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Steven E. Shladover, et al.

California PATH Research Report
UCB-ITS-PRR-2009-23

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Effects of Cooperative Adaptive Cruise Control on Traffic Flow: Testing Drivers' Choices of Following Distances

PATH Research Report on
Task Order 6202

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Abstract

A Cooperative Adaptive Cruise Control (CACC) system has been developed by adding a wireless vehicle-vehicle communication system and new control logic to an existing commercially available adaptive cruise control (ACC) system. The CACC is intended to enhance the vehicle-following capabilities of ACC so that drivers will be comfortable using it at shorter vehicle-following gaps than ACC. If this is shown to be the case, it offers a significant opportunity to increase traffic flow density and efficiency without compromising safety or expanding roadway infrastructure.

This report describes the design and implementation of the CACC system on two Infiniti FX-45 test vehicles, as well as the data acquisition system that has been installed to measure how drivers use the system, so that the impacts of such a system on highway traffic flow capacity and stability can be estimated. The results of quantitative performance testing of the CACC on a test track are presented, followed by the experimental protocol to be followed for on-road testing with human subjects. Finally, the results from the first pilot test are presented to show how the data are analyzed to reveal the implications of CACC for driving behavior and user acceptance.

Key Words: Adaptive Cruise Control, Cooperative Adaptive Cruise Control, Driver Behavior, Vehicle-Vehicle Communication

Executive Summary

This report provides documentation of the design and implementation of a Cooperative Adaptive Cruise Control (CACC) system on two Infiniti FX-45 vehicles that were provided to the project by Nissan Motor Company. The CACC system has been developed by adding a wireless vehicle-vehicle communication system and new control logic to an existing commercially available adaptive cruise control (ACC) system. The CACC is intended to enhance the vehicle-following capabilities of ACC so that drivers will be comfortable using it at shorter vehicle-following gaps than ACC. If this is shown to be the case in the experiments that will be conducted in a follow-on project, it offers a significant opportunity to increase traffic flow density and efficiency without compromising safety or expanding roadway infrastructure.

The CACC concept is defined and described, and then the specific implementation for this project is described. The control logic of the CACC system is explained, and its implementation on the test vehicles is described. Quantitative measurements of the performance of the system in controlled tests at Nissan's Arizona proving ground are shown so that its advantages over conventional autonomous ACC can be understood. The enhanced performance makes it possible to operate the CACC at time gaps between 0.6 s and 1.1 s, compared to a range of 1.1 s to 2.2 s for the ACC. The shorter CACC gaps could enable significant highway capacity increases, while the longest CACC gap was set identical to the shortest ACC gap to provide a direct comparison.

Because the most important experiments involving these vehicles will require measurements of the performance and behavior of drivers chosen from the general public, an important element of the project is a digital data acquisition system that records how the vehicles are driven. This system will be used to record baseline driving data when the test drivers drive one of the vehicles as their regular personal car for two weeks, recording quantitative measurements of vehicle motions and driver actions, together with five channels of video data. When the same drivers drive the other vehicle using CACC during comparable test drives accompanied by a PATH researcher, the same measurements will be recorded so that they can be compared with the baseline driving. The design of the data acquisition system and the information that it records are described here for reference. The experimental protocol to be followed for the driver tests is explained and then illustrated with examples from the first pilot test.

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1 Introduction

This project is an element of PATH's research on methods for mitigating congestion via the application of Intelligent Transportation Systems. The first part of this research focused on the evaluation of the impact of Adaptive Cruise Control (ACC) and Cooperative Adaptive Cruise Control (CACC) vehicles on traffic patterns via computer simulations [1, 2]. ACC systems are now commercially available on high-end vehicles. These systems enable the drivers to set a desired cruising speed as well as a desired following gap with respect to a lead vehicle. If no lead vehicle is present, then the system will regulate the vehicle speed, as any conventional cruise control does, but once a lead vehicle is detected, the system will adjust the vehicle's speed to maintain the gap set by the driver, with no intervention needed from the driver. The ACC functions with information it senses about the lead vehicle, and needs to sense a change in the lead vehicle's motion important enough to trigger a slowing down. Because of this delay in sensing a change in the vehicle following situation, there is a threshold for the minimum gap than can be technically achieved. On the other hand, a CACC benefits from the communication of information regarding the speed and brake actuation of the lead vehicle, which allows it to have faster responses, and therefore allows, from a technical point of view, a considerable reduction in the size of the gap that can be safely controlled by the system.

One of the primary questions raised during the simulation research relates to the size of car following gaps that drivers would be willing to use with comfort. This question led to the current research initiative, which includes three main thrusts: i) development, implementation and testing of the technical performance of a CACC; ii) Data collection regarding its use by naïve drivers and analysis of those data; and iii) integration of the knowledge gained about driver use of the system into a traffic flow simulation. The CACC driver can choose a gap from 0.6 to 1.1 s, in contrast to the available ACC settings from 1.1 s to 2.2 s. The shorter CACC gaps could lead to a significant highway capacity increase, while the longest CACC gap provides a basis for direct comparison with the shortest available ACC gap.

This report describes the design and development of the Cooperative ACC system that was implemented by modifying the factory-installed ACC system on the (Nissan) Infiniti FX-45 vehicles and the data acquisition system that was added to the vehicles. It also includes the results of the testing of the technical performance of the system and the design and pilot verification of the protocols for evaluation testing by naïve drivers. This provides the starting point for a subsequent project that conducts the human factors experiments to learn about how drivers use the system and what they like or dislike about it. The results of the human factors experiments will be addressed in a subsequent report.

2 Definitions of terms

Some of the important terms that will be used in the rest of this report include:

Adaptive cruise control (ACC) – a system that automatically controls the gap between vehicles driving at highway speeds (by actuating engine and brake controls) based on measurements of the distance to the preceding vehicle.

Cooperative adaptive cruise control (CACC) – an enhancement to ACC that enables more accurate gap control and operations at smaller gaps by adding communication of vehicle status information (primarily speed) from the preceding vehicle

DSRC – dedicated short-range communication, a wireless communication system that provides very reliable and low-latency communication of data between vehicles and the roadside or between vehicles and other vehicles (as it is used here)

ECM – electronic control module

Lidar – laser radar, a sensor that uses an infrared laser to measure the distance to the back of a preceding vehicle

Gap – the time between when the rear end of the lead vehicle and the front end of the following (ACC) vehicle pass the same location along the roadway. This is measured in terms of seconds. The distance corresponding to this gap is the clearance (the product of the time gap and the following vehicle speed).

This research focuses on the evaluation of drivers' comfort when following a lead vehicle at a short range controlled by an automation system. The vehicle that the observed drivers will be using is called the Subject Vehicle, or SV. As the prototype that is tested involves the presence of a specific vehicle as the predecessor of the SV, this vehicle is called the Lead Vehicle, or LV. Because the data collection protocol involves two distinct phases, we will further distinguish the names of the vehicles. In the first phase, the participant will be using a commercially available ACC in the silver-colored Infiniti FX45, while in the second phase the driver will be using a prototype CACC implemented in the copper-colored Infiniti FX45 (following the silver Infiniti, which will act as its lead vehicle, communicating data to it). The Principal Other Vehicle (POV) is the vehicle immediately ahead of the CACC lead vehicle during the CACC testing. The naming convention is illustrated in the two figures below.

