# EVALUATING THE IMPACTS OF ADVANCED DRIVER ASSISTANCE SYSTEMS USING A DRIVING SIMULATOR – AN EXPLORATORY STUDY

By

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To my parents, sister and boyfriend

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There is an increasing number of vehicle technologies being developed and deployed during the past few years. Some of these technologies can take control over specific functions of the vehicle, while others provide warnings to assist drivers in a variety of driving tasks. These are called Advanced Driver Assistance Systems (ADAS), and were designed mainly to improve roadway safety and provide comfort to drivers. There is evidence that these systems may be able to result in traffic operational improvements and congestion mitigation, but a limited amount of research has been conducted to assess these potential impacts.

This thesis evaluated traffic operations under two types of ADAS in a driving simulator (STISIM Drive) environment. Two systems, which are more likely to affect traffic operations, were evaluated: Adaptive Cruise Control (ACC) and Lane Change Assist (LCA). A specific route was created in the driving simulator, which consisted of an arterial section followed by a freeway. This route was driven twice by drivers: first without the systems and secondly using the two ADAS. There were a total of 25 participants. During the test, performance measures such as speed, lane change

maneuvers and headway with the front vehicle were collected. The analysis compared the data obtained without the systems to those obtained while the systems were used. Results showed changes in driving behavior due to the systems and a potential positive impact of these technologies in traffic operations.

# CHAPTER 1
# INTRODUCTION

## Background

Advanced Driver Assistance Systems (ADAS) are electronic devices installed in vehicles to assist drivers in tasks such as lane changing, merging and speed control by providing warnings or even taking control of the vehicle. These systems have shown promise in the improvement of road safety, as proven in several tests (Golias et al. 2002; Touran et al. 1999). An important aspect, brought recently by research, is that these systems may also be able to result in traffic improvements and congestion mitigation. Some papers already show positive effects of one particular system (Adaptive Cruise Control), but the integration of these systems' impact has not been evaluated yet.

Driving simulators have proven to be a great tool used in experiments to assess various changes in the driving environment, vehicle control, and driver behavior. They provide a controlled environment, necessary to expose the driver to situations without putting the participant in danger.

## Problem Statement

Existing literature regarding ADAS is focused primarily on safety effects. Also, research related to traffic operations typically consider each system separately and do not consider their combined effects. Finally, the literature has not evaluated specific traffic measures in depth considering different driver's characteristics, such as age, gender and aggressiveness.

With the constant increase of these technologies on the market, traffic impacts represent an important subject to be considered.

## Research Objectives

This thesis evaluates selected traffic operational performance measures under two types of ADAS in a driving simulator environment. This research is a first step towards a broader evaluation of ADAS impacts on traffic, by addressing two systems integrated in one vehicle. The user acceptance of the systems will also be evaluated through a simple questionnaire.

More specifically the objectives of this study are:

- To implement two types of ADAS, Adaptive Cruise Control and Lane Change Assist, in the STISIM driving simulator, with scenarios that include arterial and freeway driving.
- To collect data from human subjects in two types of driving environments (with and without the ADAS) in the driving simulator and to obtain information about the experience involving these new technologies and the factors that could affect the behavior of the drivers through a questionnaire.
- To compare the trajectories of vehicles with and without instrumentation, focusing on headways with the front vehicle, average speed and completed lane change maneuvers.
- To evaluate driving behavior changes due to the systems in different driver types.

## Document Organization

Chapter 2 presents a literature review on Advanced Driver Assistance Systems, focusing on the ones used in this project (Adaptive Cruise Control and Lane Change Assist), the use of driving simulators to test these systems, and the known impacts of these technologies. Chapter 3 describes the methodology used to conduct the experiments and procedures to analyze the data. Chapter 4 presents the description of data collection, and Chapter 5 presents the data analysis. The final chapter presents a summary of the research, along with conclusions and recommendations.

# CHAPTER 2
# LITERATURE REVIEW

This chapter summarizes past research related to Advanced Driver Assistance Systems and the use of driving simulators. The first section describes the advanced driver assistance systems (ADAS) that will be examined in the thesis: Adaptive Cruise Control and Lane Change Assist. The second section summarizes previous research that used driving simulators to assess these systems. The third part presents previous research that evaluated the impact of ADAS on traffic. The chapter concludes with a summary of the literature findings.

## Advanced Driver Assistance Systems (ADAS)

ADAS refer to electronic devices for the support of drivers in performing various driving tasks (such as merging, speed control or lane keeping), by providing real-time advice, instruction and warnings or even intervening in the vehicle control and maneuvering tasks. The use of these systems is expected to improve road safety, increase road capacity and also attenuate environmental load in traffic (Golias et al. 2002, Wiethoff et al. 2002). Improvement of road safety is related to the alleviation of the driving task, decreasing accident consequences. Brookhuis et al. (2001) discussed the behavioral impacts of ADAS, showing that these systems may increase driver's reaction time and situation awareness. Experiments for safety assessment of these technologies have been extensively conducted over the past years. An increase in road capacity is related to the changes in traffic dynamics, reflected in measures such as mean driving speed and optimized headway distances (Golias et al. 2002).

This research focuses on the autonomous systems, instead of the cooperative systems. The first ones use on-board equipment to assess the surrounding environment, and can be implemented on the current road infrastructure; the cooperative approach relies on the communication between all vehicles or road infrastructure's special features (Piao and McDonald 2008). Since the autonomous systems are already available on the market, they are the ones tested in this thesis. The choice of which systems would be implemented in this research was based on Table 2.1, edited from Golias et al. (2002), which summarizes the traffic efficiency expected by each of the available systems.

Platooning, adaptive cruise control and lane change and merge collision avoidance are the only vehicle support systems that have a potential to impact traffic efficiency. Although platooning has a probable impact on both speed and headway adjustment, its application areas are usually restricted to highway network sections with a reduced speed limit (usually up to 53 mi/hr), and it was not tested in this experiment. The two systems evaluated in this thesis are the Adaptive Cruise Control and Lane Change Assist.

**Adaptive Cruise Control**

Adaptive Cruise Control (ACC) is an upgrade of the conventional cruise control. It requires the driver inputing into the system a maximum speed and a time headway. When the ACC is being used, it maintains the set maximum speed when there are no vehicles ahead, and adjusts the speed automatically to follow other vehicles at a constant time-gap previously defined by the driver, when a slower vehicle appears in front ("Adaptive cruise control - A new generation of radar control" 2005). ACC is a longitudinal control system and uses a sensor to detect the presence of the front vehicle, measuring the relative speed and distance to it (Guvenc and Kural 2006). In this system, the throttle and brake are controlled by the computer, while only the steering is controlled manually. When the sensor detects a front vehicle, the computer sends the appropriate command to the throttle and brake. (Ioannou and Chien 1993). ACC systems are now available on a wide range of passenger vehicles and they are the most common form of ADAS since there is no need for a special infrastructure or inter-vehicle communication. (Auckland et al. 2008).

The experiments with ACC include reliability assessment, driver acceptance, safety issues, consequences on traffic flow and even environmental effects. Fancher and Ervin (1998), describe the field operational test with ten passenger cars incorporating the system, evaluating how the ACC technology would work under real operating conditions. Fancher et al. (2001), show through an operational test of ACC vehicles that drivers find the system ‘remarkably attractive’, with some complaints about the limitation of the acceleration and deceleration levels, and Hoedemaeker (2000), indicates an approval coming from both low- and high-speed drivers.

The global impact of ACC on safety of highways was studied by Touran et al. (1999), concluding that the system significantly reduces the probability of collision with the ACC and front vehicle. Another safety issue is the need from the driver to understand the capabilities of the system, including braking and sensor limitations, so the driver is able to intervene in situations that exceed ACC capabilities, and preventing them to rely on the system inappropriately (Seppelt and John D. Lee 2007). Stanton et al. (1997) observed that the ACC may result in a reduced mental workload, which may reduce the level of attention, affecting the ability of the driver to maintain awareness of the system.

Experiments by Hoedemaeker (2000) demonstrate that driver behavior with ACC leads to positive effects on traffic efficiency, since it reduces speed variability and differences in driving behavior, harmonizing traffic. Also the short headways to increase roadway capacity are accepted very well by drivers. Liang and Peng (2000) show that ACC vehicles can help improve the average speed and reduce the average acceleration levels of mixed traffic, leading to higher traffic flow rates.

Regarding environmental effects, Bose and Ioannou (2003) indicate that with 10% of vehicles having ACC, the reduction in air pollution can be up to 60%, arguing that the smooth response of ACC vehicles designed for human factor considerations filters out traffic disturbances.

**Lane Change Assist**

Lane Change Assist (also called Collision Avoidance or Warning System) is a lateral control system that monitors the position of vehicles traveling in close proximity in adjacent lanes and in the same direction, warning the driver when it is unsafe to change lanes or merge into a line of traffic. These in-vehicle electronics systems are rearward-looking, and mainly radar-based. The objective is to assist drivers who are intentionally attempting to change lanes by detecting vehicles in the driver's blind spot ("Lane Change/Merge Warning Systems" n.d.).

Most of the systems use the information from tracking vehicles just to warn the driver when their position and/or speed makes the planned lane change/merge maneuver unsafe, but more sophisticated systems may include speed and steering control intervention for enhanced collision avoidance (Golias et al. 2002).

Primarily, this technology focuses on safety improvement. Lane change maneuvers can be a dangerous situation when the driver overlooks other vehicles or underestimates their speed (Ruder et al. 2002). These systems ensure that lateral separation between vehicles in adjacent lanes are always maintained and may therefore have significant positive impacts in the reduction of traffic accidents (Mazzae et al. 1998). An extensive safety research study sponsored by the U.S. Department of Transportation (U.S. DOT), the Integrated Vehicle-Based Safety Systems (IVBSS) includes the lane change warning as one of the systems in an integrated safety system for light vehicle platforms (Ference 2006).

Golias et al. (2002) analyzed the traffic impacts observing that the optimized lane change and merging capabilities of these systems may lead to significant traffic efficiency gains, related to better headways, although they are expected to have little or no impact on the vehicle’s speed. The traffic impact of this technology needs to be studied in depth, since no research analyzing this topic was found. Most of the experiments with this system are focused on the technology related to vehicle detection, in an attempt to minimize false alarms.

## Driving Simulators

### General Use

Driving simulators are used efficiently for vehicle system development, human factors studies, and other purposes because they reproduce actual driving conditions in a safe and controlled environment. Driving simulators use computer-based technology to create a virtual reality that gives the driver an on board impression of a real driving experience. The simulator predicts vehicle motion caused by driver input and feeding back corresponding visual, motion and audio cues to the driver (Lee et al. 1998).

The use of research simulators has many advantages over similar on-road driving experiments. For example, they can be configured to simulate a variety of research problems and create different scenarios to match the requirements of a particular experiment. With simulators it is possible to control experimental conditions making every driver drive the same testing situation where systematic variation in road, vehicle or traffic situations conditions are difficult to achieve in the real world. The performance measures are also easy to be obtained and there is no risk to the drivers or other road users (Blana 1996).

However, there are some possible disadvantages that may include the lack of validation as a predictor of on-road driving performance, the accurate replication of physical sensations and, the onset of simulator sickness (Godley et al. 2002). Research using University of Florida's I-MAP (Institute for Mobillity, Activity and Participation) simulator STISIM Drive Model 500 W already found relative and absolute validity. Shechtman et al. (2009) findings support validity to the STISIM simulator, observing that the same trends when negotiating turns in the simulator can be transferred to the road when testing conditions are the same. Shechtman et al. (2010) also found relative validity in a group of healthy licensed drivers between driving tasks on road and in the simulator.

Other considerable disadvantages may occur while some subjects drive the simulator, and experience adverse effects, known as simulator adaptation response or simulator sickness. Common symptoms can be grouped into nausea, oculomotor discomfort, and disorientation (Mourant and Thattacherry 2000). In some cases this condition is a critical limitation that disables people from completing the simulated driving assessment.

The degree of the effects experienced by the onset of simulator sickness can be evaluated through the Simulator Sickness Questionnaire (SSQ) (Kennedy et al. 1993). This questionnaire constitutes 16 symptoms on side effects across oculomotor, disorientation and nausea domains, and the participant rates them using a 4-point Likert scale (0=absent, 1=slight, 2=moderate, 3=severe). A Total Severity Score (TSS) is computed, indicating severity of SS symptoms felt by the subject, where zero indicates no sickness and a high TSS severe symptoms.

**Testing ADAS**

In the last few years, many experiments to assess different types of ADAS used driving simulator experiments, demonstrating it as a suitable tool to be used in these studies.

Riener and Ferscha (2008) used a driving simulator to evaluate a vehicle-control system, based on vibro-tactile feedback, against the common used interaction modalities vision and sound of driver assistance systems. Their experiments demonstrate that this approach is a viable alternative to on-road user studies.

Most of the experiments assessing ADAS using a driving simulator are related to ACC. Lin et al. (2009) conducted a study on a bus driving simulator to investigate the effects of time-gap settings and contents of secondary tasks on drivers' performance while reclaiming control from ACC in a car following scenario of emergency brake by the lead vehicle. Lee et al. (2006) conducted a study to assess drivers' ability to change from ACC to manual control when warned with different alerts, by comparing headway maintenance performance for drivers with or without ACC during brake events in a driving simulator. Park et al. (2006) used a driving simulator to create virtual ACC failure situations and measured magnitude of brake, steering input, drivers' reaction time and distance between cars, to investigate the effect of behavioral adaptation on drivers' driving and control ability. The behavioral influences of ACC were studied by Saad (2004), showing considerable changes in speed, safety margins to the front vehicle and frequency of lane change maneuvers, but he points out the need to account for long-term adaptation.

Regarding other types of ADAS, a serial steering assist controller to help avoid road departure was described by Chen and Ulsoy (2006), using driving simulator experiments to provide validation for the technology.

## Impact of ADAS on Traffic

The research developed for evaluation of these assistance systems is not just focused on safety, but also on their potential impact on traffic. The majority of the papers use models and simulation to study the effects of ACC vehicles. Kerner (2003) showed that ACC vehicles can improve the efficiency of the systems by suppressing wide moving jams and therefore traffic flow can be stabilized and harmonized in a synchronized mode. But on the downside, at certain parameters, ACC vehicles can induce congestion at bottlenecks.

Through detailed simulations of a section of the German autobahn, Treiber and Helbing (2001) reported that nearly all congestion would be eliminated if 20% of the vehicles were equipped with ACC system. Even with 10%, travel times due traffic jams were reduced by more than 80%. The results from Bose and Ioannou (2003), through simulation of mixed traffic, demonstrated that ACC vehicles help smooth traffic flow by filtering the response of rapidly accelerating lead vehicles. The same simulations were used by Ioannou and Stefanovic (2005) to analyze disturbances that may arise due to lane changes, demonstrating that ACC vehicle response can attenuate the perturbation due to a cut-in vehicle.

A hybrid model was used by Yuan et al. (2009) to investigate the traffic breakdown probability from free flow to congested flow, and the transition probability from synchronized flow to jams. ACC vehicles were demonstrated to enhance the traffic stability of synchronized flows.

Other experiments show the negative impact of ACC, like Vander Werf et al. (2002) who shows that increases above 60% of ACC vehicles can lead to a modest loss of highway capacity, based on average time gaps longer than those for manual vehicles.

## Literature Findings

According to the literature, ADAS represent a new set of technologies with great potential to improve safety and road capacity by changing the way people drive. Previous research has shown that these systems have a behavioral impact on drivers, but most of them do not show the effects of these impacts on traffic flow.

Although studies with ACC already showed positive effects on traffic, the majority of the experiments with ADAS are linked to safety issues. Lane Change assist systems have not yet been evaluated in depth regarding their potential traffic impacts. The literature also shows a lack of experiments integrating some of the systems and evaluations that consider different driver types. In an attempt of being more realistic, the well consolidated systems should be tested together in the same vehicle, so the evaluation can account with the effects of all the systems, including the possible interaction between them.

According to the literature, driving simulators are a suitable tool extensively used to test and evaluate new technologies, as well as driver behavior aspects. Therefore, it is appropriate to use a driving simulator for the purposes of this research.

Table 2-1. Assessment of traffic efficiency of advanced driver-assistance systems

| VEHICLE | | Traffic efficiency: Speed adjustment | Traffic efficiency: Headway adjustment |
|---|---|---|---|
| general vehicle control | automatic stop and go | L | L |
| | Platooning | H | H |
| | speed control | L | L |
| | adaptive cruise control | H | H |
| collision avoidance | road and lane departure collision avoidance | L | L |
| | lane change and merge collision avoidance | L | H |
| | rear end collision avoidance | L | L |
| | obstacle and pedestrian detection | L | L |
| | intersection collision avoidance | L | L |
| vehicle monitoring | Tachograph | L | L |
| | alerting systems | L | L |
| | vehicle diagnostics | L | L |

H: high, important impact; L: low, limited or insignificant impact

# CHAPTER 3
# METHODOLOGY

This chapter presents the methodology used in the experiment to evaluate the two ADAS. The chapter first provides a description of the driving simulator at the University of Florida, and then summarizes the steps through which it was prepared for the given experiment. These consist of the implementation of ACC and Lane Change Assist algorithms and the creation of the scenarios to be displayed. In order to assess user acceptance of the two systems, a methodology found in the literature was used and is described in the fourth part of the chapter. The data collection and the data analysis plan are briefly presented in the fifth and sixth parts of this chapter respectively.

## Description of the Driving Simulator

The Driving Simulator is located at the Institute for Mobility, Activity an Participation at the University of Florida. It provides a large forward field-of-view of 180 degrees and displays virtual objects behind the car (real image side and rear-view mirrors), making the entire scene computer-generated. Figure 3-1 shows a picture of the simulator field-of-view.

Three 3 x 6 foot flat screens connected with scenes provided by three high intensity projectors (Sanyo, 2000 ANSI Lumens) make the large field-of-view possible. In order to better represent the forward scene it would be preferable to have a continuous curvilinear surface, but subjects indicate that they notice no partitioning of the three separate segments after a few minutes of practice (“NODRTC Virtual Driving” n.d.). The overall contrast can be altered to simulate reduced visibility associated with heavy rainfalls or fog.

The simulator is integrated with a vehicle (1997 Dodge Neon), where the driver operates normal accelerator, brake, and signalizing and steering controls with the corresponding visual scene responding accordingly.  Longitudinal and lateral movement allows the driver to speed up or slow down, come to a halt, and steer sideways, including making lane changes and changing of direction at intersections.  All these changes are controlled by software that interfaces with a junction box under the hood of the vehicle, shown in Figure 3-2.

The simulator is built on a computerized platform developed by the Systems Technology Inc. (STI) of Hawthorne, CA.  The specific configuration is the STISIM Drive Model 500W produced by STI. The vehicle-and-tire model runs on a dedicated processor that is linked to the simulation via a network.  It operates at fast update rates necessary to provide high-fidelity simulation of the vehicle dynamic responses and provides proper steering force/feel feedback.  Road-feel is also captured via a low-frequency audio woofer and amplifier providing engine, transmission and road noise at varying intensities and frequencies, all of this simulated by the STISIM Drive software. The software also has the capability of substituting standard sounds provided with the simulator's customized sound files and playing recorded messages at specific locations in the driving scenario.

A control area and a workstation are situated to the rear of the vehicle overlooking the driver, vehicle and viewing screens.  From this area the researcher can communicate with the subject by a two-way communication, maintained via speakers and microphones in the vehicle and at the workstation.  The three visual screens are duplicated at the workstation and a fourth control monitor allows the experimenter to set parameters for each trial and to monitor data being collected.

The recording software permits the acquisition of up to 40 vehicle, driver and simulation parameters. Specific data recorded depends upon the driving scenario being used and the assessment goals (“NODRTC Virtual Driving” n.d.).

### Implementation of ACC and Lane Change Assist

The systems were implemented in the driving simulator through the STISIM Drive Open Module Programming, by creating a custom Open Module DLL. The code was programmed by computer science students in Visual Basic 6.0 and is available in Appendix A.

The ACC algorithm was based on Fancher et al. (1998), employing an approach that uses speed to control headway. The main conceptual features of this algorithm are that it maintains the maximum speed set up by the driver if no impeding traffic prevails, it adjusts the speed to maintain the desired headway with slower traffic, and it autonomously switches back and forth between the two operational modes. Figure 3-3 illustrates this concept.

The algorithm is based on the following functions and operations that characterize the system:

- Driver’s actions override the system’s actions
- The system will never achieve a speed higher than that selected by the driver
- If the driver brakes, the system disengages and does not automatically reengage thereafter
- If the driver accelerates, the system automatically reengages thereafter with the previous set up parameters
- Preceding vehicles at 525 ft or less are the only ones considered.

The first step of the algorithm is to search for the first vehicle in front of the subject vehicle and in the same lane and compute the distance between them. Following that, the algorithm is divided in a simple case, when there is no slower traffic ahead (beyond 525 ft), and an advanced case, when the headway is adjusted according to the lead vehicle (less than 525 ft away).

For the simple case, the system adjusts the subject's speed to achieve and maintain the maximum speed set up by the driver ($V_{max}$). The acceleration (a) has to be computed every time step to adjust the control, and is calculated according to Mezny et al. (2009):

$$a = \frac{Vmax - V}{T} \tag{3-1}$$

Where:

- a is the acceleration sent to the subject's vehicle,
- $V_{max}$ is the maximum speed set up by the driver,
- V is the current speed of the subject's vehicle,
- T is a calibrated parameter to control the reaction time of the algorithm.

This parameter allows for a smooth transition of speeds during ACC control, and it is not related to the driver's reaction time. Using a value close to a driver's reaction time could result in extremely high acceleration values when the difference between $V_{max}$ and V is very high. Therefore, this parameter can be interpreted as the reaction time of the system. For this simulator, after a series of tests, the selected value of T was 5. The maximum acceleration defined was 10ft/sec$^2$, and the maximum deceleration was 20 ft/sec$^2$ (based on the simulator capabilities).

The advanced case requires the desired time headway set up by the driver ($T_h$ in seconds), which is a control-system parameter. The desired gap distance ($R_h$ in feet) is a linear function of lead vehicle speed ($V_l$):

$$Rh = Vl.Th \tag{3-2}$$

$R_h$ is considered as the desired gap distance (from the ACC vehicle to the lead vehicle) towards which the controller attempts to converge. Figure 3-4 illustrates these parameters.

The parameter $R_h$ is used by the algorithm to compute the speed command ($V_c$), which is the desired speed for the ACC vehicle to achieve the desired gap ($R_h$) in a smooth manner:

$$Vc = Vl + \frac{R-Rh}{T_0} \tag{3-3}$$

Where

- $V_c$ is the speed command (the maximum is $V_{max}$),
- $V_l$ is the speed of the leading vehicle,
- R is the current gap distance,
- $R_h$ is the desired gap,
- $T_0$ determines the closing rate and as suggested by Fancher et al. (1998) equals 11 sec.

The desired acceleration is calculated according to equation (3-1), substituting $V_{max}$ for $V_c$. According to Mezny et al. (2009), to limit the number of repetitions and avoid the algorithm reacting to minor changes, the acceleration is updated only if either of these conditions is met:

- R differs from $R_h$ by more than 1% (if R equals 199ft and Rh is 200ft, the difference is 0.5% and the condition is not met),
- $V_l$ differs from $V_c$ by more than 5% (if $V_l$ equals 100 ft/sec and $V_c$ is 98 ft/sec, the difference is 2% and the condition is not met),
- The difference between $V_l$ and $V_c$ is greater than the difference between $V_c$ and V (If $V_l$ (100 ft/sec) minus $V_c$ (98 ft/sec), that is 2 ft/sec, then V needs to at least 96.9 ft/sec for this condition to be met).

The Lane Change Assist algorithm was based on LeBlanc et al. (2008). The algorithm implemented used a simplified rationale, adjusted to the simulator characteristics. It provides a warning sound when the subject vehicle is changing lanes and has the turn signal on, and at least one vehicle is within the unsafe zone (Figure 3-5). The warning sound beeps continuously when the turn signal is on until there is no vehicle inside the zone. If the subject vehicle attempts a lane change maneuver without turning on the signal indicating the target lane, the system is not triggered; therefore there is no warning sound.

## Driving Scenarios

A driving scenario constitutes the environment that the driver will navigate through while interacting with different events at specific times. It defines the roadway design, the surrounding traffic, background, signs, pedestrians, and many other events related to a driving environment.

All subjects drove the simulator 4 times, including a total of 3 scenarios, the same for all drivers. The first was an acclimation scenario so drivers could adapt to the differences between a simulator and a real car. It starts at low speeds, with signalized intersections to provide stop-and-go conditions. Consequently, drivers face an increase on speed limits and have to make turns. Along this scenario there is no traffic in the same direction as the subject vehicle. The duration was at most 12 minutes (scenario files have a fixed highway length, so depending on each driver's speed, the duration of the scenario changes as a function of the subject's travel time). Data on vehicle performance was not collected during the acclimation scenario.

The second scenario participants drove was the main one created, and it was used twice to collect vehicle performance data, both without and with the ADAS. This scenario was created so drivers would surely use the systems and experience various situations to analyze their impact. It starts on an arterial with three 12-feet lanes in each direction, and a speed limit of 40 mi/hr. There is heavy traffic surrounding the vehicle, and most of the time surrounding vehicles are fairly slower than the speed limit, restraining the vehicle’s motion and creating situations where the drivers would be most likely to change lanes. This tactic was used because the simulated vehicles cannot change lanes as a function of traffic and do not vary their speed according to the scenario files (vehicles are assigned to a lane and a certain speed). They do vary their speed, but just as a consequence to the traffic ahead, including the subject vehicle’s speed (speed changes are not controlled by parameters in the scenario file). The subjects have to go through signalized intersections and make turns. The entire arterial section is presented in Figure 3-6. The arrows show the path subjects were instructed to drive through.

The freeway section is 19,500 feet long, with two 12-feet lanes in each direction separated by a median. There are 3 curves along the freeway, and the speed limit along the entire freeway is 65 mi/hr. Traffic along the freeway is heavy and vehicles brake and accelerate according to traffic ahead, and can reach speeds as low as 40 mi/hr. This freeway section was created to maximize car-following opportunities. There are no merge/diverge situations because the simulator cannot handle them accurately (there is a possibility to create these facilities, but the simulator does not recognize them properly). The entire scenario (arterial and freeway) could be completed in 9 to 11 minutes, depending on the subject’s travel speed.

