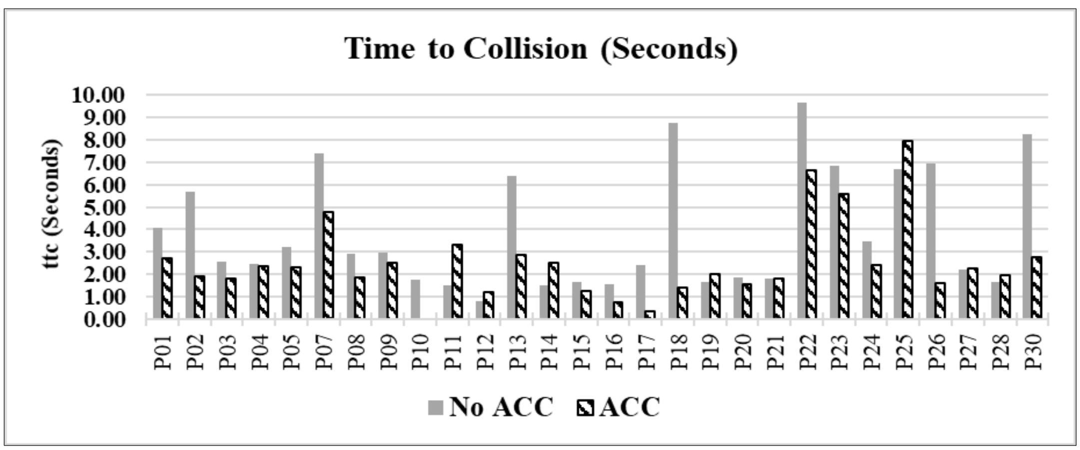


Figure 5-17: Time to collision to the merging vehicle

The SPSS analysis for the time to collision to the merging vehicle resulted in a p-value of 0.002 shown in Table 5-10, indicating a significant difference between the means of the two phases of the drive. The average time to collision for the no ACC phase was 3.88 seconds while for the phase with the ACC was 2.52 seconds. This indicated that participants driving with the ACC were on average 1.36 seconds (35%) slower in reacting to the merging vehicle than without the ACC.

Table 5-10: Paired sample t-statistics for the sudden merging event

		Mean	N	Std. Deviation	Std. Error Mean
ttc	No ACC	3.882	28	2.645	.499
	ACC	2.515	28	1.772	.335
Braking Force	No ACC	28.702	25	15.758	3.152
	ACC	36.860	25	20.698	4.140
Deceleration	No ACC	-12.982	25	5.644	1.129
	ACC	-16.032	25	6.974	1.395

		Mean	Std. Dev	Std. Error Mean	95% CI of the Difference Lower	Upper	t	df	Sig. (2-tailed)
ttc	No ACC - ACC	1.367	2.145	.405	.536	2.199	3.373	27	.002
Brk F	No ACC - ACC	-8.157	13.864	2.773	-13.880	-2.435	-2.942	24	.007
Decel	No ACC - ACC	3.050	5.036	1.007	.972	5.129	3.029	24	.006

The maximum force applied on the brake pedal during the event was recorded. The braking force variable assists in deducing the level of urgency experienced by the driver. For example, in Figure 5-18, participant P10 exerted a large amount of braking force during the event. The time to collision value for this participant was very low during the no ACC drive and included a collision during the drive with the ACC system. The variable is used to determine whether participants brake more aggressively or suddenly during any of the two phases of the drive.

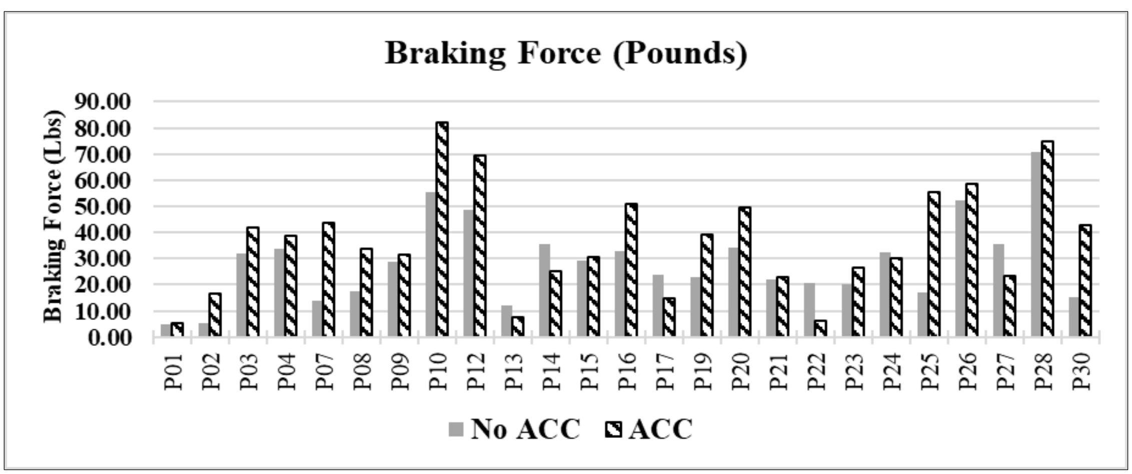


Figure 5-18: Amount of brake force applied to avoid collision

The SPSS paired t-test resulted in a p-value of 0.007 as shown in Table 5-10, indicating a significant difference between the means of the two phases of the drive. During the ACC portion of the drive, participants were observed to brake with a greater force than those without the ACC. On average, drivers used eight pounds (28.4%) of more force while braking with the ACC system than without the ACC system. Overall, drivers during the sudden merging vehicle event, drivers used brakes more aggressively (eight pounds of more force) while driving with the ACC than without the ACC.

The deceleration rate of the driver while applying the brakes to avoid a collision was also recorded. The deceleration rate is directly proportional to the braking force applied. The greater the amount of brake force applied, the larger the rate of deceleration. The paired t-test resulted in a p-value of 0.006, indicating a significant difference in the deceleration rates of the two phases of the drive. Participants required larger decelerations to successfully avoid the merging vehicle during the ACC phase than without the ACC.

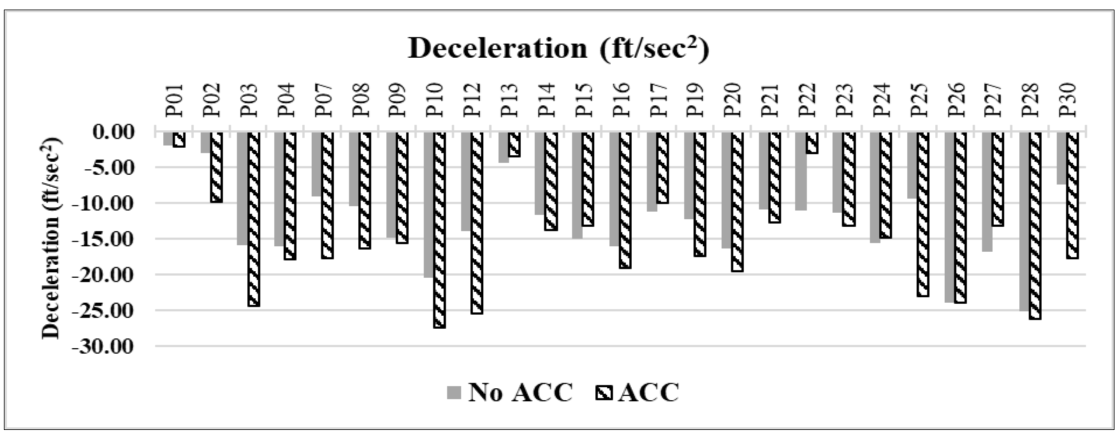


Figure 5-19: Maximum deceleration experienced during the event

The ANOVA was also carried out for the three variables. However, no significant differences resulting from age or gender were established.

5.3.2. Move Over or Slow Down Law

Each designed scenario contained three locations where the move over law could be observed. A value of one was assigned to every location where the law was observed during the drive. Each participant could achieve a maximum number of three observed locations per scenario. If the law was not observed at any location, a value of zero is be recorded.

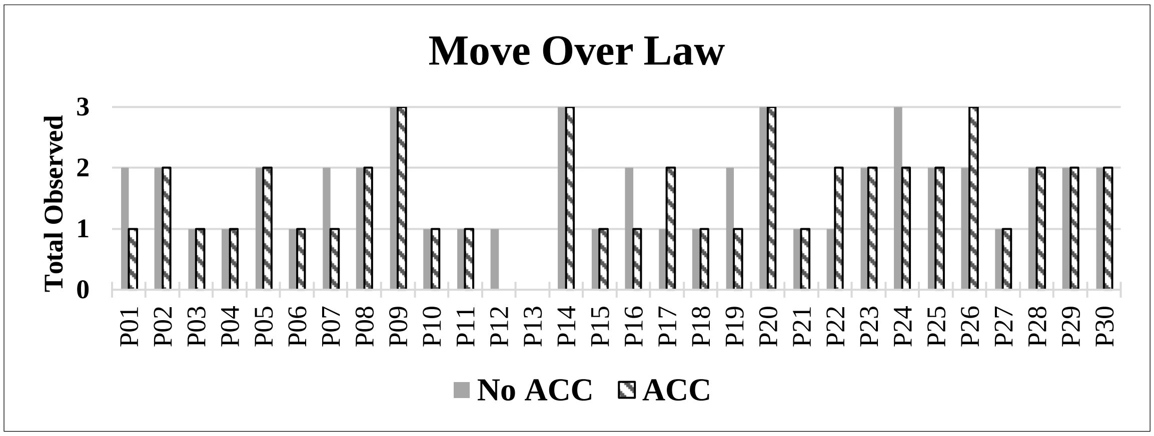


Figure 5-20: Total number of move over events observed

Table 5-11: Paired sample t-statistic for the move over law

		Mean	N	Std. Deviation	Std. Error Mean
Move Law	No ACC	1.67	30	.758	.138
	ACC	1.57	30	.817	.149

	Mean	Std. Dev	Std. Error Mean	95% CI of the Difference Lower	95% CI of the Difference Upper	t	df	Sig. (2-tailed)
No ACC - ACC	.100	.548	.100	-.105	.305	1.000	29	.326

The paired t-test resulted in a p-value of 0.326, which is much greater than 0.05. This indicated that the data obtained from the sample population failed to reject the null hypothesis, thus showing no significant difference in driving behavior when obeying the move over law. The ANOVA resulted in no significant differences in the move over law resulting from age or gender.

5.3.3. Distraction in Vehicle

The distraction in the vehicle was induced through an application and complementary voice commands as described in section 4.3.7. Figure 5-21 shows the total number of hits attempted by the participants during the two phases of their drive.

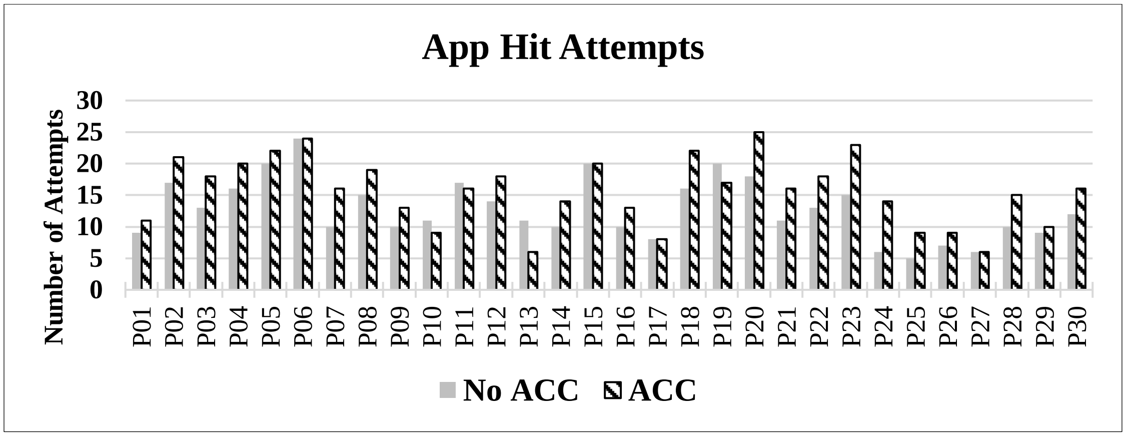


Figure 5-21: Total number of hit attempts during the distraction event

Participants driving with the ACC recorded much higher average hit attempts (15.6 hits) than those driving without the ACC (12.8 hits). The SPSS paired t-test resulted in a p-value of less than 0.001, indicating a significant difference between the means of the hit attempts of the two phases of the drive. Table 5-12 shows the obtained paired t-test results and multiple dependency comparisons.

Older participants were observed to have lower hit attempts than the other age groups in the study. The ANOVA, comprising of Tukey's and Bonferroni's multiple comparison tests, resulted in a significant difference in the hit attempts between age groups 1 and 2 and age group 3. This could be attributed to the exposure to touchscreen devices

Table 5-12: Paired sample t-statistic and multiple dependency comparisons

		Mean	N	Std. Deviation	Std. Error Mean
Hit Attempts	No ACC	12.77	30	4.783	.873
	ACC	15.60	30	5.379	.982

	Mean	Std. Dev	Std. Error Mean	95% CI of the Difference Lower	95% CI of the Difference Upper	t	df	Sig. (2-tailed)
No ACC - ACC	-2.833	3.163	.578	-4.014	-1.652	-4.906	29	.000

Multiple Comparisons

Dependent Variable		(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% CI Lower Bound
No ACC	Tukey HSD	1	2	-1.600	1.727	.628	-5.88
			3	5.300*	1.727	.013	1.02
		2	1	1.600	1.727	.628	-2.68
			3	6.900*	1.727	.001	2.62
		3	1	-5.300*	1.727	.013	-9.58
			2	-6.900*	1.727	.001	-11.18
	Bonferroni	1	2	-1.600	1.727	1.000	-6.01
			3	5.300*	1.727	.015	.89
		2	1	1.600	1.727	1.000	-2.81
			3	6.900*	1.727	.001	2.49
		3	1	-5.300*	1.727	.015	-9.71
			2	-6.900*	1.727	.001	-11.31
ACC	Tukey HSD	1	2	-.100	1.991	.999	-5.04
			3	6.700*	1.991	.006	1.76
		2	1	.100	1.991	.999	-4.84
			3	6.800*	1.991	.006	1.86
		3	1	-6.700*	1.991	.006	-11.64
			2	-6.800*	1.991	.006	-11.74
	Bonferroni	1	2	-.100	1.991	1.000	-5.18
			3	6.700*	1.991	.007	1.62
		2	1	.100	1.991	1.000	-4.98
			3	6.800*	1.991	.006	1.72
		3	1	-6.700*	1.991	.007	-11.78
			2	-6.800*	1.991	.006	-11.88

5.4. Cognitive Workload

5.4.1. Quality of DRT data

In order to check the quality of data obtained from the DRT device, a frequency plot of the response time for the test population is recommended in ISO 17488: 2016. Figure 5-22 shows frequency plots of the response times of all participants in the study during the two scenarios.