Figure 1: Vehicle naming convention for ACC system familiarization (Phase 1 testing)

Figure 2: Vehicle naming convention for CACC system testing (Phase 2 testing)

3 Cooperative Adaptive Cruise Control (CACC) System

The CACC prototype has been built on top of the commercially available ACC of the Infiniti FX 45. Only the CACC characteristics are presented in this report, as the commercially available ACC characteristics are the property of Nissan and were not developed under this project.

3.1 CACC concept

All production-level ACC systems are autonomous, which means that they can only obtain information about their distance and closing rate to the lead vehicle using their forward ranging sensors (typically radar or lidar). These sensors are subject to noise, interference and inaccuracies, which require that their outputs be filtered heavily before being used for control. That introduces response delays and limits the ability of the ACC to follow other vehicles accurately and respond quickly to speed changes of the other vehicles, which in turn limits the potential for ACC to contribute favorably to traffic flow capacity and stability. Augmenting the forward ranging sensor data with additional information communicated over a wireless data link from the preceding vehicle, (e.g., speed, acceleration, braking capability) makes it possible to overcome these limitations. Such a Cooperative ACC (CACC) system can be designed to follow the preceding vehicle with significantly higher accuracy and faster response to changes. This would in turn enable the regulation of shorter gaps than current systems can provide. From this perspective, CACC should be better able to dampen shock waves in the traffic stream.

However, the potential performance advantages cannot be realized in practice unless drivers are interested in acquiring and using the system. This is why the experiments with the drivers are important, to learn what they like and dislike about the cooperative ACC and which performance settings they prefer. If drivers like the shorter gap settings, CACC could produce significant improvements in lane capacity. However, if they do not find the shorter gaps acceptable these improvements will not be achievable.

3.2 System design

The primary elements of the CACC system, in addition to the underlying ACC system on which it is based, are the wireless system used for communication from the target vehicle to the subject vehicle, the CACC control system, which decides how to modify the driving commands issued to the vehicle's engine, transmission and brakes, and the driver interface, which is an expanded version of the ACC driver interface.

3.2.1 Communication System

Data are communicated from the CACC lead vehicle to the CACC subject vehicle using WAVE Radio Modules (WRMs) supplied by Denso (WAVE stands for Wireless Access in the Vehicular Environment). These use the IEEE 802.11p DSRC standard, but were developed and installed prior to the completion of the IEEE 1609 standards and therefore do not rely on those standards. The WRM radios are connected to antennas, which are temporarily mounted on the roofs of the test vehicles for the CACC testing.

3.2.2 CACC control system

3.2.2.1 CACC control implementation

Figure 3 shows the configuration of the ACC controller. The ACC sensor is a fixed five-beam LIDAR on the silver FX-45 and a scanning LIDAR on the copper FX-45, representing two different generations of the Nissan ACC product. The sensor provides measurements relative to the preceding vehicle such as distance and relative speed, which is sent to the ACC control unit through the CAN bus. Limited brake actuation (<0.3 g) is realized with a brake booster. A brake pressure sensor is installed to provide brake pressure information for fine brake control. The ACC control unit also sends CAN messages to actuate the engine through the engine ECM. The ACC controller is housed in the ACC control unit with a two-layer architecture. At low level, a speed servo controls the vehicle brake and engine so that vehicle speed will track the speed command V_{spc} generated by the upper level quickly and accurately. At the upper level, the ACC controller sends out appropriate speed commands based on the ACC sensor measurements so that a desired time gap to the preceding vehicle is maintained.

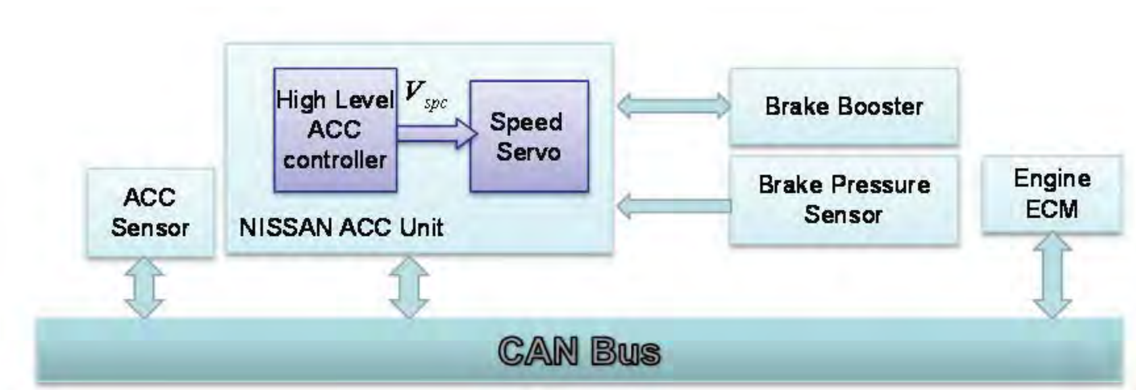


Figure 3: Configuration of Existing Nissan ACC Controller

To develop a CACC control system, it is necessary for the prototype controller to have the capability to actuate the vehicle's brake and engine one way or another. Based on the existing ACC controller structure shown in Figure 3, this could potentially be accomplished in three different ways:

1. The prototype CACC controller directly actuates vehicle engine and brake (in this case, the brake booster). In this way, the prototype controller would have the full control authority for the vehicle longitudinal control purpose. However, actuating engine/brake directly would involve extensive modifications to the existing vehicle's hardware and software.

2. The prototype CACC controller sends out the same desired speed command as the higher level ACC controller. Although this would reduce the flexibility of the prototype controller design compared with the first option, the existing speed servo function could be utilized for the CACC controller design. Since the desired speed command is inside

the ACC control unit, substantial hardware/software modifications to the existing vehicle would still be required.

3. As shown in Figure 4, the ACC sensor sends the relative distance and speed of the preceding vehicle to the ACC control unit through the CAN bus. A simple way for implementing the cooperative vehicle longitudinal control is that the prototype CACC controller accepts the ACC sensor measurement information and sends out calculated virtual relative distance and speed to the ACC control unit instead. Although this includes the existing Nissan ACC controller in the loop and poses additional difficulties for the CACC controller design, it only requires minimum modifications to the existing Nissan software.

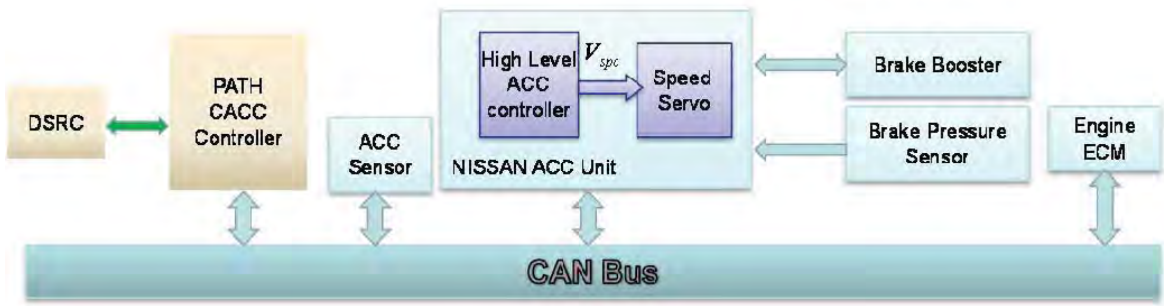


Figure 4: Add-on System Design for PATH CACC

Given the time frame of this project, the third option was chosen for the prototype CACC controller implementation. The configuration of the add-on system design for the prototype CACC is shown in Figure 4. With the CAN message definitions provided by Nissan, the prototype CACC controller can access the ACC sensor measurement and vehicle information such as wheel speed, gear position and engine RPM through the vehicle CAN bus. At the same time, the prototype CACC controller can also receive information about the preceding vehicle such as wheel speed, gear position, engine RPM, throttle pedal position and accelerator pedal position via DSRC wireless communication. A CACC control algorithm, which will be detailed in the following sections, calculates the virtual distance and relative speed command and sends it to the ACC control unit through the CAN bus.