This scenario was driven by participants first without any advanced system, and all relevant data were collected. Afterward each participant drove the third scenario, consisting of a straight roadway section and low traffic levels, to familiarize themselves with the technologies tested (3 minutes total). The last scenario to drive was the second one with the addition of the assistance systems, where data were also collected.

The second scenario file used on this experiment to collect data is presented in Appendix B.

## User Acceptance Questionnaire

A simple procedure for the assessment of acceptance of new automotive technologies is described in Van Der Laan et al. (1997). The questionnaire they developed provides a five-point scale to assess nine attributes of a technology, and has been used to measure driver acceptance for a large number of research products. Since the attribute set is sufficiently broad, the procedure can be used directly to compare the acceptance of different systems.

For each item, the scale is anchored by two polar adjectives, and drivers are asked to rate their perception of the system by marking a box between the two poles. The scale is scored from -2 to +2, with positive numbers corresponding to values closer to the positive adjectives (being +2 the closest to the positive adjective) and vice versa. Table 3-1 shows the nine items in the questionnaire (Van Der Laan et al. 1997).

After a principal components analysis, Van Der Laan et al. (1997) suggests that the scale can reliably be reduced to two subscales: usefulness (items 1, 3, 5, 7 and 9) and satisfaction (items 2, 4, 6 and 8). The first step in the analysis of the responses is to determine whether the items within each subscale correlate well with each other. To determine this correlation, the authors recommend obtaining a Cronbach's alpha of at least 0.65 as a scale reliability analysis. Cronbach's alpha is a measure of internal consistency, that is, how closely related a set of items are as a group. It determines the internal consistency or average correlation of items in a survey instrument to measure its reliability (Reynaldo and Santos, 1999). After this criterion is met, the component scores for each subject will be averaged to get usefulness and satisfaction scores for each subject.  The two scores averaged across subjects represent the overall perception associated with the systems, where positive numbers lead to positive perception and vice-versa.

This questionnaire was conducted after the driving experience to measure acceptance of both ACC and Lane Change Assist, as well as the combination of the systems.

## Data Collection

Data were collected during the two times participants drove the second scenario (one without the tested systems and the other using them). The data included information related to the subject vehicle, such as speed, acceleration, lane position and longitudinal position, and also information related to each vehicle that is in the roadway display, such as lateral position, longitudinal position with respect to the subject vehicle and difference in speed relative to the subject vehicle. This dataset was used to analyze the impact of the advanced systems. A more detailed description of the data collection process is presented in Chapter 4.

## Data Analysis

The final step of the methodology includes the data analysis procedure. The purpose of this effort is to observe how driver behavior changes when the two assistance systems are used during driving experience. Driving characteristics were observed during particular driving tasks that could affect traffic dynamics. To analyze whether ACC could lead to driving behavior changes, car-following situations without and with the system were statistically compared using space headways. Driving characteristics with the use of the LCA were evaluated using the number of completed lane change maneuvers and accepted gaps during lane changing. Average speeds were used to analyze the overall impact of both systems. The complete analysis of the data is presented in Chapter 5.

Figure 3-1. Simulator field of view (including rear view mirror display) and computer workstation (Source: http://driving.phhp.ufl.edu/virtual)

Figure 3-2. Junction box that distributes computerized signals to steering wheel, accelerator, brake and retrieves turn-signal indications (Source: http://driving.phhp.ufl.edu/virtual)

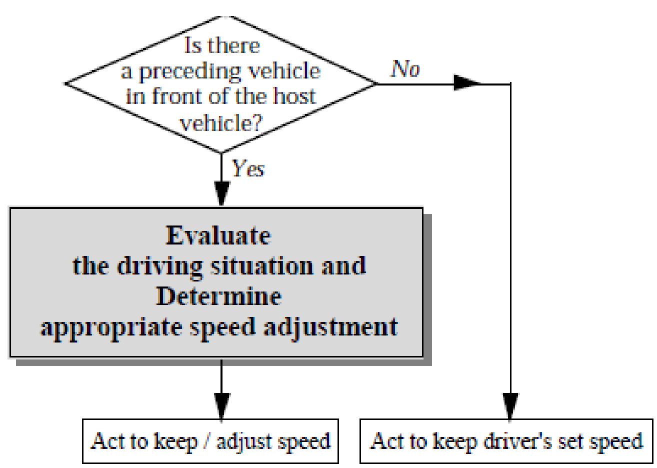


Figure 3-3. Employing speed to control headway (Source: Fancher et al. (1998))

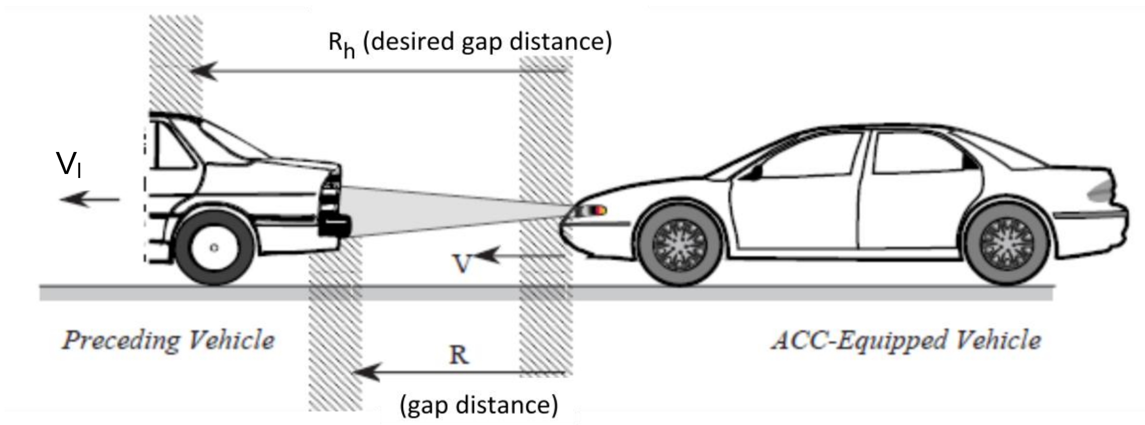


Figure 3-4. Parameters for headway control (Modified from Fancher et al. (1998))

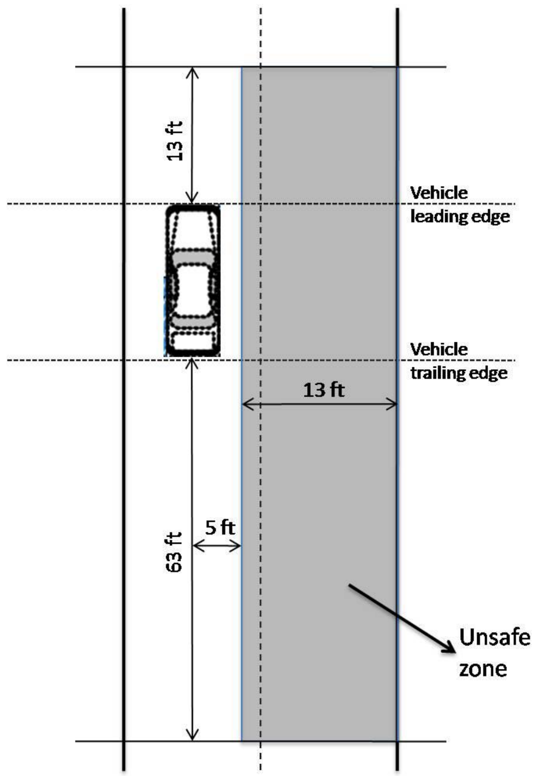


Figure 3-5. Unsafe zone for Lane Change Assist (both sides are symmetric)

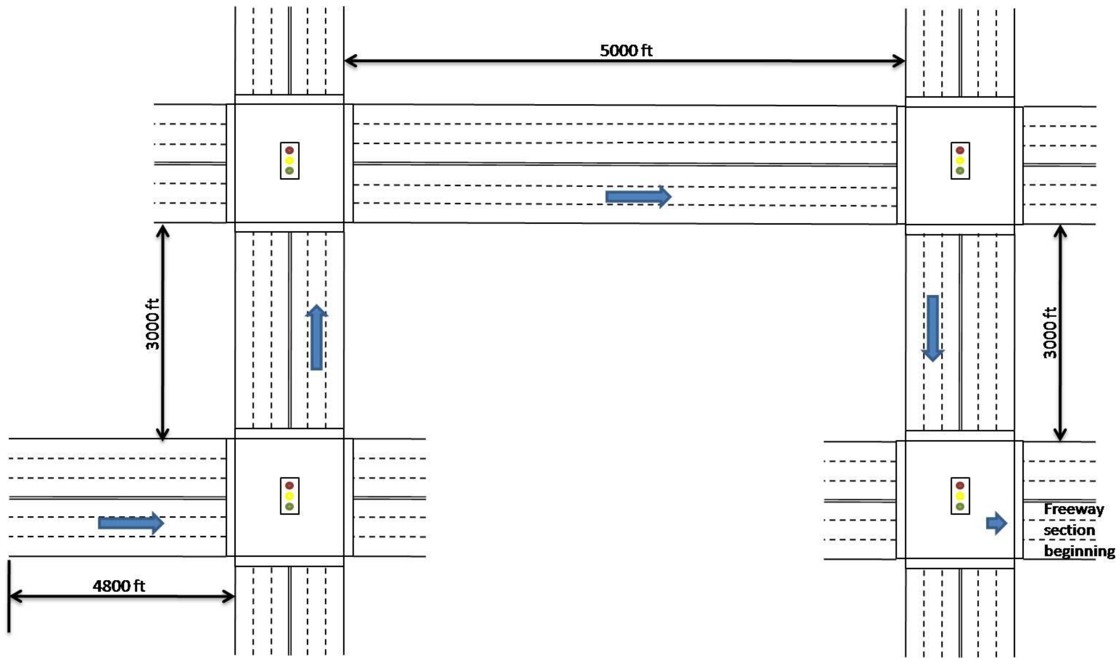


Figure 3-6. Arterial section used in the second scenario

Table 3-1. User acceptance questionnaire

| My judgements of the (…) system are … (please tick a box on every line) | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | useful | ☐ | ☐ | ☐ | ☐ | ☐ | useless |
| 2 | pleasant | ☐ | ☐ | ☐ | ☐ | ☐ | unpleasant |
| 3 | bad | ☐ | ☐ | ☐ | ☐ | ☐ | good |
| 4 | nice | ☐ | ☐ | ☐ | ☐ | ☐ | annoying |
| 5 | effective | ☐ | ☐ | ☐ | ☐ | ☐ | superfluous |
| 6 | irritating | ☐ | ☐ | ☐ | ☐ | ☐ | likeable |
| 7 | assisting | ☐ | ☐ | ☐ | ☐ | ☐ | worthless |
| 8 | undesirable | ☐ | ☐ | ☐ | ☐ | ☐ | desirable |
| 9 | raising alertness | ☐ | ☐ | ☐ | ☐ | ☐ | sleep-inducing |

# CHAPTER 4
# DATA COLLECTION

This chapter presents the data collection effort. Obtaining behavioral data requires the involvement of the Institutional Review Board (IRB) of the University of Florida. The Behavioral/Non-Medical department of IRB is responsible for reviewing and monitoring all research studies that involve human subjects, such as this one. Thus, all appropriate forms, questionnaires, as well as the research methodology, were approved by the IRB prior to the data collection. The questionnaires are provided in Appendix C. The data collection occurred during the months of August and September 2010, at Oak Hammock at the University of Florida, where the simulator is located. The process involving the selection of participants, data collection procedures and final data types and formats are described below.

## Participant Selection

### Recruitment and Prescreening

The advertisement for recruitment was posted at public locations including several supermarkets and University of Florida campus, at http://gainesville.craigslist.org/, and sent to graduate students. A prescreening procedure was designed to obtain age, gender, driving experience and health conditions. Respondents could download the questionnaire from the website (https://sites.google.com/site/drivingsimulatorproject/) or send an email to the researcher, and respond offline through email or mail.

Any person with a valid driver license, with at least 3 years of experience and no health problems was considered a qualified candidate. Age and gender were also considered to ensure a diverse group of participants. Following the questionnaire, each participant considered for the experiment was assessed for cognitive function through the Mini-Mental State Examination (MMSE) (Folstein et al. 1975). This is a brief 30-point questionnaire test that is used to screen for cognitive impairment. Part of it was administered through telephone, assessing 22 items, and the rest was performed in person before the testing. A minimum of 17 out of 22 was necessary for the first part to schedule an appointment, and the minimum in general had to be 26 over the 30 points to participate in the experiment (participants with no cognitive impairment).

**Characteristics**

This section presents participants' demographics (age and gender), their Total Severity Score (TSS) in relation to simulator sickness, and a driver behavior type analysis. Age, gender and driver behavior type groups will be used in the data analysis chapter.

A total of 32 subjects participated in the experiment, but 7 of them did not complete the test due to excessive simulator sickness. The demographics of the participants, the maximum TSS (where zero indicates no sickness), and whether the subject completed the test or not are presented in Table 4-1.

As shown in this table, there were a total of 9 female and 16 male participants that completed the test. With respect to age distribution, 11 participants were between 25 and 30 years old, while 7 were between 31 and 40, and 7 between 41 and 60 years old. The goal of having participants distributed equally among gender and age was not accomplished as a consequence of the high propensity of sickness in older and female drivers. A simple analysis was conducted after the experiments to observe how SSQ scores correlated to age and gender. Table 4-2 shows the maximum TSS averaged by gender group.

A comparison of means through a t-test (at 95% confidence level) confirms that male participants had lower scores than females, and consequently felt less sick. The comparison between age groups is presented in Table 4-3.

Regarding age groups, the only significant difference was observed between 40-60 and 25-29 years old participants, where the oldest one had greater SSQ scores than the youngest at 90% confidence level. This confirms that females and older adults are more susceptible to SS (Allen et al. 2006).

In order to analyze how the variability in driver behavior affected the impact of the two technologies tested, driver behavior types were identified after the experiments. Three types of driver behavior were distinguished: aggressive, average and conservative behavior. The assessment was based on two criteria (AAA Foundation for Traffic Safety, 2009): (i) observed speed under free-flowing and not car-following conditions, and (ii) number of discretionary lane changes. Given the design of the scenarios (i.e., heavy traffic throughout the driving scenario), these criteria were adapted to fit the data. Therefore, number of lane changes on the arterial and freeway, and how many mile/hour over the speed limit participants achieved were used in this assessment. As such, participants that performed at least 10 lane changes on the arterial and 4 on the freeway or achieved a speed over 10 mi/hr the speed limit in one facility and more than 5 in the other were considered aggressive. Participants that met either 2 of the criteria: (i) performed between 7 and 9 lane changes on the arterial, (ii) 2 or 3 on the freeway, (iii) achieved speed over 10 mi/hr the speed limit on the freeway, (iv) achieved a speed over 10 mi/hr the speed limit on the arterial; were considered to be average. Participants that did not achieve speeds over 10 mi/hr the speed limit (arterial or freeway) and performed less than 7 lane changes on the arterial and 2 or less on the freeway were considered conservative. Table 4-4 presents the results of the driver behavior analysis for participants, along with the parameters they chose for ACC (maximum speed and time headway) and the background survey responses. Although choices for ACC parameters can agree with some driver types (for example, conservative drivers chose the lowest maximum speeds), the fact that participants are first-time users of the systems needs to be taken in consideration. More familiarity with the systems may lead these choices to correspond more accurately with the driver behavior types. The background survey responses (questionnaire presented in Appendix C) to some degree come in agreement with the results of the driving behavior analysis. Most of the drivers characterized by themselves and others as somewhat conservative were considered as conservative drivers in this analysis. The ones that considered themselves somewhat aggressive are divided in aggressive and average drivers. The inconsistencies presented may be due to the fact that participants respond to the questionnaire by comparing themselves with their peers, which does not provide objective responses (Kondyli 2009).

The sample's demographics with the assigned driver type are presented in Table 4-5. Although the sample is not equally divided in gender and age groups, it was possible to achieve the goal of having a diverse sample in terms of aggressiveness.

## Data Collection Procedures

After taking the prescreening questionnaire and part of the MMSE on the phone, selected participants scheduled an appointment. They were asked to take their driver's license, and have a light snack before the testing session, but not a heavy, large or greasy meal. The session could last as little as 1 hour and as long as 2 hours, and the compensation was set at $50 per participant.

Once in the simulator, a set of steps was undertaken as illustrated in Figure 4-1. A description for each one of these steps is provided.

Step 1 - Upon arrival and before starting the experiment, a check-in procedure was undertaken as follows: 1) sign the informed consent form and give a copy to the subject, 2) complete the background survey form, and 3) provide a photocopy of the driver's license. The informed consent form is a requirement of the IRB; it explains the entire experiment, followed by the agreement of the driver. At this point, the research discussed the early signs of simulator sickness and told the subject that as soon as they notice any symptom, they need to stop the simulation and take a break. They were also informed that they would be kept for some minutes after the simulation if they were not feeling fine. The background survey questionnaire provided information related to their driving habits and also to their perceived degree of aggressiveness.

Step 2 - Participants were screened for simulator sickness using the Simulator Sickness Questionnaire-SSQ (Kennedy et al. 1993), to identify subjects that could experience simulator sickness. If there was a sign that the subject was prone to feel sick, a ReliefBand® was offered to those who didn't have a pacemaker. This is a FDA approved medical device that provides a relief from nausea due to motion sickness by gentle electrical stimulation of the nerves in the wrist.

Step 3 - They were taken to the vehicle, and the researcher explained exactly how the simulator works. The participant was then subjected to an acclimation period in the simulator, beginning with a less complex visual representation of the road environment, with progressive increases in complexity.

Step 4 - After the acclimation period, participants completed the SSQ again, identifying those that experienced any symptom of simulator sickness. If this happened, the steps 5a through 8a were followed:

- Step 5a – The participant took a break, until he/she felt well again;
- Step 6a – The driver answered the SSQ;
- Step 7a – and then drove another acclimation period.
- Step 8a – The SSQ was answered again. If the symptom persisted, the simulation was discontinued (Step 9) and the participant was dismissed (Step 10). If no symptom was observed, the experiment continued with Step 5b.

Step 5b - The participant was asked to drive the first scenario as he/she would normally do on the road. This first scenario was driven without the assistance systems and it took about 9-11 minutes.

Step 6b - In this step the researcher demonstrated to the subject how the two assistance systems work by letting them drive a 3-minute scenario with the systems. They were then asked what was the maximum speed they would achieve in a freeway with a speed limit of 65 mi/hr, and what was their preferable time headway.

Step 7b - The participant drove the second scenario using the two assistance systems.

Step 8b - After finishing the driving experiment, the participant answered a questionnaire related to user acceptance of the new systems and the SSQ, so he/she did not leave the place feeling any sick.

Step 10 – The participant was paid and dismissed.

## Final Data Types and Formats

The simulator provided an output file for each time the participant drove the second scenario (without and with the system). This file contains information of the subject vehicle and the other vehicles on the display every 0.5 second. For the subject vehicle, the output provides speed (mi/hr), acceleration (ft/sec$^2$), longitudinal and lateral position (ft). For the other vehicles, the file contains vehicle ID, difference in speed (ft/sec) and longitudinal position (ft) in relation to the subject vehicle and lateral position (ft). An example of this raw data is presented in Table 4-6. This table shows information for only one vehicle (Vehicle ID 29) in addition to the subject's, but the data obtained contain information on all vehicles in the display for every time step.

For the case where the participants used the systems, two other files were generated with information on when the systems were being used (when ACC was on, and when LCA made the warning sound). This information was aggregated in the output files. From these files, detailed information on car-following situations and lane change maneuvers were extracted along with average speeds. The analysis of this dataset is provided in Chapter 5.

Table 4-1.  Participants' characteristics

| Subj ID | Gender | Age | TSS | Completion |
|---|---|---|---|---|
| 1 | F | 38 | 0.00 | Y |
| 2 | M | 53 | 0.00 | Y |
| 3 | M | 29 | 0.00 | Y |
| 4 | M | 57 | 0.00 | Y |
| 5 | M | 31 | 7.48 | Y |
| 6 | F | 46 | 14.96 | Y |
| 7 | M | 26 | 0.00 | Y |
| 8 | M | 36 | 0.00 | Y |
| 9 | F | 31 | 26.18 | Y |
| 10 | M | 25 | 0.00 | Y |
| 11 | F | 28 | 7.48 | Y |
| 12 | M | 32 | 0.00 | Y |
| 13 | F | 29 | 18.70 | N |
| 14 | M | 28 | 0.00 | Y |
| 15 | M | 38 | 0.00 | Y |
| 16 | F | 29 | 3.74 | Y |
| 17 | F | 28 | 18.70 | N |
| 18 | F | 55 | 26.18 | N |
| 19 | F | 26 | 0.00 | Y |
| 20 | F | 50 | 14.96 | Y |
| 21 | M | 47 | 14.96 | Y |
| 22 | F | 42 | 0.00 | Y |
| 23 | M | 59 | 3.74 | N |
| 24 | F | 38 | 18.70 | N |
| 25 | M | 44 | 0.00 | Y |
| 26 | M | 25 | 0.00 | Y |
| 27 | F | 28 | 14.96 | N |
| 28 | F | 29 | 0.00 | Y |
| 29 | M | 54 | 18.70 | N |
| 30 | M | 25 | 0.00 | Y |
| 31 | M | 26 | 0.00 | Y |
| 32 | M | 40 | 18.70 | Y |

*F- female, M- male, Y-yes, N- no.

Table 4-2.  TSS score for gender groups

| | n | Average TSS | Standard deviation |
|---|---|---|---|
| F | 14 | 11.75 | 9.71 |
| M | 18 | 3.53 | 6.72 |

Table 4-3. TSS score for age groups

| Age | n | Average TSS | Standard deviation |
|---|---|---|---|
| 25-29 | 14 | 4.54 | 7.36 |
| 30-39 | 7 | 7.48 | 10.80 |
| 40-60 | 11 | 10.20 | 9.62 |

Table 4-4. Driver behavior type results

| | Experiment observations: Arterial | | Freeway | | | Background Survey Responses | | | | ACC parameters | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Subj ID | Over 40 (mi/hr) | #LC | Over 65 (mi/hr) | # LC | Driver Type | Speed (mi/hr) | Lane Change | Aggressiveness by themselves | Aggressiveness by others | Vmax (mi/hr) | Th (sec) |
| 1 | 11.34 | 5 | 7.09 | 3 | Aggressive | 70-75 | Very often | Somewhat aggr. | Somewhat aggr. | 75 | 2 |
| 2 | 10.20 | 10 | 6.65 | 0 | Aggressive | 70-75 | Sometimes | Somewhat cons. | Somewhat cons. | 75 | 2 |
| 12 | 14.46 | 10 | 22.36 | 1 | Aggressive | 70-75 | Very often | Somewhat aggr. | Somewhat aggr. | 75 | 2 |
| 15 | 6.57 | 6 | 14.74 | 2 | Aggressive | 70-75 | Very often | Somewhat cons. | Somewhat cons. | 70 | 2 |
| 23 | 4.91 | 11 | 3.04 | 4 | Aggressive | 70-75 | Very often | Somewhat aggr. | Somewhat aggr. | 75 | 2 |
| 24 | 12.65 | 10 | 16.33 | 2 | Aggressive | 70-75 | Sometimes | Somewhat aggr. | Somewhat aggr. | 75 | 2 |
| 25 | 12.08 | 14 | 10.19 | 4 | Aggressive | 70-75 | Very often | Somewhat cons. | Somewhat cons. | 75 | 2 |
| 4 | 3.20 | 7 | 5.01 | 3 | Average | 70-75 | Very often | Somewhat aggr. | Somewhat cons. | 65 | 2 |
| 5 | 5.52 | 10 | 3.87 | 3 | Average | 70-75 | Sometimes | Somewhat cons. | Somewhat cons. | 72 | 2 |
| 7 | 2.91 | 7 | 12.94 | 2 | Average | 70-75 | Very often | Somewhat cons. | Somewhat aggr. | 80 | 2 |
| 9 | 8.99 | 8 | 0.62 | 2 | Average | 70-75 | Very often | Somewhat aggr. | Very cons. | 70 | 2 |
| 16 | 13.38 | 6 | 1.92 | 2 | Average | 70-75 | Very often | Somewhat aggr. | Somewhat aggr. | 70 | 2 |
| 19 | 5.26 | 9 | 2.05 | 5 | Average | 70-75 | Very often | Somewhat aggr. | Somewhat aggr. | 70 | 1.5 |
| 20 | 9.38 | 6 | 7.45 | 2 | Average | 70-75 | Very often | Somewhat aggr. | Somewhat aggr. | 75 | 1.5 |
| 22 | 8.39 | 5 | 8.39 | 0 | Average | 70-75 | Very often | Somewhat aggr. | Somewhat aggr. | 75 | 1.5 |
| 3 | 2.22 | 6 | 7.29 | 1 | Conservative | 65-70 | Very often | Very cons. | Very cons. | 65 | 2 |
| 6 | -0.55 | 4 | 6.09 | 1 | Conservative | 70-75 | Sometimes | Somewhat cons. | Somewhat cons. | 75 | 2 |
| 8 | -0.58 | 6 | 0.92 | 1 | Conservative | 70-75 | Very often | Somewhat cons. | Somewhat cons. | 70 | 2 |
| 10 | 3.18 | 4 | 5.34 | 1 | Conservative | 70-75 | Sometimes | Somewhat cons. | Somewhat cons. | 70 | 2 |
| 11 | -0.67 | 4 | 1.08 | 0 | Conservative | 70-75 | Sometimes | Somewhat cons. | Somewhat cons. | 73 | 2 |
| 13 | 0.59 | 5 | 2.08 | 0 | Conservative | 70-75 | Sometimes | Somewhat cons. | Somewhat aggr. | 70 | 2 |
| 14 | 3.75 | 6 | 2.36 | 0 | Conservative | 70-75 | Very often | Somewhat cons. | Somewhat cons. | 70 | 2 |
| 17 | -1.48 | 6 | -0.04 | 1 | Conservative | 70-75 | Sometimes | Somewhat cons. | Somewhat aggr. | 65 | 2 |
| 18 | 0.88 | 5 | 5.11 | 1 | Conservative | 70-75 | Very often | Very cons. | Very cons. | 75 | 2 |
| 21 | -2.09 | 5 | 2.62 | 2 | Conservative | 70-75 | Sometimes | Somewhat aggr. | Somewhat aggr. | 69 | 2 |