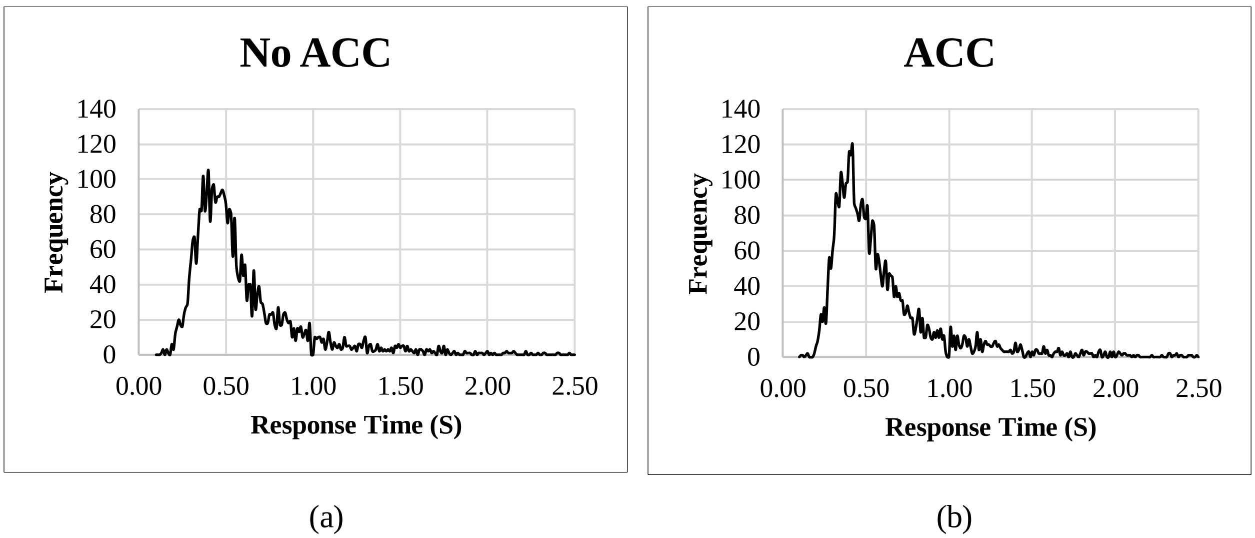


Figure 5-22: DRT data quality – No ACC (a) and ACC (b)

The frequency plots of the RT are seen to be positively skewed as specified in the ISO 17488: 2016. This indicates that the study yielded data of sufficient quality for analysis. Participants were also monitored for cheating/guessing strategies through video data. No participant during this study was excluded due to significantly higher responses than the presented number of stimuli.

5.4.2. Without Events

The RT and HR for both phases of the drive without any incidents were recorded for each participant. Data from two participants, P03 and P06, were excluded from the study due to corrupted output files. The drive with the ACC recorded a 1.5% greater HR than that without the

ACC. However, this did not present a significant difference to reject the null hypothesis. Table 5-13 shows the obtained means and p-values from the SPSS analysis. The RT and HR data also showed no significant difference between the two phases of the drive. The average value for RT during the no ACC phase was 0.611 seconds and during the ACC phase was 0.608 seconds. The ANOVA was also carried out to determine any significant differences in the RTs and HRs resulting from age and gender of participants. However, no significant results were observed.

This can be interpreted as a compensation mechanism exhibited by the participants due to their lack of experience and trust in the capabilities of the ACC system, therefore using the same cognitive resources as the drive without ACC. Figure 5-23 and Figure 5-24 show the observed RTs and HRs during both phases of the drive, for 28 participants.

Table 5-13: Paired sample t-statistic for RT and HR during the drive without incidents

		Mean	N	Std. Deviation	Std. Error Mean
Response Time	No ACC	.611	28	.142	.027
	ACC	.608	28	.125	.024
Hit Rate	No ACC	84.6	28	12.22	2.309
	ACC	86.1	28	13.16	2.488

		Mean	Std. Dev	Std. Error Mean	95% CI of the Difference Lower	95% CI of the Difference Upper	t	df	Sig. (2-tailed)
RT	No ACC - ACC	.003	.101	.0191	-.037	.042	.137	27	.892
HR	No ACC - ACC	-1.517	8.587	1.623	-4.847	1.813	-.935	27	.358

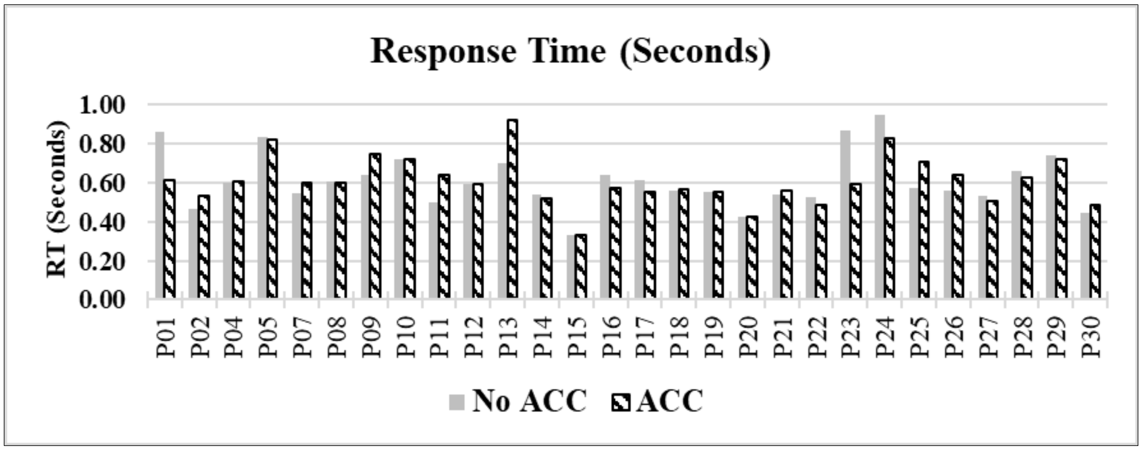


Figure 5-23: Response time when no incidents occurred

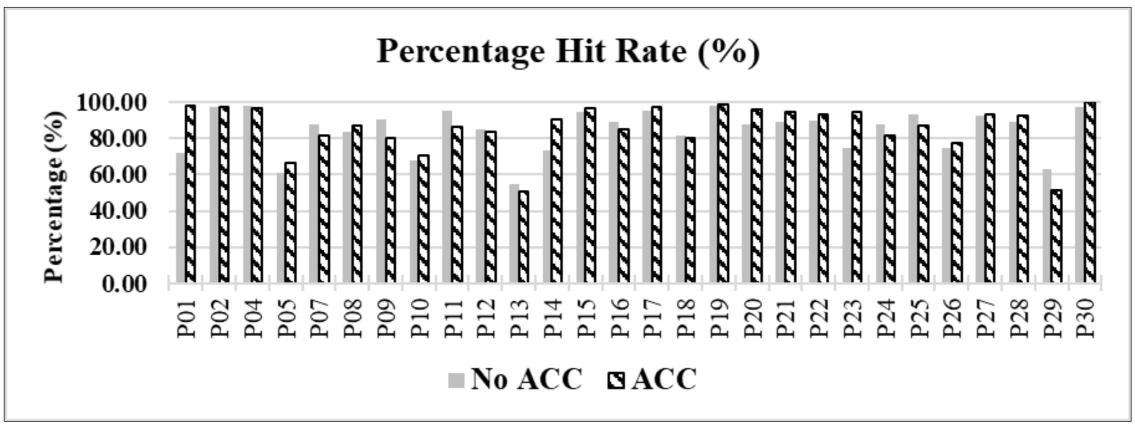


Figure 5-24: Hit rate when no incidents occurred

5.4.3. Car Following Event

Figure 5-25 and Figure 5-26 show the RTs and HRs for the participants during the car following event. The mean RTs for the participants were 0.528 and 0.560 for the phase without the ACC and with the ACC, respectively. The HRs during the car following event were 93.3% (without the ACC) and 88.5% (with the ACC).

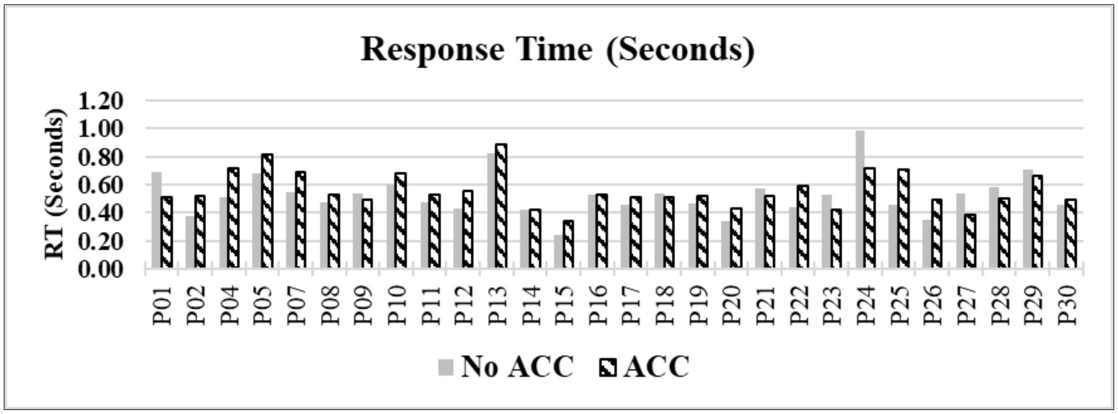


Figure 5-25: Response time during the car following event

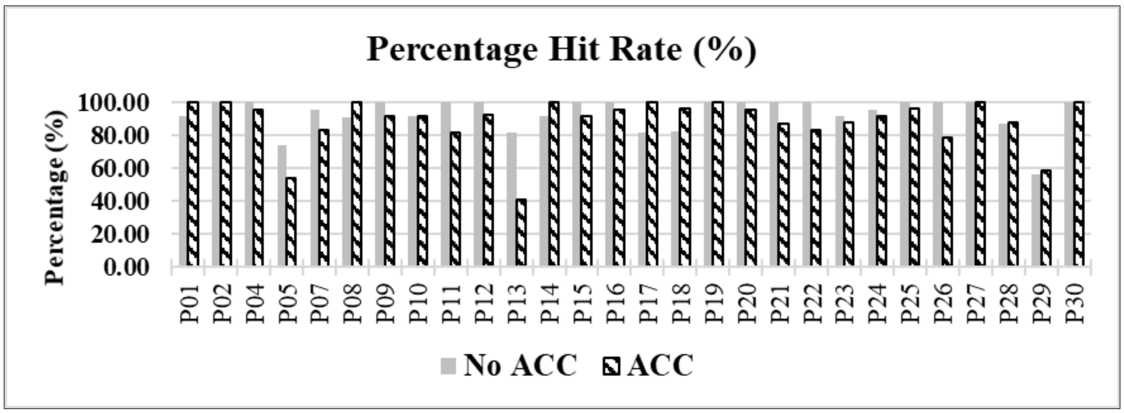


Figure 5-26: Hit rate during the car following event

The paired sample t-test resulted in no significant difference between the RTs and HRs of the two phases of the drive. P-values of 0.158 and 0.045 were obtained for the difference in the means of the RTs and HRs, respectively, as shown in Table 5-14. However, participants were observed to have quicker response times and higher hit rates during the phase without the ACC. The video and quantitative data revealed that the slower RTs and lower HRs during the phase with the ACC were as a result of participants setting the ACC to their preferred time gap. The car following event was the first one encountered and participants were involved in engaging the ACC and personalizing the time gap. The ANOVA was also carried out to determine any significant effects of age and gender on the RTs and HRs. However, no significant results were observed.

Table 5-14: Paired sample t-statistic for RT and HR during the car following event

		Mean	N	Std. Deviation	Std. Error Mean
Response Time	No ACC	.528	28	.151	.029
	ACC	.560	28	.129	.024
Hit Rate	No ACC	93.3	28	10.355	1.957
	ACC	88.5	28	14.806	2.798

		Mean	Std. Dev	Std. Error Mean	95% CI of the Difference Lower	Upper	t	df	Sig. (2-tailed)
RT	No ACC - ACC	-.032	.118	.022	-.078	.013	-1.452	27	.158
HR	No ACC - ACC	4.759	11.954	2.259	.124	9.395	2.107	27	.045

5.4.4. Distraction while Driving

The average RT and HR for each participant were calculated for the three distraction events in each drive. The mean response time of the 28 participants increased by 7.7% during the drive with the ACC. However, the hit rates increased by 26.3% during the ACC phase of the drive. A p-value of 0.013 (< 0.025) was obtained as shown in Table 5-15, indicating a significant difference between the two phases of the drive.

When the DRT data without any incidents is compared to the one with induced distraction application, it is clear that the change in the HRs and RTs was caused due to the distraction. Participants showed a 34.6% decrease in HR during the phase without ACC and a 18.8% decrease in the phase with the ACC. From these results, it can be seen that participants used less cognitive resources (lower mental workload) when responding to a distraction in the phase with the ACC than without the ACC, due to the increased percentage of HRs. Increase in HR indicate that participants missed less stimuli. Using less cognitive resources when distracted and driving with ACC can be attributed to the reduced application of manual brakes resulting from the automatic braking capabilities of the ACC system. Figure 5-27 and Figure 5-28 show the RT and HR results recorded for each participant. The ANOVA did not result in any significant differences resulting from age and gender of participants.