3.2.2.2 CACC State Machine and CACC Vehicle Identification

Figure 5 illustrates the state machine for the prototype CACC controller. The nominal mode of CACC operation is gap regulation, but it is important to account for how this mode is initiated and terminated. The transition from conventional ACC operation to CACC gap regulation is accomplished through the target ID mode, which is needed to verify consistency between the ACC sensor data and the DSRC communication data. If the gap is larger than a suitable threshold for gap regulation, the gap closing mode is invoked.

Whenever there is a target change (e.g., a vehicle cuts in between the CACC and its lead vehicle), the prototype CACC controller retreats to the ACC mode by sending ACC sensor measurements directly to the ACC control unit. The following step is to identify if the preceding vehicle is the vehicle exchanging information through DSRC wireless communication. If the preceding vehicle is identified as one of the CACC vehicles, the gap between these two vehicles will be accessed. If the vehicle gap is too large, the PATH CACC controller will switch to gap closing mode until the vehicle gap is shortened below a predetermined threshold. The function of the gap regulation mode is to maintain the desired gap between the two vehicles.

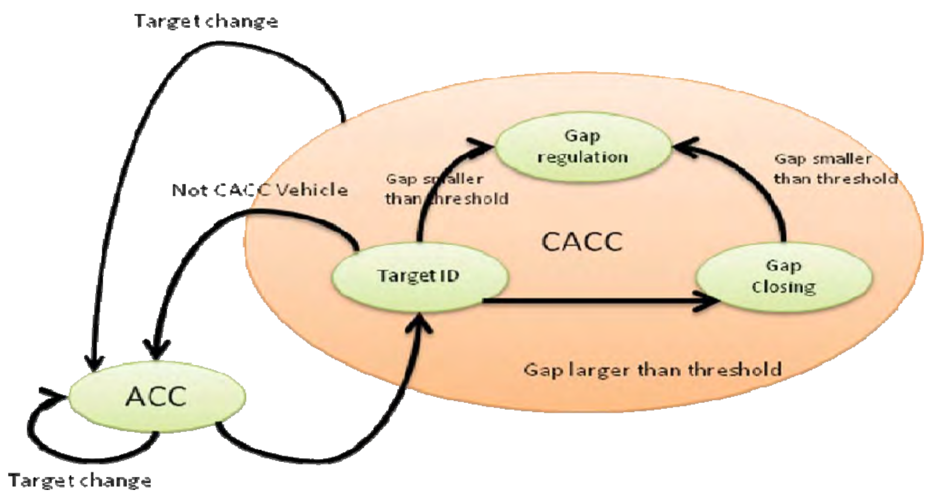


Figure 5: State Machine for PATH CACC controller

Before using the information from DSRC wireless communication for CACC control purpose, we really need to identify if the ACC sensor target is the vehicle that is communicating through the DSRC wireless communication. This is the primary function of the target ID mode. This problem would be much more complicated if there were multiple vehicles with DSRC wireless communication around, but that is not being addressed in these experiments, which are focused on the human factors issues of driver use of the system. The complete target association problem will have to be addressed in future research before the CACC system can be commercialized. Since there will only be two DSRC equipped vehicles during our testing, a simple method is adopted for the target ID purpose. Figure 6 shows the comparison of relative speed output between the ACC sensor and DSRC when the ACC sensor target is the DSRC vehicle. The ACC sensor output follows the DSRC output with about 0.5 sec time delay. This characteristic is used to confirm the target ID.

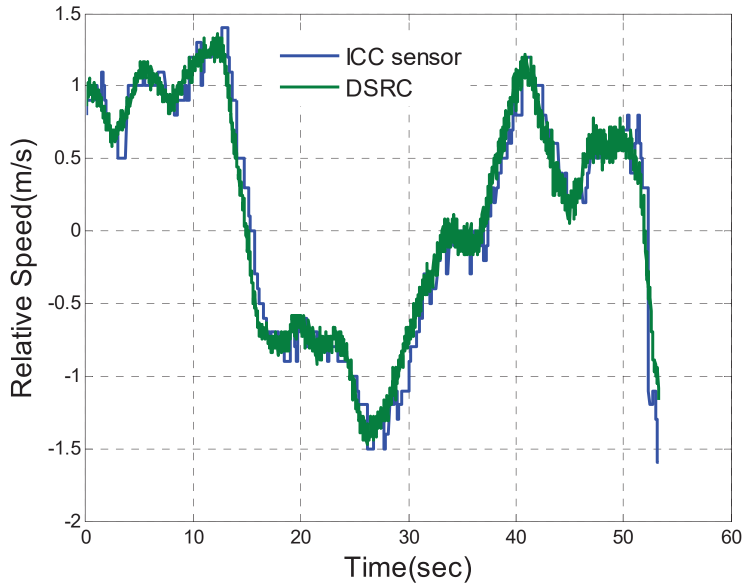


Figure 6: Comparison of relative speed output between ACC sensor and DSRC

3.2.2.3 CACC Controller Structures and Enhanced Speed Servo Loop

Figure 7 and Figure 8 show the controller structures for the CACC gap closing controller and CACC gap regulation controller. One of the important components of the prototype CACC controller is the enhanced speed servo. As mentioned in the previous section, the actuation of the existing engine/brake is implemented by sending virtual relative distance/speed commands to the ACC control unit through the CAN bus. To fully utilize the existing ACC controller and simplify CACC controller design, the enhanced speed servo is designed to maintain the vehicle speed according to the desired speed command from the higher level controllers (e.g., speed trajectory planning for the prototype CACC gap closing controller). In the implementation, the virtual relative distance command is always kept at the desired time gap and the virtual relative speed command is used as the control input. After extensive frequency response testing, the enhanced speed servo loop was designed using the loop shaping method. This controller structure is very similar to the successful existing ACC controller.