Table 4-5. Demographics characteristics by driver behavior type

| Driver type | Male | | Female | | Average age |
|---|---|---|---|---|---|
| Aggressive | 5 | (71%) | 2 | (29%) | 34.7 |
| Average | 4 | (50%) | 4 | (50%) | 35.8 |
| Conservative | 7 | (70%) | 3 | (30%) | 35.2 |
| All | 16 | (64%) | 9 | (36%) | 35.2 |

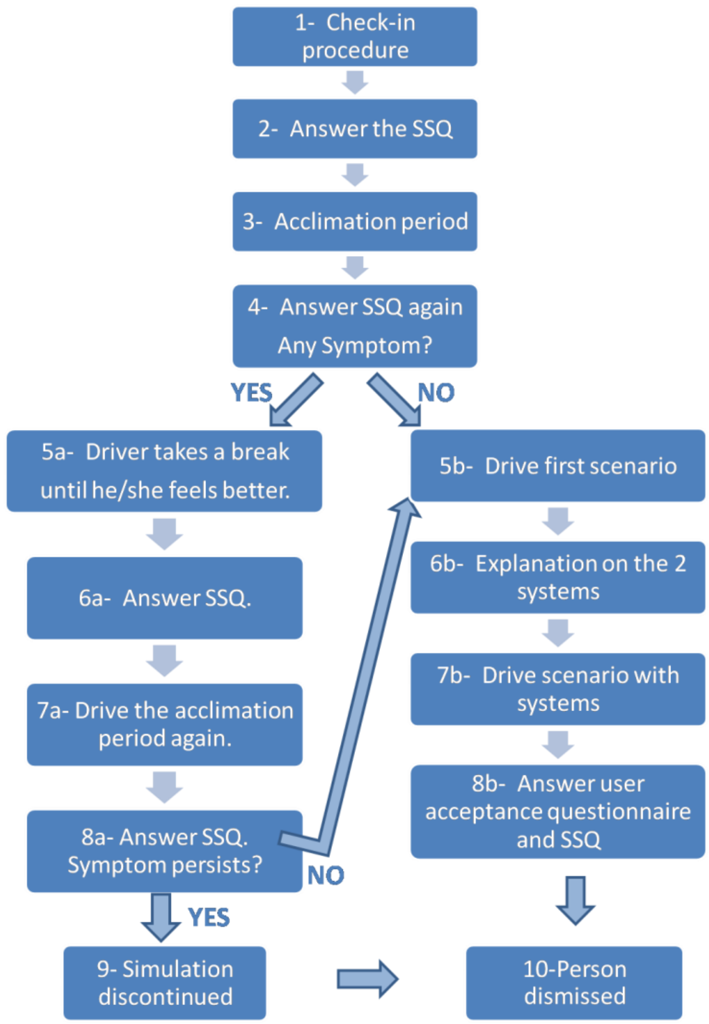


Figure 4-1. Data collection steps

Table 4-6. Raw data for subject 25 with the systems

| Time (sec) | Speed (mi/hr) | Accel (ft/sec2) | Long dist (ft) | Lateral position (ft) | Min range (ft) | Vehicle ID | Diff. in speed (ft/sec) | Diff. long position (ft) | Lateral position (ft) |
|---|---|---|---|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.5 | 0.0 | 6 | 43.5 | 29.0 | 58.7 | -817.1 | 30 |
| 0.5 | 0.1 | 0.5 | 0.0 | 6 | 63.5 | 29.0 | 45.7 | -791.3 | 30 |
| 1.0 | 0.1 | 0.5 | 0.0 | 6 | 83.5 | 29.0 | 32.8 | -771.9 | 30 |
| 1.5 | 1.7 | 6.3 | 0.7 | 6 | 102.8 | 29.0 | 27.2 | -758.1 | 30 |
| 2.0 | 3.9 | 6.6 | 2.9 | 6 | 120.6 | 29.0 | 28.0 | -744.3 | 30 |
| 2.5 | 6.1 | 6.7 | 6.7 | 6 | 136.8 | 29.0 | 28.7 | -730.2 | 30 |
| 3.0 | 8.4 | 6.7 | 12.2 | 6 | 151.3 | 29.0 | 29.4 | -715.7 | 30 |
| 3.5 | 10.7 | 6.7 | 19.4 | 6 | 146.3 | 29.0 | 30.1 | -700.9 | 30 |
| 4.0 | 12.9 | 6.6 | 28.2 | 6 | 123.3 | 29.0 | 30.8 | -685.7 | 30 |
| 4.5 | 15.2 | 6.6 | 38.6 | 6 | 102.0 | 29.0 | 31.5 | -670.2 | 30 |
| 5.0 | 17.4 | 6.5 | 50.7 | 6 | 82.5 | 29.0 | 30.2 | -654.8 | 30 |
| 5.5 | 19.6 | 6.5 | 64.4 | 6 | 64.7 | 29.0 | 27.8 | -640.4 | 30 |
| 6.0 | 21.8 | 6.4 | 79.8 | 6 | 48.8 | 29.0 | 25.3 | -627.3 | 30 |
| 6.5 | 24.0 | 6.3 | 96.7 | 6 | 35.1 | 29.0 | 22.6 | -615.4 | 30 |
| 7.0 | 25.5 | 2.8 | 115.1 | 6 | 24.1 | 29.0 | 20.9 | -604.8 | 30 |
| 7.5 | 26.4 | 2.7 | 134.2 | 6 | 17.5 | 29.0 | 19.8 | -594.7 | 30 |
| 8.0 | 27.3 | 2.7 | 153.9 | 6 | 17.0 | 29.0 | 18.7 | -585.1 | 30 |
| 8.5 | 28.2 | 2.6 | 174.3 | 6 | 17.3 | 29.0 | 17.6 | -576.1 | 30 |

# CHAPTER 5
# DATA ANALYSIS

The first part of this chapter summarizes the findings regarding the traffic impact of the two technologies. This impact was analyzed through three different evaluations, one focusing on the impact of ACC, the other on the impact of LCA and the last one on the general impact of both systems.

The second section of the chapter applies the methodology described in chapter 3 (Methodology – User Acceptance Questionnaire) to evaluate the user acceptance of the technologies. This procedure evaluates how drivers perceive the two technologies by assessing the usefulness and satisfaction of each system. The chapter concludes with a summary of the findings regarding the impact of the two systems.

## Traffic Impact of the Technologies

This analysis evaluates the impacts of the technologies on traffic operational performance measures. It focuses on (a) the impact of the ACC as expressed by the space headways of the subject vehicle with the front vehicle, (b) the impact of LCA as expressed by the number of lane changing maneuvers completed by the subject and the characteristics of the gaps accepted, and (c) the general impact of both systems as expressed by the speed of the subject vehicle. These performance measures obtained from the two driving experiences (with and without the systems) were statistically compared at 95% confidence level, to evaluate changes in drivers' behavior due to the availability of the systems. Means, standard deviations, and distributions were statistically compared to assess differences in the two scenarios driven by the same driver, and also between groups of drivers (gender, age and aggressiveness).

## Impact of ACC

The Adaptive Cruise Control was used by drivers only along the simulated freeway (not on the arterial), because the system works during high speeds only. Prior to the beginning of the simulation, drivers were asked to choose a maximum speed that the vehicle would automatically achieve in case there was no slower traffic ahead, and a time headway that the vehicle would maintain when it encountered a slower lead vehicle. The subjects were asked to base their decision on their driving experience and regular practices, and to facilitate the perception of time headway, three options were presented: 2.0, 1.5 and 1.0 sec.

The impact of ACC was evaluated through car-following situations along the freeway segment. These situations were selected such that the subject vehicle followed the same lead vehicle for a minimum of 20 seconds. For the scenario with the systems, the ACC had to be on during the selected car-following situations. On average, participants used the ACC on the freeway 77% of time. This percentage represents the time the system was on. The system can be turned on by pushing the button, and letting the algorithm control the vehicle and off by using the brake pedal. These conditions were repeated several times along the freeway). For both scenarios, the first 1,200 ft of the freeway were not considered, as this area constitutes the transitional area from arterial to freeway.

Depending on the lane change maneuvers performed, the number of car-following situations recorded for each participant varied between 1 and 5 per participant per scenario. The space headway recorded every 0.5 second was averaged for each car-following situation, and the respective standard deviation was also computed. Table 5-1 shows a typical car-following situation using ACC with the subject vehicle having higher speeds until it reached the lead vehicle. At that time it starts adjusting its speed to maintain the headway selected by the driver (subject 1).

In many cases, the number of car-following situations was more than one per participant per scenario. The average space headway and standard deviation of headways for these cases were calculated aggregating all car following situations per participant. Table 5-2 presents this information for each subject, with and without the systems.

As shown, the average space headway was reduced for most, but not all subjects when ACC was used. The average difference of space headway between without and with the system was 42.5 ft. A paired samples difference t-test was performed to determine whether the space headway per participant during car following was higher without the system than with it. The t-test indicates that the use of ACC resulted in significantly smaller headways.

To compare the standard deviation with and without the systems, F-tests were performed for each driver. From this analysis, two subjects (7 and 16) did not exhibit differences in the variability of headways during car following (calculated F was lower than the critical value). For 7 subjects (2, 10, 11, 17, 20, 23 and 24) the standard deviation was actually higher with the ACC, but for most of the subjects (16 of the 25) the standard deviation with ACC was smaller than without it.

Table 5-3 presents a detailed car-following analysis for subjects 19 and 25, showing the average space headway and standard deviation for each car-following situation performed with and without ACC. These two drivers performed three or more car-following situations during the freeway segment, and exhibited a great variance across average space headway when the system was not available, in agreement with the previous analysis. Subject 25 presents lower standard deviations per car-following situation when the system is being used, although the average space headway per car-following situation seems higher with ACC than without it. This table illustrates the fact that there is variability under different situations even for the same driver.

Figure 5-1 shows the distribution of headways for all car following situations without and with the ACC. These graphs show that when the ACC was used, the space headway distribution shifted significantly toward the left of the graph, and the frequency of longer headways was minimized.

Figures 5-2 and 5-3 show vehicle trajectories for a given subject (subject 14), without and with ACC. These trajectories illustrate the difference between the two cases for the same driver. Comparing them, it can be noticed that the subject vehicle with ACC decelerated in a smoother way as it approached the lead vehicle. In contrast, the subject vehicle without the ACC was more impacted by the deceleration of the lead vehicle, and the space headway between the two was not as smooth as with the ACC. When the lead vehicle braked, the subject vehicle without ACC got closer to it and took longer to adjust its headway. When the lead vehicle was accelerating, the subject vehicle without ACC also took longer to get closer to the lead vehicle than with ACC.

Next, the impact of ACC on car-following situations is evaluated by gender, age, and driver behavior groups.

**Gender groups.** This sub-section evaluates how gender affects the differences in outcomes between the two tests (with and without the systems), and also whether there is a significant difference in driving performance between these two groups. Table 5-4 shows the average space headway and overall standard deviation for female and male groups, for both driving tests. The overall standard deviation is obtained by aggregating car-following situations from all drivers in the specific group.

A paired samples difference t-test was performed to determine whether the use of the system shortened the space headway during car following compared to when the system was not present. In the last column of the table, it can be observed that this difference was approximately 40 ft for the male group and 47 ft for the females. The t-test indicated that this difference is statistically significant for the female group, but not for the male one. Comparison of the standard deviation with and without the systems (last column of Table 5-4) shows that both groups had significantly less variability when using the systems (F equals 2.06 for male and 1.24 for female, F critical equals 1.21). The difference in space headway between female and male drivers is not statistically significant in both tests (with or without the systems). Without the ACC, male participants had a higher standard deviation in headways compared to female participants. However, with the ACC, both groups exhibited the same variability in headways. Therefore, ACC is significantly helping male drivers maintain their space headway more stable during car following. Along the freeway section, female participants used the ACC 75% of the time in average, while male ones used it 79% of the time.

**Age groups.** The second subdivision grouped subjects in 2 categories: between 25 and 30 years old, and between 31 and 60 years old. This categorization was used because the number of younger participants was bigger (less susceptible to simulator sickness) and because previous analysis with two older groups (31 to 40 and 41 to 60 years old) did not exhibit additional information. In results, these two were grouped in drivers between 31 to 60 years old.

Table 5-5 presents the results for each group and differences between scenarios driven without and with the system and between the two groups. Older and younger drivers reacted differently to ACC. As shown in the table, for younger participants, the standard deviation was the same with the ACC and without it. In contrast, for older ones, the system significantly contributed to smaller headways (about 100 ft) and less variability of headways. Comparison of the two groups shows that without the system older drivers presented higher standard deviation of headways than younger ones, while with the system this was inverted having older drivers varying their headways less than younger ones.

Although younger drivers used the system for more time than older ones (younger used it 81% of time, older 75%), the older ones were the ones positively affected by the system.

**Driver behavior types.** The last subdivision uses driver behavior types to group participants. Table 5-6 summarizes the results for each group. The conservative group was the only one that contributed significantly to shorter headways with the ACC (space headways were about 105 ft shorter with the system).

Regarding the variability of headways, all 3 groups showed smaller standard deviations of headways with the system comparing to without it. Conservative drivers, compared to aggressive and average ones, had significantly longer headways without the ACC, but not with the system (headway among the groups became equivalent). For standard deviation, conservative drivers presented the highest values, while average ones presented the lowest one (both with and without the ACC). Interestingly, aggressive drivers had a higher variability of headways than average drivers in both tests. These drivers used the system 67% of the time, while average and conservative ones used it 81% of the time.

**Summary of ACC impact.** Along the simulated freeway, participants in general had smaller space headways with the lead vehicle and less headway variability during car-following situations. The analysis by group showed that female drivers, older and conservative ones were the ones that reduced their headways the most when using the ACC. All groups drove more smoothly, and reduced the variability of their headways. This finding is consistent with the literature findings which indicate the ACC system contributes to more stable traffic. The use of the ACC also contributed to eliminating differences in space headways between driver behavior types

### Impact of LCA

The Lane Change Assist was available along the entire scenario (both freeway and arterial), providing a warning sound if the driver was attempting an unsafe lane change maneuver while the indicator to the target lane was on. The system was activated (it beeped) on average 4.2 times per test.

### Number of lane changes

The first measure used to evaluate the impact of LCA is the number of lane change maneuvers performed by each driver without and with the system, separately on the arterial and the freeway, as well as the total number of lane changes for the entire scenario.

The simulator output provided the lateral position of the center of the subject vehicle every time step. The beginning of a lane change maneuver was considered as the time step when the center of the vehicle was more than 3 feet away from the center of the 12 feet lane (same rationale applied to the end of the maneuver). This deviation was determined by observing the lane changing patterns in the driving simulator (no specifics found in the literature). Table 5-7 presents the number of lane change maneuvers for each driver.

As shown, in most cases lane changes increased when the LCA was used. Statistical comparison showed that the average number of lane change maneuvers increased significantly for the arterial and the entire scenario (combined arterial and freeway) when LCA was present. The increase in lane changes for the freeway section was not found to be significant. Along the freeway section, drivers were also using the ACC systems, which could have given them some comfort related to braking and accelerating tasks. It is possible that subjects did not feel the need to change lanes once they didn’t have to actually react to the traffic ahead, since the ACC was performing such tasks.

Next, this dataset was subdivided in age, gender and driver behavior groups to evaluate the LCA impact on each subgroup. A paired samples difference t-test was performed to compare average number of lane changes.

**Gender groups.** The summary of the analysis by gender group is presented in Table 5-8. Statistical comparison shows that male participants performed significantly more lane changes along the entire route when using the system (1.9 more lane changes). The difference between the number of lane change maneuvers with and without the system for female drivers on the arterial and in total was 1.9 and 1.1 which was not found to be statistically significant. In contrast, the t-test shows that female participants performed less lane changes on the freeway with the LCA. Also on the freeway, male participants performed more lane changes when using the system in comparison to females.

**Age groups.** The data aggregated by age is presented in Table 5-9. Statistical comparison shows that a significant increase in number of lane changes on the arterial (1.4) and for the entire scenario (1.7) occurred for the older group when using the system. The differences for the younger category between with and without the system presented in the first row of the table were not significant, showing that these drivers were not affected by the technology. The number of lane changes from the younger group did not differ statistically from the older one in any of the tests (with and without).

**Driver behavior types.** Data on driver behavior groups is presented in Table 5-10. Although there was an increase in number of lane changes for aggressive and average drivers when using the LCA on the arterial and entire test, these differences were not statistically significant. However, the system contributed to significant more lane changes along the scenario for conservative drivers. Comparison between average and aggressive drivers shows no difference in number of lane changes, whether with or without the system. But when comparing these two groups with the conservative group, it was statistically shown that they performed more lane changes when the system was not present. The presence of the systems eliminated this difference for the freeway section (all three groups performed statistically the same number of lane changes along this facility).

**Minimum distances during accepted gaps**

Another aspect that was used to evaluate the impact of LCA is the distances during accepted gaps and how they change with the assistance system. In this section, the minimum distances compared refer to the ones between the subject vehicle and the adjacent vehicles (on the target lane), both with the vehicle in front and back of the subject vehicle. These measures were compared with and without the technology. The analysis is performed for the arterial and freeway portions separately. For each segment, the minimum of the total gap and the individual distances to both vehicles (front and back of the subject vehicle) on the adjacent target lane were analyzed. Tables 5-11 and 5-12 show the minimum distances between all the lane changes performed per subject, for the arterial and freeway portions respectively.

As shown in Table 5-11, drivers on the arterial accepted total gaps significantly shorter when using the LCA. Without the system, the average minimum gap accepted was 199 ft, while with it this distance dropped to 150 ft. The other distances (with the back and front vehicle on the target lane) did not show significant differences when the system was available compared to without LCA.

On the freeway, the average of minimum distances accepted was significantly shorter when considering the back and front vehicle separately, having a decrease of approximately 30 and 170 ft respectively when the system was available. Although the total gaps without the system were 120 ft bigger than with it, this difference was not statistically significant.

In order to explore the impact of LCA on different driver’s characteristics, the following analysis groups the participants in gender, age and driver behavior types. A paired samples difference t-test was performed to compare minimum distances across groups and tests (with and without the system).

**Gender groups.** Table 5-13 shows the average of minimum distances for each gender group on the arterial, while Table 5-14 presents this information for the freeway. On the arterial, female drivers had a significant decrease on the accepted distances with the back vehicle and as a total during lane change when the system was available (65.5 and 110.4 ft respectively). Female group had accepted distance with the front vehicle as the only one significantly bigger than the male groups when the system was not available. With the LCA, this difference no longer existed.

On the freeway, the difference of 44.1 ft between distances with the back vehicle without and with the LCA for the male group, and of 223.9 with the front vehicle is statistically significant. The female group exhibited no significant difference for accepted distance. Although some differences between groups (last row of Table 5-14) seem large, they are not statistically significant.

**Age groups.** The data is presented for each age group on Tables 5-15 and 5-16, for arterial and freeway respectively. On the arterial, the younger group was the only one affected by the LCA. This group accepted significant shorter distances with the vehicle behind (difference of 43.7 ft comparing without and with the system test) and total gaps (58.1 ft difference). Comparing the younger with the older group, there was no significant difference.

Although the differences between without and with the system test on the freeway seem of a great magnitude, they were not statistically significant. The comparison between younger and older group was not significant with or without the LCA.

**Driver behavior types.** Tables 5-17 and 5-18 present the average of minimum distances grouped for driver behavior types, on the arterial and freeway. On the arterial, the system had no contribution to significant smaller headways for any specific driver behavior type. Comparison between these groups showed that aggressive and average drivers accepted distances with the back vehicle significantly shorter than the conservative ones, regardless of whether the system was available.

On the freeway, conservative drivers accepted shorter distances with the front vehicle with the system compared to without it. Average and aggressive drivers presented significantly shorter accepted distances when changing lane compared to conservative drivers without the LCA. The presence of the system eliminated these differences.

**Average distances during accepted gaps**

The next analysis used the overall average distances during accepted gaps for each participant. Table 5-19 shows the average accepted distances between all the lane changes performed per subject.

Analysis with average accepted distances shows that in general, drivers accepted significantly shorter distances with the LCA than without it. The distance with the vehicle behind dropped 38 ft; the one with the vehicle in front of the subject's vehicle decreased 60 ft, and the total gap accepted dropped 112 ft.

The impact of LCA on different driver's characteristics is presented below with an analysis divided in gender, age and driver behavior groups.

**Gender groups.** Average distances for each gender group is presented in Table 5-20. For both female and male participants, the average of total gap and distance with the front vehicle accepted during lane change were significantly shorter with the LCA than without it. The female group notably dropped their accepted gap from 524 ft to 359 ft. Comparing the female group to the male one, no significant difference was found.

**Age groups.** The data is presented for each age group on Table 5-21. For the two age groups, the average of total gap and distance with the front vehicle accepted were significantly shorter with the LCA. Both groups dropped their accepted total gaps by approximately 110 ft. Comparison between younger and older group showed no significant difference.

**Driver behavior types.** Table 5-22 presents the average accepted distances grouped in driver behavior types. Conservative drivers accepted shorter average total gaps and distance with the front vehicle, with the LCA than without it. The difference in total accepted gap for this group between without and with the system tests was 172.5 ft. For average drivers, only the average distance with the front vehicle was significantly shorter (difference of 57.8 ft), when using the LCA. Aggressive drivers did not change their gap acceptance characteristics when using the system. Average and aggressive drivers exhibited shorter distances with the back vehicle compared to conservative ones when the system was not available. For total gaps, aggressive drivers accepted shorter distances than the conservative ones without the LCA. When the system was used, these differences no longer appeared.

**Summary of LCA impact.** The impact of LCA was analyzed through the number of completed lane change maneuvers and with minimum and average accepted distances during a lane change maneuver for each driver. The number of lane change maneuvers, in general, was significantly higher with the system along the arterial and total route, indicating that drivers may feel more comfortable to perform lane changing when the system is available. For the freeway section the number of lane changes did not change significantly, possibly because the ACC was also being used. The male, older and conservative groups were the ones that mostly changed their behavior when using the system.

For the minimum accepted distances on the arterial during lane changing, total gaps and distance with the vehicle behind were shorter with the system. Female and younger drivers presented shorter minimum distances on the arterial when using the system, while male and conservative ones presented shorter minimum distances on the freeway.

For average accepted distances during completed lane change maneuvers, drivers in general accepted shorter distances when using LCA. For both age and gender groups, the average accepted distances dropped. Regarding driver behavior, conservative drivers were the most affected by the system, accepting shorter distances.

**General Impact of Both Systems**

The presence of the two assistance systems may have an impact on driver behavior that is not directly related to the functionality of them (ACC may impact not just car-following situations and LCA may impact more than the lane change maneuvers). In this section, average speed was used as a parameter to evaluate the overall impact of these two technologies when used together. Table 5-23 provides the average speed (mi/hr) for each driver and for each test. Data are provided for each analysis segment: arterial, freeway and total scenario.

As shown in the table, on the average the subject’s speeds in the scenario with ADAS were higher than those without it. Statistical comparison shows that average speed increased under two of all three cases (arterial and total scenario) when the systems were available. For the freeway section, there was a tendency to higher speeds with the systems that approached statistical significance. Additionally an analysis comparing maximum and minimum speeds was performed for the freeway section showing no statistical significance.

Next, this dataset is subdivided into groups to analyze the impact of ADAS as a function of different driver characteristics.

**Gender groups.** The data summary for each group is presented on Table 5-24. Female drivers increased their speed on the arterial section (0.9 mi/hr higher with the systems) and on the entire scenario (0.5 mi/hr higher). For male participants the same happened on the arterial (0.7 mi/hr higher). The male group achieved higher speeds on the arterial and as a total compared to the female group when there was no ADAS. When the systems were used, only the speed on the freeway was significantly higher for male participants compared to female ones.

**Age groups.** Table 5-25 shows the aggregated data by age group. On the arterial, both groups achieved significantly higher speeds with the systems compared to without them (average of 0.8 mi/hr higher). The total average speed only increased for the younger group (0.6 mi/hr). Comparing the older to the younger group, no significant difference was found.

**Driver behavior groups.** Table 5-26 summarizes the data for different driver behavior groups. As observed before, aggressive drivers did not change their behavior due to the technologies.  For the speed comparison, only average drivers had significantly higher speeds on the arterial and total scenario (1.2 mi/hr and 0.6 mi/hr increase respectively). Without the systems, aggressive drivers had higher speeds than the average ones, who had higher speeds than the conservatives for all three cases (arterial, freeway and total). When the systems were available, the only significant difference was between aggressive and conservative drivers on the arterial.

**Summary of general impact.** The systems tested resulted in an increase in speeds for both segments (arterial, freeway) and for the entire scenario. Age groups (female and male) and gender groups (younger and older) were positively affected by the systems (higher speeds). For driver behavior types, only the average drivers significantly increased their speed when using the systems.

## User Acceptance of the Technologies

Another important way to analyze these technologies is to evaluate how drivers accept them. This can determine whether drivers would be willing to use these systems in the long term. This section applies the methodology presented in Chapter 3 to determine the usefulness of the systems and how satisfied the drivers were in relation to their use. Table 5-27 shows the data for this analysis, divided in ACC, LCA and the combination of the two technologies. The scale for usefulness and satisfaction has a maximum of 2 and minimum of -2. The estimation of Cronbach's alpha is a requirement of the methodology, and it needs to be at least 0.65 (the criterion was met for all cases). In general, subjects thought the systems were useful, and were satisfied more with ACC and the combined technologies, than with just the LCA. This was a consequence of the sound chosen to warn drivers, classified as annoying by most subjects.

Further analysis of these results showed that age, gender or driver behavior types makes no difference in how drivers perceive the usefulness and satisfaction of the two ADAS systems and the combination of them. All drivers, independent of their characteristics, accepted positively these systems.

## Summary and Findings

The analysis of the impact of the two ADAS on this experiment has shown positive results regarding traffic improvements. In general, the presence and use of the two systems along an arterial followed by a freeway section resulted in higher speeds, smaller space headways and less variability in them during car-following situations on high speeds. The technologies increased the number of lane change maneuvers performed by a driver, and shortened the accepted gaps during lane changing. Besides these traffic impacts, drivers thought these technologies were useful and were satisfied with their performance. These changes in driving behavior indicate that these technologies have the potential to achieve better traffic conditions.

Interesting particularities were observed in this dataset. Female drivers were more likely to change their driving behavior than male ones. Younger and older drivers changed their driving behavior, but in different ways. Older drivers improved their headways and performed more lane changes, while younger drivers accepted shorter gaps. Aggressive drivers did not change their driving behavior significantly in any of the cases. In contrast, the behavior of conservative drivers was significantly affected by the systems in every case. The presence of the systems seemed to eliminate differences between groups, contributing to more uniform and stable traffic conditions.