Table 5-15: Paired sample t-statistic for RT and HR during the distraction events

		Mean	N	Std. Deviation	Std. Error Mean
Response Time	No ACC	.775	28	.306	.058
	ACC	.835	28	.270	.051
Hit Rate	No ACC	55.3	28	27.779	5.250
	ACC	69.9	28	25.079	4.739

				Std. Error	95% CI of the Difference				
		Mean	Std. Dev	Mean	Lower	Upper	t	df	Sig. (2-tailed)
RT	No ACC - ACC	-.060	.373	.071	-.204	.085	-.845	27	.406
HR	No ACC - ACC	-14.579	28.997	5.480	-25.823	-3.335	-2.660	27	.013

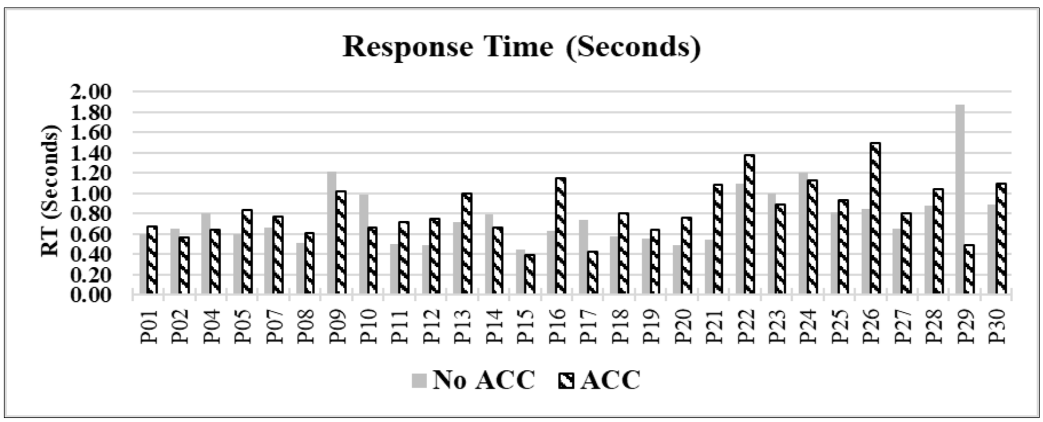


Figure 5-27: Average response time during the distraction events

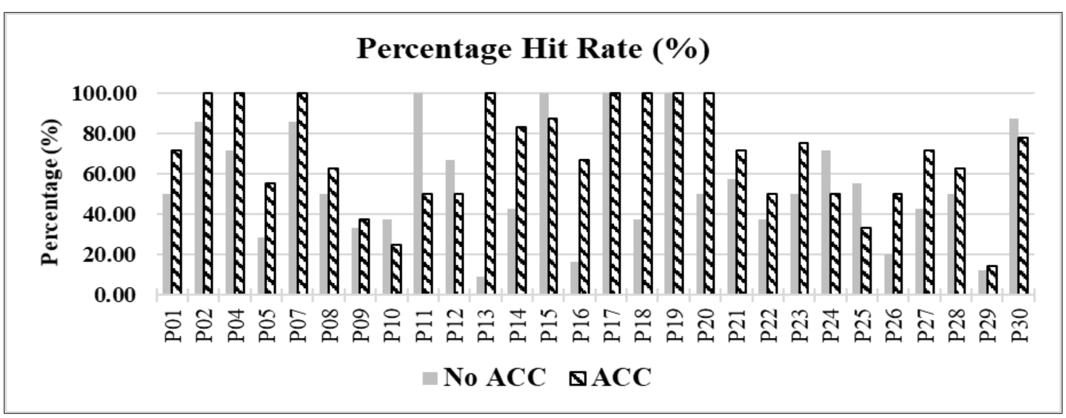


Figure 5-28: Average hit rate during the distraction events

5.4.5. Work Zone

The work zone event was considered as a busy visual environment due to the presence of traffic channelizers, safety signs, and construction vehicles. Intuitively, drivers approach work zones with more caution due to increased traffic fines and unpredictability of the surroundings. For the 28 participants, the work zone event with the ACC showed no significant difference in RTs and HRs than the work zone event without the ACC. When compared to the drive without any incidents, the work zone event observed 5% higher mean RTs in both phases, with and without the ACC.

Figure 5-29 and Figure 5-30 show the RT and HR per participant during the two phases. No significant difference between the means of the RTs or HRs was observed (Table 5-16).

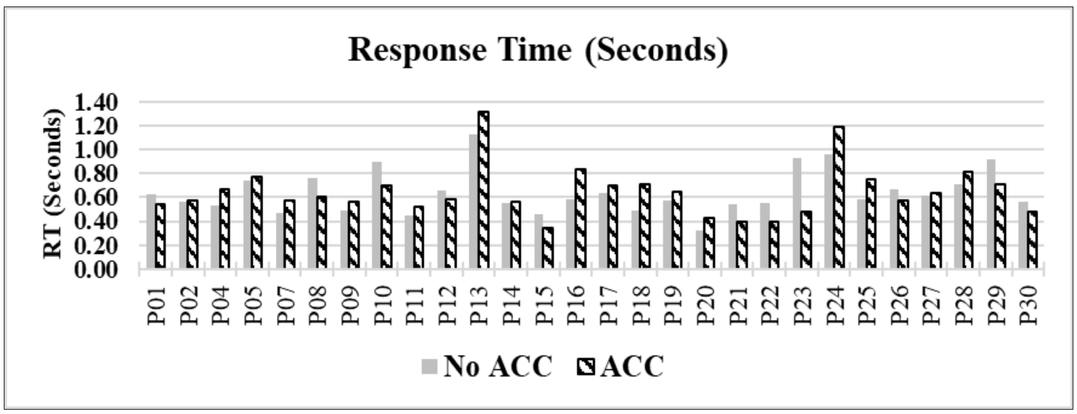


Figure 5-29: Response time during the work zone event

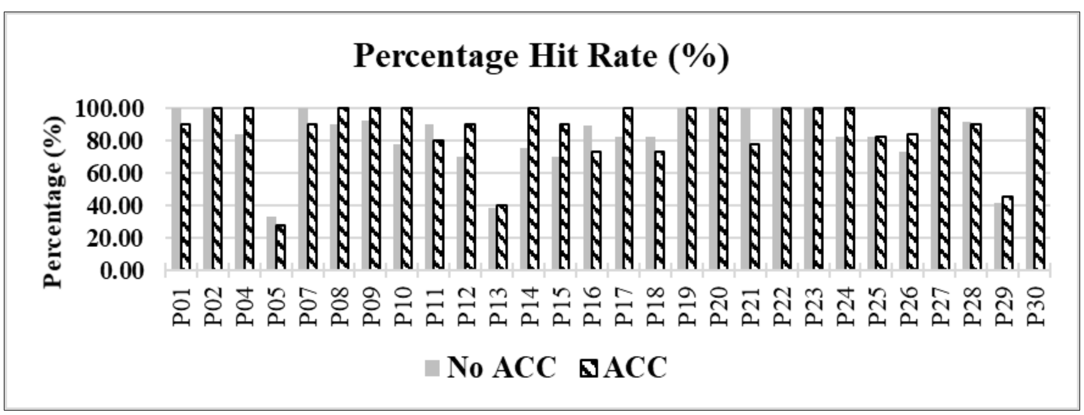


Figure 5-30: Average hit rate during the work zone event

Table 5-16: Paired sample t-statistic for RT and HR during the work zone event

		Mean	N	Std. Deviation	Std. Error Mean
Response Time	No ACC	.641	28	.184	.0347
	ACC	.643	28	.213	.0403
Hit Rate	No ACC	83.6	28	19.10	3.609
	ACC	86.8	28	19.71	3.726

				Std. Error	95% CI of the Difference				
		Mean	Std. Dev	Mean	Lower	Upper	t	df	Sig. (2-tailed)
RT	No ACC - ACC	-.003	.161	.030	-.065	.060	-.092	27	.927
HR	No ACC - ACC	-3.217	12.235	2.312	-7.961	1.527	-1.391	27	.176

5.5. Summary of the Results

A summary of all the results obtained from the study are shown in Table 5-17 and Table 5-18. A total of ten significant variables, grouped by events, were obtained from the statistical analysis. All participants preferred the 3-second time gap setting to the other two settings during their entire drive with the ACC. The Maximum speed was found to be significantly different, higher without the ACC than with the ACC, in the three events that collected the variable. The distance headway was found to be significant in two out of the three events that were designed to record it. The mean headway values showed participants maintaining larger headways when driving with the ACC, by up to 20.5% during the car following event and 29.6% during the desk drop event.

The statistical analysis resulted in two significant time to collision variables for the crossing animal and sudden merging events. The results showed a decrease in time to collision when driving with the ACC. A reduction in time to collision indicates an increase in reaction time as the participants reacted when the object/vehicle was closer. Participants showed a 30% average reduction in time to collision in the crossing animal event and a 35% average reduction in the sudden merging vehicle event. However, the desk drop event did not show a significant difference in the time to collision values for the drive without the ACC and with the ACC.

Table 5-17: Summary of results collected in MiniSim

	Data Variable	Phase	Mean	Significance (2-tailed)	Rejected null hypothesis
Whole Drive	Collision Count	No ACC	1.27	0.264	
		ACC	1.17		
	Maximum Recorded Speed (mph)	No ACC	80.9	0.000	✓
		ACC	75.5		
Car Following	Distance Headway (feet)	No ACC	357.3	0.022	✓
		ACC	430.6		
	Maximum Recorded Speed (mph)	No ACC	77.3	0.000	✓
		ACC	73.3		
	Average Speed (mph)	No ACC	68.7	0.128	
		ACC	68.1		
	Speed Standard Deviation (mph)	No ACC	5.39	0.462	
		ACC	5.88		
	Lane Position Deviation (feet)	No ACC	0.97	0.049	
		ACC	1.06		
Crossing Animal	Distance Headway (feet)	No ACC	334.7	0.217	
		ACC	371.4		
	Time to Collision (s)	No ACC	0.37	0.002	✓
		ACC	0.26		
	Maximum Recorded Speed (mph)	No ACC	73.4	0.000	✓
		ACC	70.6		
	Lane Position Deviation (feet)	No ACC	0.87	0.852	
		ACC	0.84		
Desk Drop	Distance Headway (feet)	No ACC	310.5	0.016	✓
		ACC	402.2		
	Time to Collision (s)	No ACC	2.09	0.404	
		ACC	2.37		
	Lane Position Deviation (feet)	No ACC	1.23	0.324	
		ACC	1.34		
Sudden Merging Vehicle	Time to Collision (s)	No ACC	3.88	0.002	✓
		ACC	2.52		
	Braking Force (Lbs)	No ACC	28.70	0.007	✓
		ACC	36.86		
	Deceleration (ft/sec^2)	No ACC	-12.98	0.006	✓
		ACC	-16.03		
Move Over Law	Total Observed	No ACC	1.67	0.326	
		ACC	1.57		
App Hit Attempts	Attempts	No ACC	12.77	0.000	✓
		ACC	15.60		

During the sudden merging event, two other variables apart from time to collision were found to be significant, the braking force and deceleration rate. Participants were observed to brake using greater force (28.4%) and decelerate much quicker when using the ACC than without the ACC. This could be because drivers tend to keep their feet further away from the pedals when engaged in CC or ACC, increasing the distance to the brake pedal thus decreasing the time to collision and increasing the amount of brake force applied.

Participants were also observed to have a greater number of hit attempts when driving with the ACC, during the distraction event. This event also revealed that participants from the older age category (group 3) showed significantly lower application hit attempts than those from the other two age groups (groups 1 and 2).

Table 5-18: Summary of results collected using the DRT device

	Data Variable	Phase	Mean	Significance (2-tailed)	Rejected null hypothesis
Without Events	RT (s)	No ACC	0.611	0.892	
		ACC	0.608		
	HR (%)	No ACC	84.6	0.358	
		ACC	86.1		
Car Following	RT (s)	No ACC	0.528	0.158	
		ACC	0.560		
	HR (%)	No ACC	93.3	0.045	
		ACC	88.5		
Distraction While Driving	RT (s)	No ACC	0.775	0.406	
		ACC	0.835		
	HR (%)	No ACC	55.3	0.013	✓
		ACC	69.9		
Work Zone	RT (s)	No ACC	0.641	0.927	
		ACC	0.643		
	HR (%)	No ACC	83.6	0.176	
		ACC	86.8		

The data from the DRT device only resulted in one significant variable from the three categories shown in Table 5-18. The average HR while driving distracted showed a significant increase when driving with the ACC, by up to 26.3%. This meant that participants were less likely to miss a stimulus when driving distracted with the ACC than without the ACC. The findings based on the obtained results are stated in the next section.

6. SUMMARY AND CONCLUSIONS

This section presents the summary, conclusions, and recommendations. The summary will consist of an overview of the literature, methodology, and results. The findings will provide a comparison of the findings from the literature review with the results obtained from the analysis. Then, possible improvements and future research potential will be briefly discussed.

6.1. Summary

The thesis was aimed at determining the effects of adaptive cruise control on driver behavior and awareness using a FB driving simulator. The first step was to define the qualitative and quantitative measures of driver behavior and awareness. Driver behavior and awareness includes, but is not limited to, aspects such as driver reaction times in case of sudden lane changes or crossing animals, distractions caused by cell phones or other electronic devices, adhering to speed limits, perceiving vehicles violating traffic regulations, mental workload during various aspects of driving, and overall situational awareness.

A review of existing literature was carried out to determine similar studies. The literature revealed information on modeling the ACC in driving simulators and the effects of the ACC on driver behavior. Based on this, a methodology was developed consisting of six main tasks. First, participants were recruited and screened using a questionnaire. The questionnaire provided a quick way to select participants from a particular demographic and screen for any medical conditions. The simulator was then prepared for the study by configuring the ACC, setting up the DRT device, configuring the distraction application, and designing events targeted to capture changes in driver behavior and awareness with and without the ACC. Pilot testing was carried out to determine bugs in the scenario missed during the design. After configuring events, data were collected during the drive of the participants.

The next step was to reduce and analyze the data. Two tailed paired t-test and ANOVA were carried out to determine significant between the variables collected during the drive without the ACC and with the ACC.