Figure 7: PATH CACC Gap Closing Controller

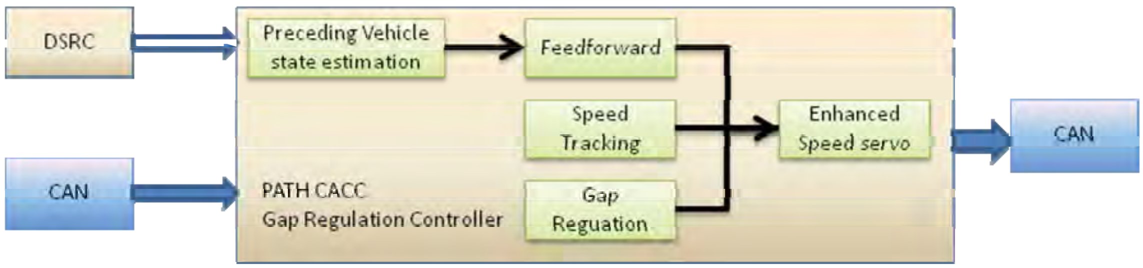


Figure 8: PATH CACC Gap Regulation Controller

3.2.2.4 CACC Gap Closing Controller Design

When the relative distance between two vehicles is much larger than the desired time gap, controller saturation will occur if the high-gain gap regulation controller is engaged immediately. Such controller saturation will generate an oscillating response and make the driver uncomfortable. One way to resolve this problem is to introduce controller switching. The CACC gap closing controller will be engaged before the relative distance reaches a predetermined threshold value. The CACC gap closing controller is a "semi" open loop controller. A trapezoidal relative speed trajectory is planned with respect to relative distance as shown in Figure 9. All the parameters (e.g. Δv) can be tuned to provide different driver comfort levels.

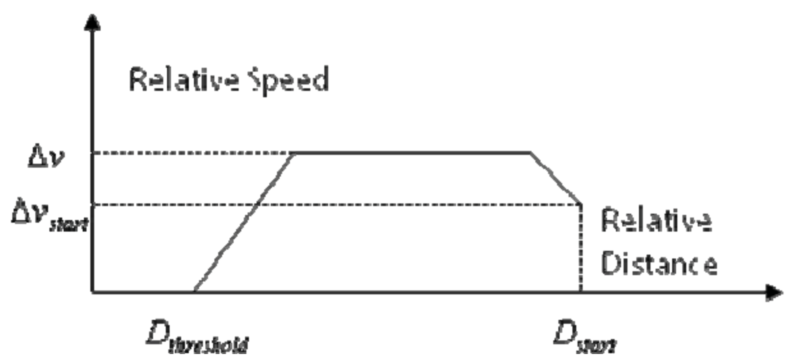


Figure 9: Trajectory Planning for CACC Gap Closing Controller

3.2.2.5 CACC Gap Regulation Controller Design

When the distance between two vehicles is reduced below a certain threshold by the CACC gap closing controller or when the distance between two vehicles is already below that threshold, the CACC gap regulation controller is engaged to maintain a desired time gap between two vehicles. As shown in Figure 8, the CACC gap regulation controller consists of preceding vehicle state estimation, speed tracking and gap regulation.

Lead Vehicle State Estimation and Feedforward

One of the advantages of CACC is that lead vehicle information such as throttle pedal position, brake pedal position, gear position and engine RPM can be transmitted to the following subject vehicle through DSRC wireless communication. Such information is related to the specific vehicle and cannot be used in the CACC controller design directly. The function of lead vehicle state estimation is to assess the lead vehicle motion states. In the prototype CACC controller design, lead vehicle acceleration is estimated and used in the feedforward control part.

Speed Tracking

The speed tracking module is designed to provide fast response to the speed changes of the lead vehicle. In the CACC controller, a bandpass filter is used for speed tracking. It has low gain at low frequency, high gain from 1 Hz to 5 Hz and 40 db roll-off above 5 Hz.

Gap Regulation

The gap regulation controller is a high gain linear controller designed with the loop shaping method.

3.2.2.6 Proving ground test results

To fine tune the control design and controller parameters, two testing trips were made to the Nissan Arizona vehicle proving ground. At the end of the second field trip, a series of scenarios was performed to test the performance of the final controller under a range of representative driving conditions:

- change of time gap setting while CACC car is approaching the leading car
- leading car brakes moderately while CACC car is approaching it and closing the gap
- leading car does repeated accelerate and decelerate maneuvers while CACC car follows it
- a manually-driven POV does repeated accelerate and decelerate maneuvers, followed by the ACC car acting as the leading car for the CACC car, following in sequence.

Figures 10-12 show performance in the scenario when the CACC car is approaching the leading car, and the time gap setting is changed from 1.1 sec to 0.9 sec. Smooth action is taken by the CACC car to approach the leading car and the time gap is then well regulated at 0.9 sec