Table 5-1.  Car-following data for subject 1 with the ACC

| Time (sec) | Subject's vehicle | | | Lead vehicle | | Space headway (ft) |
|---|---|---|---|---|---|---|
| | Speed (mph) | Longitudinal Distance (ft) | Accel (ft/sec2) | Speed (mph) | Longitudinal Distance (ft) | |
| 582.8 | 56.0 | 29169.7 | 3.6 | 53.2 | 29584.9 | 422.2 |
| 583.3 | 57.2 | 29211.3 | 3.5 | 54.2 | 29624.3 | 420.1 |
| 583.8 | 58.3 | 29253.7 | 3.3 | 55.1 | 29664.4 | 417.7 |
| 584.3 | 59.4 | 29297.0 | 3.1 | 55.9 | 29705.1 | 415.2 |
| 584.8 | 60.5 | 29341.0 | 3.0 | 56.6 | 29746.4 | 412.4 |
| 585.3 | 61.5 | 29385.8 | 2.8 | 57.2 | 29788.2 | 409.4 |
| 585.8 | 62.4 | 29431.2 | 2.6 | 57.7 | 29830.3 | 406.1 |
| 586.3 | 63.2 | 29477.3 | 2.3 | 58.0 | 29872.8 | 402.5 |
| 586.8 | 63.9 | 29524.0 | 2.0 | 57.9 | 29915.3 | 398.3 |
| 587.3 | 64.5 | 29571.2 | 1.7 | 57.4 | 29957.6 | 393.5 |
| 587.8 | 65.0 | 29618.7 | 1.2 | 56.5 | 29999.4 | 387.7 |
| 588.3 | 65.3 | 29666.5 | 0.6 | 55.0 | 30040.2 | 380.7 |
| 588.8 | 65.4 | 29714.5 | 0.0 | 53.3 | 30079.9 | 372.4 |
| 589.3 | 65.3 | 29762.4 | -0.6 | 51.4 | 30118.2 | 362.8 |
| 589.8 | 65.0 | 29810.2 | -1.2 | 49.4 | 30155.1 | 351.9 |
| 590.3 | 64.5 | 29857.7 | -1.7 | 47.5 | 30190.5 | 339.8 |
| 590.8 | 63.8 | 29904.7 | -2.2 | 45.7 | 30224.6 | 326.9 |
| 591.3 | 63.0 | 29951.1 | -2.6 | 44.1 | 30257.5 | 313.3 |
| 591.8 | 62.1 | 29997.0 | -2.9 | 42.6 | 30289.2 | 299.2 |
| 592.3 | 61.0 | 30042.0 | -3.2 | 41.1 | 30319.8 | 284.8 |
| 592.8 | 59.9 | 30086.3 | -3.5 | 39.6 | 30349.3 | 270.0 |
| 593.3 | 58.6 | 30129.6 | -3.8 | 38.1 | 30377.8 | 255.1 |
| 593.8 | 57.3 | 30172.0 | -4.0 | 36.8 | 30405.1 | 240.1 |
| 594.3 | 55.9 | 30213.4 | -4.2 | 35.5 | 30431.6 | 225.1 |
| 594.8 | 54.4 | 30253.8 | -4.3 | 34.4 | 30457.1 | 210.3 |
| 595.3 | 53.0 | 30293.1 | -4.3 | 33.5 | 30482.0 | 195.9 |
| 595.8 | 51.5 | 30331.3 | -4.3 | 32.9 | 30506.3 | 182.0 |
| 596.3 | 50.0 | 30368.4 | -4.2 | 32.5 | 30530.2 | 168.8 |
| 596.8 | 48.6 | 30404.5 | -4.1 | 32.4 | 30554.0 | 156.5 |
| 597.3 | 47.3 | 30439.5 | -3.9 | 32.5 | 30577.7 | 145.2 |
| 597.8 | 46.0 | 30473.6 | -3.6 | 32.9 | 30601.7 | 135.1 |
| 598.3 | 44.9 | 30506.9 | -3.3 | 33.5 | 30626.0 | 126.2 |
| 598.8 | 43.8 | 30539.3 | -2.9 | 34.3 | 30650.9 | 118.6 |
| 599.3 | 42.9 | 30571.0 | -2.5 | 35.4 | 30676.5 | 112.5 |
| 599.8 | 42.1 | 30602.1 | -2.1 | 36.6 | 30702.9 | 107.8 |
| 600.3 | 41.5 | 30632.7 | -1.6 | 38.0 | 30730.3 | 104.6 |
| 600.8 | 41.0 | 30662.9 | -1.1 | 39.5 | 30758.7 | 102.8 |
| 601.3 | 40.7 | 30692.9 | -0.7 | 41.1 | 30788.3 | 102.5 |
| 601.8 | 40.6 | 30722.7 | -0.2 | 42.7 | 30819.1 | 103.4 |
| 602.3 | 40.6 | 30752.4 | 0.2 | 44.3 | 30851.0 | 105.6 |
| | | | | | Average = | 267.1 |
| | | | | | Standard Deviation = | 120.7 |

Table 5-2. Car-following aggregate data for each driver, without and with ACC

| Subject ID | Without ADAS: # of CF* | Without ADAS: Average Space Headway (ft) | Without ADAS: Standard Deviation | With ADAS: # of CF* | With ADAS: Average Space Headway (ft) | With ADAS: Standard Deviation | Differences: Average Space Headway (ft) | Differences: F-test for variances (F-test critical=1.31) |
|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 278.48 | 116.91 | 4 | 208.74 | 96.14 | 69.74 | 1.48 |
| 2 | 1 | 127.88 | 65.22 | 2 | 166.81 | 75.87 | -38.93 | 1.35 |
| 3 | 1 | 302.93 | 101.92 | 3 | 183.28 | 41.61 | 119.65 | 6.00 |
| 4 | 1 | 160.78 | 84.40 | 4 | 187.96 | 46.96 | -27.18 | 3.23 |
| 5 | 3 | 233.85 | 112.43 | 1 | 181.21 | 43.88 | 52.64 | 6.56 |
| 6 | 1 | 295.49 | 96.66 | 2 | 196.44 | 66.23 | 99.05 | 2.13 |
| 7 | 2 | 131.20 | 43.22 | 3 | 179.38 | 43.91 | -48.18 | 1.03 |
| 8 | 1 | 310.03 | 154.08 | 3 | 209.35 | 81.32 | 100.68 | 3.59 |
| 9 | 3 | 225.69 | 88.98 | 2 | 198.93 | 59.97 | 26.76 | 2.20 |
| 10 | 1 | 211.15 | 57.69 | 4 | 278.35 | 133.78 | -67.20 | 5.38 |
| 11 | 1 | 282.47 | 103.06 | 1 | 225.07 | 144.16 | 57.40 | 1.96 |
| 12 | 2 | 297.62 | 179.08 | 2 | 129.42 | 49.75 | 168.20 | 12.96 |
| 13 | 1 | 185.24 | 87.47 | 3 | 186.55 | 66.98 | -1.31 | 1.71 |
| 14 | 1 | 381.67 | 111.17 | 2 | 197.04 | 58.40 | 184.64 | 3.62 |
| 15 | 3 | 139.70 | 65.38 | 1 | 187.47 | 49.68 | -47.77 | 1.73 |
| 16 | 2 | 255.37 | 101.13 | 2 | 236.85 | 96.92 | 18.52 | 1.09 |
| 17 | 1 | 394.18 | 49.73 | 2 | 223.44 | 84.02 | 170.74 | 2.85 |
| 18 | 1 | 597.22 | 241.24 | 3 | 246.50 | 156.47 | 350.72 | 2.38 |
| 19 | 4 | 161.37 | 86.56 | 3 | 153.05 | 44.83 | 8.32 | 3.73 |
| 20 | 2 | 110.71 | 64.65 | 3 | 168.52 | 90.92 | -57.81 | 1.98 |
| 21 | 2 | 241.20 | 147.21 | 4 | 208.56 | 79.95 | 32.64 | 3.39 |
| 22 | 1 | 179.33 | 91.73 | 2 | 156.34 | 77.86 | 22.99 | 1.39 |
| 23 | 3 | 124.42 | 65.05 | 1 | 248.56 | 125.76 | -124.14 | 3.74 |
| 24 | 1 | 186.05 | 70.17 | 2 | 202.63 | 90.92 | -16.58 | 1.68 |
| 25 | 4 | 182.77 | 183.25 | 5 | 176.27 | 46.60 | 6.50 | 15.46 |
| | | | | | | Average = | 42.40 | |

*Number of car-following situations

Table 5-3. Detailed car-following analysis for subjects 19 and 25

| | Without ACC | | | With ACC | | |
|---|---|---|---|---|---|---|
| Subj ID | Car-following situation | Average space headway (ft) | Standard Deviation | Car-following situation | Average space headway (ft) | Standard Deviation |
| 19 | 1 | 158.54 | 40.00 | 1 | 165.77 | 42.10 |
| | 2 | 114.65 | 32.07 | 2 | 168.75 | 20.62 |
| | 3 | 118.55 | 41.30 | 3 | 136.22 | 46.62 |
| | 4 | 237.35 | 56.71 | | | |
| | Standard Deviation | 56.95 | | | 17.98 | |
| 25 | 1 | 115.81 | 34.49 | 1 | 116.11 | 18.71 |
| | 2 | 154.92 | 51.45 | 2 | 193.64 | 38.10 |
| | 3 | 105.67 | 43.96 | 3 | 201.27 | 22.58 |
| | 4 | 252.51 | 44.75 | 4 | 215.65 | 18.62 |
| | | | | 5 | 180.35 | 30.23 |
| | Standard Deviation | 66.98 | | | 38.67 | |

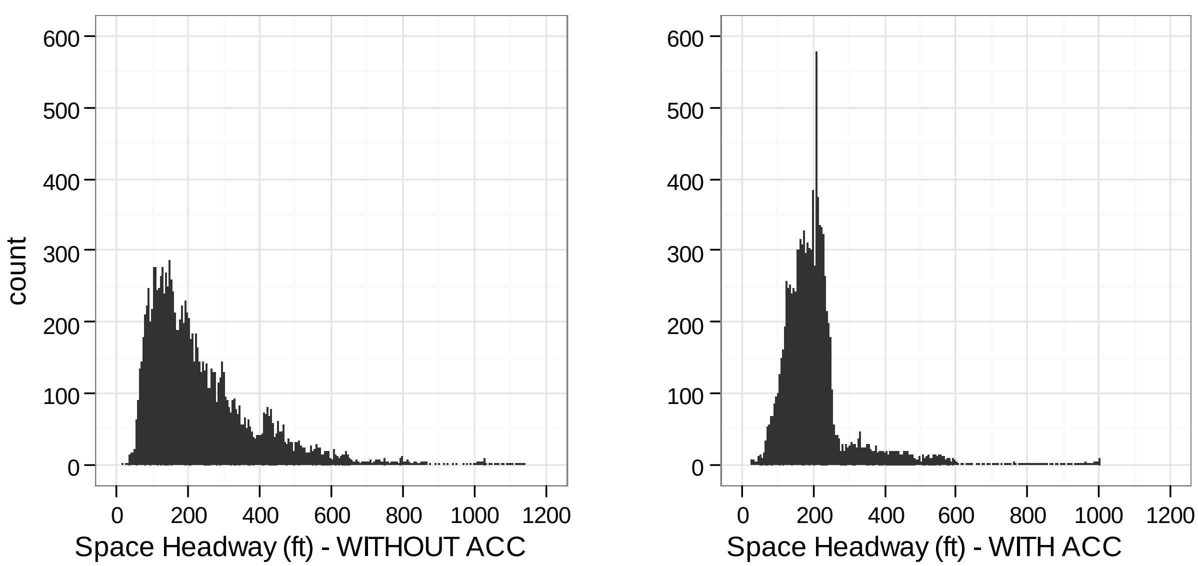


Figure 5-1. Distribution of headway without and with ACC

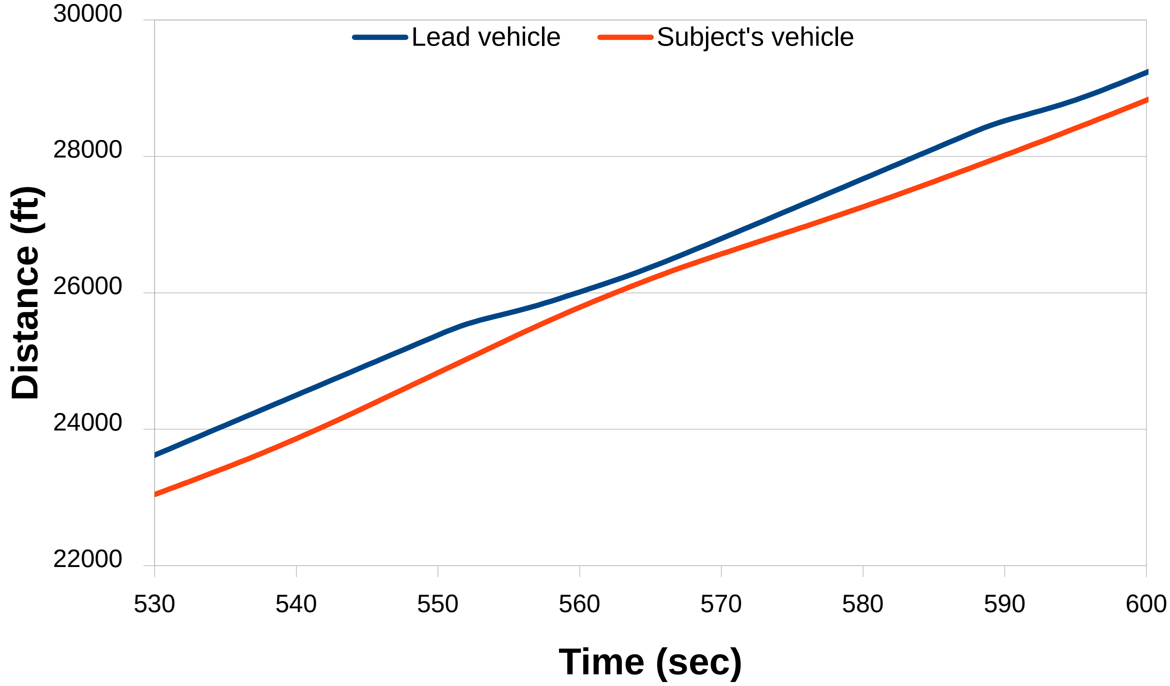


Figure 5-2.  Vehicle trajectory for a car-following situation (Subject 14) without ACC

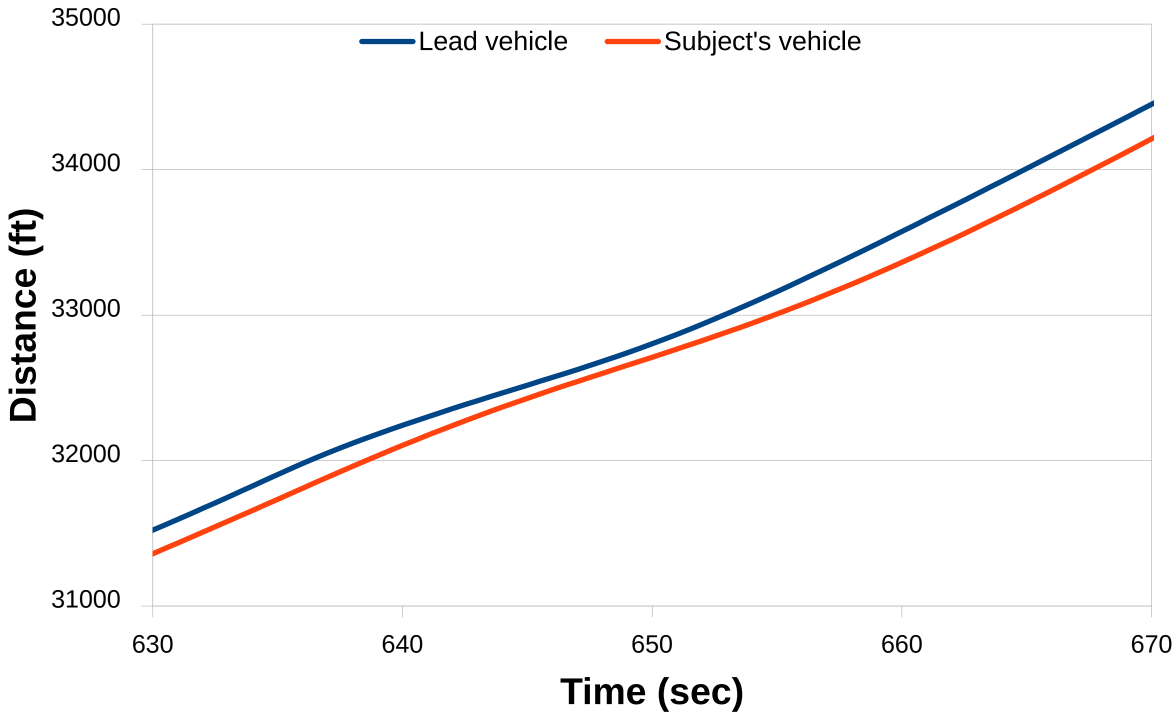


Figure 5-3.  Vehicle trajectory for a car-following situation (Subject 14) with ACC

Table 5-4. Average headway (ft) and standard deviation for gender groups

| | Without | | With | | Difference | |
|---|---|---|---|---|---|---|
| | Average space headway (ft) | Standard deviation | Average space headway (ft) | Standard deviation | Average space headway (ft) | F-test (F critical=1.21) |
| Female | 245.79 | 88.91 | 198.48 | 79.98 | 47.31 | 1.24 |
| Male | 236.55 | 110.52 | 196.90 | 77.07 | 39.65 | 2.06 |
| Difference and F-test | 9.24 | 1.55 | 1.58 | 1.08 | | |

Table 5-5. Average headway (ft) and standard deviation for age groups

| | Without | | With | | Difference | |
|---|---|---|---|---|---|---|
| Age | Average space headway (ft) | Standard deviation | Average space headway (ft) | Standard deviation | Average space headway (ft) | F-test (F critical=1.21) |
| 25-30 | 203.55 | 84.91 | 208.46 | 86.50 | -4.91 | 1.04 |
| 31-60 | 284.87 | 131.17 | 188.83 | 71.52 | 96.04 | 3.36 |
| Difference and F-test | -81.32 | 2.39 | 19.62 | 1.46 | | |

Table 5-6. Average headway (ft) and standard deviation for driver behavior types

| | Without | | With | | Difference | |
|---|---|---|---|---|---|---|
| | Average space headway (ft) | Standard deviation | Average space headway (ft) | Standard deviation | Average space headway (ft) | F-test (F critical=1.21) |
| Aggressive | 190.99 | 106.44 | 188.56 | 76.39 | 2.43 | 1.94 |
| Average | 182.29 | 84.14 | 182.78 | 63.16 | -0.49 | 1.77 |
| Conservative | 320.16 | 115.02 | 215.46 | 91.29 | 104.70 | 1.59 |
| Aggr-Avg | 8.70 | 1.60 | 5.78 | 1.46 | | |
| Avg-Conser | -137.87 | 1.87 | -32.68 | 2.09 | | |
| Aggr-Conser | -129.17 | 1.17 | -26.90 | 1.43 | | |

Table 5-7. Number of lane change maneuvers per subject, without and with LCA

| | Without LCA | | | With LCA | | | Difference | | |
|---|---|---|---|---|---|---|---|---|---|
| Subject ID | Art | Fwy | Total | Art | Fwy | Total | Art | Fwy | Total |
| 1 | 5 | 3 | 8 | 9 | 2 | 11 | 4 | -1 | 3 |
| 2 | 10 | 0 | 10 | 12 | 0 | 12 | 2 | 0 | 2 |
| 3 | 6 | 1 | 7 | 7 | 3 | 10 | 1 | 2 | 3 |
| 4 | 7 | 3 | 10 | 13 | 1 | 14 | 6 | -2 | 4 |
| 5 | 10 | 3 | 13 | 7 | 2 | 9 | -3 | -1 | -4 |
| 6 | 4 | 1 | 5 | 3 | 0 | 3 | -1 | -1 | -2 |
| 7 | 7 | 2 | 9 | 4 | 4 | 8 | -3 | 2 | -1 |
| 8 | 6 | 1 | 7 | 8 | 1 | 9 | 2 | 0 | 2 |
| 9 | 8 | 2 | 10 | 10 | 0 | 10 | 2 | -2 | 0 |
| 10 | 4 | 1 | 5 | 9 | 0 | 9 | 5 | -1 | 4 |
| 11 | 4 | 0 | 4 | 3 | 0 | 3 | -1 | 0 | -1 |
| 12 | 10 | 1 | 11 | 12 | 8 | 20 | 2 | 7 | 9 |
| 13 | 5 | 0 | 5 | 6 | 3 | 9 | 1 | 3 | 4 |
| 14 | 6 | 0 | 6 | 6 | 2 | 8 | 0 | 2 | 2 |
| 15 | 6 | 2 | 8 | 10 | 1 | 11 | 4 | -1 | 3 |
| 16 | 6 | 2 | 8 | 6 | 0 | 6 | 0 | -2 | -2 |
| 17 | 6 | 1 | 7 | 4 | 1 | 5 | -2 | 0 | -2 |
| 18 | 5 | 1 | 6 | 7 | 2 | 9 | 2 | 1 | 3 |
| 19 | 9 | 5 | 14 | 14 | 4 | 18 | 5 | -1 | 4 |
| 20 | 6 | 2 | 8 | 8 | 4 | 12 | 2 | 2 | 4 |
| 21 | 5 | 2 | 7 | 7 | 4 | 11 | 2 | 2 | 4 |
| 22 | 5 | 0 | 5 | 11 | 1 | 12 | 6 | 1 | 7 |
| 23 | 11 | 4 | 15 | 14 | 2 | 16 | 3 | -2 | 1 |
| 24 | 10 | 2 | 12 | 6 | 0 | 6 | -4 | -2 | -6 |
| 25 | 14 | 4 | 18 | 13 | 4 | 17 | -1 | 0 | -1 |
| Average | 7.0 | 1.7 | 8.7 | 8.4 | 2.0 | 10.3 | 1.36 | 0.24 | 1.6 |

*Art – Arterial, Fwy – Freeway

Table 5-8. Number of lane change maneuvers for gender groups

| | Without | | | With | | | Difference | | |
|---|---|---|---|---|---|---|---|---|---|
| | Arterial | Freeway | Total | Arterial | Freeway | Total | Arterial | Freeway | Total |
| Female | 5.9 | 1.8 | 7.7 | 7.8 | 1.0 | 8.8 | 1.9 | -0.8 | 1.1 |
| Male | 7.6 | 1.7 | 9.3 | 8.7 | 2.5 | 11.2 | 1.1 | 0.8 | 1.9 |
| Diff. | -1.7 | 0.1 | -1.6 | -0.9 | -1.5 | -2.4 | | | |

Table 5-9. Number of lane change maneuvers by age groups

| | Without | | | With | | | Difference | | |
|---|---|---|---|---|---|---|---|---|---|
| Age | Arterial | Freeway | Total | Arterial | Freeway | Total | Arterial | Freeway | Total |
| 25-30 | 6.3 | 1.5 | 7.7 | 7.5 | 1.6 | 9.2 | 1.3 | 0.2 | 1.5 |
| 31-60 | 7.6 | 1.9 | 9.5 | 9.0 | 2.2 | 11.2 | 1.4 | 0.3 | 1.7 |
| Difference | -1.3 | -0.5 | -1.8 | -1.5 | -0.6 | -2.0 | | | |

Table 5-10. Number of lane change maneuvers for driver behavior groups

| | Without | | | With | | | Difference | | |
|---|---|---|---|---|---|---|---|---|---|
| | Arterial | Freeway | Total | Arterial | Freeway | Total | Arterial | Freeway | Total |
| Aggressive | 9.4 | 2.3 | 11.7 | 10.9 | 2.4 | 13.3 | 1.4 | 0.1 | 1.5 |
| Average | 7.3 | 2.4 | 9.6 | 9.1 | 2.0 | 11.1 | 1.9 | -0.4 | 1.6 |
| Conservative | 5.1 | 0.8 | 5.9 | 6.0 | 1.6 | 7.6 | 0.9 | 0.8 | 1.7 |
| Aggr-Avg | 2.2 | -0.1 | 2.1 | 1.7 | 0.4 | 2.2 | | | |
| Avg-Conser | 2.2 | 1.6 | 3.7 | 3.1 | 0.4 | 3.5 | | | |
| Aggr-Conser | 4.3 | 1.5 | 5.8 | 4.9 | 0.8 | 5.7 | | | |

Table 5-11. Minimum distances (ft) for lane changes performed on the arterial

| Subject | Without | | | With | | |
|---|---|---|---|---|---|---|
| ID | BACK | FRONT | TOTAL | BACK | FRONT | TOTAL |
| 1 | 2.23 | 104.81 | 121.04 | 22.05 | 22.85 | 128.14 |
| 2 | 25.30 | 32.66 | 122.03 | 45.82 | 41.91 | 126.84 |
| 3 | 176.91 | 43.27 | 266.25 | 41.20 | 28.31 | 127.75 |
| 4 | 32.24 | 14.20 | 126.65 | 35.41 | 43.13 | 128.60 |
| 5 | 39.21 | 31.97 | 129.56 | 49.20 | 23.72 | 127.73 |
| 6 | 176.39 | 18.06 | 271.61 | 46.50 | 7.87 | 126.38 |
| 7 | 92.93 | 20.66 | 227.03 | 67.61 | 43.28 | 124.89 |
| 8 | 135.23 | 12.43 | 161.66 | 165.71 | 27.03 | 216.55 |
| 9 | 27.73 | 31.69 | 207.98 | 41.36 | 22.27 | 195.96 |
| 10 | 67.60 | 42.36 | 123.96 | 42.79 | 48.10 | 129.12 |
| 11 | 99.28 | 30.42 | 143.70 | 63.95 | 27.20 | 126.17 |
| 12 | 31.06 | 54.38 | 127.91 | 39.56 | 33.94 | 128.60 |
| 13 | 207.29 | 14.49 | 235.78 | 51.53 | 19.58 | 120.60 |
| 14 | 46.39 | 31.05 | 126.70 | 137.75 | 17.66 | 176.05 |
| 15 | 64.76 | 17.27 | 119.99 | 41.24 | 20.06 | 125.67 |
| 16 | 60.63 | 35.14 | 223.74 | 46.51 | 61.45 | 121.96 |
| 17 | 373.22 | 59.36 | 656.53 | 80.70 | 55.21 | 149.91 |
| 18 | 92.81 | 36.90 | 522.62 | 161.69 | 55.90 | 488.60 |
| 19 | 54.70 | 51.79 | 120.49 | 33.39 | 29.84 | 122.37 |
| 20 | 37.38 | 15.09 | 121.50 | 41.14 | 9.33 | 119.98 |
| 21 | 63.14 | 33.04 | 120.31 | 61.40 | 33.65 | 135.36 |
| 22 | 119.98 | 42.34 | 347.42 | 13.73 | 11.37 | 122.29 |
| 23 | 48.10 | 9.82 | 131.11 | 25.23 | 21.76 | 125.85 |
| 24 | 14.90 | 8.47 | 85.84 | 79.47 | 33.17 | 126.64 |
| 25 | 38.54 | 21.75 | 126.61 | 38.98 | 35.10 | 126.88 |
| Average | 85.12 | 32.54 | 198.72 | 58.96 | 30.95 | 149.96 |

Table 5-12. Minimum distances (ft) for lane changes performed on the freeway

| Subject | Without | | | With | | |
|---|---|---|---|---|---|---|
| ID | BACK | FRONT | TOTAL | BACK | FRONT | TOTAL |
| 1 | 127.97 | 82.77 | 224.74 | 161.79 | 20.98 | 196.77 |
| 2 | - | - | - | - | - | - |
| 3 | 239.32 | 629.26 | 882.58 | 91.25 | 40.21 | 216.97 |
| 4 | 175.42 | 33.26 | 222.68 | 130.98 | 92.55 | 237.53 |
| 5 | 142.97 | 65.42 | 222.39 | 180.00 | 25.96 | 219.96 |
| 6 | 208.32 | 622.38 | 844.70 | - | - | - |
| 7 | 110.19 | 97.09 | 221.28 | 68.04 | 31.44 | 202.73 |
| 8 | 205.45 | 775.99 | 995.44 | 200.36 | 23.85 | 238.21 |
| 9 | 119.91 | 78.70 | 218.68 | - | - | - |
| 10 | 302.66 | 375.35 | 692.01 | - | - | - |
| 11 | - | - | - | - | - | - |
| 12 | 74.12 | 146.31 | 234.43 | 42.14 | 18.10 | 176.15 |
| 13 | - | - | - | 24.34 | 33.90 | 120.81 |
| 14 | - | - | - | 190.66 | 26.16 | 237.58 |
| 15 | 146.92 | 38.16 | 199.08 | - | 50.60 | - |
| 16 | 143.74 | 35.62 | 193.36 | - | - | - |
| 17 | 89.86 | 135.33 | 239.19 | 107.96 | 116.43 | 238.39 |
| 18 | - | 971.11 | - | 371.17 | 41.44 | 426.61 |
| 19 | 90.27 | 73.42 | 217.29 | 44.24 | 46.04 | 187.26 |
| 20 | 174.71 | 28.34 | 217.05 | 108.79 | 53.86 | 211.78 |
| 21 | 142.61 | 63.20 | 219.81 | 61.30 | 31.85 | 215.35 |
| 22 | - | - | - | 143.31 | 16.44 | 173.75 |
| 23 | 72.61 | 101.71 | 235.55 | 76.45 | 40.18 | 212.96 |
| 24 | 165.21 | 37.21 | 216.42 | - | - | - |
| 25 | 110.89 | 27.77 | 196.43 | 48.25 | 76.91 | 209.98 |
| Average | 149.64 | 220.92 | 352.27 | 120.65 | 43.72 | 218.99 |

*Dashes in the table represent no lane changes performed or no presence of the specific vehicle in the vicinity.