6.2. Conclusions

The following conclusions were obtained from the analysis:

- The study found significant differences between some of the variables collected. Participants were observed to reach lower maximum speeds when driving with the ACC, in all the three events configured to capture this variable. The average from the three scenarios resulted in a 5.2% decrease in the highest speed achieved during the drive. This was consistent with the findings of Ma and Kaber in 2005, who determined a decrease in following speed when using the ACC.

- The distance headway was found to be significantly different in two out of the three scenarios. The drive with the ACC showed that participants maintained longer headways. The average of the two significant scenarios resulted in a 25% increase in the following distance (headway). This finding was consistent with the study carried out by Ohno in 2001, where participants were observed maintain longer headways when using the ACC.

- The study found that the preferred ACC time gap setting used by the participants was 3 seconds. This was not consistent with the results from the study carried out by Cho, Nam, and Lee, in 2006. They found that participants preferred a 1.5 second time-gap. This could be because the lead vehicle in the Cho, Nam, and Lee, study was configured to travel at 90 km/h (56 mph). However, as many highways in the United States have a speed limit of 113km/h (70 mph), a longer headway might be preferred by the participants due to the higher travelling speeds.

- Time to collision (ttc) at the instance of an evasive maneuver was determined during the study. The statistical analysis found the variable to be significant in two out of the three events. The average of the two significant events resulted in a 32.5% decrease in ttc during the ACC phase. This can also be interpreted as a 32.5% increase in reaction time to an event as participants performed an evasive maneuver later than the no ACC phase. The increase in reaction time was consistent with the study carried out in 2004 by Rudin-Brown and Parker. However, it is not clear whether the delay in reaction time is because of using the ACC or as a result of an increase in distance/time to reach the brake pedal from a relaxed foot position.

- There was no significant difference observed in the lane position deviations of the participants between the two phases of the drive. This was inconsistent with the findings from Cho, Nam, and Lee, 2006 and Rudin-Brown and Parker, 2004. In these studies participants driving with the ACC were observed to have reduced lane keeping abilities. However, the decrease in lane keeping could be attributed to the complexity of engaging the ACC and not fully familiarizing the participants with the process of engaging the ACC.

- The results also showed a significant difference in the brake force and deceleration rates of participants when reacting to a sudden merging vehicle. During the ACC phase, participants were observed to brake with a greater force and have more rapid decelerations.

- Participants did not demonstrate a lack of situational awareness with respect to the work zone event. No participant was observed to blindly follow the lead vehicle, configured to violate the speed limit of the work zone.

- The hit attempts recorded by the application that was used to simulate distraction showed a significant difference between the two phases of the drive. Participants were observed to have a better attempt score when using the ACC, implying that the secondary task was performed better when engaged in ACC. This could be as a result of a decrease in cognitive resources required to drive the vehicle.

- The results from the DRT device did not show significant differences in mental workload when driving without the ACC and with the ACC. The response times in both phases without any incidents were consistent, not showing any changes in workload between the two drives.

- In the instance of the distraction, RTs increased during the ACC phase. However, as described by Xiong in 2013, this could be a result of the compensation effect experienced by participants to account for not being fully comfortable with the capabilities of the ACC system.

- The HRs during the distraction events were significantly higher during the ACC phase, suggesting that participants were able to perform a secondary task better with the ACC.

- From the results, it can be established that vehicles equipped with the ACC, additionally require an active collision avoidance system in order to compensate for the delayed reaction times, especially in unforeseen situations.

6.3. Recommendations and Future Research

This section provides recommendations and scope for future research. They include:

- Recruiting participants with experience using the ACC systems. This will provide a better understanding of the trust between the drivers and the ACC system, thus reducing the compensation effects raised from unfamiliarity with the system. However, since the technology is relatively new, it will be difficult to find willing participants for the study.

- Assessing the effects of the ACC on tired/fatigued participants can provide key insights into the role played by the ACC in reducing physical and mental effort on the driver.

- Comparing the drives with conventional cruise control and adaptive cruise control can provide more insights on the difference in reaction times as both systems allow drivers to relax their foot positions from the brake/accelerator pedal, thus increasing the distance/time when responding to a critical event.

- Using eye-tracking devices to accurately measure perception-reaction time of participants when subject to critical situations that require evasive action.

- Also, introducing more complex visual environments such as fog and rain during the study can provide information on the role played by the ACC in guiding/assisting driver to safely navigate to their destination. The cognitive workload can also be assessed to monitor any changes.

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APPENDIX A – ACC Study Flyer

SCHOOL OF ENGINEERING
The University of Kansas

Participants Required for Driving Simulator Research

Aim:

To study the effects of Adaptive Cruise Control (ACC) on driver awareness using a driving simulator

Experimental Procedure:

30 participants are required to drive specific simulated scenarios designed to study the effects of ACC.

Participants will be required to drive for **30 minutes**. Information on braking, lateral position, speed, time gap, acceleration, and ACC disengaging time will be recorded using software and video cameras.

Location:

2441 LEEP 2

Possible Risks:

Motion/simulator sickness

Requirements & Compensation:

- Participants must have a valid **U.S. driver license** with at least one year of driving experience.
- Age of participants must be **18 - 65 years**
- Participants will receive a $20 gift card as compensation for their time and effort.
- Participants must complete a pre-screening questionnaire. This can be obtained via **email** or **room 2160** (see contact information below).

For More Information or To Participate:

Contact: Vishal Kummetha
Email: vishalkummetha@ku.edu
Phone: (785) 312-0845
2160 Learned Hall
Department of Civil, Envir. & Arch. Engineering
Faculty Supervisor: Dr. Alexandra Kondyli

What is ACC?

ACC systems are similar to the conventional Cruise Control systems in terms of engaging and disengaging. However, unlike Cruise Control, ACC provides enhanced assistance by automatically adjusting vehicle speed according to the time gap to the lead vehicle, set by the driver.

About the Simulator:

https://ceae.ku.edu/driving-simulator

APPENDIX B – Screening Survey

KU Driving Simulator

What is **Adaptive Cruise Control (ACC)?**

ACC systems are similar to the conventional Cruise Control systems in terms of engaging and disengaging. However, unlike Cruise Control, ACC provides enhanced assistance by automatically adjusting vehicle speed according to the headway preference selected by the driver. This is done by either accelerating or decelerating based on the in-lane traffic flow detected by sensors, without constant input from the driver.

A Transportation Engineering graduate student is studying the **"Effects of Adaptive Cruise Control (ACC) on Drivers"**. This survey's objectives are:

- To determine users' familiar with ACC systems; and
- To establish suitable candidates to participate in the driving simulator study.

Characterization of You

1. Do you have a valid United States driver's license?
   - ☐ Yes
   - ☐ No

2. How willing are you to participate in a driving simulator study?
   - ☐ Very willing
   - ☐ Willing
   - ☐ Less willing
   - ☐ Not willing

3. What is your gender?
   - ☐ Male
   - ☐ Female

4. What is your age? ____________________

VEHICLE

5. What vehicle do you own/drive (make & year)?

   ____

6. Have you ever used ACC in any vehicle?
   - ☐ Yes
   - ☐ No

7. What is a safe car following (headway) distance in seconds?

   ____

8. Is your current vehicle equipped with ACC?
   - ☐ Yes
   - ☐ No
   - ☐ Not sure

9. If **YES**, how often do you use ACC in your commute?
   - ☐ Frequent (once per day)
   - ☐ Moderate (once per week)
   - ☐ Low (once per month)
   - ☐ N/A

10. If **NO,** how willing are you to try using ACC?
    - ☐ Very willing
    - ☐ Willing
    - ☐ Less willing
    - ☐ Not willing
    - ☐ N/A

MEDICAL CONDITIONS

Due to pre-existing health conditions, not all people are eligible to participate in this study.

11. Do you suffer from any health conditions? If so, please list them below **(females should include pregnancy)**.

    a) __________________________

    b) __________________________

    c) __________________________

14. Do you suffer from a heart condition? If **YES**, please describe.

    ____

    ____

12. Have you ever experienced seizures? If **YES**, please state when it occurred **(MM/YY).**

    ____

13. Have you ever experienced problems with hearing or inner ear? Please state if you use any hearing aid devices.

    ____

15. Do you experience motion sickness? Please state the mode of transport **(train, bus, car, and plane)** and the frequency of your motion sickness.
    Scale 0 to 5, where 0 = Never and 5 = Always

    ____

16. Please state the intensity of your motion sickness symptoms.
    Scale 0 to 5, where 0 = Low and 5 = Incapacitated

    ____

CONTACT INFORMATION

Please note that any personal information provided will not be distributed, but will solely be used for purposes relating to this research.

a) Full Name

____

b) Email

____

c) Contact number

____

APPENDIX C – Wellness Questionnaire

WELLNESS QUESTIONNAIRE

PLEASE INDICATE IF YOU EXPERIENCED ANY OF THESE SYMPTOMS

1. Eye Strain?
   - ☐ Severe
   - ☐ Moderate
   - ☐ Slight
   - ☐ None
2. Headache?
   - ☐ Severe
   - ☐ Moderate
   - ☐ Slight
   - ☐ None
3. Nausea?
   - ☐ Severe
   - ☐ Moderate
   - ☐ Slight
   - ☐ None
4. Vomiting?
   - ☐ Severe
   - ☐ Moderate
   - ☐ Slight
   - ☐ None
5. Dizziness?
   - ☐ Severe
   - ☐ Moderate
   - ☐ Slight
   - ☐ None
6. Sweating?
   - ☐ Severe
   - ☐ Moderate
   - ☐ Slight
   - ☐ None
7. Fatigue?
   - ☐ Severe
   - ☐ Moderate
   - ☐ Slight
   - ☐ None
8. *Vertigo?
   - ☐ Severe
   - ☐ Moderate
   - ☐ Slight
   - ☐ None
9. **Stomach awareness?
   - ☐ Severe
   - ☐ Moderate
   - ☐ Slight
   - ☐ None
10. General discomfort?
    - ☐ Severe
    - ☐ Moderate
    - ☐ Slight
    - ☐ None

***Vertigo:** is a feeling of disorientation

****Stomach awareness:** uneasy feeling in the stomach

CONTACT INFORMATION

Please note that any personal information provided will not be distributed, but will solely be used for purposes relating to this research.

11. Name

    ____

12. Contact number

    ____

Table C-1: Participant wellness responses after the no ACC drive

ID	Question Number									
	1	2	3	4	5	6	7	8	9	10
P01	Slight	None	None	None	None	Severe	None	None	None	None
P02	None	None	None	None	None	None	None	None	None	None
P03	None	Slight	None	None	Slight	None	None	None	None	Slight
P04	Slight	Slight	Mod	None	None	None	Slight	Mod	None	Slight
P05	None	None	Slight	None	Slight	Slight	Slight	None	Mod	Slight
P06	None	None	None	None	None	None	None	None	None	None
P07	None	None	None	None	None	None	None	None	None	None
P08	None	None	None	None	None	None	None	None	None	None
P09	None	None	None	None	Slight	Slight	Slight	Slight	Slight	Slight
P10	None	None	Slight	None	Mod	None	Slight	None	Slight	Slight
P11	None	None	None	None	None	None	None	None	None	None
P12	Slight	Mod	Mod	None	Mod	Mod	None	Slight	Mod	Mod
P13	Slight	Slight	None	None	None	None	Slight	None	None	Slight
P14	None	None	None	None	None	None	Slight	None	None	Slight
P15	None	None	None	None	None	None	None	Slight	None	None
P16	Slight	None	Slight	None	Mod	Slight	Slight	Slight	None	Mod
P17	Slight	None	None	None	Slight	None	None	None	None	None
P18	None	Mod	Slight	None	None	None	None	None	Mod	Mod
P19	Slight	None	None	None	Slight	None	None	None	None	Slight
P20	None	None	None	None	None	None	None	None	None	None
P21	None	Slight	Mod	Mod	Mod	Mod	Mod	None	None	Slight
P22	Mod	Mod	Slight	None	Slight	Slight	None	Slight	Mod	Slight
P23	None	None	Slight	None	None	None	None	None	None	None
P24	Slight	None	None	None	None	None	None	Slight	None	None
P25	Slight	None	None	None	Slight	Slight	Mod	Slight	None	Slight
P26	None	None	None	None	Slight	None	None	None	None	None
P27	Slight	Slight	None	None	Slight	None	None	None	None	None
P28	Slight	None	None	None	None	None	Slight	None	Slight	Slight
P29	Slight	None	Slight	None	None	None	Slight	None	Slight	Slight
P30	None	None	None	None	None	None	None	None	None	None

Legend-Questions

1	Eye Strain	**6**	Sweating
2	Headache	**7**	Fatigue
3	Nausea	**8**	Vertigo
4	Vomiting	**9**	Stomach awareness
5	Dizziness	**10**	General Discomfort

Table C-2: Participant wellness responses after the ACC drive

ID	Question Number									
	1	2	3	4	5	6	7	8	9	10
P01	Slight	None	None	None	None	Mod	None	None	None	None
P02	None	None	None	None	None	None	None	None	None	None
P03	Slight	Slight	None	None	Slight	None	Slight	None	None	None
P04	None	None	Slight	None	None	None	Slight	Slight	None	None
P05	Slight	None	Slight	None	None	None	Slight	None	Slight	Slight
P06	None	None	None	None	None	None	None	None	None	None
P07	None	None	None	None	None	None	None	None	None	None
P08	None	None	None	None	None	None	None	None	None	None
P09	Slight	None	None	None	Slight	None	Slight	Slight	Slight	Slight
P10	None	Slight	Slight	None	None	None	None	None	None	Slight
P11	None	None	None	None	None	None	None	Slight	None	None
P12	Slight	Slight	Slight	None	Slight	Slight	None	Slight	Slight	Slight
P13	Slight	Slight	None	None	None	None	Slight	None	None	Slight
P14	None	None	None	None	None	None	Slight	None	None	None
P15	None	None	None	None	None	None	None	None	None	None
P16	Slight	None	Slight	None	None	None	None	Slight	Slight	Slight
P17	Slight	None	None	None	Slight	None	None	None	None	None
P18	Slight	Mod	Mod	None	None	None	None	None	Slight	Mod
P19	Slight	Slight	None	None	Slight	None	None	None	None	Slight
P20	None	None	None	None	None	None	None	None	None	None
P21	None	None	Slight	None	None	None	Slight	None	None	Slight
P22	Mod	Mod	Slight	None	Slight	Slight	None	Slight	Mod	Slight
P23	None	None	Slight	None	None	None	None	None	None	None
P24	None	None	None	None	None	None	None	Slight	None	None
P25	Slight	None	Slight	None	Slight	Mod	Slight	Slight	None	Slight
P26	None	None	None	None	Slight	None	None	None	None	None
P27	None	Slight	Slight	None	Slight	None	None	None	None	None
P28	Slight	Slight	None	None	None	None	Slight	None	Slight	None
P29	None	None	None	None	None	None	Slight	None	Slight	None
P30	None	None	None	None	None	None	None	None	None	None

Legend-Questions			
1	Eye Strain	**6**	Sweating
2	Headache	**7**	Fatigue
3	Nausea	**8**	Vertigo
4	Vomiting	**9**	Stomach awareness
5	Dizziness	**10**	General Discomfort

APPENDIX D – Consent Form and Approval Letter

INFORMED CONSENT DOCUMENT

Analysis of the Effects of Adaptive Cruise Control (ACC) on Driver Behavior and Awareness Using a Driving Simulator

INTRODUCTION

The Department of Civil, Environmental, and Architectural Engineering at the University of Kansas supports the practice of protection for human subjects participating in research. The following information is provided for you to decide whether you wish to participate in the present study. You may refuse to sign this form and not participate in this study. You should be aware that even if you agree to participate, you are free to withdraw at any time. If you do withdraw from this study, it will not affect your relationship with this unit, the services it may provide to you, or the University of Kansas.