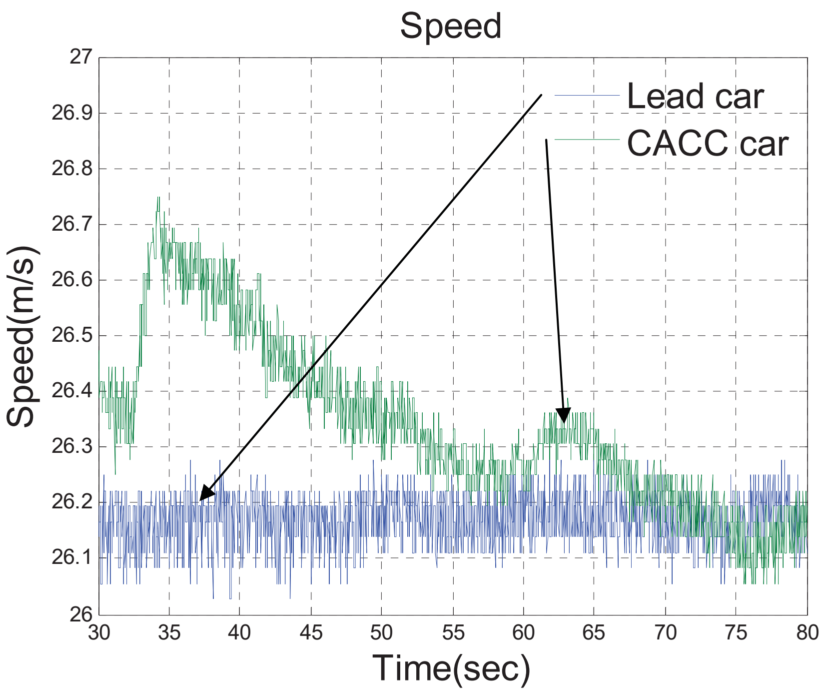


Figure 10: Proving ground test: steady state speed performance

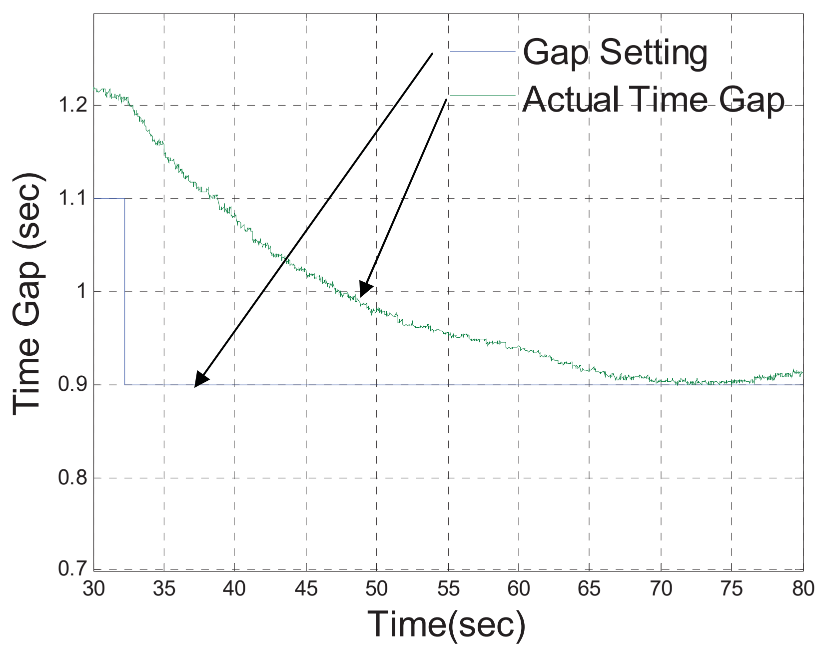


Figure 11: Proving Ground Test: steady state time gap performance

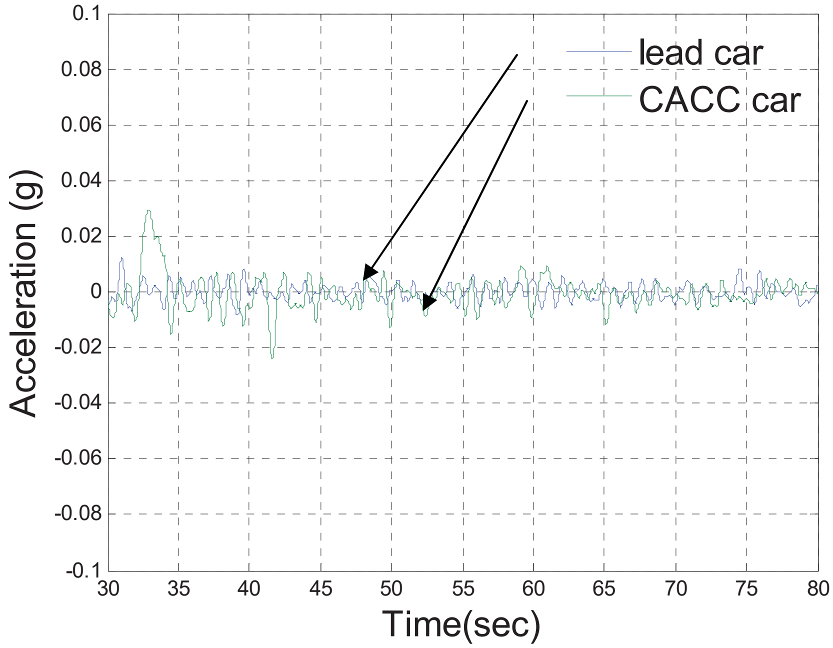


Figure 12: Proving Ground Test: steady state acceleration performance

Figures 13-16 show the scenario when the leading car brakes at about 0.16 g while the CACC car approaches. With the feedforward information from the wireless communication, the CACC controller reacts very quickly, as can be seen in both Fig. 15 and Fig. 16. Therefore, the CACC car can always follow the speed of the leading car and regulate the time gap at the desired time gap setting at the end.

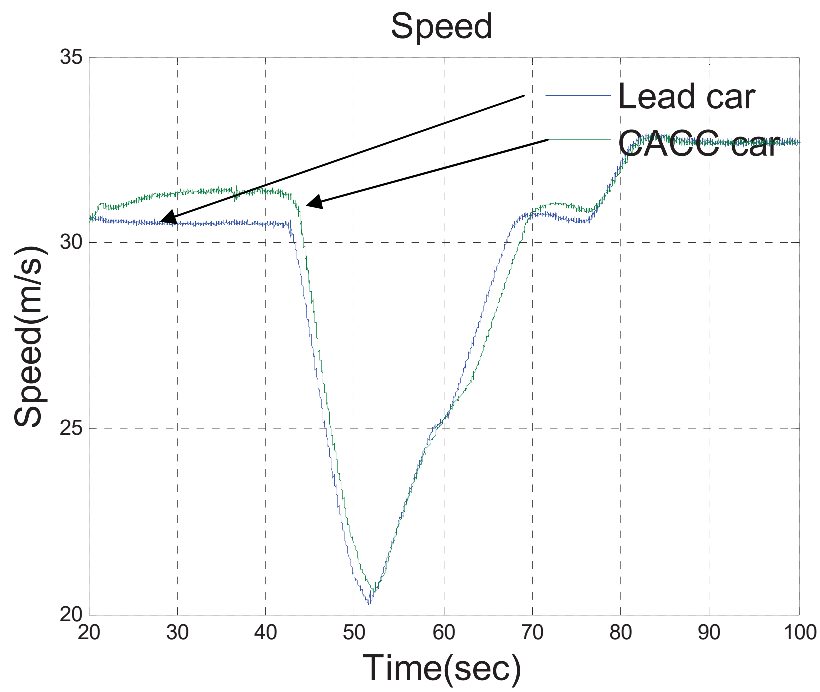


Figure 13: Speed response when leading car brakes while CACC car is approaching

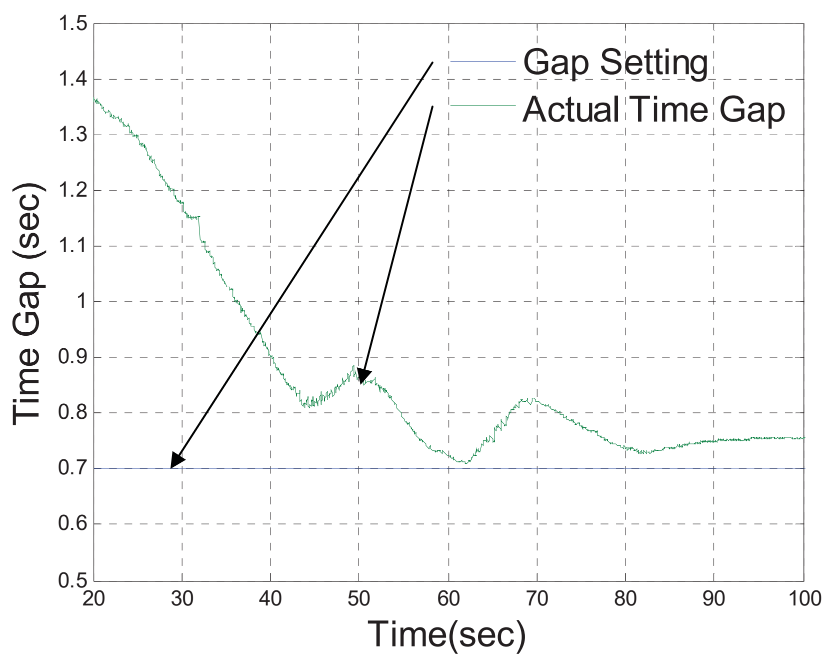


Figure 14: Time gap response when leading car brakes while CACC car is approaching