Table 5-13. Average of minimum distances (ft) for arterial for gender groups

| | Without | | | With | | | Difference | | |
|---|---|---|---|---|---|---|---|---|---|
| | BACK | FRONT | TOTAL | BACK | FRONT | TOTAL | BACK | FRONT | TOTAL |
| Female | 108.8 | 43.4 | 245.8 | 43.3 | 28.7 | 135.4 | 65.5 | 14.8 | 110.4 |
| Male | 71.8 | 26.4 | 172.2 | 67.8 | 32.2 | 158.1 | 4.0 | -5.8 | 14.1 |
| Difference | 37.0 | 17.0 | 73.6 | -24.5 | -3.5 | -22.7 | | | |

Table 5-14. Average of minimum distances (ft) for freeway for gender groups

| | Without | | | With | | | Difference | | |
|---|---|---|---|---|---|---|---|---|---|
| | BACK | FRONT | TOTAL | BACK | FRONT | TOTAL | BACK | FRONT | TOTAL |
| Female | 132.4 | 152.3 | 305.3 | 114.3 | 50.1 | 199.0 | -2.0 | 23.9 | 19.6 |
| Male | 159.7 | 257.8 | 379.7 | 122.6 | 41.3 | 225.1 | 44.1 | 223.9 | 150.6 |
| Difference | -27.3 | -105.5 | -74.4 | -8.3 | 8.8 | -26.1 | | | |

Table 5-15. Average of minimum distances (ft) for arterial for age groups

| | Without | | | With | | | Difference | | |
|---|---|---|---|---|---|---|---|---|---|
| Age | BACK | FRONT | TOTAL | BACK | FRONT | TOTAL | BACK | FRONT | TOTAL |
| 25-30 | 92.3 | 27.0 | 184.1 | 48.6 | 31.6 | 126.0 | 43.7 | -4.6 | 58.1 |
| 31-60 | 79.5 | 36.9 | 210.2 | 67.1 | 30.4 | 168.8 | 12.4 | 6.5 | 41.5 |
| Difference | 12.9 | -9.8 | -26.1 | -18.5 | 1.2 | -42.7 | | | |

Table 5-16. Average of minimum distances (ft) for freeway for age groups

| | Without | | | With | | | Difference | | |
|---|---|---|---|---|---|---|---|---|---|
| Age | BACK | FRONT | TOTAL | BACK | FRONT | TOTAL | BACK | FRONT | TOTAL |
| 25-30 | 165.4 | 172.2 | 357.5 | 77.4 | 34.9 | 190.4 | 66.9 | 147.0 | 177.8 |
| 31-60 | 138.2 | 253.4 | 348.5 | 144.2 | 49.3 | 234.6 | 18.6 | 182.36 | 94.8 |
| Difference | 27.2 | -81.2 | 9.1 | -66.8 | -14.4 | -44.1 | | | |

Table 5-17. Average of minimum distances (ft) for arterial for driver behavior groups

| | Without | | | With | | | Difference | | |
|---|---|---|---|---|---|---|---|---|---|
| | BACK | FRONT | TOTAL | BACK | FRONT | TOTAL | BACK | FRONT | TOTAL |
| Aggressive | 32.1 | 35.6 | 119.2 | 41.8 | 29.8 | 126.9 | -9.6 | 5.8 | -7.7 |
| Average | 58.1 | 30.4 | 188.0 | 41.0 | 30.5 | 133.0 | 17.1 | -0.2 | 55.1 |
| Conservative | 143.8 | 32.1 | 262.9 | 85.3 | 32.1 | 179.6 | 58.5 | 0.1 | 83.3 |
| Aggr-Avg | -26.0 | 5.2 | -68.8 | 0.7 | -0.7 | -6.0 | | | |
| Avg-Conser | -85.7 | -1.8 | -74.9 | -44.3 | -1.5 | -46.7 | | | |
| Aggr-Conser | -111.7 | 3.5 | -143.7 | -43.6 | -2.2 | -52.7 | | | |

Table 5-18. Average of minimum distances (ft) for freeway for driver behavior groups

| | Without | | | With | | | Difference | | |
|---|---|---|---|---|---|---|---|---|---|
| | BACK | FRONT | TOTAL | BACK | FRONT | TOTAL | BACK | FRONT | TOTAL |
| Aggressive | 116.3 | 72.3 | 217.8 | 82.2 | 41.4 | 199.0 | 14.2 | 38.0 | 23.8 |
| Average | 136.7 | 58.8 | 216.1 | 112.6 | 44.4 | 205.5 | 32.3 | 9.5 | 8.3 |
| Conservative | 198.0 | 510.4 | 645.6 | 149.6 | 44.8 | 242.0 | 54.1 | 464.2 | 357.0 |
| Aggr-Avg | -20.5 | 13.5 | 1.7 | -30.4 | -3.0 | -6.5 | | | |
| Avg-Conser | -61.3 | -451.5 | -429.5 | -37.0 | -0.5 | -36.5 | | | |
| Aggr-Conser | -81.8 | -438.1 | -427.8 | -67.4 | -3.5 | -43.0 | | | |

Table 5-19. Average distances (ft) for lane changes performed on the arterial

| | Without | | | With | | |
|---|---|---|---|---|---|---|
| Subj ID | BACK | FRONT | TOTAL | BACK | FRONT | TOTAL |
| 1 | 241.2 | 267.2 | 545.1 | 199.1 | 184.4 | 245.1 |
| 2 | 201.5 | 239.7 | 455.2 | 204.4 | 166.7 | 385.1 |
| 3 | 352.9 | 346.0 | 708.7 | 193.3 | 173.6 | 376.2 |
| 4 | 174.8 | 145.8 | 342.4 | 132.6 | 121.7 | 273.3 |
| 5 | 211.9 | 246.3 | 480.9 | 225.4 | 209.7 | 452.9 |
| 6 | 430.2 | 231.4 | 728.9 | 96.9 | 67.9 | 147.8 |
| 7 | 235.9 | 200.7 | 474.4 | 140.7 | 89.2 | 244.0 |
| 8 | 336.9 | 282.1 | 693.9 | 340.8 | 216.9 | 590.7 |
| 9 | 180.4 | 149.6 | 350.0 | 310.9 | 184.8 | 527.8 |
| 10 | 223.5 | 132.2 | 371.2 | 219.8 | 139.6 | 369.7 |
| 11 | 224.9 | 200.8 | 371.9 | 171.5 | 128.6 | 223.2 |
| 12 | 245.8 | 237.8 | 488.0 | 181.0 | 150.9 | 347.2 |
| 13 | 423.4 | 267.5 | 699.0 | 145.9 | 97.0 | 256.9 |
| 14 | 232.8 | 233.7 | 483.2 | 282.9 | 108.3 | 426.3 |
| 15 | 191.1 | 117.6 | 326.4 | 137.6 | 142.6 | 265.9 |
| 16 | 249.0 | 312.2 | 575.2 | 310.0 | 232.9 | 556.9 |
| 17 | 350.6 | 279.0 | 678.8 | 287.1 | 247.9 | 535.9 |
| 18 | 408.5 | 391.7 | 900.6 | 371.7 | 332.5 | 762.0 |
| 19 | 196.8 | 238.6 | 449.5 | 200.3 | 152.9 | 367.2 |
| 20 | 228.3 | 188.8 | 431.2 | 232.5 | 167.7 | 424.6 |
| 21 | 144.7 | 215.0 | 338.5 | 270.1 | 271.3 | 560.6 |
| 22 | 333.5 | 308.8 | 690.4 | 178.3 | 169.3 | 361.6 |
| 23 | 204.8 | 195.3 | 374.9 | 159.7 | 147.1 | 320.8 |
| 24 | 130.1 | 163.5 | 308.6 | 226.0 | 184.5 | 450.9 |
| 25 | 142.1 | 117.0 | 261.9 | 121.1 | 116.9 | 252.0 |
| Average | 251.8 | 228.3 | 501.1 | 213.6 | 168.2 | 389.0 |

Table 5-20. Average of distances (ft) for gender groups

| | Without | | | With | | | Difference | | |
|---|---|---|---|---|---|---|---|---|---|
| | BACK | FRONT | TOTAL | BACK | FRONT | TOTAL | BACK | FRONT | TOTAL |
| Female | 266.4 | 233.9 | 524.0 | 210.2 | 167.9 | 359.0 | 56.2 | 66.0 | 165.0 |
| Male | 243.6 | 225.2 | 488.3 | 215.5 | 168.4 | 405.8 | 28.1 | 56.8 | 82.5 |
| Difference | 22.8 | 8.7 | 35.7 | -5.3 | -0.4 | -46.8 | | | |

Table 5-21. Average of distances (ft) for age groups

| | Without | | | With | | | Difference | | |
|---|---|---|---|---|---|---|---|---|---|
| Age | BACK | FRONT | TOTAL | BACK | FRONT | TOTAL | BACK | FRONT | TOTAL |
| 25-30 | 246.7 | 223.6 | 476.3 | 195.7 | 161.4 | 362.4 | 51.0 | 62.2 | 113.9 |
| 31-60 | 255.8 | 232.1 | 520.7 | 227.6 | 173.5 | 409.8 | 28.2 | 58.5 | 110.8 |
| Difference | 9.1 | 8.5 | 44.4 | 31.9 | 12.1 | 47.4 | | | |

Table 5-22. Average of distances (ft) for driver behavior groups

| | Without | | | With | | | Difference | | |
|---|---|---|---|---|---|---|---|---|---|
| | BACK | FRONT | TOTAL | BACK | FRONT | TOTAL | BACK | FRONT | TOTAL |
| Aggressive | 193.8 | 191.2 | 394.3 | 175.6 | 156.2 | 323.9 | 18.2 | 35.0 | 70.4 |
| Average | 226.3 | 223.9 | 474.2 | 216.3 | 166.0 | 401.0 | 10.0 | 57.8 | 73.2 |
| Conservative | 312.8 | 257.9 | 597.5 | 238.0 | 178.4 | 424.9 | 74.8 | 79.6 | 172.5 |
| Aggr-Avg | -32.6 | -32.7 | -79.9 | -40.8 | -9.9 | -77.2 | | | |
| Avg-Conser | -86.5 | -34.1 | -123.2 | -21.7 | -12.3 | -23.9 | | | |
| Aggr-Conser | -119.1 | -66.8 | -203.2 | -62.4 | -22.2 | -101.1 | | | |

Table 5-23. Average speed (mi/hr) for each subject

| Subject | Without ADAS | | | With ADAS | | |
|---|---|---|---|---|---|---|
| ID | Arterial | Freeway | Total | Arterial | Freeway | Total |
| 1 | 25.4 | 52.2 | 36.7 | 26.0 | 52.4 | 37.3 |
| 2 | 27.0 | 53.6 | 38.5 | 27.9 | 54.2 | 39.4 |
| 3 | 25.8 | 53.7 | 37.5 | 27.4 | 54.8 | 39.2 |
| 4 | 26.6 | 53.3 | 38.1 | 28.2 | 55.1 | 39.9 |
| 5 | 26.5 | 53.4 | 38.0 | 26.8 | 53.3 | 38.3 |
| 6 | 24.0 | 54.1 | 36.1 | 24.6 | 52.6 | 36.2 |
| 7 | 25.2 | 52.9 | 36.8 | 25.1 | 53.3 | 36.8 |
| 8 | 23.8 | 53.8 | 35.8 | 24.5 | 52.8 | 36.2 |
| 9 | 24.3 | 51.9 | 35.7 | 24.9 | 52.6 | 36.4 |
| 10 | 24.5 | 53.6 | 36.4 | 26.3 | 53.7 | 38.0 |
| 11 | 24.2 | 53.2 | 36.0 | 24.7 | 53.0 | 36.4 |
| 12 | 25.3 | 54.2 | 37.2 | 26.8 | 53.7 | 38.3 |
| 13 | 25.7 | 53.3 | 37.3 | 27.4 | 54.2 | 39.0 |
| 14 | 24.8 | 52.8 | 36.4 | 24.9 | 52.6 | 36.4 |
| 15 | 26.7 | 52.9 | 38.0 | 27.5 | 53.5 | 38.8 |
| 16 | 25.3 | 52.7 | 36.8 | 26.3 | 52.9 | 37.7 |
| 17 | 22.4 | 50.5 | 32.2 | 21.6 | 50.9 | 31.5 |
| 18 | 22.4 | 51.1 | 33.8 | 21.3 | 52.1 | 31.6 |
| 19 | 25.3 | 53.7 | 37.1 | 28.2 | 53.0 | 38.1 |
| 20 | 25.8 | 53.2 | 37.4 | 27.4 | 52.8 | 37.3 |
| 21 | 25.6 | 52.3 | 35.7 | 26.2 | 53.9 | 36.6 |
| 22 | 24.6 | 52.6 | 36.2 | 26.3 | 53.1 | 36.6 |
| 23 | 27.3 | 52.6 | 38.4 | 28.9 | 54.0 | 38.9 |
| 24 | 28.2 | 54.3 | 38.4 | 26.5 | 52.5 | 36.6 |
| 25 | 27.7 | 53.0 | 37.7 | 27.6 | 54.2 | 37.9 |
| Average | 25.4 | 53.0 | 36.7 | 26.1 | 53.2 | 37.2 |

Table 5-24. Average of average speed (mi/hr) for gender groups

| | Without ADAS | | | With ADAS | | | Difference | | |
|---|---|---|---|---|---|---|---|---|---|
| | Arterial | Freeway | Total | Arterial | Freeway | Total | Arterial | Freeway | Total |
| Female | 24.7 | 52.6 | 36.1 | 25.6 | 52.6 | 36.5 | 0.9 | 0.0 | 0.5 |
| Male | 25.8 | 53.2 | 37.1 | 26.4 | 53.6 | 37.5 | 0.7 | 0.4 | 0.4 |
| Difference | -1.1 | -0.5 | -1.0 | -0.9 | -0.9 | -1.0 | | | |

Table 5-25. Average of average speed (mi/hr) for age groups

| | Without ADAS | | | With ADAS | | | Difference | | |
|---|---|---|---|---|---|---|---|---|---|
| Age | Arterial | Freeway | Total | Arterial | Freeway | Total | Arterial | Freeway | Total |
| 25-30 | 25.7 | 53.1 | 37.0 | 26.6 | 53.5 | 37.7 | 0.9 | 0.4 | 0.6 |
| 31-60 | 25.1 | 52.9 | 36.5 | 25.8 | 53.0 | 36.8 | 0.7 | 0.1 | 0.3 |
| Difference | 0.6 | 0.2 | 0.6 | 0.8 | 0.5 | 0.9 | | | |

Table 5-26. Average of average speed (mi/hr) for driver behavior groups

| | Without ADAS | | | With ADAS | | | Difference | | |
|---|---|---|---|---|---|---|---|---|---|
| | Arterial | Freeway | Total | Arterial | Freeway | Total | Arterial | Freeway | Total |
| Aggressive | 26.8 | 53.3 | 37.8 | 27.3 | 53.5 | 38.2 | 0.5 | 0.2 | 0.3 |
| Average | 25.5 | 53.0 | 37.0 | 26.6 | 53.3 | 37.6 | 1.2 | 0.3 | 0.6 |
| Conservative | 24.3 | 52.8 | 35.7 | 24.9 | 53.1 | 36.1 | 0.6 | 0.2 | 0.4 |
| Aggr-Avg | 1.3 | 0.3 | 0.8 | 0.7 | 0.2 | 0.6 | | | |
| Avg-Conser | 1.1 | 0.1 | 1.3 | 1.8 | 0.2 | 1.5 | | | |
| Aggr-Conser | 2.5 | 0.4 | 2.1 | 2.4 | 0.4 | 2.1 | | | |

Table 5-27. Average user acceptance for all subjects

| | Cronbach's alpha | Usefulness | Satisfaction |
|---|---|---|---|
| | 0.89 | 0.98 | 1.02 |
| LCA | 0.90 | 1.34 | 0.65 |
| Combination | 0.90 | 1.17 | 1.00 |

# CHAPTER 6
# CONCLUSIONS

This chapter summarizes the research conducted in this thesis and presents the conclusions drawn from the experiments. Future research and recommendations are also offered.

## Research Summary

The thesis evaluated the impacts of two ADAS (Adaptive Cruise Control and Lane Change Assist) in a driving simulator environment. This evaluation was divided in traffic impact of the systems, and user acceptance of them. These systems were implemented in the simulator by adapting algorithms from the literature. Scenarios were created in the simulator to provide specific situations for using these systems. Once the simulator software was prepared, the main objective was accomplished by having drivers driving the scenario first without these systems and secondly using both of them. The observed difference in driver behavior due to the systems was afterward analyzed by comparing various traffic performance measures. User acceptance of these systems was also evaluated using a questionnaire. Results show significant changes in driving behavior that could affect traffic dynamics positively, and also a positive acceptance of these systems by drivers.

## Research Conclusions

This research is an addition to better understand how drivers perceive different types of vehicle technologies. The experiment performed in this thesis evaluated two systems integrated in one vehicle and it provides a broad evaluation of ADAS impacts, and how they could affect traffic conditions.

The research conclusions based on the traffic impacts of these two systems are presented here.

Along the simulated freeway, participants in general had smaller space headways with the lead vehicle and less headway variability (determined by standard deviation) during car-following situations with the ACC, harmonizing traffic. The division in groups showed that all types of drivers changed their behavior, but older drivers and conservative ones were more affected by this system. Changes in driving behavior for these drivers represent a great possibility of traffic improvement. The system also contributed to more stable and homogeneous traffic conditions by eliminating differences due to different driver's characteristics.

The number of lane change maneuvers was significantly higher on the arterial and as a total for participants in general when using the LCA. This pattern indicates that drivers may have felt more relaxed to change lanes when the system was available. On the freeway, this pattern was not observed most likely because the ACC was being used at the same time. The ACC probably provided comfort to drivers since they did not have to perform tasks such as accelerating and braking. All types of drivers changed their behavior in some aspect, except aggressive and young ones. These two types of drivers were more likely to change lane more often than others in normal conditions (without the LCA). Older drivers, male and conservative ones were the most affected by this system, increasing the number of lane changes performed.

Minimum accepted distances with the adjacent vehicle behind and as a total were shorter for participants in general on the arterial when LCA was available. Female drivers and young ones decreased their minimum accepted distances on the arterial.

Minimum accepted distances on the freeway were shorter with LCA in all three cases (total gap, distance with adjacent vehicle in front and behind subject vehicle) for participants in general with the LCA. Male and conservative drivers were the most affected by the system on the freeway. Differences between driver behavior types on how they perceived minimum distances on the freeway were eliminated when the system was used.

Average distances (total gap, distance with vehicle in front and behind the subject vehicle) during lane change maneuvers were shorter for participants in general. Aggressive drivers did not change their behavior regarding accepted gaps, while conservative ones were the most affected. The system eliminated differences between all driver behavior types when LCA was used, contributing to more homogeneous traffic.

Average speed was higher for participants in two of all three cases (arterial and as total). Unexpectedly, average drivers were the only ones that significantly increased their speed with the systems. Differences between female and male groups and among driver types were eliminated when the systems were available.

Analysis on acceptance indicated that drivers were satisfied with the systems and thought of them as useful instruments to support driving tasks in the simulator. This indicates that a great percentage of drivers would be willing to use these systems in the future.

In summary, the presence and use of the two ADAS provided, in general, shorter headways and less variability of them under car following, more lane change maneuvers, with shorter minimum and average accepted distances with adjacent vehicles, and higher average speeds. In some cases, the systems eliminate significant differences between groups, providing more uniform and stable traffic conditions. These are all signs of change in driving behavior due to technologies that could be used or even adjusted to achieve better traffic conditions by just changing how drivers drive. In this experiment, the systems contributed significantly to improve traffic.

## Future Research and Recommendations

The following recommendations and directions for future research are offered here.

A validation study comparing on-road measures with the ones obtained in the simulator should be performed to refine results from this study. An on-road experiment with greater sample could quantify differences in traffic performance measures due to these systems.

The driving simulator was an appropriate tool to analyze driving behavior changes, but is limited to one vehicle. The traffic impact analyzed for one vehicle in this experiment should be extended to different market penetrations in a traffic simulator. This would make possible the evaluation of changes in traffic dynamics.

Before conducting an experiment as the one on this study, the researcher should analyze in detail the limitations and capabilities of the driving simulator that will be used. Specific facilities and a dynamic traffic could not be incorporated in this study because of these limitations. Following studies should analyze additional facilities and a more realistic traffic.

The sound used for LCA was a probable constraint to the full acceptance of this system. Before the actual testing of the system, a human-factor analysis should be performed with different indicators.

Safety studies should focus on specific types of drivers to evaluate how their driving behavior is affected by these systems. As an example shown in this thesis, aggressive drivers rarely changed their driving behavior due to the systems.

Collaboration with other study areas, like the one performed with the Occupational Therapy in this study, should be encouraged because it results in a more complete understanding of this topic.

These systems should be tested with specific driver types that may include older drivers with decreased awareness due to cognitive aging.

# APPENDIX A
# CODE FOR SYSTEM'S IMPLEMENTATION

Author: Hariharan Sridharan and Alok Whig

This document is intended to be used as a starting point to develop Open Module based Visual Basic modules for the driving simulator STISIM Drive. It also documents the two algorithms (Adaptive Cruise Control and Lane Change Assist) already implemented.

The Open Module Programming Guide (provided by STISIM) is the main bible and reference through which all modules may be written (all references to the word guide in this document refer to the Open Module Programming Guide).

All programming can only be based out of a computer on which the simulator is installed. This is because there are registered DLLs that come with the simulator which have to be linked with any code you may write.

It is essential to read the following topics in the guide before proceeding: Introduction, Open Module Programming and Visual Basic, STISIM Drive Variables and Objects, Open Module Methods. A dinner-table reading of the other topics would suffice initially.

While reading the above topics or once done reading, there are two projects provided with the simulator you should go through. They are located inside "C:\STISIM\Open Module". The folders are "OM_Sample" and "OM_Sample_New". You must copy these folders to another folder location on the simulator before proceeding. Play around with the code contained in the copied versions of these modules, link them with the simulator and have fun!

## Building your own Open Module

The chapter “Open Module Programming and Visual Basic” in the guide contains every bit of information to build your own module. For more information, read the Hints and Tips section in this document.

In case you are continuing with the Assist Driving module for Cruise Control or ACC, you could continue building the Assist_Driving module I have built  for the Lane-Change/Merge-Assist feature.