PURPOSE OF THE STUDY

The research is part of a Master's thesis and will analyze the effects of Adaptive Cruise Control (ACC) on Driver Behavior and Awareness using a Driving Simulator. The findings of this research will help us better understand Information on braking, lateral position, speed, time gap, acceleration, ACC engaging, and disengaging times of drivers under various situations. We are asking you to participate in a research study.

PROCEDURES

This study is part of a Master's thesis. The study will recruit 30 drivers to participate in the experiments, from 18 to 65 years old. During the experiment, you will be asked to drive the driving simulator for approximately 30 minutes. The first 5 minutes will be for you to familiarize with the vehicle/simulator and also to see if you have any signs of motion sickness. After that, and provided you do not have motion sickness, we will start collecting data related to your driving along the simulated scenarios. We will be recording you during the entire duration of the experiment. You will be having intermediate breaks every 5-15 minutes. The principle investigator (PI) will be analyzing your drive and video recordings after the experiment is finished. Only people that are related to this research (Vishal Kummetha - PI, and Dr. Alexandra Kondyli) will have access to these recordings, which will be securely stored in hard drives and kept in the Driving Simulator Lab.

The research team is committed to confidentiality. Your identity will not be revealed in the final report for this project, nor in any of the manuscripts produced. Instead, you will be assigned a participant ID number.

RISKS

The risks for this experiment are primarily related to motion sickness that you might experience as you are driving in the simulator. Motion sickness does not happen to everyone, but typical motion sickness symptoms include: general discomfort, fatigue, headache, eye strain, difficulty focusing, increased salivation, sweating, nausea, difficulty concentrating, fullness of head, blurred vision, dizzy eyes, vertigo, stomach awareness, and burping.

We will be monitoring you during the entire duration of the experiment for signs of motion sickness. During the frequent breaks, we will also ask you several questions on how you feel, so we determine whether you start to experience motion sickness or not.

Additionally, you might experience mild stress during decision-making during the driving portion of the study, but this stressor is no more than most people experience on a daily basis. You might also experience mild anxiety about being video recorded while you are driving.

BENEFITS

There are no direct personal benefits from participating in this research.

PAYMENT TO PARTICIPANTS

You will be given $20 compensation (in the form of a gift card) for participating in this driving simulator data collection experiment. You will be receiving cash at the end of the experiment. Investigators may ask for your social security number in order to comply with federal and state tax and accounting regulations.

PARTICIPANT CONFIDENTIALITY

Your name will not be associated in any publication or presentation with the information collected about you or with the research findings from this study. Instead, the researchers will use a study number or a pseudonym rather than your name. Your identifiable information will not be shared unless (a) it is required by law or university policy, or (b) you give written permission.

Permission granted on this date to use and disclose your information remains in effect indefinitely. By signing this form, you give permission for the use and disclosure of your information for purposes of this study at any time in the future.

INSTITUTIONAL DISCLAIMER STATEMENT

In the event of injury, the Kansas Tort Claims Act provides for compensation if it can be demonstrated that the injury was caused by the negligent or wrongful act or omission of a state employee acting within the scope of his/her employment.

REFUSAL TO SIGN CONSENT AND AUTHORIZATION

You are not required to sign this Consent and Authorization form and you may refuse to do so without affecting your right to any services you are receiving or may receive from the University of Kansas or to participate in any programs or events of the University of Kansas. However, if you refuse to sign, you cannot participate in this study.

CANCELLING THIS CONSENT AND AUTHORIZATION

You may withdraw your consent to participate in this study at any time, without consequence, and receive part of the compensation of $10 in gift card. If participants do not show up at appointment time or withdraw before the start of the study, no compensation will be provided.

QUESTIONS ABOUT PARTICIPATION

If you have any questions or concerns about the research study, please contact Vishal Kummetha or Dr. Kondyli. They will be glad to answer any of your concerns (Contact information is provided below).

PARTICIPANT CERTIFICATION

I have read this Consent and Authorization form. I have had the opportunity to ask, and I have received answers to, any questions I had regarding the study. I understand that if I have any additional questions about my rights as a research participant, I may call (785) 864-7429 or (785) 864-7385, write the Human Subjects Committee Lawrence Campus (HSCL), University of Kansas, 2385 Irving Hill Road, Lawrence, Kansas 66045-7568, or email irb@ku.edu.

I agree to take part in this study as a research participant. By my signature I affirm that I am at least 18 years old and that I have received a copy of this Consent and Authorization form.

_______________________________ _____________________
Type/Print Participant's Name Date

____
Participant's Signature

RESEARCHER CONTACT INFORMATION

Vishal Kummetha, Graduate Research Assistant
Principal Investigator
Department of Civil, Environmental, and Architectural Engineering
1530 W. 15th Street
2160 Learned Hall
University of Kansas
Lawrence, KS 66045
(785) 312-0845

Dr. Alexandra Kondyli, PhD
Faculty Supervisor
Department of Civil, Environmental, and Architectural Engineering
1530 W. 15th Street
2159A Learned Hall
University of Kansas
Lawrence, KS 66045
(785) 864-6521

THE UNIVERSITY OF KANSAS
Research

APPROVAL OF PROTOCOL

February 1, 2017

Vishal Chandra Kummetha
vishalkummetha@ku.edu

Dear Vishal Chandra Kummetha:

On 2/1/2017, the IRB reviewed the following submission:

Type of Review:	Initial Study
Title of Study:	Analysis of the Effects of Adaptive Cruise Control (ACC) on Driver Awareness Using a Driving Simulator
Investigator:	Vishal Chandra Kummetha
IRB ID:	STUDY00140495
Funding:	Name: University of Kansas, Funding Source ID: Kondyli SU, Funding source 2225514-094
Grant ID:	
Documents Reviewed:	• HSCL_Signed Consent Form-vishal.pdf, • HIPAA completion-vishal.pdf, • Social and behavioral research completion-vishal.pdf, • Initial Submission Application-filled.pdf, • Wellness Survey for participants, • ACC participant selection email.pdf, • Screening survey for Study, • Simulator realism survey, • Flyer-ACC participants.pdf, • Equipment manual

The IRB approved the study from 2/1/2017 to 1/31/2018.

1. Before 1/31/2018 submit a Continuing Review request and required attachments to request continuing approval or closure.
2. Any significant change to the protocol requires a modification approval prior to altering the project.
3. Notify HSCL about any new investigators not named in original application. Note that new investigators must take the online tutorial at https://rgs.drupal.ku.edu/human_subjects_compliance_training.
4. Any injury to a subject because of the research procedure must be reported immediately.
5. When signed consent documents are required, the primary investigator must retain the signed consent documents for at least three years past completion of the research activity.

If continuing review approval is not granted before the expiration date of 1/31/2018 approval of this protocol expires on that date.

Please note university data security and handling requirements for your project:
https://documents.ku.edu/policies/IT/DataClassificationandHandlingProceduresGuide.htm

You must use the final, watermarked version of the consent form, available under the "Documents" tab in eCompliance.

Sincerely,

Stephanie Dyson Elms, MPA
IRB Administrator, KU Lawrence Campus

Human Research Protection Program
Youngberg Hall | 2385 Irving Hill Rd | Lawrence, KS 66045 | (785) 864-7429 | research.ku.edu/hrpp

APPENDIX E – Simulator Realism Questionnaire

REALISM OF THE SIMULATOR

Please circle the level of realism experienced during the drive. Realism indicates how accurately the simulator depicts a real vehicle in terms of performance, appearance, and response.

	Aspects of driving	**0 = Not realistic and 5 = Very Realistic**						**Please suggest any improvements**
1	Car external appearance	0	1	2	3	4	5	
2	Car interior	0	1	2	3	4	5	
3	Startup sounds	0	1	2	3	4	5	
4	Response of speedometer	0	1	2	3	4	5	
5	Appearance of vehicles in rear view mirror	0	1	2	3	4	5	
6	Appearance of vehicles in side mirrors	0	1	2	3	4	5	
7	Response of gear shift	0	1	2	3	4	5	
8	Response of the brake pedal	0	1	2	3	4	5	
9	Feel when brakes are applied	0	1	2	3	4	5	
10	Response of the accelerator pedal	0	1	2	3	4	5	
11	Sensation of acceleration	0	1	2	3	4	5	
12	Sensitivity of steering wheel	0	1	2	3	4	5	
13	Driving along curves	0	1	2	3	4	5	
14	Feel of cars passing by	0	1	2	3	4	5	
15	Sensation of speed at 20 mph	0	1	2	3	4	5	
16	Sensation of speed at 40 mph	0	1	2	3	4	5	
17	Sensation of speed at 55 mph	0	1	2	3	4	5	
18	Sensation of speed at 65 mph	0	1	2	3	4	5	
19	Sensation of speed at 75 mph	0	1	2	3	4	5	
20	ACC engaging	0	1	2	3	4	5	
21	ACC alerts	0	1	2	3	4	5	
22	Overall appearance of driving scenarios	0	1	2	3	4	5	
23	Similarity to actual driving	0	1	2	3	4	5	

Table E-1: Participant responses on the realism of the simulator

ID	Question Number																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
P01	5	5	5	3	4	4	3	4	3	5	3	4	5	3	3	3	3	3	4	4	3	4	4
P02	3	5	4	4	5	5	5	3	3	4	4	5	3	5	5	5	4	4	4	3	5	4	4
P03	5	5	5	2	4	4	5	4	4	4	3	0	3	4	5	5	5	5	5	4	4	4	4
P04	5	5	4	4	4	5	5	5	4	4	4	5	4	3	4	4	4	3	3	5	5	5	4
P05	5	5	5	4	5	5	5	5	4	4	4	5	5	4	4	4	4	4	4	5	5	5	4
P06	5	5	5	5	5	5	5	4	5	5	4	4	3	3	5	5	5	5	5	5	5	4	4
P07	5	5	5	4	4	4	5	5	5	3	5	5	5	5	5	5	5	5	5	5	5	5	5
P08	5	5	4	4	3	3	5	3	3	3	4	3	3	4	4	4	4	4	4	5	-	4	4
P09	5	5	4	3	3	4	5	3	0	3	1	5	4	4	2	3	4	4	4	4	4	4	3
P10	4	5	4	3	3	3	3	3	3	2	2	4	4	3	2	2	2	2	2	3	3	3	3
P11	5	5	4	4	5	4	3	4	4	4	5	5	5	4	4	4	5	5	4	3	4	4	4
P12	4	5	4	4	4	3	4	3	5	5	4	4	4	4	4	5	5	5	4	4	4	4	4
P13	5	5	5	3	3	3	-	2	1	2	2	3	4	3	4	4	4	4	4	2	-	3	4
P14	5	4	5	5	5	4	5	5	3	3	3	5	3	5	5	5	5	5	5	5	-	5	3
P15	5	5	5	5	5	5	5	5	2	5	4	5	5	5	3	5	5	5	5	5	5	5	5
P16	3	5	5	3	5	5	5	2	3	3	2	5	4	4	4	3	4	4	3	3	-	4	3
P17	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	-	5	5
P18	5	5	4	3	3	2	4	3	2	5	5	4	5	4	4	5	5	5	4	4	5	3	4
P19	5	5	5	5	5	5	5	4	4	4	4	5	5	4	2	2	3	3	4	4	3	4	2
P20	5	5	4	5	5	5	5	3	3	4	4	5	5	5	3	3	3	4	5	5	5	5	5
P21	5	5	5	4	5	5	5	4	5	5	4	5	5	5	5	5	5	5	5	5	-	5	5
P22	5	5	5	3	5	5	5	3	3	3	4	1	5	5	-	-	-	-	-	-	-	5	4
P23	5	5	5	5	5	5	5	3	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
P24	5	5	4	4	4	4	4	3	3	3	3	2	4	4	4	4	4	4	4	3	4	4	4
P25	4	5	5	5	5	5	-	-	4	5	5	3	4	-	5	5	5	5	5	4	4	4	5
P26	5	5	5	3	3	2	4	3	2	4	5	2	4	3	5	5	5	5	5	3	4	3	3
P27	5	5	5	3	5	5	5	4	4	3	4	5	5	5	5	5	5	5	5	5	-	4	5
P28	5	5	3	3	4	4	4	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4
P29	5	5	4	3	4	4	5	5	4	4	3	2	2	4	3	4	5	5	5	4	4	4	3
P30	5	5	5	4	5	5	5	4	5	4	4	5	5	5	5	5	5	5	5	4	4	5	5

Qn	1	2	3	4	5	6	7	8	9	10	11	12
Avg	4.8	5.0	4.6	3.8	4.3	4.2	4.6	3.7	3.5	3.9	3.7	4.0