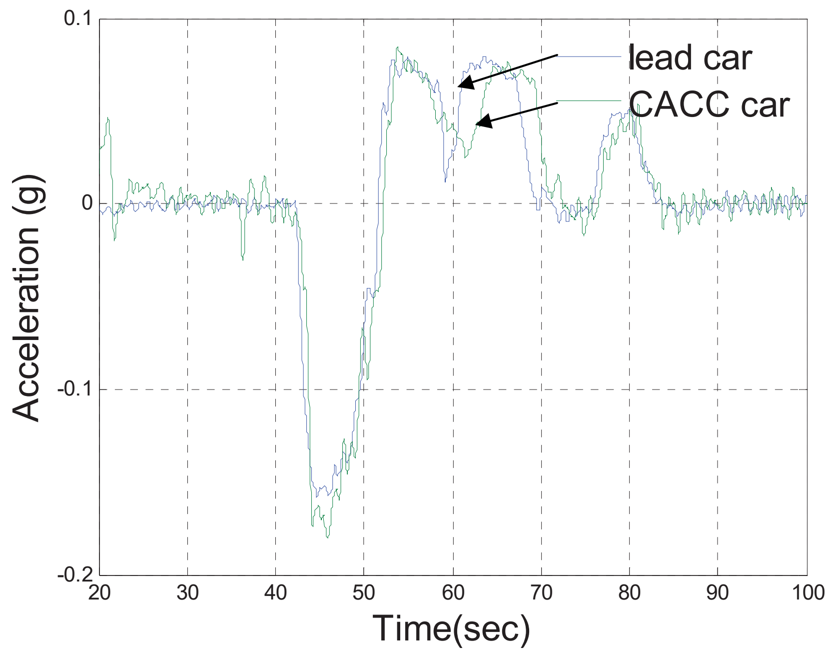


Figure 15: Acceleration response when leading car brakes while CACC car is approaching

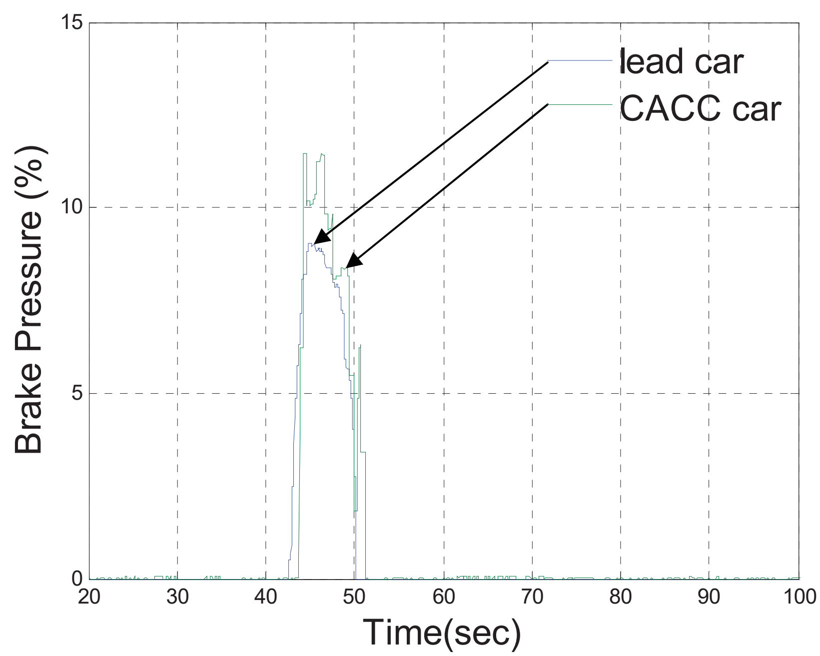


Figure 16: Brake pressure response when leading car brakes while CACC car is approaching

To further illustrate the advantages of the feedforward information from wireless communication, Figures 17-20 show the scenario that the leading car makes repeated braking and acceleration transients. The largest magnitude of braking is around 0.25 g, which is close to the maximum capability of the brake actuator. As shown in Fig. 17, the CACC car is always able to track the leading car's velocity, even with this aggressive braking. Fig. 19 and Fig. 20 also show that the CACC car brakes almost immediately following the lead car's braking.