## Lane-Change/Merge-Assist

The code for this feature is located in C:\STISIM\Open Module\Assist_Driving

To implement this feature, I have modified the OM_Sample_New project. The details of the changes made are:

- New beep file added to STISIM sounds at C:\STISIM\Sound\beep-4.wav
- Changed line of code to point to this beep file in the Initialize method
- Added the following to the Update Method:

```
      Dim switchOnSound As Boolean
      If (Driver.Right = 0) Then
             If ((switchOnSound = False) And _
                    (Events.Vehicles(EIndex(I)).InitialHeading = 0) And _
                    (Events.Vehicles(EIndex(I)).LatPos - Vehicle.YLanePos) >
8 And _
                    (Events.Vehicles(EIndex(I)).LatPos - Vehicle.YLanePos) <
15) Then
                        If ((EDist(I) > -63) And (EDist(I) < 13)) Then
                             switchOnSound = True
                             Open "C:\\STISIM\\Open Module\\LCA.txt" For
Append As #17
                                    Print #17, "LEFT Indicator ON at time = "
& DV.TimeSinceStart & vbNewLine
                              Close #17
                        End If
              End If
      ElseIf (Driver.Left = 0) Then
              If ((switchOnSound = False) And _
                    (Events.Vehicles(EIndex(I)).InitialHeading = 0) And _
```

```
                    (Events.Vehicles(EIndex(I)).LatPos - Vehicle.YLanePos) <
-8 And _
                    (Events.Vehicles(EIndex(I)).LatPos - Vehicle.YLanePos) >
-15) Then
                        If ((EDist(I) > -63) And (EDist(I) < 13)) Then
                             switchOnSound = True
                             Open "C:\\STISIM\\Open Module\\LCA.txt" For
Append As #17
                                   Print #17, "RIGHT Indicator ON at time = "
& DV.TimeSinceStart & vbNewLine
                              Close #17
                        End If

              End If
      Else
            'do nothing don't beep
      End If
```

The code above contains distance extents based on which the beep will sound.

## Adaptive Cruise Control

The ACC is divided into two parts. Each version of the algorithm is deployed depending on constrains it satisfies. The foremost condition required to decide what version of ACC to use (simple or advanced) is to determine whether there is any leading vehicle in driver's lane that is close enough to be less than a threshold distance of 525 feet.

The simple ACC is deployed when the closest leading vehicle is more than 525 feet away from driver. This version enables driver to steadily increase its speed with a limit of top speed as set by the driver before starting a simulation. The driver (simulated vehicle) thinks that the road is clear of any traffic or obstruction.

Common output structure to carry results is of type NODE defined as:

```
Public Type NODE
   NewSpeed As Double
   NewAcl As Double
End Type
Dim NewParams As NODE
```

Given below is the block that executes simple ACC.

```
Private Function Apply_Simple_ACC(MyVehicle As DYNAMICSParams, DV As
OMDynamicVariables, ACCFlag As Boolean, MaxSpeed As Double) As NODE

     'Variables used
     Static CurV As Double                          'Current speed of driver
     Dim Vmax As Double                           'For storing maximum speed.
     Dim Acl As Double                               'For storing computed
acceleration.
     Dim Params As NODE                          'Output structure that stores
acceleration and speed.


     'Maximum speed allowed to be achieved by driver.
     Vmax = MaxSpeed

     'Temporary copying for intermediate calculations.
      CurV = MyVehicle.U

      'Block executed when ACC (red button) button is pressed by a driver
      If ACCFlag Then

               'Compute the acceleration term
               Acl = (Vmax - CurV) / 5

               If (Acl > 10) Then
                 Acl = 10
               ElseIf (Acl < -20) Then
                  Acl = -20
               Else
                  'Let it remain as it is
               End If

              'Where time spent (third variable) on one frame (here it is
0.05 sec for 20fps)
               If CurV Then
                 CurV = CurV + Acl * DV.TimeInc
               Else
                 CurV = 0
               End If

               If ((Math.Abs(CurV - Vmax) / Vmax * 100 < 1)) Then
                CurV = Vmax
                Acl = 0
               End If
      End If
      'Pass on parameters to main loop by initialing the output variable of
type structure
      'NODE
      Params.NewAcl = Acl
      Params.NewSpeed = CurV
```

```
     Apply_Simple_ACC = Params          ‘Return Control
End Function
```

Given below is the advanced variant of ACC.

```
Private Function Apply_Adv_ACC(MyVehicle As DYNAMICSParams, DV As
OMDynamicVariables, Vp As
                                                          Double, R As
Double, counter As Long, switchOnSound As Boolean, _
                                                          MaxSpeed As Double,
Th As Double, ACCSwitch As Boolean) As NODE

     ‘Variables used.
     Static CurV As Double  ‘Current speed of driver taken as input.
     Static Vc As Double
    Static Rh As Double   ‘desired headway distance between closest leading
vehicle in driver’s lane and driver.

     Static T As Double         ‘control parameter


     Static RDot As Double   ‘Speed differential between driver and closest
leading vehicle in driver’s lane.
     Dim Acl As Double         ‘Acceleration

     Dim Vmax As Double     ‘Maximum allowable speed.

     ‘useful in deciding what formula to use to compute final acceleration of
driver.
     Static Target_Diff_Percent As Double
     Static Target_Diff_Speed As Double

     ‘Temporary boolean variables
     Dim Cond1 As Boolean
     Dim Cond2 As Boolean
     Dim Cond3 As Boolean

     Dim percent As Double
     Dim Params As NODE      ‘output structure carrying final speed and
acceleration of driver.


     CurV = MyVehicle.U
     Acl = MyVehicle.UDot  'Dynamics Longitudinal acceleration
     Vmax = MaxSpeed


     ‘Execute this section on ACC button press and greater than zero speed of
driver.
```

```
        If ((ACCSwitch = True) And CInt(CurV)) Then

            'A useful control parameter
            T = 11

            'Step #1 – Compute the speed difference between closest leading
vehicle and driver.
            RDot = Vp - CurV

            'Step #2 - compute Rh ..desired headway distance ... it varies too
             Rh = Vp * Th

            'Step #3 - Compute Vc – commanded velocity for driver.
             Vc = Vp + (R - Rh) / T

             'Step #4 - Find Acceleration Needed when simulator approaches
leading vehicle
              If ((Math.Abs(CurV - Vp) / Vp * 100 < 1) And ((Math.Abs(R - Rh) /
Rh * 100 < 1))) Then
                  CurV = Vp
                  Acl = 0
              Else
                  'Test and Apply following.
                  'Cond 1
                   Target_Diff_Percent = Math.Abs((R - Rh)) / Rh * 100
                   If (Target_Diff_Percent > 1) Then
                     Cond1 = True
                   Else
                     Cond1 = False
                   End If
                   'Cond 2
                   Target_Diff_Speed = Math.Abs((Vc - CurV)) / Vc * 100
                   If (Target_Diff_Speed > 5) Then
                     Cond2 = True
                   Else
                     Cond2 = False
                   End If

                   'Cond 3
                   If ((Vc - Vp) > (CurV - Vc)) Then
                     Cond3 = True
                   Else
                     Cond3 = False
                   End If

                   If ((Cond1 = True) Or (Cond2 = True) Or (Cond3 = True)) Then
                       'Acclerration formula to be applied.
                       Acl = (Vc - CurV) / 5
                   Else
                       Acl = Vp - CurV
```

```
              End If
          End If

         If (Acl > 4) Then 'If (Acl > 0.25) Then
           Acl = 4
         ElseIf (Acl < -20) Then
           Acl = -20
         Else
           'let it remain same
         End If

         '0.05 is the time step  at frame rate 20 /sec - check configuration
settings
         CurV = CurV + Acl * DV.TimeInc

         If (CurV > Vmax) Then
             CurV = Vmax
         End If

    End If

   'Store the final computed acceleration and speed values to output
structure and return control.
    Params.NewAcl = Acl
    Params.NewSpeed = CurV

    Apply_Adv_ACC = Params

End Function
```

After the ACC computes acceleration and speed for driver, actual adjustments take place in the Dynamics() function of the STITIM system engine. It is here that dynamic variables are allowed to be modified.

Following shows Dynamics function where modification take place

```
Public Function Dynamics(Dyn As DYNAMICSParams) As Boolean
'
'   Function for handling all Open Module dynamic updates
'   Parameters:
'   Dyn - User defined type containing the driver's vehicle dynamic variables
'   Returns:
'   True if everything initialized fine, otherwise false. If false use the
ErrorMessage
'   parameter to return a message that the program can display to the user
'   Set the error handling
On Error GoTo ErrorOccurred
```

```
Dim CurSpeed As String

    ‘Block to determine whether there is any pedal press by driver.
    If (Driver.Throttle) Then
      ThrottleFlg = True
    Else
      ThrottleFlg = False
    End If

    'Modify the simulator speed as changed by ACC in Update()
    If ((NewParams.NewSpeed > 1) And (Dyn.U > 0) And (ACCSwitch = True) And
(ThrottleFlg = False)) Then

           ‘This line tells system to simulate gas / brake pedal press when
ACC adjusts speed.
           Dyn.DTh = Driver.Throttle
           Dyn.U = NewParams.NewSpeed

            'Modifying velocity dependent parameters
              Dyn.AbsU = NewParams.NewSpeed
              Dyn.UDot = NewParams.NewAcl
    Else
              NewParams.NewSpeed = Dyn.U
             NewParams.NewAcl = Dyn.Ax
    End If

‘For creating a digital speedometer to reflect speed of driver on screen
If StaticVars.DisplaySystem = "CenterDisplay" Then
    CurSpeed = CStr(CInt(Dyn.U * 0.681))
    With FormSpeed
      '.Height = Screen.Height / 10
      '.Width = Screen.Width / 10
      .lblSpeed.FontSize = 25
      .lblSpeed = CurSpeed
      .BorderStyle = 0
   End With
End If
'   Setup the return from function
Dynamics = True
Exit Function
'   Handle any errors
ErrorOccurred:
ErrorMessage = ProcessError("Dynamics")
Dynamics = False
End Function
```

The other important function is the Update() where logic of determining traffic flow and also to filter traffic to determine vehicles that should be considered for ACC calculations.

Only the portion where the logic is applied to find vehicles in driver's lane will be covered here.

```
Public Function Update(DV As OMDynamicVariables, Vehicle As DYNAMICSParams, _
Events As SimEvents, NumEvents As Integer, EDist() As Single, EDes() As
Integer, _
EIndex() As Integer, SimSounds() As SoundEffects) As Boolean

'   Function for handling all Open Module action during the actual simulation
loop
'
'
'   Parameters:
'
'            DV - User defined type containing the simulation parameters that
are changing at each time step
'       Vehicle - User defined type containing the driver's vehicle dynamic
variables
'        Events - UDT that contains the parameter settings for each supported
event
'     NumEvents - Number of events that are in the current display list
'       EDist() - Distance from the driver to the event
'        EDes() - Event designator for each active event
'      EIndex() - Event index for each event in the display list. This value
is the index into the Events UDT
'                 so that you can get the parameters for each individual
event in the display list
'   SimSounds() - Contains the sound buffer references to the simulator sound
effects
'
'   Returns:
'
'   True if everything initialized fine, otherwise false. If false use the
ErrorMessage
'   parameter to return a message that the program can display to the user
'
…..
      'There are three kinds of traffic based on direction of their flow.
     'A' stands for traffic flowing opposite to driver's direction
     'V' stands for traffic flowing in same direction to driver.
     'CT' stands for cross traffic with traffic direction perpendicular to
driver's direction.
       Case 15
                   ' checking if turn indicator is switched on
                      If switchOnSound = False And
(Events.Vehicles(EIndex(I)).InitialHeading = 0) And

(Math.Abs(Events.Vehicles(EIndex(I)).LatPos - Vehicle.YLanePos)
                                                  < 13) Then

                            If (EDist(I) > -63 And EDist(I) < 13) Then 'Or
```

```
(Events.Vehicles(EIndex(I)).Dist <
                            63 And Events.Vehicles(EIndex(I)).Dist > 0) Then
                            If Driver.Right = 0 Or Driver.Left = 0 Then
                               switchOnSound = True

                              ‘Print the time and status of indicator on lane
change.
                              Open "C:\\STISIM\\Open Module\\LCA.txt" For
Append As #17
                                   Print #17, "Indicator ON at time = " &
DV.TimeSinceStart & vbNewLine
                              Close #17
                            End If
                        End If
                    End If


                   'Task is to identify vehicles in same direction and same
lane.
                   'Assume: One direction traffic that is no approaching
vehicle.[No event A]
                   'Find vehicles in same lane as simulator.
                   'Find vehicles in same lane that is being followed
closest.
                    If counter = 1 Then
                        vehDis(Events.Vehicles(EIndex(I)).VehNum) =
Events.Vehicles(EIndex(I)).Dist
                    End If

                  'To determine traffic direction
                   If (Events.Vehicles(EIndex(I)).CosTerm = 1) Then


                        If (Math.Abs(Events.Vehicles(EIndex(I)).LatPos -
Vehicle.YLanePos) < 7) Then

                   vehDis(Events.Vehicles(EIndex(I)).VehNum) = EDist(I)

                              'Find vehicles that are being followed and that
are following sim

                                If (vehDis(Events.Vehicles(EIndex(I)).VehNum)
< 0) Then

                      'Last task is to find closest vehicle among leading
vehicles and then apply ACC

                                      'maintain simulator speed
                              Else
```

```
                                 'replaced Range by EDist. Value 15 is subtracted
to compensate for
                                  'vehicle's body length which should not be
ignored.
                                 If (clstLeadVehRng > EDist(I) - 15) Then
                                             clstLeadVehRng = EDist(I) - 15

                                   'Activate ACC if range between simulator and
the leading vehicle is < 525
                                    If (clstLeadVehRng < 525) Then
                                      'Call wrapper function that internally calls
ACC after reading from
                                      'ACCSwitchFile.txt and further activating
ACC() depending on switch value.

                                                     Vp =
Events.Vehicles(EIndex(I)).Speed
                                                      R = EDist(I) - 15

                                       'apply the advanced case of ACC. Speed and
acceleration adjusted.
                                        NewParams = Apply_Adv_ACC(Vehicle, DV, Vp,
R, counter,

switchOnSound,  MaxSpeed, Th,

ACCSwitch)

                                    Else
                                        'apply the simple case
                                        NewParams = Apply_Simple_ACC(Vehicle, DV,
ACCSwitch, MaxSpeed)
                              End If

                                End If
                            End If
                            Else

                       End If

                   Else
                                 'Else the vehicle is flowing opposite to
driver..ignore
                        End If

  ….
End of Function
```

Lastly, the headway time (variable Th in ACC) and the maximum allowable speed for driver is supplied through an external file read inside Initialize() function – system provided. Below is an extract from the function where file is read.

```
ACCSwitch = False
Open "C:\\STISIM\\Open Module\\ACC_Param.OM" For Input As #1
    Line Input #1, snextline
    snextline = snextline & vbCrLf
    MaxSpeed = snextline

    Line Input #1, snextline
    snextline = snextline & vbCrLf
    Th = snextline
Close #1
```

### All Hints and Tips

1. To get started, it is highly recommended to continue building from one of the two sample projects “OM_Sample”/“OM_Sample_New”. Copy them to a work location; edit the code to suit your needs to get started. Most/all of what you’ll be doing will be very similar to the samples provided in the Update method of these projects.

2. Make sure you use IntelliSense in VB to find out what objects or functions you can currently use on the STISIM object you are working with (hit Ctrl-Tab). The guide’s reference sections in Appendix A and B (towards the end) are the most useful sections that will tell you what all those letters and functions will do.

3. If the guide doesn’t clear your query/doubt, the forum is your one-stop shop for any questions you may have about the STISIM objects/methods. It is located at:
http://forums.systemstech.com/viewforum.php?f=2
You will need to login to be able to post on the forum. To apply for your own login, register at the forum and then email Ted asking him to activate your credentials.

You can expect responses to your queries within 1-2 days. If you don’t get a response after 3 working days, consider emailing Ted only then.

4. To link your Open Module DLL with the simulator, *TODO: fill this up at the simulator*

5. Every single time you edit the code, you will need to do the following to link it with the simulator.

a) Build the DLL again (refer guide “Creating and Registering a DLL”).
b) Copy it to the same folder locations in the Left and Right systems too as it is currently in the center system. (For Ex: C:\STISIM\Open Module\My Module on all 3 systems – Center, Left and Right).
c) Register the DLL on all 3 systems as outlined in the guide.