Qn	13	14	15	16	17	18	19	20	21	22	23
Avg	4.2	4.1	4.1	4.2	4.4	4.4	4.3	4.1	4.3	4.2	4.0

APPENDIX F – Participant Database and Categorization

Table F-1: Participant database with scheduled appointments

No.	ID	Age	Study Group	Gender	Appointment Date & Time	ACC Familiarity 1 = Yes, 0 = No
1	P01	23	1	F	Wednesday 24th May at 4:30 PM	0
2	P02	21	1	M	Monday 15th May at 11:00 AM	0
3	P03	32	2	M	Tuesday 16th May at 11:30 AM	0
4	P04	31	2	F	Friday 12th May at 11:00 AM	0
5	P05	49	2	M	Monday 15th May at 1:30 PM	0
6	P06	29	2	F	Tuesday 16th May at 3:00 PM	0
7	P07	20	1	F	Wednesday 31st May at 10:00 AM	0
8	P08	26	2	F	Friday 2nd June at 5:30 PM	0
9	P09	21	1	F	Wednesday 24th May at 2:00 PM	0
10	P10	24	1	M	Saturday 13th May at 11:00 AM	0
11	P11	41	2	M	Wednesday 17th May at 5:15 PM	0
12	P12	20	1	F	Friday 12th May at 4:00 PM	0
13	P13	60	3	F	Wednesday 24th May at 11:30 AM	0
14	P14	27	2	M	Thursday 1st June at 6:00 PM	0
15	P15	20	1	M	Wednesday 10th May at 5:30 PM	0
16	P16	40	2	F	Tuesday 16th May at 9:00 AM	0
17	P17	53	3	F	Thursday 1st June at 2:00 PM	0
18	P18	20	1	F	Friday 19th May at 4:00 PM	0
19	P19	27	2	M	Wednesday 17th May at 2:00 PM	0
20	P20	20	1	M	Monday 15th May at 4:00 PM	0
21	P21	31	2	F	Friday 19th May at 11:00 AM	0
22	P22	63	3	F	Wednesday 31st May at 2:00 PM	0
23	P23	20	1	M	Wednesday 24th May at 6:30 PM	0
24	P24	52	3	M	Tuesday 6th June at 5:10 PM	0
25	P25	65	3	M	Thursday 1st June at 8:45 AM	0
26	P26	65	3	M	Tuesday 6th June at 2:00 PM	0
27	P27	56	3	F	Thursday 8th June at 3:00 PM	0
28	P28	65	3	M	Thursday 8th June at 11:00 AM	0
29	P29	62	3	M	Friday 9th June at 5:30 PM	0
30	P30	51	3	F	Thursday 15th June at 11:00 AM	0

Table F-2: Assigning participants to the no ACC scenario

Age	Scenario 1	Scenario 2	Scenario 3	Total	
18-24	P01(F), P02(M), P09(F)	P20(M), P18(F), P23(M)	P15(M), P12(F), P10(M), P07(F)	5M 5F	10
25-49	P03(M), P04(F), P05(M)	P06(F), P19(M), P14(M), P21(F)	P16(F), P11(M), P08(F)	5M 5F	10
50-65	P22(F), P24(M), P26(M), P27(F)	P13(F), P28(M), P30(F)	P17(F), P25(M), P29(M)	5M 5F	10
Total	5M 5F	5M 5F	5M 5F	30	
	10	10	10		

Table F-3: Assigning participants to the ACC scenario

NO ACC	Scenario 1		Scenario 2		Scenario 3		Total	
ACC	Scenario 2	Scenario 3	Scenario 1	Scenario 3	Scenario 1	Scenario 2		
18-24	P02(M), P09(F)	P01(F)	P20(M)	P18(F), P23(M)	P15(M), P07(F)	P12(F), P10(M)	5M 5F	10
25-49	P03(M)	P04(F), P05(M)	P06(F), P19(M)	P21(F), P14(M)	P11(M), P08(F)	P16(F)	5M 5F	10
50-65	P22(F), P26(M)	P24(M), P27(F)	P28(M), P30(F)	P13(F)	P25(M)	P17(F), P29(M)	5M 5F	10
Total	3M 2F	2M 3F	3M 2F	2M 3F	3M 2F	2M 3F	30	
	5	5	5	5	5	5		

APPENDIX G – Sorted Raw Data from MiniSim

Table G-1: Total collisions per participant

ID	Gender	Age	Group	No ACC	ACC
P01	F	23	1	1	1
P02	M	21	1	1	1
P03	M	32	2	2	1
P04	F	31	2	1	1
P05	M	49	2	1	2
P06	F	29	2	1	1
P07	F	20	1	2	2
P08	F	26	2	1	1
P09	F	21	1	2	2
P10	M	24	1	1	1
P11	M	41	2	1	1
P12	F	20	1	2	1
P13	F	60	3	1	1
P14	M	27	2	1	1
P15	M	20	1	1	2
P16	F	40	2	1	1
P17	F	53	3	2	2
P18	F	20	1	1	1
P19	M	27	2	1	1
P20	M	20	1	2	1
P21	F	31	2	1	1
P22	F	63	3	1	1
P23	M	20	1	1	1
P24	M	52	3	1	1
P25	M	65	3	1	1
P26	M	65	3	1	1
P27	F	56	3	2	1
P28	M	65	3	2	1
P29	M	62	3	1	1
P30	F	51	3	1	1

Table G-2: Whole drive with all events

ID	Gender	Age	Group	Max Speed (mph)		Avg Speed (mph)		Speed SD (mph)		Lane Dev	
				No ACC	ACC	No ACC	ACC	No ACC	ACC	No ACC	ACC
P01	F	23	1	87.8	73.2	67.9	68.0	8.78	8.29	1.180	1.006
P02	M	21	1	78.9	72.25	67.6	67.7	7.40	5.48	0.986	1.190
P03	M	32	2	90.9	75.28	68.2	67.6	10.89	8.39	1.557	1.490
P04	F	31	2	80.54	73.85	65.3	66.6	11.14	10.00	1.256	1.380
P05	M	49	2	80.57	75.7	62.9	67.3	14.11	7.92	2.605	1.670
P06	F	29	2	77.87	72.16	65.4	66.0	7.22	10.34	1.388	1.263
P07	F	20	1	83.46	78.84	67.2	68.2	12.20	8.11	2.460	1.160
P08	F	26	2	79.87	72.67	69.1	68.6	6.54	6.46	1.249	1.122
P09	F	21	1	83.07	71.7	65.0	65.9	12.06	8.97	1.371	1.417
P10	M	24	1	80.08	74.98	67.1	70.7	8.13	6.84	1.345	1.486
P11	M	41	2	76.3	81.77	68.7	68.9	9.21	8.61	1.256	1.200
P12	F	20	1	82.75	81.54	70.9	70.0	8.13	8.70	1.163	1.317
P13	F	60	3	71.24	70.5	52.5	60.3	11.14	11.47	2.559	2.058
P14	M	27	2	83.37	78.01	68.4	68.5	9.74	6.47	1.284	1.463
P15	M	20	1	77.28	83.29	70.0	68.5	9.43	8.02	1.307	1.117
P16	F	40	2	79.06	77.61	69.0	70.6	5.75	6.24	1.262	1.136
P17	F	53	3	83.92	77.16	70.2	71.9	5.49	7.44	0.977	1.230
P18	F	20	1	79.03	71.05	68.3	67.9	6.25	6.53	1.147	1.332
P19	M	27	2	75.27	75.14	67.9	67.9	5.58	7.14	1.209	1.313
P20	M	20	1	86.33	82.62	67.8	70.1	8.59	7.82	1.180	1.191
P21	F	31	2	82.01	75.38	69.3	68.4	5.18	6.16	1.209	1.423
P22	F	63	3	82.28	76.78	65.7	66.4	10.67	8.36	1.283	1.152
P23	M	20	1	84.62	72.64	68.6	68.6	16.80	4.08	1.472	1.271
P24	M	52	3	79.53	73.82	68.1	67.7	8.13	7.58	1.505	1.456
P25	M	65	3	79.16	81.52	62.7	66.9	9.42	8.52	1.229	1.485
P26	M	65	3	86.33	75.4	69.5	68.3	9.22	6.07	1.410	1.676
P27	F	56	3	76.52	72.07	67.9	68.9	8.49	5.72	1.758	1.370
P28	M	65	3	78.37	74.05	69.1	68.9	5.22	7.46	1.862	1.698
P29	M	62	3	81.18	73.25	61.4	65.2	9.83	9.37	1.669	1.642
P30	F	51	3	79.13	70.45	60.9	60.6	9.21	8.29	1.207	1.344

Table G-3: Car following event

ID	Gender	Age	Group	Avg Headway (ft)		Max Speed (mph)		Avg Speed (mph)		Speed SD (mph)		Lane Dev	
				No ACC	ACC	No ACC	ACC	No ACC	ACC	No ACC	ACC	No ACC	ACC
P01	F	23	1	165.78	297.55	83.2	71.2	70.2	68.4	4.85	5.68	1.055	0.665
P02	M	21	1	408.80	583.04	73.7	70.4	68.9	69.4	4.07	1.96	0.927	1.089
P03	M	32	2	327.15	366.64	88.6	71.0	70.1	69.3	13.08	3.13	1.233	1.464
P04	F	31	2	82.97	316.57	74.7	71.8	70.2	68.4	2.34	5.92	1.206	1.173
P05	M	49	2	404.82	234.98	77.1	75.7	68.7	63.3	4.84	10.28	1.176	1.097
P06	F	29	2	548.94	589.26	73.4	72.2	66.8	67.3	5.85	7.64	1.255	1.379
P07	F	20	1	161.36	295.12	77.1	76.7	69.3	68.7	5.72	5.30	1.098	1.026
P08	F	26	2	271.58	329.02	79.9	72.5	69.9	69.1	7.18	4.98	1.114	0.935
P09	F	21	1	274.51	318.70	79.0	71.4	71.2	69.3	2.99	3.17	0.734	0.928
P10	M	24	1	493.71	688.42	78.5	75.0	68.4	70.0	11.49	7.39	0.976	0.889
P11	M	41	2	143.69	233.48	76.3	80.0	69.4	68.5	5.50	12.20	0.941	1.088
P12	F	20	1	156.04	641.87	79.1	78.0	69.4	69.0	6.07	7.69	0.589	0.843
P13	F	60	3	720.34	688.03	71.2	70.5	59.0	62.8	3.51	5.84	1.028	1.638
P14	M	27	2	432.80	303.59	80.5	73.1	69.2	68.6	6.18	5.51	1.042	1.096
P15	M	20	1	143.10	376.78	74.2	80.9	69.6	68.4	3.20	9.68	0.634	0.834
P16	F	40	2	426.72	304.04	75.8	75.0	68.0	69.6	7.28	2.06	1.098	0.957
P17	F	53	3	222.30	306.38	75.1	75.1	69.2	71.3	5.70	3.11	0.461	0.592
P18	F	20	1	371.16	303.77	78.5	71.0	70.5	69.0	5.17	3.80	0.831	0.826
P19	M	27	2	544.36	404.24	72.4	70.2	68.1	67.9	3.09	6.06	0.762	1.038
P20	M	20	1	189.47	519.93	78.9	75.8	69.4	68.1	4.52	9.52	0.979	0.892
P21	F	31	2	358.76	469.88	77.4	72.6	70.0	68.4	3.84	7.16	0.881	1.160
P22	F	63	3	314.78	624.57	76.2	72.2	70.4	68.2	3.95	3.06	0.906	0.705
P23	M	20	1	233.21	559.40	83.0	72.6	71.2	64.4	3.98	4.66	0.850	1.296
P24	M	52	3	569.06	415.89	78.0	71.0	68.6	68.3	6.17	5.58	1.325	1.007
P25	M	65	3	577.44	517.98	79.2	73.7	67.2	66.6	8.15	5.38	0.507	1.077
P26	M	65	3	370.06	317.36	73.5	71.9	68.8	69.4	3.65	3.58	0.703	1.054
P27	F	56	3	398.83	396.87	74.8	72.1	69.7	68.9	4.59	6.72	1.306	1.163
P28	M	65	3	510.10	496.84	71.2	72.0	69.2	67.7	2.98	6.92	1.498	1.711
P29	M	62	3	366.97	559.22	81.2	73.3	64.3	68.2	7.92	6.49	0.817	0.834
P30	F	51	3	531.12	457.77	76.6	69.6	66.8	66.8	3.77	5.85	1.123	1.312