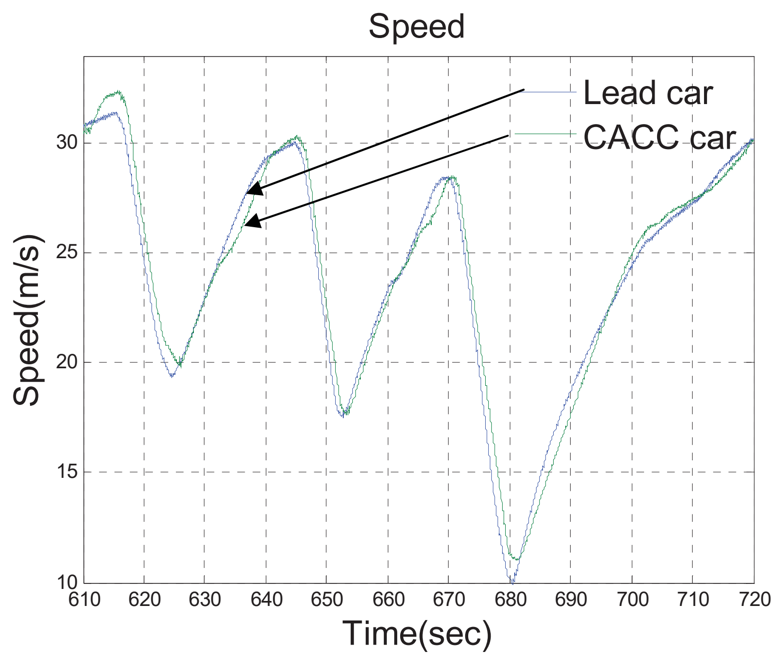


Figure 17: Speed profiles when leading car brakes and accelerates repeatedly

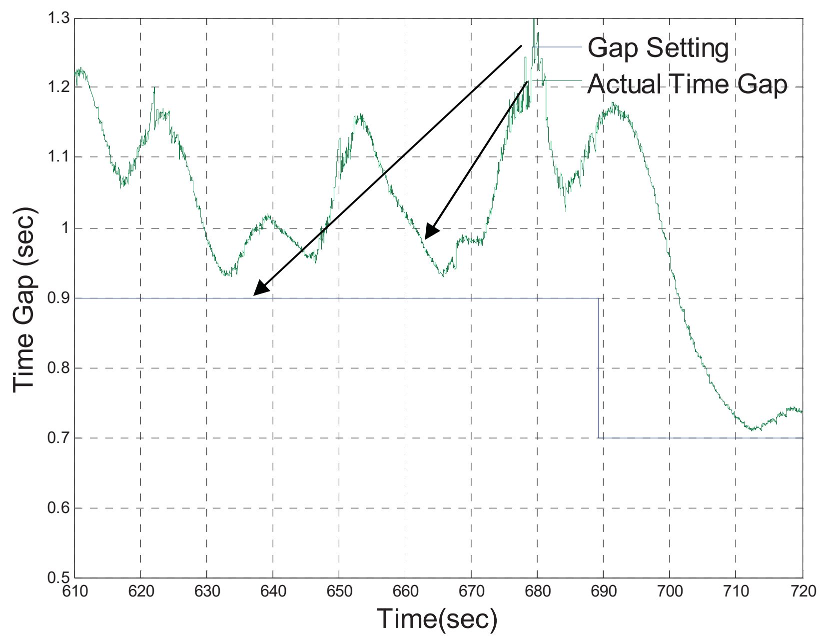


Figure 18: Time gap profiles when leading car brakes and accelerates repeatedly

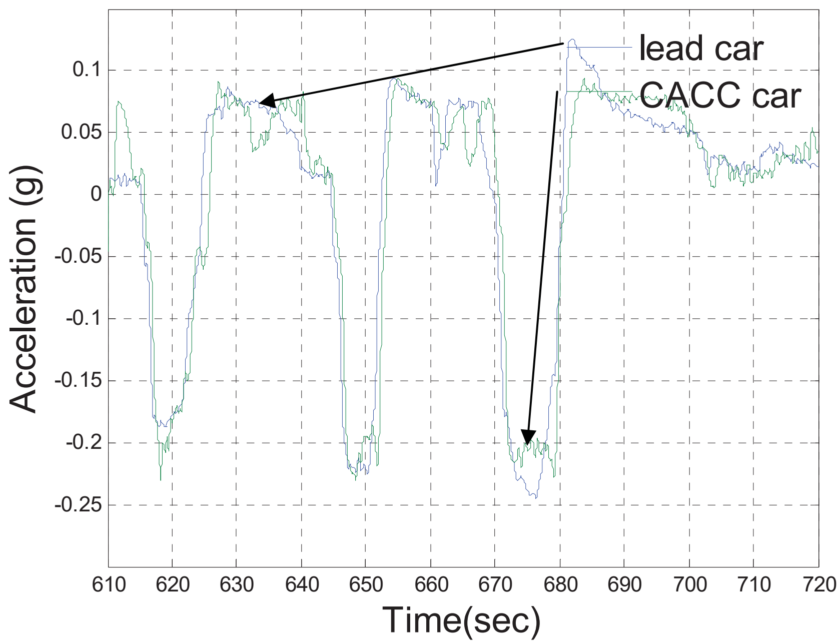


Figure 19: Acceleration profiles when leading car brakes and accelerates repeatedly

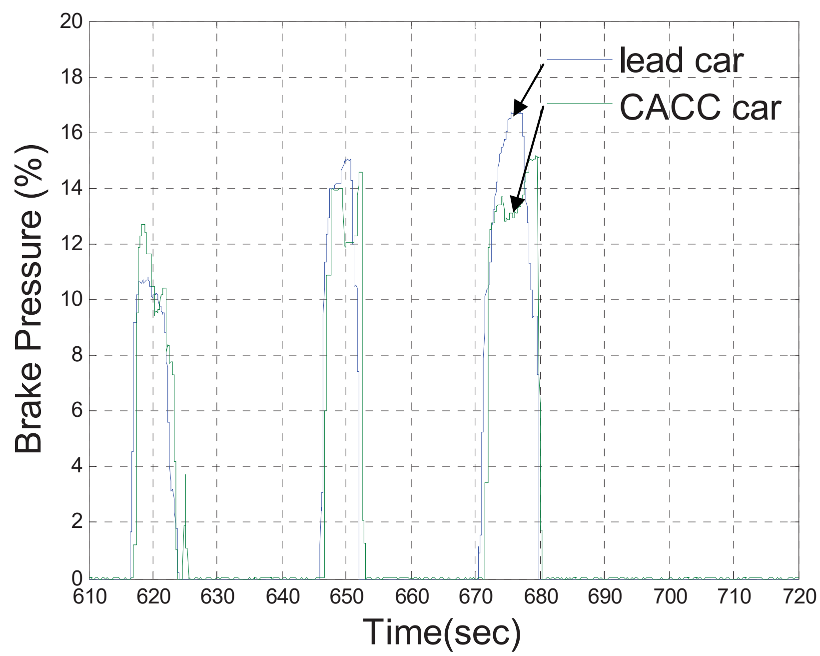


Figure 20: Brake pressure profiles when leading car brakes and accelerates repeatedly

At the end of the performance testing, a three car platoon scenario was conducted to test the string stability effect and compare the performance between the conventional autonomous ACC controller and the CACC controller. A manually driven Infiniti G35 led the platoon and the silver

Infiniti FX45 followed it with the factory ACC controller turned on. The copper Infiniti FX45 followed the silver one with the PATH CACC controller turned on. The G35 made repeated aggressive braking and acceleration maneuvers. As shown in Fig. 21, the autonomous ACC equipped silver FX45 tracked the leading car's speed with a much larger time lag compared with the CACC equipped copper FX45's tracking of the silver FX45. Therefore, a large variation of time gap regulation is shown in Figure 22 for the autonomous ACC equipped silver FX45. More importantly, the amplification of the time gap variations for the autonomous ACC shows a potential loss of string stability, which is compensated successfully by the cooperative ACC's enhanced vehicle following capability.

Figure 23 shows how the acceleration transients of the lead car are attenuated by the ACC car following it, while the CACC car is able to keep the acceleration transients at a similarly attenuated level, smoothing the ride for the vehicle occupants. Similarly, Figure 24 shows how the brake pressure transient for the CACC car is attenuated from that for the preceding ACC car. This attenuation is only possible because of the use of the vehicle-vehicle communication of the CACC system; in its absence these transients would have been amplified.