## Code that generated the DLL

```
Option Explicit
Public ACCSwitch As Boolean
Public MaxSpeed As Double
Public Th As Double
Public Type NODE
     NewSpeed As Double
     NewAcl As Double
End Type
Dim NewParams As NODE
Public ThrottleFlg As Boolean 'added july 16
Dim Tools As New TJRWinToolsCls
Dim Graphics As New TJR3DGraphics
Dim Terrain As New STI_3D_Terrain
Dim Ds As DirectSound
Public ErrorMessage As String
Public LogFileHandle As Long
Public NewForm As Form
Public TextMessage As String
Public WillHandleCrash As Long
Type DriverControlInputs
    Steer As Single                     ' Steering angle count from the
controller card
    Throttle As Single                  ' Throttle control count from the
controller card
    brake As Single                     ' Brake control count from the
controller card
    Gear As Integer                     ' Current transmission gear
    Horn As Integer                     ' Current state of the horn button, 0
- Activated
    Left As Integer                     ' Current state of the left turn
signal, 0 - Activated
    Right As Integer                    ' Current state of the right turn
signal, 0 - Activated
End Type
Dim Driver As DriverControlInputs
Type SoundFiles
    Active As Boolean                   ' True if sound is currently
available for playing
    Buffer As DirectSoundBuffer         ' DirectSoundBuffer object that holds
the WAV file to be played
    FileName As String                  ' File name of the WAV file that will
be played
    Running As Boolean                  ' True if the current sound effect is
being played
End Type
Dim Sounds() As SoundFiles
Type Vehicle
    SixDof As SixDOFPosition            ' Inertial orientation of the vehicle
```

```
    Lat As Single                           ' Lane postion with respect to the
roadway centerline
    Lon As Single                           ' Distance into the run (from the
beginning)
    Speed As Single                         ' Vehicle speed
    Acceleration As Single                  ' Vehicle acceleration
    Index(1) As Long                        ' 0 - Lights off, 1 - Lights on
    VisFlag(1) As Long                      ' 0 - Lights off, 1 - Lights on
    InitialHeading As Single                ' Vehicle initial heading when it is
activated
End Type
Dim V() As Vehicle
Dim Bool As Boolean                         ' Temporary boolean variable for use
anytime a throw away boolean is needed
Dim DataFileName As String                  ' Name of the open module data file
that will hold data during the run
Dim DataFileNum As Integer                  ' File number for the data file that
will hold data during the run
Dim DynVars As OMDynamicVariables           ' UDT containing STISIM Drive
variables that change as the run progresses
Dim ImagePointers() As Long                 ' Array containing the handles of the
screen images that will be used
Dim NumImages As Integer                    ' Number of screen images that will
be used
Dim NumSounds As Integer                    ' Number of sound effect files that
will be used
Dim NumVehicles As Integer                  ' Number of vehicles that will be
displayed
Dim ScreenObjects() As SixDOFPosition       ' Array of screenobjects that will
displayed
Dim St As String                            ' Temporary string variable for use
anytime a throw away string is needed
Dim StaticVars As OMStaticVariables         ' UDT containing STISIM Drive
variables that are fixed by the simulator
Public Function AddNew(OMVars As OMParameters) As Boolean
On Error GoTo ErrorOccurred
AddNew = True
Exit Function
ErrorOccurred:
ErrorMessage = ProcessError("AddNew")
AddNew = False
End Function
Public Function ControlInputs(Dyn As DYNAMICSParams, Steering As Single,
Throttle As Single, _
brake As Single, Gear As Integer, DInput As Integer) As Boolean
On Error GoTo ErrorOccurred
Driver.brake = brake
Driver.Steer = Steering
Driver.Throttle = Throttle
Driver.Gear = Gear
```

```
Driver.Horn = DInput And 1
Driver.Left = DInput And 2
Driver.Right = DInput And 4
ControlInputs = True
Exit Function
ErrorOccurred:
ErrorMessage = ProcessError("ControlInputs")
ControlInputs = False
End Function

Public Function Dynamics(Dyn As DYNAMICSParams) As Boolean
On Error GoTo ErrorOccurred
Dim CurSpeed As String
    If (Driver.Throttle) Then
      ThrottleFlg = True
    Else
      ThrottleFlg = False
    End If
    If ((NewParams.NewSpeed > 1) And (Dyn.U > 0) And (ACCSwitch = True) And
(ThrottleFlg = False)) Then
            Dyn.DTh = Driver.Throttle
            Dyn.U = NewParams.NewSpeed
            Dyn.AbsU = NewParams.NewSpeed
            Dyn.UDot = NewParams.NewAcl
    Else
            NewParams.NewSpeed = Dyn.U
            NewParams.NewAcl = Dyn.Ax
    End If
If StaticVars.DisplaySystem = "CenterDisplay" Then
    CurSpeed = CStr(CInt(Dyn.U * 0.681))   'convert ft/sec to mph
    With FormSpeed
      .lblSpeed.FontSize = 40
      .lblSpeed = CurSpeed
      .BorderStyle = 0
    End With
End If
Dynamics = True
Exit Function
ErrorOccurred:
ErrorMessage = ProcessError("Dynamics")
Dynamics = False
End Function

Public Function HandleCrash(Override As Integer) As Boolean
On Error GoTo ErrorOccurred
Override = 0
HandleCrash = True
Exit Function
ErrorOccurred:
ErrorMessage = ProcessError("HandleCrash")
```

```
HandleCrash = False
End Function
Dim FileNum As Integer
Dim I As Integer
Dim SoundFileNames(1) As String

Dim snextline As String 'added july 20
On Error GoTo ErrorOccurred
StaticVars = SV
ACCSwitch = False
Open "C:\\STISIM\\Open Module\\ACC_Param.OM" For Input As #1
    Line Input #1, snextline
    snextline = snextline & vbCrLf
    MaxSpeed = snextline

    Line Input #1, snextline
    snextline = snextline & vbCrLf
    Th = snextline
Close #1
Graphics.Renderer = StaticVars.Renderer
SoundFileNames(0) = "C:\STISIM\Sound\beep-4.wav"
SoundFileNames(1) = "C:\STISIM\Sound\Horn.Wav"
If StaticVars.DisplaySystem = "CenterDisplay" Then
    NumSounds = 2
    If NumSounds Then
        If StaticVars.SoundOn = True Then
            ReDim Sounds(NumSounds - 1)
            For I = 0 To NumSounds - 1
                Sounds(I).FileName = SoundFileNames(I)
                If Tools.FileExist(Sounds(I).FileName) = False Then
                    ErrorMessage = "The warning sound file " &
Sounds(I).FileName & " could not be found! The simulation run will be
aborte!"
                    Initialize = False
                    Exit Function
                End If
            Next
            For I = 0 To NumSounds - 1
                Sounds(I).Active = Tools.CreateDSBFromWaveFile(Ds,
Sounds(I).FileName, Sounds(I).Buffer)
            Next
        End If
    End If
End If
With CommForm.MSComm1
    If .PortOpen = False Then
        .CommPort = 1
        .Settings = "9600,N,8,1"
        .RThreshold = 0
        .InBufferSize = 128
```

```
        .InputLen = 0
        .InputMode = comInputModeText
        .NullDiscard = False
        .OutBufferSize = 128
        .ParityReplace = ""
        .RThreshold = 0
        .PortOpen = True
    End If
End With
With FormSpeed
  .Height = 1400
  .Width = 1800
  .Visible = True
  .Top = Screen.Height * 0.4
  .Left = 1.25 * Screen.Width
  .BorderStyle = 0
  .Caption = "Your Speed"
  .lblSpeed.Alignment = 0
  .lblSpeed.FontName = "Verdana"
  .lblSpeed.Top = 0
End With
Tools.WindowOnTop (FormSpeed.hWnd)
ACCSwitch = False
Initialize = True
Exit Function
ErrorOccurred:
ErrorMessage = ProcessError("Initialize")
Initialize = False
End Function
Public Function InitializeTerrain(RCL() As RoadCenterLine, NumRoadSegs As
Long, Road() As EventROADType, NumRoad As Long, Vc() As EventVCType, NumVC As
Long) As Boolean
SDL scenario file)
On Error GoTo ErrorOccurred
Call Terrain.AssignRCLVariables(RCL(), NumRoadSegs)
Call Terrain.AssignRoadVariables(Road(), NumRoad)
Call Terrain.AssignVCVariables(Vc(), NumVC)
Terrain.NumRoadSeg = NumRoadSegs
InitializeTerrain = True
Exit Function
ErrorOccurred:
ErrorMessage = ProcessError("initializeTerrain")
InitializeTerrain = False
End Function
Public Function PostRun(Comments As String, DriverName As String, RunNumber
As
On Error GoTo ErrorOccurred
Set Ds = Nothing
Set Tools = Nothing
PostRun = True
```

```
Exit Function
ErrorOccurred:
ErrorMessage = ProcessError("PostRun")
PostRun = False
End Function
Public Function Shutdown(RunCompleted As Integer) As Boolean
Dim I As Integer
On Error GoTo ErrorOccurred
If StaticVars.DisplaySystem = "CenterDisplay" Then
    If NumSounds Then
        For I = 0 To NumSounds - 1
            If Sounds(I).Active = True Then
                Sounds(I).Buffer.Stop
                Set Sounds(I).Buffer = Nothing
            End If
        Next
    End If
End If
Set Graphics = Nothing
Set Terrain = Nothing
Shutdown = True
Exit Function
ErrorOccurred:
ErrorMessage = ProcessError("Shutdown")
Shutdown = False
End Function
Public Function StartUp(Config As GAINSParams, BackForm As Object, SV As
OMStaticVariables, UseNew As Boolean, DsIn As DirectSound) As Boolean
On Error GoTo ErrorOccurred
If SV.SoundOn = True Then
    Set Ds = DsIn
    DirectSoundCreate ByVal 0&, Ds, Nothing
    Ds.SetCooperativeLevel SV.ActiveHandle, DSSCL_NORMAL
End If
UseNew = False
StartUp = True
Exit Function
ErrorOccurred:
ErrorMessage = ProcessError("StartUp")
StartUp = False
End Function
Public Function Update(DV As OMDynamicVariables, Vehicle As DYNAMICSParams, _
Events As SimEvents, NumEvents As Integer, EDist() As Single, EDes() As
Integer, _
EIndex() As Integer, SimSounds() As SoundEffects) As Boolean
Dim ElapsedTime As Single
Dim FirstLight As Boolean
Dim I As Integer
Dim J As Integer
Dim LightIndex As Integer
```

```
Dim switchOnSound As Boolean
Dim snextline As String 'Simulates hardware switch that activates ACC().
Dim CurSpeed As Long   'Will be removed later. For testing only whether ctrl
goes to ACC
Static counter As Long  'Temporary counter used to change ACC flag after a
limit to simulate
Dim K As Double  'for testing
Static FLG As Integer
Dim DstTravelled As Long
Static clstLeadVehRng As Double   'Closest leading Vehicle Distance to
Simulator Static vehDis(250) As Double
Static Vp As Double
Static R As Double
Dim Err As Double
Static Range(250) As Double
clstLeadVehRng = 100000 'Init with a large number
On Error GoTo ErrorOccurred
If StaticVars.DisplaySystem = "CenterDisplay" Then
    switchOnSound = False
    counter = counter + 1 ' July 22, 2010 - for printing ACC state
     Open "C:\\STISIM\\Open Module\\ACCState.txt" For Append As #29
          If ((DV.KeyCommand = 71) Or (DV.KeyCommand = 103)) Then
                  ACCSwitch = True
                  switchOnSound = True
                  Print #29, "ACC is TRUE at time =" & DV.TimeSinceStart &
vbNewLine
          End If
             If ((ACCSwitch = True) And Driver.brake) Then
                    ACCSwitch = False
                    Print #29, "ACC is FALSE at time = " & DV.TimeSinceStart
& vbNewLine & vbNewLine
            End If
     Close #29
    For I = 1 To NumEvents
        Select Case EDes(I)
            Case 15
         If (Driver.Right = 0) Then
             If ((switchOnSound = False) And _
                    (Events.Vehicles(EIndex(I)).InitialHeading = 0) And _
                    (Events.Vehicles(EIndex(I)).LatPos - Vehicle.YLanePos) >
8 And _
                    (Events.Vehicles(EIndex(I)).LatPos - Vehicle.YLanePos) <
15) Then
                        If ((EDist(I) > -63) And (EDist(I) < 13)) Then
                             switchOnSound = True
                             Open "C:\\STISIM\\Open Module\\LCA.txt" For
Append As #17
                                   Print #17, "LEFT Indicator ON at time = "
& DV.TimeSinceStart & vbNewLine
                              Close #17
```

```
                        End If
              End If
      ElseIf (Driver.Left = 0) Then
              If ((switchOnSound = False) And _
                    (Events.Vehicles(EIndex(I)).InitialHeading = 0) And _
                    (Events.Vehicles(EIndex(I)).LatPos - Vehicle.YLanePos) <
-8 And _
                    (Events.Vehicles(EIndex(I)).LatPos - Vehicle.YLanePos) >
-15) Then
                        If ((EDist(I) > -63) And (EDist(I) < 13)) Then
                             switchOnSound = True
                             Open "C:\\STISIM\\Open Module\\LCA.txt" For
Append As #17
                                   Print #17, "RIGHT Indicator ON at time = "
& DV.TimeSinceStart & vbNewLine
                              Close #17
                        End If

              End If
      Else
      End If
                    If counter = 1 Then
                        vehDis(Events.Vehicles(EIndex(I)).VehNum) =
Events.Vehicles(EIndex(I)).Dist
                    End If
                   If (Events.Vehicles(EIndex(I)).CosTerm = 1) Then
                        If (Math.Abs(Events.Vehicles(EIndex(I)).LatPos -
Vehicle.YLanePos) < 7) Then
                                vehDis(Events.Vehicles(EIndex(I)).VehNum) =
EDist(I)
                                If (vehDis(Events.Vehicles(EIndex(I)).VehNum)
< 0) Then
                                Else
                                    If (clstLeadVehRng > EDist(I) - 15) Then
                                        clstLeadVehRng = EDist(I) - 15
'Discussed on July 13
                                        If (clstLeadVehRng < 525) Then
                                                Vp =
Events.Vehicles(EIndex(I)).Speed
                                                R = EDist(I) - 15
                                                NewParams =
Apply_Adv_ACC(Vehicle, DV, Vp, R, counter, switchOnSound, MaxSpeed, Th,
ACCSwitch)
                                        Else
                                       NewParams = Apply_Simple_ACC(Vehicle,
DV, ACCSwitch, MaxSpeed)
                                        End If
                                  End If
                                 End If
                        Else
```

```
                        End If
                    Else
                         'Implies the vehicle is of type 'A' or travelling in
opposite direction
                    End If
            Case 16
                If EDist(I) < 100 Then
                End If
            Case 17
                    With Events.Sl(EIndex(I))
                        LightIndex = EIndex(I)
                    End With
            Case 21
                With Events.Ped(EIndex(I))
                    If Events.Sl(LightIndex).LightState(1) = 2 Then
                        If Int(.Direction) = 1 Or Int(.Direction) = 4 Then
                            .Walking = 1
                            .Velocity = (DV.RoadWidthL + DV.RoadWidthR + 4) /
(Events.Sl(LightIndex).RedOnTime - 3)
                        End If
                        If .Walking Then
                            If .LatPos < -(DV.RoadWidthL + 4) Then
                                .Velocity = 0
                                .Direction = 0
                                .Walking = 0
                            End If
                        Else
                            .Dist = 0
                        End If
                    ElseIf Events.Sl(LightIndex).LightState(1) = 0 Then
                        If Events.Sl(LightIndex).FreezeOnGreen = True Then
                            If Int(.Direction) = 0 Or Int(.Direction) = 3
Then
                                .Walking = 1
                                .Velocity = 3.5
                                .Dist = .Dist + .Velocity * DV.TimeInc
                            End If
                            If Abs(.Dist) > (DV.RoadWidthL + DV.RoadWidthR +
7) Then
                                .Walking = 0
                                .Velocity = 0
                                .Image = 0
                                .Direction = 4.7124
                            End If
                        End If
                    End If
                  End With
          End Select
    Next
    Call AuditoryWarning(switchOnSound, 0)
```

```
End If
With CommForm.MSComm1
    If .PortOpen = True Then
        .Output = "Test"
        DoEvents
    End If
End With

'De-allocate memory from array variables -- Added July 27,2010
Erase vehDis, Range
DynVars = DV
Update = True
Exit Function
ErrorOccurred:
ErrorMessage = ProcessError("Update")
Update = False
End Function
Private Sub AuditoryWarning(Setting As Boolean, Index As Integer)
Dim DSBStatus As Long
If Setting = True Then
    If Sounds(Index).Running = False Then
        If Sounds(Index).Active = True Then
            Sounds(Index).Buffer.Play 0, 0, 1
            Sounds(Index).Running = True
        End If
    End If
ElseIf Sounds(Index).Running = True Then
    Call Sounds(Index).Buffer.GetStatus(DSBStatus)
    If DSBStatus <> DSBSTATUS_PLAYING Then
        Sounds(Index).Running = False
        Sounds(Index).Buffer.Stop
        Sounds(Index).Buffer.SetCurrentPosition 0
    End If
End If
End Sub
Private Function ProcessError(ModuleName As String) As String
St = "Simulation run aborted! An error has occurred in Open Module " &
ModuleName & ":" & vbCrLf & vbCrLf
St = St & "Error number:" & vbTab & Trim(Str(Err.Number)) & vbCrLf
St = St & "Description:" & vbTab & Err.Description & vbCrLf
St = St & "Error source:" & vbTab & Err.Source & vbCrLf
ProcessError = St & "Last DLL Error:" & vbTab & Err.LastDllError & vbCrLf
Bool = Tools.WriteToTJRFile(StaticVars.LogFileHandle, ProcessError)
End Function
Private Function Apply_Simple_ACC(MyVehicle As DYNAMICSParams, DV As
OMDynamicVariables, ACCFlag As Boolean, MaxSpeed As Double) As NODE
     Static CurV As Double   'current speed of driver
     Dim Vmax As Double      'maximum speed allowed
     Dim Acl As Double       'computed acceleration
```

```
     Dim Params As NODE      'A structure carrying final computed speed and
accelration of driver
     Vmax = MaxSpeed
      CurV = MyVehicle.U
               Acl = (Vmax - CurV) / 5
               If (Acl > 10) Then
                 Acl = 10
               ElseIf (Acl < -20) Then
                  Acl = -20
               Else
               End If
               If CurV Then
                 CurV = CurV + Acl * DV.TimeInc
               Else
                 CurV = 0
               End If
               If ((Math.Abs(CurV - Vmax) / Vmax * 100 < 1)) Then
                CurV = Vmax
                Acl = 0
               End If
      End If
      Params.NewAcl = Acl
      Params.NewSpeed = CurV
      Apply_Simple_ACC = Params
End Function
Private Function Apply_Adv_ACC(MyVehicle As DYNAMICSParams, DV As
OMDynamicVariables, Vp As Double, _
                               R As Double, counter As Long, switchOnSound As
Boolean, _
                               MaxSpeed As Double, Th As Double, ACCSwitch As
Boolean) As NODE
     Static CurV As Double  'current speed of driver
     Static Vc As Double    'commanded speed
     Static Rh As Double    'head way distance
     Static T As Double     ' control paramter
     Static RDot As Double  'rate of change of speed difference between
driver and closest leading vehicle
     Dim Acl As Double      'final acceleration of driver
     Dim Vmax As Double     'max allowed speed
     Static Target_Diff_Percent As Double    'used as a threshold
     Static Target_Diff_Speed As Double      'used as a threshold

     Dim Cond1 As Boolean
     Dim Cond2 As Boolean
     Dim Cond3 As Boolean
     Dim percent As Double        'temp variable
     Dim Params As NODE           'output parameter carrying final speed and
acceleration of driver
     CurV = MyVehicle.U
     Acl = MyVehicle.UDot          'Dynamics Longitudinal acceleration
```

```
     Vmax = MaxSpeed
     If ((ACCSwitch = True) And CInt(CurV)) Then
            T = 11 'average
         RDot = Vp - CurV
          Rh = Vp * Th
          Vc = Vp + (R - Rh) / T
           If ((Math.Abs(CurV - Vp) / Vp * 100 < 1) And ((Math.Abs(R - Rh) /
Rh * 100 < 1))) Then
               CurV = Vp
               Acl = 0
           Else
                Target_Diff_Percent = Math.Abs((R - Rh)) / Rh * 100
                If (Target_Diff_Percent > 1) Then
                  Cond1 = True
                Else
                  Cond1 = False
                End If
                Target_Diff_Speed = Math.Abs((Vc - CurV)) / Vc * 100
                If (Target_Diff_Speed > 5) Then
                  Cond2 = True
                Else
                  Cond2 = False
                End If
                If ((Vc - Vp) > (CurV - Vc)) Then
                  Cond3 = True
                Else
                  Cond3 = False
                End If
                If ((Cond1 = True) Or (Cond2 = True) Or (Cond3 = True)) Then
                    Acl = (Vc - CurV) / 5
                Else
                    Acl = Vp - CurV
                End If
           End If
          If (Acl > 10) Then 'If (Acl > 0.25) Then
            Acl = 10
          ElseIf (Acl < -20) Then
            Acl = -20
          Else
          End If
          CurV = CurV + Acl * DV.TimeInc
          If (CurV > Vmax) Then
              CurV = Vmax
          End If
    End If
    Params.NewAcl = Acl
    Params.NewSpeed = CurV
    Apply_Adv_ACC = Params
End Function
```

APPENDIX B
SCENARIO FILES

**Second Scenario**

```
-1, output
0, BSAV, 1, 0.495, SPEED, 1, 23, 2, 6, 7, 36, 19

-1, Roadway arterial
0, ROAD, 12, 6, 3, 2, 0, 10, 10, 0.333, 0.333, 400, 0, 0, 0, 5, 0, 5
800, ROAD, 12, 6, 3, 2, 0, 10, 10, 0.333, 0.333, 400, 0, 0, 0, 5, 0, 5
2400, ROAD, 12, 6, 3, 2, 0, 10, 10, 0.333, 0.333, 400, 0, 0, 0, 5, 0, 5
3600, ROAD, 12, 6, 3, 2, 0, 10, 10, 0.333, 0.333, 400, 0, 0, 0, 5, 0, 5
4400, ROAD, 12, 6, 3, 2, 0, 10, 10, 0.333, 0.333, 400, 0, 0, 0, 5, 0, 5
6200, ROAD, 12, 6, 3, 2, 0, 10, 10, 0.333, 0.333, 400, 0, 0, 0, 5, 0, 5
13800, ROAD, 12, 4, 2, 2, 0, 10, 10, 0.333, 0.333, 400, 0, 0, 0, 5, 0, 5
17300, ROAD, 12, 4, 2, 2, 0, 10, 10, 0.333, 0.333, 400, 0, 0, 0, 5, 0, 5,0,0,0,0,6

-1 curves
16500,C,0,0,500,0,-.00025
19000,C,0,0,800,0,-.0005
26300, C,0,0,800,0,-.0003
35800, C,0,0,800,0,-.0005

-1, intersection
4800,I,0,0,3,0,0,2
7800,I,0,0,2,0,0,1
12800,I,0,0,2,0,0,1
15800,I,0,0,3,0,0,2

-1, Signals
2400, SL,-2400,15,3,15,0,0,2,1,0
5400, SL,-2400,15,3,15,0,0,2,1,0
10400, SL,-2400,15,3,15,0,0,2,1,0
13400, SL,-2400,15,3,15,0,0,2,1,0

-1, Speed limit Signs
0, SIGN, 100, 200, C:\STISIM\Data\Signs\Sp40Mph.3ds
2200, SIGN, 100, 1000, C:\STISIM\Data\Signs\Sp40Mph.3ds
4900, SIGN, 100, 400, C:\STISIM\Data\Signs\Sp40Mph.3ds
7900, SIGN, 100, 400, C:\STISIM\Data\Signs\Sp40Mph.3ds
10800, SIGN, 100, 1000, C:\STISIM\Data\Signs\Sp40Mph.3ds
12900, SIGN, 100, 300, C:\STISIM\Data\Signs\Sp40Mph.3ds
12900,SIGN, 100, 600, C:\STISIM\Data\Signs\NARROWS.3ds
15900, SIGN, 100, 200, C:\STISIM\Data\Signs\SP65MPH.3DS
17200, SIGN, 100, 1000, C:\STISIM\Data\Signs\SP65MPH.3DS
18200, SIGN, 4, 600, 0, 0
```

```
23200, SIGN, 100, 1000, C:\STISIM\Data\Signs\SP65MPH.3DS
25500, SIGN, 4, 600, 0, 0
29200, SIGN, 100, 1000, C:\STISIM\Data\Signs\SP65MPH.3DS
32000, SIGN, 100, 1000, C:\STISIM\Data\Signs\SP65MPH.3DS
35000, SIGN, 4, 600, 0, 0
36500, SIGN, 100, 1000, C:\STISIM\Data\Signs\Sp65Mph.3ds

-1 sounds
3500, PR, C:\STISIM\Data\FHWA\Sounds\IntersectionLeft.wav,0,10
6500, PR, C:\STISIM\Data\FHWA\Sounds\IntersectionRight.wav,0,10
11500, PR, C:\STISIM\Data\FHWA\Sounds\IntersectionRight.wav,0,10
14500, PR, C:\STISIM\Data\FHWA\Sounds\IntersectionLeft.wav,0,10
16500, PR, C:\STISIM\Data\FHWA\Sounds\accsound.wav,0,10

-1,vehicles on the same side
0, V,40,60,6,1, *1~4
0, V,45,150,18,1, *18~27
0, V,45,100,30,1, *31~35
0, V,50,200,30,1, *31~35
0, V,49,260,18,1, *1~4
0, V,50,380,30,1, *31~35
0, V,48,300,6,1, *1~4
0, V,49,450,6,1, *18~27
0, V,52,490,6,1, *18~27
0, V,52,390,18,1, *31~35
0, V,52,460,30,1, *1~4
0, V,53,480,18,1, *1~4
0, V,55,550,6,1, *1~4
0, V,57,530,18,1, *31~35
0, V,55,620,30,1, *18~27
0, V,55,600,6,1, *1~4
0, V,55,700,30,1, *1~4
0, V,61,730,6,1, *18~27
0, V,62,600,18,1, *1~4
0, V,62,750,30,1, *31~35
0, V,63,-500,6,1, *18~27
0, V,/2,-450,18,1, *1~4
0, V,64,-350,30,1, *31~35
0, V,61,-650,6,1, *18~27
0, V,65,-700,18,1, *31~35
0, V,62,-750,30,1, *18~27
0, V,63,-800,6,1, *1~4
0, V,70,-850,18,1, *31~35
0, V,60,-820,30,1, *1~4
4850, v, 44, 150, 6, 1, *18~27
4850, v, 42, 430, 18, 1, *31~35
```

4850, v, 44, 250, 30, 1, *1~4, 1, 0, *10, 2
4850, v, 44, 500, 6, 1 , *18~27
4850, v, 46, 550, 18, 1, *18~27
4850, v, 48, 400, 30, 1, *31~35
4850, v, 50, 600, 6, 1, *18~27
4850, v, 51, 650, 18, 1, *18~27
4850, v, 51, 800, 30, 1, *1~4
4850, v, 53, 630, 6, 1, *18~27
4850, v, 53, 680, 18, 1, *18~27
4850, v, 54, 890, 30, 1, *1~4
4850, v, 44, -200, 18, 1, *31~35
4850, v, 46, -200, 30, 1, *18~27
5400, V, 63, -500,6,1, *18~27
5400, V, /2, -450,18,1, *1~4
5400, V, 64, -350,30,1, *31~35
5400, V, 61, -450,6,1, *18~27
5400, V, 65, -300,18,1, *31~35
5400, V, 52, -450,30,1, *18~27
5400, V, 63, -550,6,1, *1~4
7850, v, 44, 200, 6, 1, *18~27
7850, v, 46, 320, 18, 1, *18~27
7850, v, 44, 330, 30, 1, *18~27
7850, v, 49, 350, 6, 1, *18~27
7850, v, 50, 390, 18, 1, *18~27
7850, v, 50, 500, 30, 1, *18~27
7850, v, 52, 450, 6, 1, *18~27
7850, v, 52, 500, 18, 1, *18~27
7850, v, 53, 700, 30, 1, *18~27
7850, v, 55, 620, 6, 1, *18~27
7850, v, 55, 580, 18, 1, *18~27
7850, v, 57, 820, 30, 1, *18~27
7850, v, 58, 700, 6, 1, *18~27
7850, v, 59, 710, 18, 1, *18~27
7850, v, 60, 850, 30, 1, *1~4
7850, v, 45, 850, 18, 1, *18~27
7850, v, 48, 970, 30, 1, *1~4
7850, v, 65, -100, 30, 1, *1~4
7850, v, 48, -200, 18, 1, *18~27
7850, v, 60, -250, 18, 1, *18~27
7850, v, 60, -250, 30, 1, *18~27
7850, v, 65, -350, 6, 1, *18~27
7850, v, 65, -350, 30, 1, *18~27
8400, V, 63, -500,6,1, *18~27
8400, V, /2, -450,18,1, *1~4
8400, V, 64, -350,30,1, *31~35
8400, V, 61, -450,6,1, *18~27

8400, V, 65, -300,18,1, *31~35
8400, V, 52, -450,30,1, *18~27
8400, V, 63, -550,6,1, *1~4
12830, V,73,-800,18,1, *18~27
12830, V,70,-600,6,1, *1~4
12830, V,51,500,6,1, *31~35
12830, V,57,550,18,1, *1~4
12830, V,60,600,6,1, *1~4
12830, V,61,650,18,1, *31~35
12830, V,55,700,6,1, *18~27

-1 freeway vehicles
15850, V,95,350,9,1, *1~4
15850, V,103,500,21,1, *18~27
15850, v, 91, 800, 9, 1, *1~4
16000, V,94,850,9,1, *31~35
16450, v, 95, 800, 21,1, *18~27
16950, v, 97, 800, 9,1, *31~35
17200, V,88,800,9,1, *1~4
17350, v, 98, 800, 21,1,*31~35
18050, v,97, 800, 21,1, *18~27
18650, v, 92, 800, 21,1,*31~35
19350, v, 91, 800, 21,1,*1~4
19750, V,103,850,21,1, *31~35
19900, V,101,800,9,1,  *18~27
20200, V,95,800,9,1, *31~35
20350, v, 95, 800, 21,1,*1~4
21200, V,97,800,9,1, *31~35
24800, V,98,800,9,1,  *18~27
25200, V,92,900,9,1, *31~35
26850, V,94,850,21,1, *1~4
26900, V,95,900,21,1, *31~35
27800, V,89,800,9,1,  *18~27
27900, V,91,900,21,1, *31~35
28500, V,95,800,21,1,*1~4
29200, V,97,900,9,1, *31~35
29850, V,98,850,21,1,  *18~27
30500, V,89,950,9,1, *31~35
30850, V,100,850,21,1, *1~4
31350, v, 95, 900, 21,1,*31~35
31500, V,92,850,9,1, *31~35
31800, V,94,900,9,1, *1~4
31850, V,97,850,21,1, *31~35
32850, V,98,950,21,1,  *18~27
34500, V,95,850,9,1, *31~35
34850, V,95,950,21,1, *1~4

36700, V,94,800,9,1,  *18~27
38250, V,100,950,9,1, *31~35
38350, v,94, 900, 21,1, *1~4
38500, V,95,850,9,1, *31~35
39700, V,97,900,21,1,  *18~27
16400, V, 93, -500,9,1, *18~27
16400, V, 98, -450,21,1, *1~4
16400, V, 97, -350,9,1, *31~35
16400, V, 86, -450,9,1, *18~27
16400, V, 95, -300,21,1, *31~35
16400, V, 92, -450,9,1, *18~27
16400, V, 83, -550,21,1, *1~4

-1, cross traffic
300, A,45,1000,-6,*1~4
600, A,50,1000,-18,*31~35
900, A,66,1000,-30,*1~4
1100, A,55,1000,-6,*18~27
1300, A,45,1000,-6,*31~35
1600, A,50,1000,-18,*18~27
1900, A,66,1000,-30,*1~4
2300, A,55,1000,-6,*18~27
2600, A,45,1000,-30,*1~4
3100, A,50,1000,-18,*31~35
3700, A,66,1000,-30,*1~4
4100, A,55,1000,-6,*31~35
4100, A,45,1000,-30,*18~27
4600, A,50,1000,-18,*1~4
4650, A,45,900,-6,*18~27
4650, A, 50,900,-18,*18~27
4600, A,45,850,-6,*18~27
4600, A, 50,900,-18,*18~27
4650, A, 53,1000,-30,*18~27
4650, A, 53,1150,-18,*18~27
4700, A, 53,1250,-6,*18~27
4700, A, 53,1400,-6,*18~27
4700, A, 53,1500,-18,*18~27
4700, A, 53,1300,-30,*18~27
4900, A,66,1000,-30,*31~35
4950, A,55,1000,-6,*1~4
5200, A,45,1000,-30,*18~27
5700, A,50,1000,-18,*1~4
6000, A,66,1000,-30,*31~35
6400, A,55,1000,-6,*31~35
7100, A,45,1000,-30,*1~4
7300, A,50,1000,-18,*31~35

7850, A, 53,1000,-30,*1~4
8000, A,66,1000,-30,*18~27
8350, A,55,1000,-6,*31~35
8600, A,45,1000,-30,*1~4
9100, A,50,1000,-18,*18~27
9600, A,66,1000,-30,*18~27
10100, A,55,1000,-6,*31~35
10600, A,45,1000,-30,*1~4
10700, A,50,1000,-18,*18~27
11200, A, 53,1000,-30,*1~4
11900, A,66,1000,-30,*31~35
12350, A,55,1000,-6,*31~35
12600, A,45,1000,-30,*1~4
12850, A,50,1000,-18,*31~35
12900, A,66,1000,-6,*18~27
13100, A,55,1000,-6,*1~4
13100, A,45,1000,-18,*31~35
13600, A,50,1000,-18,*31~35
13900, A, 53,1000,-6,*1~4
14400, A,66,1000,-18,*31~35
14750, A,55,1000,-6,*18~27
15300, A,60,1000,-6,*18~27
15300, A,55,850,-18,*18~27
15300, A,58,1200,-6,*18~27
15300, A,55,1400,-18,*18~27
15300, A,53,700,-6,*18~27

-1, cross traffic - freeway
15850, A,90,1000,-9, *1~35
16000, A,95,1000,-21, *1~35
16200, A,88,1000,-9,*1~4
16850, A,90,1000,-9, *1~35
16900, A,95,1000,-21, *1~35
16950, A,88,1000,-9,*1~35
17450, A,100,1000,-9, *1~35
17700, A,95,1000,-21, *1~4
17900, A,88,1000,-21,*1~35
18250, A,90,1000,-9, *1~35
18400, A,103,1000,-21, *1~4
19550, A,90,1000,-9, *1~35
20000, A,95,1000,-21, *1~35
20800, A,103,1000,-9,*1~35
21350, A,90,1000,-9, *1~35
21900, A,95,1000,-21, *1~4
22650, A,88,1000,-9,*1~35
23450, A,100,1000,-9, *1~35

24300, A,95,1000,-21, *1~4
25100, A,88,1000,-21,*1~35
26250, A,90,1000,-9, *1~35
27000, A,102,1000,-21, *1~4
27950, A,88,1000,-9,*1~35
29000, A,95,1000,-21, *1~4
30800, A,88,1000,-9,*1~35
31350, A,98,1000,-9, *1~35
32900, A,95,1000,-21, *1~35
33650, A,88,1000,-9,*1~35
34450, A,99,1000,-9, *1~35
35300, A,95,1000,-21, *1~4
36100, A,88,1000,-9,*1~35
37250, A,95,1000,-9, *1~4
38000, A,95,1000,-21, *1~35
38950, A,88,1000,-9,*1~35

-1,buildings
-1 buildings right side of road
0, BLDG,  50, 80, S1
0, BLDG, 170, 80, S3
0, BLDG, 270, 76, S4
0, BLDG, 400, 80, S5
0, BLDG, 450, 80, S6
0, BLDG, 530, 85, S7
0, BLDG, 630, 80, S17
0, BLDG, 730, 80, S9
0, BLDG, 820, 85, G1
0, BLDG, 890, 80, G7
0, BLDG, 930, 75, G8
0, BLDG, 1030, 80, S1
0, BLDG, 1130, 80, S3
0, BLDG, 1230, 76, S4
0, BLDG, 1330, 80, S5
0, BLDG, 1430, 80, S6

-1 first intersection
0, BLDG, 1700, 80, S1
0, BLDG, 1820, 80, S3
0, BLDG, 1920, 76, S4
0, BLDG, 2050, 80, S5
0, BLDG, 2100, 80, S6
0, BLDG, 2180, 85, S7
0, BLDG, 2280, 80, S17
0, BLDG, 2380, 80, S9
0, BLDG, 2470, 85, G1