Table G-4: Crossing animal event

ID	Gender	Age	Group	Avg Headway (ft)		Max Speed (mph)		Avg Speed (mph)		Speed SD (mph)		Lane Dev	
				No ACC	ACC	No ACC	ACC	No ACC	ACC	No ACC	ACC	No ACC	ACC
P01	F	23	1	431.5	409.6	76.1	70.0	70.7	70.0	2.42	0.00	0.661	0.226
P02	M	21	1	523.9	491.1	75.9	70.8	71.6	68.1	4.13	1.56	0.774	0.369
P03	M	32	2	162.2	333.9	70.3	72.9	65.9	64.5	2.79	9.62	0.663	0.970
P04	F	31	2	302.5	305.3	80.2	73.2	72.3	71.0	6.04	0.91	0.603	0.960
P05	M	49	2	503.2	251.9	68.8	70.0	64.2	65.3	3.34	6.12	0.651	0.863
P06	F	29	2	514.3	304.8	72.2	70.1	67.9	67.6	2.99	3.77	0.385	0.918
P07	F	20	1	158.3	283.6	70.8	69.4	64.8	62.5	5.91	4.15	0.738	0.352
P08	F	26	2	244.0	302.1	71.7	70.8	67.1	68.6	3.03	2.86	0.293	0.156
P09	F	21	1	309.6	776.6	73.9	70.5	53.5	68.2	16.14	2.35	0.226	1.036
P10	M	24	1	332.5	248.7	77.2	73.0	73.4	73.0	4.35	0.00	0.197	1.169
P11	M	41	2	406.4	459.1	74.0	71.9	60.9	67.9	17.75	5.16	0.877	0.383
P12	F	20	1	146.3	-	74.9	74.0	70.6	74.0	2.58	0.05	1.822	0.194
P13	F	60	3	-	686.4	66.5	68.6	55.4	37.9	11.23	28.46	0.840	1.917
P14	M	27	2	314.3	302.3	76.8	70.9	46.6	68.2	21.14	3.04	0.422	2.382
P15	M	20	1	265.2	396.9	72.0	69.0	67.3	63.2	5.21	8.22	0.666	0.381
P16	F	40	2	178.2	298.0	73.8	70.0	71.0	69.5	1.84	0.61	0.484	0.655
P17	F	53	3	115.9	11.4	75.0	75.0	69.5	75.0	2.75	0.01	0.375	2.254
P18	F	20	1	321.4	383.3	71.8	71.0	68.0	69.0	4.33	3.12	0.907	0.781
P19	M	27	2	350.8	350.2	72.5	70.9	66.2	67.7	7.76	4.44	0.319	1.122
P20	M	20	1	238.7	316.1	72.1	70.4	66.4	64.2	4.67	6.60	0.865	0.336
P21	F	31	2	158.1	481.9	75.9	69.5	70.7	69.5	5.21	0.02	0.656	0.407
P22	F	63	3	692.0	657.9	74.9	68.1	64.0	61.2	9.49	8.51	0.300	0.549
P23	M	20	1	241.2	360.6	76.8	70.0	72.0	70.0	2.43	0.00	0.559	0.782
P24	M	52	3	365.1	377.3	75.5	66.3	69.1	63.4	5.25	3.78	1.132	1.455
P25	M	65	3	631.9	473.5	68.5	67.9	65.8	64.7	2.33	1.27	2.918	0.523
P26	M	65	3	285.5	335.2	81.4	72.2	68.5	72.0	13.00	0.53	1.061	1.665
P27	F	56	3	305.0	301.4	73.2	70.1	68.7	68.2	4.36	3.01	0.413	0.499
P28	M	65	3	144.0	334.0	70.1	71.1	69.1	71.1	0.71	0.05	3.218	0.217
P29	M	62	3	-	556.6	73.8	71.0	64.9	60.5	9.30	13.80	2.708	1.252
P30	F	51	3	541.7	480.2	65.2	67.9	56.4	55.3	7.03	14.60	0.418	0.284

Table G-5: Desk drop event

ID	Gender	Age	Group	Avg Headway (ft)		Max Speed (mph)		Avg Speed (mph)		Speed SD (mph)		Lane Dev	
				No ACC	ACC	No ACC	ACC	No ACC	ACC	No ACC	ACC	No ACC	ACC
P01	F	23	1	200.3	527.4	74.0	73.0	66.9	73.0	5.95	0.00	1.155	0.724
P02	M	21	1	322.8	399.6	72.9	65.0	68.6	65.0	2.61	0.00	2.053	1.635
P03	M	32	2	243.9	350.5	72.2	66.5	51.9	66.5	17.16	0.00	0.733	0.500
P04	F	31	2	677.0	484.5	66.0	71.9	61.0	71.9	2.91	0.02	2.135	2.568
P05	M	49	2	212.3	126.2	72.7	71.0	64.1	70.9	3.70	0.16	1.292	1.102
P06	F	29	2	580.7	850.6	71.1	70.7	62.9	70.7	3.94	0.00	1.070	0.718
P07	F	20	1	110.4	97.5	75.2	75.7	68.5	67.4	4.49	4.86	0.583	2.007
P08	F	26	2	107.9	424.0	71.6	72.2	68.6	72.0	1.13	0.18	0.933	0.675
P09	F	21	1	283.6	460.3	71.8	70.0	38.7	47.0	26.16	22.40	0.532	0.841
P10	M	24	1	265.4	433.0	71.7	73.0	70.7	73.0	1.05	0.00	1.382	0.591
P11	M	41	2	164.3	394.0	73.1	66.7	72.5	61.0	0.30	5.23	0.489	0.759
P12	F	20	1	128.7	545.7	71.9	64.1	68.5	64.1	2.81	0.00	0.524	0.820
P13	F	60	3	1010.0	707.5	61.2	65.7	44.2	60.1	11.39	3.79	3.030	2.919
P14	M	27	2	127.2	220.3	69.9	72.2	65.1	67.8	3.38	1.20	2.243	2.494
P15	M	20	1	-	137.6	72.0	70.1	70.3	65.7	1.02	6.33	0.666	0.657
P16	F	40	2	172.5	348.2	76.2	74.5	66.4	74.3	6.69	0.29	1.504	1.722
P17	F	53	3	106.7	-	72.5	76.4	66.4	76.3	3.75	0.07	0.575	0.808
P18	F	20	1	190.6	334.1	70.1	70.5	66.2	70.4	3.50	0.13	1.822	0.918
P19	M	27	2	165.4	364.4	73.0	75.1	66.8	69.5	5.37	3.53	1.368	1.896
P20	M	20	1	183.1	-	73.1	72.0	60.5	71.8	10.27	0.31	0.780	0.885
P21	F	31	2	153.2	299.8	73.1	71.0	68.3	65.7	3.68	6.03	1.459	1.348
P22	F	63	3	400.0	356.4	69.6	71.0	55.7	52.3	10.91	14.98	1.686	1.962
P23	M	20	1	-	216.3	-	70.0	-	64.4	-	4.66	-	1.296
P24	M	52	3	214.6	324.6	72.9	72.0	69.6	71.8	2.13	0.28	1.180	1.790
P25	M	65	3	453.4	310.0	65.0	71.1	46.9	57.3	11.26	12.63	0.473	2.712
P26	M	65	3	131.9	233.3	73.3	70.4	70.2	70.1	2.39	0.10	1.748	1.774
P27	F	56	3	159.0	382.3	72.1	71.5	66.3	69.7	5.94	1.76	1.128	1.368
P28	M	65	3	438.6	659.0	69.2	70.2	68.5	66.9	0.41	2.04	0.342	0.520
P29	M	62	3	474.8	352.2	69.1	71.2	44.8	56.4	17.14	13.95	2.050	1.669
P30	F	51	3	683.6	473.0	63.9	65.2	58.4	47.1	2.82	11.23	0.683	0.525

Table G-6: Work zone event

ID	Gender	Age	Group	Max Speed (mph)		Avg Speed (mph)		Speed SD (mph)		Lane Dev	
				No ACC	ACC	No ACC	ACC	No ACC	ACC	No ACC	ACC
P01	F	23	1	62.3	70.0	57.6	64.0	2.66	5.20	0.634	1.122
P02	M	21	1	67.6	70.0	62.8	62.6	2.67	5.11	1.268	0.420
P03	M	32	2	68.3	67.0	56.2	55.9	4.25	2.75	0.647	1.148
P04	F	31	2	68.4	59.2	56.6	54.0	4.00	2.23	1.342	1.576
P05	M	49	2	61.7	70.3	53.0	61.0	2.32	7.85	1.022	1.616
P06	F	29	2	72.5	70.3	56.2	56.9	4.56	3.64	1.951	1.518
P07	F	20	1	74.3	73.9	61.1	63.4	4.16	3.51	0.660	1.150
P08	F	26	2	73.4	66.1	62.6	60.1	2.99	1.40	1.275	1.225
P09	F	21	1	69.9	68.4	55.5	60.1	1.77	1.46	1.334	0.899
P10	M	24	1	76.0	73.5	67.3	70.8	5.61	2.09	1.689	1.374
P11	M	41	2	73.3	74.5	62.2	64.9	8.91	6.15	1.136	1.104
P12	F	20	1	81.5	66.0	70.2	61.5	5.95	1.37	1.064	1.151
P13	F	60	3	60.6	66.4	49.6	58.3	3.87	5.03	1.372	2.006
P14	M	27	2	70.1	67.1	57.0	59.8	4.01	2.56	0.605	1.576
P15	M	20	1	76.8	70.8	66.8	64.7	3.76	1.89	1.225	0.465
P16	F	40	2	73.0	71.3	66.0	62.6	5.84	2.79	1.575	1.518
P17	F	53	3	74.3	72.4	64.1	56.7	4.64	3.61	1.155	1.216
P18	F	20	1	73.6	70.5	58.3	53.5	5.01	7.18	1.081	1.532
P19	M	27	2	65.2	68.5	55.3	58.5	3.18	4.64	1.377	0.847
P20	M	20	1	63.5	67.7	55.9	60.4	2.06	2.60	0.871	1.182
P21	F	31	2	73.0	71.0	65.8	65.7	4.55	6.03	0.938	1.348
P22	F	63	3	69.8	71.3	58.7	68.2	4.00	3.06	1.252	0.705
P23	M	20	1	71.5	70.0	59.7	70.0	3.52	0.01	1.293	1.988
P24	M	52	3	75.6	69.7	60.8	57.7	6.70	3.50	1.510	1.931
P25	M	65	3	68.6	70.1	59.0	56.4	3.39	4.44	0.900	1.489
P26	M	65	3	67.0	66.8	60.8	57.2	2.08	1.69	0.938	1.359
P27	F	56	3	68.6	71.0	61.3	62.2	2.48	3.88	1.680	1.903
P28	M	65	3	69.2	64.0	68.5	58.7	0.41	2.78	0.342	1.643
P29	M	62	3	59.9	67.9	50.6	53.2	4.97	3.92	1.295	1.407
P30	F	51	3	60.9	60.0	51.4	52.5	7.44	2.57	0.936	0.868

Table G-7: Time to collision for the desk drop and crossing animal event

ID	Group	Desk drop event						Crossing animal event					
		No ACC			ACC			No ACC			ACC		
		Dist (ft)	Speed (mph)	TTC (s)	Dist (ft)	Speed (mph)	TTC (s)	Dist (ft)	Speed (mph)	TTC (s)	Dist (ft)	Speed (mph)	TTC (s)
P01	1	113.9	66.1	1.7	284.5	72.8	3.91	6.4	72.6	0.09	3.1	70.0	0.04
P02	1	182.2	66.0	2.8	289.6	65.0	4.46	39.4	71.6	0.55	25.1	66.7	0.38
P03	2	77.8	62.9	1.2	164.0	66.5	2.47	20.7	69.7	0.30	14.6	70.7	0.21
P04	2	201.2	58.8	3.4	120.4	71.9	1.67	15.4	69.8	0.22	12.2	70.4	0.17
P05	2	234.7	60.7	3.9	0.0	71.0	0.00	35.2	68.7	0.51	53.0	70.0	0.76
P06	2	-	-	-	-	-	-	13.8	74.6	0.19	22.0	70.1	0.31
P07	1	53.4	75.0	0.7	108.1	68.2	1.59	46.2	70.7	0.65	28.1	69.3	0.41
P08	2	120.8	68.2	1.8	125.2	72.1	1.74	26.9	69.6	0.39	6.8	70.1	0.10
P09	1	133.9	71.7	1.9	127.9	70.0	1.83	19.5	61.6	0.32	14.4	70.5	0.20
P10	1	187.7	71.7	2.6	364.4	73.0	4.99	14.7	77.2	0.19	0.0	73.0	0.00
P11	2	170.0	73.0	2.3	68.4	66.7	1.03	35.4	74.0	0.48	10.6	71.9	0.15
P12	1	37.9	71.8	0.5	150.0	64.1	2.34	24.5	67.2	0.36	7.8	74.0	0.11
P13	3	-	-	-	422.2	52.4	8.06	36.1	60.8	0.59	24.5	68.2	0.36
P14	2	68.6	69.2	1.0	166.7	67.1	2.48	24.3	65.6	0.37	25.9	69.9	0.37
P15	1	-	-	-	20.9	70.0	0.30	22.8	69.8	0.33	6.7	69.0	0.10
P16	2	96.5	64.7	1.5	138.8	74.5	1.86	14.2	71.8	0.20	7.1	69.9	0.10
P17	3	12.2	68.0	0.2	-	-	-	15.9	70.2	0.23	12.3	75.0	0.16
P18	1	157.4	69.7	2.3	250.0	70.5	3.55	32.9	70.6	0.47	17.5	71.0	0.25
P19	2	130.2	69.0	1.9	165.5	71.4	2.32	23.6	71.9	0.33	37.8	70.9	0.53
P20	1	66.6	69.3	1.0	-	72.0	-	29.2	72.0	0.41	5.2	70.4	0.07
P21	2	106.6	69.0	1.5	161.7	71.0	2.28	16.7	68.7	0.24	8.8	69.5	0.13
P22	3	306.6	61.4	5.0	266.7	65.4	4.08	13.4	69.1	0.19	40.8	68.0	0.60
P23	1	30.0	77.9	0.4	25.0	70.0	0.36	16.2	71.4	0.23	13.6	70.0	0.19
P24	3	100.9	71.9	1.4	127.6	72.0	1.77	22.1	67.9	0.33	19.4	66.3	0.29
P25	3	182.6	63.8	2.9	135.3	65.5	2.07	20.9	68.5	0.31	14.4	67.8	0.21
P26	3	94.3	71.9	1.3	72.0	70.0	1.03	50.2	79.0	0.64	14.2	72.2	0.20
P27	3	0.0	65.6	0.0	230.3	70.1	3.29	36.9	72.9	0.51	16.5	70.1	0.23
P28	3	155.0	68.8	2.3	154.5	63.6	2.43	23.2	69.1	0.34	20.7	71.1	0.29
P29	3	365.6	61.7	5.9	239.2	70.8	3.38	17.8	73.7	0.24	8.5	71.0	0.12
P30	3	505.4	56.7	8.9	-	-	-	56.1	60.8	0.92	48.6	67.9	0.72

Table G-8: Sudden merging event

ID	Gender	Age	Group	Brake Force (Lbs)		Deceleration (ft/s^2)		TTC (s)	
				No ACC	ACC	No ACC	ACC	No ACC	ACC
P01	F	23	1	4.8	5.5	-2.0	-2.2	4.08	2.70
P02	M	21	1	5.3	16.7	-3.1	-9.8	5.71	1.92
P03	M	32	2	32.1	41.7	-15.9	-24.3	2.54	1.81
P04	F	31	2	33.9	38.8	-16.1	-17.8	2.48	2.36
P05	M	49	2	11.8	-	-7.3	-	3.24	2.33
P06	F	29	2	22.8	-	-12.5	-	2.17	-
P07	F	20	1	13.7	43.8	-9.1	-17.7	7.41	4.77
P08	F	26	2	17.7	33.8	-10.5	-16.3	2.89	1.85
P09	F	21	1	28.6	31.6	-14.9	-15.5	2.96	2.50
P10	M	24	1	55.6	82.2	-20.4	-27.4	1.74	0.00
P11	M	41	2	54.1	-	-22.7	-	1.50	3.33
P12	F	20	1	48.8	69.6	-13.9	-25.4	0.81	1.22
P13	F	60	3	12.3	7.5	-4.4	-3.5	6.41	2.86
P14	M	27	2	35.4	25.3	-11.7	-13.7	1.50	2.50
P15	M	20	1	29.3	30.4	-15.0	-13.2	1.65	1.24
P16	F	40	2	32.9	50.7	-16.1	-19.1	1.58	0.75
P17	F	53	3	24.0	14.6	-11.3	-9.9	2.41	0.33
P18	F	20	1	35.9	-	-16.2	-	8.74	1.41
P19	M	27	2	22.9	39.2	-12.2	-17.4	1.65	2.01
P20	M	20	1	34.1	49.4	-16.4	-19.5	1.87	1.54
P21	F	31	2	22.0	22.8	-10.9	-12.7	1.83	1.82
P22	F	63	3	20.6	6.2	-11.0	-3.1	9.64	6.64
P23	M	20	1	20.1	26.7	-11.3	-13.2	6.83	5.59
P24	M	52	3	32.2	30.1	-15.6	-14.9	3.45	2.40
P25	M	65	3	16.9	55.3	-9.5	-23.1	6.71	7.93
P26	M	65	3	52.5	58.5	-24.0	-24.0	6.96	1.62
P27	F	56	3	35.7	23.4	-16.9	-13.1	2.21	2.25
P28	M	65	3	70.9	75.0	-25.1	-26.1	1.68	1.95
P29	M	62	3	-	-	-	-	-	-
P30	F	51	3	15.3	42.7	-7.4	-17.7	8.24	2.78

Table G-9: Distraction application hit attempts

ID	Gender	Age	Group	No ACC					ACC				
				1	2	3	Desk	Total	1	2	3	Desk	Total
P01	F	23	1	4	1	3	1	9	3	2	3	3	11
P02	M	21	1	4	4	6	3	17	6	5	5	5	21
P03	M	32	2	4	4	2	3	13	4	4	5	5	18
P04	F	31	2	4	5	3	4	16	5	9	3	3	20
P05	M	49	2	4	5	5	6	20	7	5	5	5	22
P06	F	29	2	4	7	8	5	24	5	6	6	7	24
P07	F	20	1	3	3	3	1	10	7	4	4	1	16
P08	F	26	2	4	3	6	2	15	4	5	6	4	19
P09	F	21	1	2	4	3	1	10	4	5	3	1	13
P10	M	24	1	3	3	3	2	11	3	2	2	2	9
P11	M	41	2	4	6	4	3	17	2	5	4	5	16
P12	F	20	1	4	3	5	2	14	3	5	5	5	18
P13	F	60	3	2	2	3	4	11	1	2	1	2	6
P14	M	27	2	1	3	5	1	10	5	4	3	2	14
P15	M	20	1	5	5	5	5	20	6	6	3	5	20
P16	F	40	2	3	5	2	0	10	5	2	4	2	13
P17	F	53	3	2	4	2	0	8	1	3	2	2	8
P18	F	20	1	4	4	5	3	16	5	6	5	6	22
P19	M	27	2	5	6	6	3	20	3	8	4	2	17
P20	M	20	1	3	5	6	4	18	6	6	7	6	25
P21	F	31	2	2	4	4	1	11	4	4	4	4	16
P22	F	63	3	4	2	5	2	13	5	5	5	3	18
P23	M	20	1	3	5	7	0	15	6	5	6	6	23
P24	M	52	3	3	3	0	0	6	4	4	4	2	14
P25	M	65	3	1	2	1	1	5	2	2	3	2	9
P26	M	65	3	2	2	1	2	7	2	2	3	2	9
P27	F	56	3	1	1	2	2	6	2	2	1	1	6
P28	M	65	3	3	2	3	2	10	3	4	5	3	15
P29	M	62	3	3	3	3	0	9	2	3	3	2	10
P30	F	51	3	2	3	3	4	12	3	4	5	4	16

Table G-10: Move over or slow down law

ID	Gender	Age	Group	Observed the Move Over Law: 1 = Yes, 0 = No, NA = Not Applicable							
				No ACC				ACC			
				Car	Truck	Police	Total	Car	Truck	Police	Total
P01	F	23	1	0	1	1	2	0	0	1	1
P02	M	21	1	0	1	1	2	0	1	1	2
P03	M	32	2	NA	0	1	1	NA	0	1	1
P04	F	31	2	0	NA	1	1	0	NA	1	1
P05	M	49	2	0	1	1	2	0	1	1	2
P06	F	29	2	0	NA	1	1	0	NA	1	1
P07	F	20	1	1	0	1	2	1	0	0	1
P08	F	26	2	1	NA	1	2	1	NA	1	2
P09	F	21	1	1	1	1	3	1	1	1	3
P10	M	24	1	0	NA	1	1	0	NA	1	1
P11	M	41	2	0	0	1	1	0	0	1	1
P12	F	20	1	1	0	NA	1	0	0	NA	0
P13	F	60	3	0	0	0	0	0	0	0	0
P14	M	27	2	1	1	1	3	1	1	1	3
P15	M	20	1	0	0	1	1	0	0	1	1
P16	F	40	2	1	NA	1	2	0	NA	1	1
P17	F	53	3	0	0	1	1	1	0	1	2
P18	F	20	1	0	NA	1	1	0	NA	1	1
P19	M	27	2	1	NA	1	2	0	NA	1	1
P20	M	20	1	1	1	1	3	1	1	1	3
P21	F	31	2	0	0	1	1	0	0	1	1
P22	F	63	3	0	0	1	1	0	1	1	2
P23	M	20	1	0	1	1	2	0	1	1	2
P24	M	52	3	1	1	1	3	0	1	1	2
P25	M	65	3	0	1	1	2	0	1	1	2
P26	M	65	3	1	0	1	2	1	1	1	3
P27	F	56	3	0	0	1	1	0	0	1	1
P28	M	65	3	NA	1	1	2	NA	1	1	2
P29	M	62	3	1	NA	1	2	1	NA	1	2
P30	F	51	3	1	NA	1	2	1	NA	1	2

APPENDIX H – Sorted DRT Data

Table H-1: DRT data collected from the drive without any incidents

ID	Gender	Age	Group	No ACC		ACC	
				RT (s)	HR (%)	RT (s)	HR (%)
P01	F	23	1	0.857	72.03	0.610	98.20
P02	M	21	1	0.468	97.48	0.532	97.46
P03	M	32	2	-	-	0.533	91.15
P04	F	31	2	0.602	98.36	0.608	96.55
P05	M	49	2	0.834	60.80	0.820	66.67
P06	F	29	2	-	-	0.535	95.83
P07	F	20	1	0.546	88.18	0.601	81.42
P08	F	26	2	0.603	83.93	0.596	86.96
P09	F	21	1	0.637	90.98	0.746	80.18
P10	M	24	1	0.722	68.14	0.718	70.37
P11	M	41	2	0.499	95.58	0.637	86.49
P12	F	20	1	0.595	85.19	0.590	83.78
P13	F	60	3	0.702	54.93	0.918	50.39
P14	M	27	2	0.538	73.45	0.518	90.57
P15	M	20	1	0.332	94.55	0.329	96.52
P16	F	40	2	0.641	89.19	0.569	84.82
P17	F	53	3	0.612	95.33	0.551	97.22
P18	F	20	1	0.559	81.58	0.565	80.00
P19	M	27	2	0.549	98.23	0.553	99.15
P20	M	20	1	0.426	87.61	0.423	96.43
P21	F	31	2	0.536	89.09	0.561	94.59
P22	F	63	3	0.526	90.00	0.485	93.16
P23	M	20	1	0.870	74.77	0.592	94.55
P24	M	52	3	0.945	87.61	0.826	81.82
P25	M	65	3	0.572	93.22	0.703	87.29
P26	M	65	3	0.562	74.78	0.640	77.68
P27	F	56	3	0.530	93.04	0.504	93.75
P28	M	65	3	0.656	89.47	0.628	92.86
P29	M	62	3	0.740	62.90	0.718	51.72
P30	F	51	3	0.445	97.69	0.488	100.00

Table H-2: DRT data collected from the car following event

ID	Gender	Age	Group	No ACC		ACC	
				RT (s)	HR (%)	RT (s)	HR (%)
P01	F	23	1	0.687	91.30	0.509	100.00
P02	M	21	1	0.375	100.00	0.525	100.00
P03	M	32	2	-	-	0.370	100.00
P04	F	31	2	0.516	100.00	0.714	95.65
P05	M	49	2	0.685	73.91	0.815	53.85
P06	F	29	2	-	-	0.409	100.00
P07	F	20	1	0.549	95.65	0.690	83.33
P08	F	26	2	0.476	90.91	0.529	100.00
P09	F	21	1	0.537	100.00	0.491	91.30
P10	M	24	1	0.604	91.67	0.682	91.30
P11	M	41	2	0.478	100.00	0.525	81.82
P12	F	20	1	0.428	100.00	0.553	92.00
P13	F	60	3	0.826	81.48	0.883	41.18
P14	M	27	2	0.423	91.67	0.426	100.00
P15	M	20	1	0.242	100.00	0.337	91.30
P16	F	40	2	0.530	100.00	0.526	95.45
P17	F	53	3	0.460	81.82	0.514	100.00
P18	F	20	1	0.535	82.61	0.515	95.83
P19	M	27	2	0.465	100.00	0.524	100.00
P20	M	20	1	0.339	100.00	0.434	95.65
P21	F	31	2	0.573	100.00	0.518	86.96
P22	F	63	3	0.440	100.00	0.590	83.33
P23	M	20	1	0.527	91.67	0.424	87.50
P24	M	52	3	0.983	95.65	0.717	91.67
P25	M	65	3	0.460	100.00	0.706	95.83
P26	M	65	3	0.355	100.00	0.493	78.26
P27	F	56	3	0.537	100.00	0.388	100.00
P28	M	65	3	0.582	86.96	0.502	87.50
P29	M	62	3	0.711	56.00	0.665	58.33
P30	F	51	3	0.454	100.00	0.489	100.00

Table H-3: DRT data collected from the three distraction events

ID	Gender	Age	Group	No ACC		ACC	
				RT (s)	HR (%)	RT (s)	HR (%)
P01	F	23	1	0.594	50.00	0.669	71.43
P02	M	21	1	0.651	85.71	0.559	100.00
P03	M	32	2	-	-	0.451	42.86
P04	F	31	2	0.801	71.43	0.639	100.00
P05	M	49	2	0.597	28.57	0.834	55.56
P06	F	29	2	-	-	0.510	85.71
P07	F	20	1	0.657	85.71	0.772	100.00
P08	F	26	2	0.509	50.00	0.604	62.50
P09	F	21	1	1.217	33.33	1.017	37.50
P10	M	24	1	0.991	37.50	0.658	25.00
P11	M	41	2	0.504	100.00	0.721	50.00
P12	F	20	1	0.486	66.67	0.751	50.00
P13	F	60	3	0.711	9.09	0.996	100.00
P14	M	27	2	0.790	42.86	0.665	83.33
P15	M	20	1	0.441	100.00	0.390	87.50
P16	F	40	2	0.629	16.67	1.154	66.67
P17	F	53	3	0.732	100.00	0.424	100.00
P18	F	20	1	0.571	37.50	0.799	100.00
P19	M	27	2	0.557	100.00	0.642	100.00
P20	M	20	1	0.493	50.00	0.759	100.00
P21	F	31	2	0.539	57.14	1.080	71.43
P22	F	63	3	1.090	37.50	1.375	50.00
P23	M	20	1	0.999	50.00	0.894	75.00
P24	M	52	3	1.203	71.43	1.126	50.00
P25	M	65	3	0.814	55.56	0.934	33.33
P26	M	65	3	0.844	20.00	1.498	50.00
P27	F	56	3	0.649	42.86	0.805	71.43
P28	M	65	3	0.873	50.00	1.036	62.50
P29	M	62	3	1.879	12.50	0.484	14.29
P30	F	51	3	0.887	87.50	1.091	77.78

Table H-4: DRT data collected from the work zone event

ID	Gender	Age	Group	No ACC		ACC	
				RT (s)	HR (%)	RT (s)	HR (%)
P01	F	23	1	0.626	100.00	0.545	90.00
P02	M	21	1	0.564	100.00	0.570	100.00
P03	M	32	2	-	-	0.482	90.91
P04	F	31	2	0.525	83.33	0.663	100.00
P05	M	49	2	0.742	33.33	0.770	27.27
P06	F	29	2	-	-	0.442	100.00
P07	F	20	1	0.473	100.00	0.571	90.00
P08	F	26	2	0.764	90.00	0.600	100.00
P09	F	21	1	0.485	91.67	0.558	100.00
P10	M	24	1	0.900	77.78	0.702	100.00
P11	M	41	2	0.450	90.00	0.524	80.00
P12	F	20	1	0.655	70.00	0.581	90.00
P13	F	60	3	1.128	38.46	1.309	40.00
P14	M	27	2	0.548	75.00	0.557	100.00
P15	M	20	1	0.457	70.00	0.345	90.00
P16	F	40	2	0.585	88.89	0.837	72.73
P17	F	53	3	0.634	81.82	0.699	100.00
P18	F	20	1	0.487	81.82	0.703	72.73
P19	M	27	2	0.571	100.00	0.650	100.00
P20	M	20	1	0.320	100.00	0.429	100.00
P21	F	31	2	0.542	100.00	0.391	77.78
P22	F	63	3	0.547	100.00	0.391	100.00
P23	M	20	1	0.930	100.00	0.483	100.00
P24	M	52	3	0.959	81.82	1.190	100.00
P25	M	65	3	0.581	81.82	0.753	81.82
P26	M	65	3	0.665	72.73	0.569	83.33
P27	F	56	3	0.610	100.00	0.630	100.00
P28	M	65	3	0.705	90.91	0.814	90.00
P29	M	62	3	0.920	41.67	0.706	45.45
P30	F	51	3	0.563	100.00	0.475	100.00