0, BLDG, 2540, 80, G7
0, BLDG, 2580, 75, G8
0, BLDG, 2680, 80, S1
0, BLDG, 2780, 80, S3
0, BLDG, 2880, 76, S4
0, BLDG, 2980, 80, S5
0, BLDG, 3080, 80, S6
0, BLDG, 3180, 80, S1
0, BLDG, 3300, 80, S3
0, BLDG, 3400, 76, S4
0, BLDG, 3530, 80, S5
0, BLDG, 3580, 80, S6
0, BLDG, 3660, 85, S7
0, BLDG, 3760, 80, S17
0, BLDG, 3860, 80, S9
0, BLDG, 3950, 85, G1
0, BLDG, 4020, 80, G7
0, BLDG, 4060, 75, G8
0, BLDG, 4160, 80, S1
0, BLDG, 4260, 80, S3
0, BLDG, 4360, 76, S4
0, BLDG, 4460, 80, S5
0, BLDG, 4560, 80, S6
0, BLDG, 4660, 80, S7
0, BLDG, 4900, 80, S3
0, BLDG, 5000, 76, S4
0, BLDG, 5130, 80, S5
0, BLDG, 5280, 80, S6
0, BLDG, 5360, 85, S7
0, BLDG, 5460, 80, S17
0, BLDG, 5560, 80, S9
0, BLDG, 5650, 85, G1
0, BLDG, 5720, 80, G7
0, BLDG, 5860, 75, G8

-1 second intersection
0, BLDG, 4880, -180, S11, 90
0, BLDG, 4880, -300, S13, 90
0, BLDG, 4880, -400, S14, 90
0, BLDG, 4880, -530, S15, 90
0, BLDG, 4880, -780, S16, 90
0, BLDG, 4880, -860, S17, 90
0, BLDG, 4880, -960, S7, 90
0, BLDG, 4880, -1060, S10, 90
0, BLDG, 4880, -1150, G8, 90
0, BLDG, 4880, -1220, G7, 90

0, BLDG, 4880, -1260, G1, 90
0, BLDG, 4880, -1360, S1, 90
0, BLDG, 4880, -1460, S2, 90
0, BLDG, 4880, -1560, S12, 90
0, BLDG, 4880, -1660, S3, 90
0, BLDG, 4880, -1760, S5, 90
0, BLDG, 4880, -1860, S6, 90
0, BLDG, 4880, -1980, S4, 90
0, BLDG, 4880, -2065, S6, 90
0, BLDG, 4880, -2155, S11, 90
0, BLDG, 4880, -2235, G1, 90
0, BLDG, 4880, -2335, G7, 90
0, BLDG, 4880, -2440, G11, 90
0, BLDG, 4880, -2530, S11, 90
0, BLDG, 4880, -2650, S2, 90
0, BLDG, 4880, -2750, S4, 90
0, BLDG, 4880, -2880, S6, 90
0, BLDG, 4880, -3150, S9, 90
0, BLDG, 4880, -3250, G1, 90
0, BLDG, 4880, -3350, G7, 90
0, BLDG, 4880, -3450, G8, 90
0, BLDG, 4880, -3550, S1, 90
0, BLDG, 4880, -3650, S3, 90
0, BLDG, 4880, -3750, S4, 90
0, BLDG, 4880, -3850, S5, 90
0, BLDG, 4880, -3950, S6, 90

-1 third intersection
0, BLDG, 5000, -2930, S1, 180
0, BLDG, 5090, -2930, S3, 180
0, BLDG, 5200, -2930, S4, 180
0, BLDG, 5300, -2930, S5, 180
0, BLDG, 5400, -2930, S6, 180
0, BLDG, 5500, -2930, S7, 180
0, BLDG, 5600, -2930, S17, 180
0, BLDG, 5700, -2930, S9, 180
0, BLDG, 5800, -2930, G1, 180
0, BLDG, 5900, -2930, G7, 180
0, BLDG, 6000, -2930, G8, 180
0, BLDG, 6100, -2930, S1, 180
0, BLDG, 6200, -2930, S3, 180
0, BLDG, 6300, -2930, S4, 180
0, BLDG, 6400, -2930, S5, 180
0, BLDG, 6500, -2930, S6, 180
0, BLDG, 6600, -2930, S4, 180

0, BLDG, 6700, -2930, S5, 180
0, BLDG, 6800, -2930, S1, 180
0, BLDG, 6890, -2930, S3, 180
0, BLDG, 7000, -2930, S4, 180
0, BLDG, 7100, -2930, S5, 180
0, BLDG, 7200, -2930, S6, 180
0, BLDG, 7300, -2930, S7, 180
0, BLDG, 7400, -2930, S17, 180
0, BLDG, 7500, -2930, S9, 180
0, BLDG, 7600, -2930, G1, 180
0, BLDG, 7700, -2930, G7, 180
0, BLDG, 7900, -2930, S1, 180
0, BLDG, 8000, -2930, S3, 180
0, BLDG, 8100, -2930, S2, 180
0, BLDG, 8200, -2930, S1, 180
0, BLDG, 8290, -2930, S3, 180
0, BLDG, 8400, -2930, S4, 180
0, BLDG, 8500, -2930, S5, 180
0, BLDG, 8600, -2930, S6, 180
0, BLDG, 8700, -2930, S7, 180
0, BLDG, 8800, -2930, S17, 180
0, BLDG, 8900, -2930, S9, 180
0, BLDG, 9000, -2930, G1, 180
0, BLDG, 9100, -2930, G7, 180
0, BLDG, 9200, -2930, G8, 180
0, BLDG, 9300, -2930, S1, 180
0, BLDG, 9400, -2930, S3, 180
0, BLDG, 9500, -2930, S4, 180

-1 forth intersection
0, BLDG, 9700, -2800, H1, 270
0, BLDG, 9700, -2600, B1, 270
0, BLDG, 9700, -2400, H2, 270
0, BLDG, 9700, -2000, H3, 270
0, BLDG, 9700, -1800, H4, 270
0, BLDG, 9700, -1600, H6, 270
0, BLDG, 9700, -1300, H5, 270
0, BLDG, 9700, -1000, H3, 270

-1 buildings of left side of the road
0, BLDG,  50,-80, S10
0, BLDG, 150,-80, S11
0, BLDG, 250,-83, S12
0, BLDG, 350,-80, S13
0, BLDG, 450,-88, S15

0, BLDG, 550,-80, S16
0, BLDG, 670,-80, S14
0, BLDG, 755,-80, S8
0, BLDG, 844,-80, S1
0, BLDG, 924,-80, G3
0, BLDG, 1030, -80, S1
0, BLDG, 1130, -80, S3
0, BLDG, 1230, -76, S4
0, BLDG, 1330, -80, S5
0, BLDG, 1430, -80, S6

-1 first intersection
0, BLDG, 1700,-80, S10
0, BLDG, 1750,-80, S11
0, BLDG, 1850,-83, S12
0, BLDG, 1950,-80, S13
0, BLDG, 2050,-88, S15
0, BLDG, 2150,-80, S16
0, BLDG, 2270,-80, S14
0, BLDG, 2355,-80, S8
0, BLDG, 2444,-80, S1
0, BLDG, 2524,-80, G3
0, BLDG, 2630, -80, S1
0, BLDG, 2730, -80, S3
0, BLDG, 2830, -76, S4
0, BLDG, 2930, -80, S5
0, BLDG, 3030, -80, S6
0, BLDG, 3130,-80, S10
0, BLDG, 3230,-80, S11
0, BLDG, 3330,-83, S12
0, BLDG, 3430,-80, S13
0, BLDG, 3530,-88, S15
0, BLDG, 3630,-80, S16
0, BLDG, 3750,-80, S14
0, BLDG, 3835,-80, S8
0, BLDG, 3924,-80, S1
0, BLDG, 4004,-80, G3
0, BLDG, 4110, -80, S1
0, BLDG, 4210, -80, S3
0, BLDG, 4310, -76, S4
0, BLDG, 4410, -80, S5
0, BLDG, 4510, -80, S6
0, BLDG, 4600,-80, S10
0, BLDG, 4650,-80, S11
0, BLDG, 4930,-80, S13
0, BLDG, 5030,-88, S15

0, BLDG, 5130,-80, S16
0, BLDG, 5250,-80, S14
0, BLDG, 5335,-80, S8
0, BLDG, 5424,-80, S1
0, BLDG, 5504,-80, G3
0, BLDG, 5610, -80, S1
0, BLDG, 5710, -80, S3
0, BLDG, 5810, -76, S4

-1 second intersection
0, BLDG, 4720, -580, S6, -90
0, BLDG, 4720, -180, S1, -90
0, BLDG, 4720, -300, S3, -90
0, BLDG, 4720, -400, S4, -90
0, BLDG, 4720, -530, S5, -90
0, BLDG, 4720, -780, S6, -90
0, BLDG, 4720, -860, S7, -90
0, BLDG, 4720, -960, S17, -90
0, BLDG, 4720, -1060, S9, -90
0, BLDG, 4720, -1150, G1, -90
0, BLDG, 4720, -1220, G7, -90
0, BLDG, 4720, -1260, G8, -90
0, BLDG, 4720, -1360, S10, -90
0, BLDG, 4720, -1460, S11, -90
0, BLDG, 4720, -1560, S12, -90
0, BLDG, 4720, -1660, S13, -90
0, BLDG, 4720, -1760, S15, -90
0, BLDG, 4720, -1860, S16, -90
0, BLDG, 4720, -1980, S14, -90
0, BLDG, 4720, -2065, S8, -90
0, BLDG, 4720, -2155, S1, -90
0, BLDG, 4720, -2235, G3, -90
0, BLDG, 4720, -2335, G8, -90
0, BLDG, 4720, -2440, G11, -90
0, BLDG, 4720, -2530, S1, -90
0, BLDG, 4720, -2650, S3, -90
0, BLDG, 4720, -2750, S4, -90
0, BLDG, 4720, -2880, S5, -90
0, BLDG, 4720, -3150, S1, -90
0, BLDG, 4720, -3250, G3, -90
0, BLDG, 4720, -3350, S1, -90
0, BLDG, 4720, -3450, S3, -90
0, BLDG, 4720, -3550, S4, -90
0, BLDG, 4720, -3650, S5, -90
0, BLDG, 4720, -3750, S6, -90
0, BLDG, 4720, -3850, S10, -90

0, BLDG, 4720, -3950, S11, -90

-1 third intersection
0, BLDG, 5000, -3100, S6
0, BLDG, 5090, -3100, S17
0, BLDG, 5200, -3100, S9
0, BLDG, 5300, -3100, G1
0, BLDG, 5400, -3100, G7
0, BLDG, 5500, -3100, G8
0, BLDG, 5600, -3100, S1
0, BLDG, 5700, -3100, S3
0, BLDG, 5800, -3100, S4
0, BLDG, 5900, -3100, S5
0, BLDG, 6000, -3100, S6
0, BLDG, 6100, -3100, S4
0, BLDG, 6200, -3100, S5
0, BLDG, 6300, -3100, S1
0, BLDG, 6400, -3100, S3
0, BLDG, 6500, -3100, S4
0, BLDG, 6600, -3100, S5
0, BLDG, 6700, -3100, S6
0, BLDG, 6800, -3100, S7
0, BLDG, 6890, -3100, S17
0, BLDG, 7000, -3100, S9
0, BLDG, 7100, -3100, G1
0, BLDG, 7200, -3100, G7
0, BLDG, 7300, -3100, G8
0, BLDG, 7400, -3100, S1
0, BLDG, 7500, -3100, S3
0, BLDG, 7600, -3100, S4
0, BLDG, 7700, -3100, S5
0, BLDG, 7900, -3100, S3
0, BLDG, 8000, -3100, S4
0, BLDG, 8100, -3100, S5
0, BLDG, 8200, -3100, S6
0, BLDG, 8290, -3100, S17
0, BLDG, 8300, -3100, S9
0, BLDG, 8400, -3100, G1
0, BLDG, 8500, -3100, G7
0, BLDG, 8600, -3100, G8
0, BLDG, 8700, -3100, S1
0, BLDG, 8800, -3100, S3
0, BLDG, 8900, -3100, S4
0, BLDG, 9000, -3100, S5
0, BLDG, 9100, -3100, S6
0, BLDG, 9200, -3100, S4

0, BLDG, 9300, -3100, S5
0, BLDG, 9400, -3100, S1
0, BLDG, 9500, -3100, S3

-1 forth intersection
0, BLDG, 9900, -2800, H6, 90
0, BLDG, 9900, -2600, H3, 90
0, BLDG, 9900, -2300, H2, 90
0, BLDG, 9900, -2000, B1, 90
0, BLDG, 9900, -1700, H5, 90
0, BLDG, 9900, -1500, H4, 90
0, BLDG, 9900, -1200, H2, 90
0, BLDG, 9900, -900, B3, 90

-1 trees
  0, TREE, 50, 0, 1, 60, 61, 0

35300, ES

APPENDIX C
QUESTIONNAIRES

## Informed Consent Form

**Protocol Title:** Data Collection Survey for Driver's Behavior Change with Advanced Driver Assistance Systems in a Driving Simulator

Please read this consent document carefully before you decide to participate in this study.

**Purpose of the research study:**

The purpose of this study is to capture important changes in driving behavior caused by advanced driver assistance systems. These changes could affect traffic and even help in mitigating congestion.

**What you will be asked to do in the study:**

In this experiment, you will be accompanied by our researcher to "drive" two scenarios in a driving simulator for about 15 minutes each scenario. Upon arrival and before starting the experiment, a check-in procedure will be undertaken as follows: 1) sign the informed consent form (this form), 2) complete the background survey form, 3) provide a photocopy of your driver's license, 4) answer the SSQ (Simulator Sickness Questionnaire) and be subjected to an acclimation in the driving simulator, 5) answer the SSQ again if no sign of symptoms is observed, continue with the experiment. Then you will be subjected to the first scenario, simulating a trip in a freeway, and an arterial, in a normal vehicle, without any additional features. After this, you will be explained how the two tested assistance systems work, and you will be subjected to the second scenario, that is similar to the first one, but simulating a vehicle implemented with the two systems. During data collection, you will not be interrupted. After the completion of each scenario, you will be asked to answer a questionnaire regarding your experience using the two assistance systems, and the SSQ again.
The data collected in the experiment, including both the driving simulator scenarios and the information obtained from the questionnaires, will be used for traffic engineering research only. Your identity will not be revealed in the final manuscript. The time planned for this activity is 75 minutes, including time for questionnaires before and after the completion of each scenario.

**Time Required:**

Up to 1 hour and 15 minutes

**Risks and Benefits:**

The risk for this experiment will be related to driving simulator sickness. Some users can experiment adverse effects, including nauseam, oculomotor discomfort, and disorientation. You will be tested for simulator sickness before the experiment, and if you experience any of this, the simulation will be discontinued. You will be accompanied by the principal investigator (Barbara Martin), and be instructed to drive the simulator as you usually do during the entire data collection. We do not anticipate that you will benefit directly by participating in this experiment.

**Compensation:**

You will receive a $50 compensation for participating in this field data collection experiment. If you withdraw after completing one of the two scenarios, you will receive $25 for compensation. No compensation will be paid for withdrawing before the completion of the first scenario.

**Confidentiality:**

Information collected from this experiment will be used for traffic engineering research only. Your identity will be kept confidential to the extent provided by law. In accordance with the Confidential Information Protection and Statistical Efficiency Act of 2002 (Title 5 of Public Law 107-347) and other applicable Federal laws, your responses will not be disclosed in identifiable form without your consent.

**Voluntary participation:**

Your participation in this study is completely voluntary. There is no penalty for not participating.

**Right to withdraw from the study:**

You have the right to withdraw from the study at anytime without consequence.

**Whom to contact if you have questions about the study:**

Barbara Martin, Graduate Student, Department of Civil and Coast Engineering, Room 518, Weil hall, Phone: (352)392-9537 x1541.

Lily Elefteriadou, Ph.D., Department of Civil and Coast Engineering, Room 512, Weil hall, Phone: (352)392-9537 x1452.

**Whom to contact about your rights as a research participant in the study:**

UFIRB Office, Box 112250, University of Florida, Gainesville, FL 32611-2250, Phone: (352)392-0433.

**Agreement:**

I have read the procedure described above. I voluntarily agree to participate in the procedure and I have received a copy of this description.

Participant:________________________________________ Date: __________________

Principal Investigator:_______________________________ Date: __________________

UNIVERSITY OF FLORIDA
**Transportation Research Center**

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# Prescreening Questionnaire for Driving Behavior Change with Advanced Drivers Assistance Systems in a Driving Simulator Research

**To Participants:** This questionnaire is used to select a diverse pool of drivers to participate in the data collection experiment. Information collected in this form will be used for traffic engineering research only. All responses will be held in complete confidential and exempted from public disclosure by law. In accordance with the Confidential Information Protection and Statistical Efficiency Act of 2002 (Title 5 of Public Law 107-347) and other applicable Federal laws, your responses will not be disclosed in identifiable form without your consent. Since drivers' diversities are highly encouraged, only the most fitful responders will be chosen. Please answer as many as possible.

**Return Address:**

By Email: **barbaramartin@ufl.edu**
By Mail: **Barbara Martin, 511 Weil Hall, PO Box 116580, Gainesville, FL 32611**

1) What is your gender?

☐ Male ☐ Female

2) What is your age range?

☐ less than 25 years ☐ 25 to 30 years ☐ 31 to 40 years
☐ 41 to 50 years ☐ 51 to 60 years ☐ 61 years or more

3) Which of the following groups do you most identify yourself as?

☐ Caucasian ☐ Native American ☐ African American
☐ Hispanic ☐ Asian ☐ Pacific Islander
☐ Other (please specify) _____

4) Where did you begin your driving practice and obtained your driver's license?

☐ North America ☐ Latin America ☐ Asia
☐ Europe ☐ Australia

☐ Other (please specify) ______

5) How long have you been driving in the U.S.?

☐ less than 1 year ☐ 1 to 3 years ☐ 3 to 9 years
☐ more than 10 years

6) Do you have a valid U.S. driver's license?

☐ Yes ☐ No

7) What is your occupation?

☐ Full time student ☐ University faculty/staff ☐ Professional driver
☐ Other (please specify) ______

8) How often do you drive to work/school?

☐ everyday ☐ usually ☐ sometimes ☐ never

9) How much time do you spend driving per week?

☐ less than 4 hr ☐ 4 to 8 hr ☐ 8 to 14 hr ☐ more than 14 hr

10) What time of the day do you usually drive?

☐ AM/PM peak hour (6am-10am; 4pm-7pm) during work days
☐ Non-peak hours (including holiday and weekend)

11) What type of vehicle do you usually drive?

☐ Sedan/Coupe ☐ Pickup/SUV ☐ Jeep ☐ Truck

12) Do you have any health problems?

☐ Yes (please specify) ______
☐ No

13) Do you use a pace-maker?

☐ Yes
☐ No

14) Will you be willing to respond a questionnaire to assess your cognitive function?

- ☐ Yes
- ☐ No

15) What time are you typically available for participating in the experiments? Please check as many as possible.

- ☐ Monday morning (9:00am to 12:00pm)
- ☐ Tuesday morning (9:00am to 12:00pm)
- ☐ Wednesday morning (9:00am to 12:00pm)
- ☐ Thursday morning (9:00am to 12:00pm)
- ☐ Friday morning (9:00am to 12:00pm)
- ☐ Monday afternoon (1:00pm to 4:00pm)
- ☐ Tuesday afternoon (1:00pm to 4:00pm)
- ☐ Wednesday afternoon (1:00pm to 4:00pm)
- ☐ Thursday afternoon (1:00pm to 4:00pm)
- ☐ Friday afternoon (1:00pm to 4:00pm)
- ☐ Weekends only
- ☐ Any time by appointment

**Participant's contact information** (at least 1 from phone/email/mail)

| | |
|---|---|
| Name (Required) | |
| Email | |
| Mail Address | |
| Phone | |
| Date | |

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# Mini-Mental State Examination (MMSE)

**Participant's Name: __________________________** **Date:______________**

**Orientation**

| | | |
|---|---|---|
| 1. (i) What day of the week is it? | Day | ☐ |
| (ii) What is today's date? | Date | ☐ |
| | Month | ☐ |
| | Year | ☐ |
| (iii) What season are we in? | Season | ☐ |
| 2. Where are you? | City | ☐ |
| | County | ☐ |
| | State | ☐ |
| | Hospital/House | ☐ |
| | Floor | ☐ |

**Registration**

| | | |
|---|---|---|
| 3. I'm going to say the names of 3 unrelated objects | Apple | ☐ |
| Please listen carefully and try to remember them. | Table | ☐ |
| When I am done, repeat the 3 names. | Penny | ☐ |

**Attention/Calculation**

| | | |
|---|---|---|
| 4. Spell "world" backwards | D | ☐ |
| | L | ☐ |
| | R | ☐ |
| | O | ☐ |
| | W | ☐ |

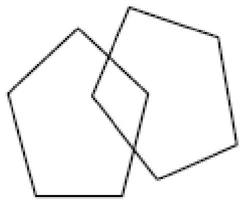
**Recall**

| | | |
|---|---|---|
| 5. Please repeat the 3 words I said before. | Apple | ☐ |
| | Table | ☐ |
| | Penny | ☐ |

**Language**

| | | |
|---|---|---|
| 6. Show the person a wristwatch and | Watch | ☐ |
| ask him/her what it is. Repeat for pencil. | Pencil | ☐ |
| 7. Repeat the following, "no ifs, ands, or buts." | No mistakes | ☐ |
| 8. Follow a 3-stage command: | | ☐ |
| "Take a paper in you right hand, | | ☐ |
| fold it in half, and | | ☐ |

put it on the floor.”
9. Read and obey the following:
Close your eyes.
Write a sentence.
Copy the following design.



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# Simulator Sickness Questionnaire

**Participant's Name:** ____________________ **Date:** ______________

Tick the box that best represents how you are feeling regarding each symptom:

**General discomfort**
☐ none ☐ slight ☐ moderate ☐ severe

**Fatigue**
☐ none ☐ slight ☐ moderate ☐ severe

**Headache**
☐ none ☐ slight ☐ moderate ☐ severe

**Eyestrain**
☐ none ☐ slight ☐ moderate ☐ severe

**Difficulty focusing**
☐ none ☐ slight ☐ moderate ☐ severe

**Increased salivation**
☐ none ☐ slight ☐ moderate ☐ severe

**Sweating**
☐ none ☐ slight ☐ moderate ☐ severe

**Nausea**
☐ none ☐ slight ☐ moderate ☐ severe

**Difficulty concentrating**
☐ none ☐ slight ☐ moderate ☐ severe

**Fullness of head**
☐ none ☐ slight ☐ moderate ☐ severe

**Blurred vision**
☐ none ☐ slight ☐ moderate ☐ severe

**Dizzy (eyes open)**
☐ none ☐ slight ☐ moderate ☐ severe

**Dizzy (eyes closed)**
☐ none ☐ slight ☐ moderate ☐ severe

**Vertigo**
☐ none ☐ slight ☐ moderate ☐ severe

**Stomach awareness**
☐ none ☐ slight ☐ moderate ☐ severe

**Burping**
☐ none ☐ slight ☐ moderate ☐ severe

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# Participants' Background Survey Form

**Participant's Name:** ______________________________ **Date:** _______________

Note: Information collected in this form will be used for traffic engineering research only. All responses will be held in complete confidential and exempt from public disclosure by law. In accordance with the Confidential Information Protection and Statistical Efficiency Act of 2002 (Title 5 of Public Law 107-347) and other applicable Federal laws, your responses will not be disclosed in identifiable form without your consent. By law, every interviewer, as well as every agent, is subject to a jail term, a fine, or both if he or she makes public ANY identifiable information you reported.

16) If the speed limit on the freeway is 70 mph, what speed are you likely to drive (assuming good visibility and good weather conditions)?

☐ less than 65 mph ☐ 65 to 70 mph ☐ 70 to 75 mph ☐ more than 80 mph

17) How often do you change lanes if the vehicle in front of you is slower?

☐ Very often ☐ Sometimes ☐ Seldom

18) What type of driver do <u>you</u> consider yourself?

☐ Very aggressive ☐ Somewhat aggressive

☐ Somewhat conservative ☐ Very conservative

19) What type of driver do your <u>friends and family</u> consider you?

☐ Very aggressive ☐ Somewhat aggressive

☐ Somewhat conservative ☐ Very conservative

20) When planning your driving trip, do you allow additional time for possible delays due to congestion, construction, or bad weather?

☐ Yes, always ☐ Sometimes ☐ Never

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# User Acceptance Questionnaire

**Participant's Name:** ______________________________ **Date:**_______________

My judgments of the Adaptive Cruise Control System are … (please tick a box on every line)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1 | useful | | | | | | useless |
| 2 | pleasant | | | | | | unpleasant |
| 3 | bad | | | | | | good |
| 4 | nice | | | | | | annoying |
| 5 | effective | | | | | | superfluous |
| 6 | irritating | | | | | | likeable |
| 7 | assisting | | | | | | worthless |
| 8 | undesirable | | | | | | desirable |
| 9 | raising alertness | | | | | | sleep-inducing |

My judgments of the Lane Change Assist System are … (please tick a box on every line)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1 | useful | | | | | | useless |
| 2 | pleasant | | | | | | unpleasant |
| 3 | bad | | | | | | good |
| 4 | nice | | | | | | annoying |
| 5 | effective | | | | | | superfluous |
| 6 | irritating | | | | | | likeable |
| 7 | assisting | | | | | | worthless |
| 8 | undesirable | | | | | | desirable |
| 9 | raising alertness | | | | | | sleep-inducing |

My judgments of the combination of the two Assistance Systems are … (please tick a box on every line)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | useful | | | | | | useless |
| 2 | pleasant | | | | | | unpleasant |
| 3 | bad | | | | | | good |
| 4 | nice | | | | | | annoying |
| 5 | effective | | | | | | superfluous |
| 6 | irritating | | | | | | likeable |
| 7 | assisting | | | | | | worthless |
| 8 | undesirable | | | | | | desirable |
| 9 | raising alertness | | | | | | sleep-inducing |

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Bárbara Barqueta Martin earned her B.S. in civil engineering from the University of São Paulo (Brazil) in 2008. In January 2009, she began work on her master's degree in transportation engineering at the University of Florida and graduated in December 2010. She intends to work on transportation projects related to the 2014 FIFA World Cup and the 2016 Summer Olympics, both hosted by cities in Brazil.