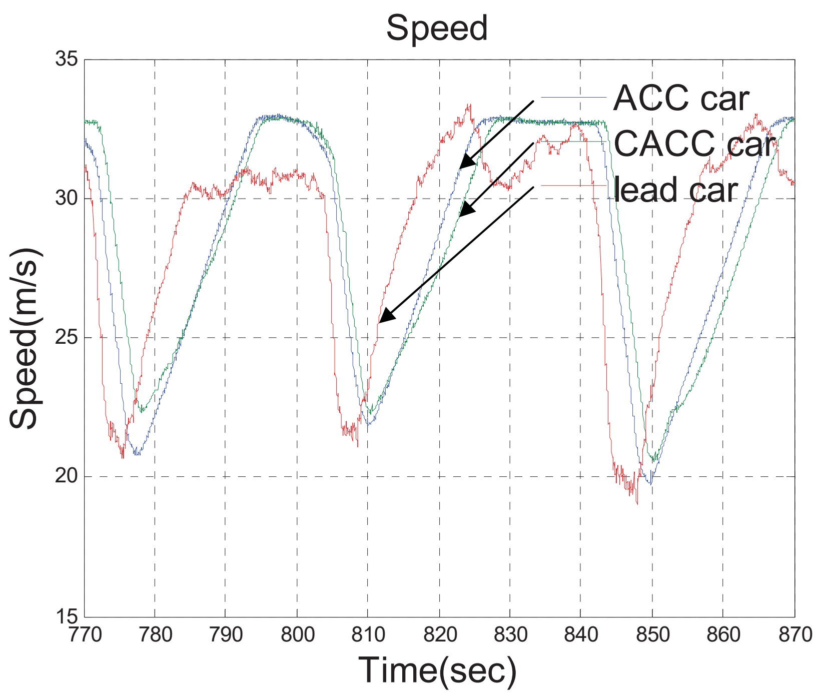


Figure 21: Three car platoon test – speed profiles

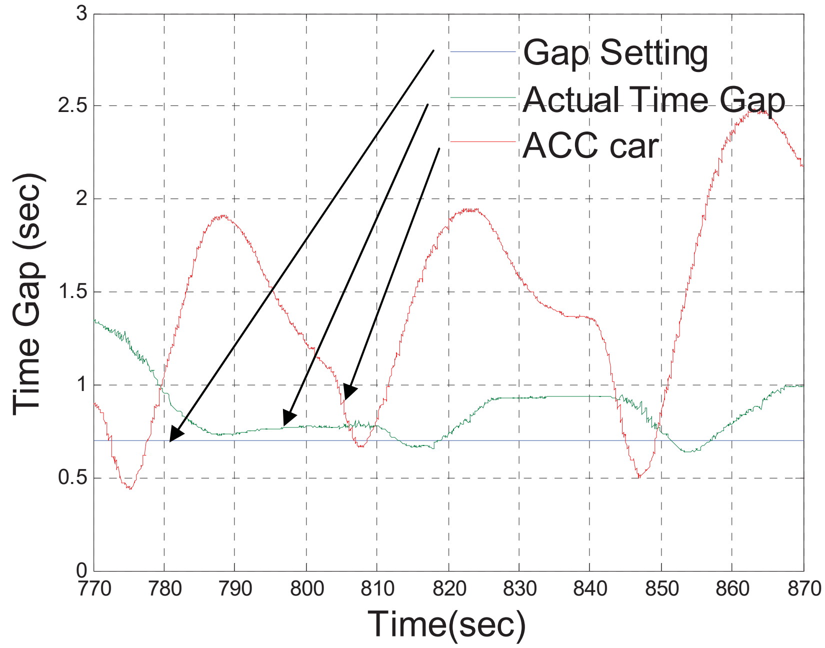


Figure 22: Three car platoon test – time gaps

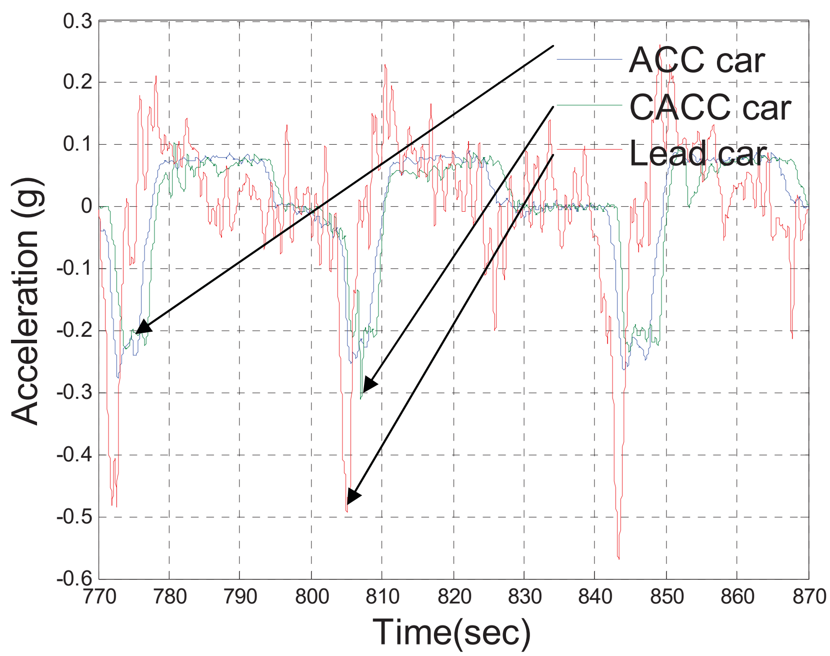


Figure 23: Three car platoon test - accelerations

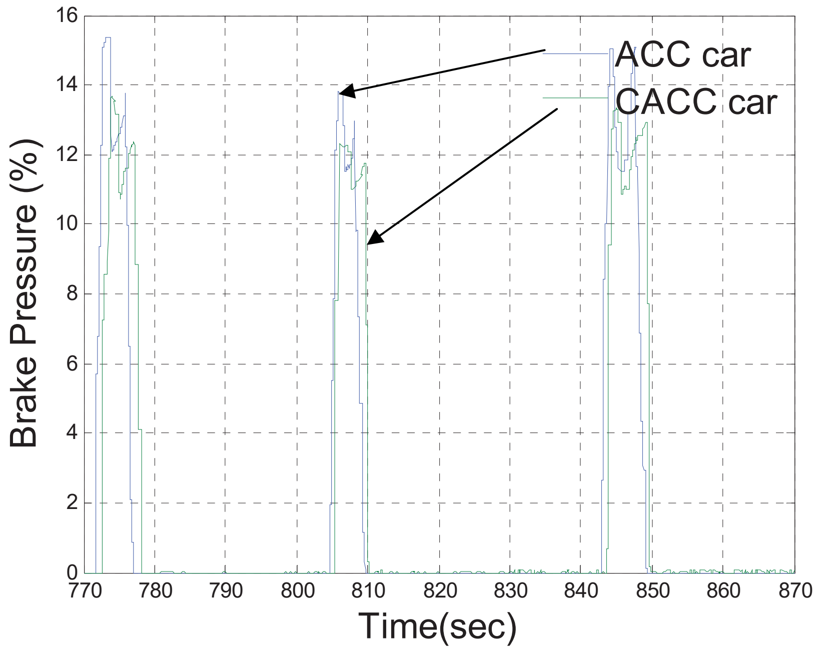


Figure 24: Three car platoon test – brake pressure

3.2.3 Driver Vehicle Interface

The Driver-Vehicle Interface (DVI) for the CACC was based on the original DVI for the Infiniti ACC. Ideally, there should have been no change in the CACC DVI; however, the standard dashboard display provided in the Infiniti vehicles could not be modified to support displaying all of the gap settings that would be available during the CACC testing. This necessitated that an additional LCD display be mounted in the CACC test vehicle to show the correct current gap setting. Both the ACC and CACC DVIs are explained in the subsequent sections.

3.2.3.1 ACC Driver-Vehicle Interface

The ACC DVI consists of a set of 4 buttons located on the right side of the steering wheel and two visual displays located on the dashboard. Figure 25 and Figure 26 depict the dashboard displays and the steering wheel controls. The main ACC display is located at the bottom of the tachometer dial on the instrument panel, adjacent to the transmission gear indicator, as shown in Figure 26. This picture shows how the display looks when the ACC has first been activated, but the set speed has not yet been selected. Additionally, the vehicle is not moving fast enough for a lead vehicle to be detected and indicated.

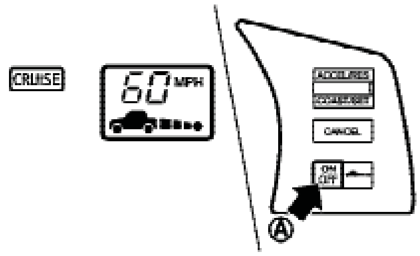


Figure 25: ACC display and controls as illustrated in vehicle owner's manual

Figure 26: ACC displays (left) and controls (right)

The first visual display is the "CRUISE" indicator light, located along the left side of the instrument cluster, which is activated with a green background when the on/off switch is pushed down. In case of system malfunction, this display background turns to orange. This light only indicates that the cruise control system has been turned on, and not that it is currently active and controlling the vehicle speed.

The second, and main, ACC display is located within the tachometer to the left of the current gear indication ("P" in Figure 26). This display shows the current ACC set speed (for example, 60 mph in Figure 25). The display also shows the current gap setting. Each square between the vehicle and dot represents an increasing gap setting. If all squares are visible, the longest gap has been selected. When the shortest gap has been selected, only the square closest to the dot is present. Finally, this display indicates whether or not a lead vehicle has been detected by the system. If no lead vehicle has been detected, there is no car icon to the left of the current gap setting (as shown in Figure 26). If a lead vehicle has been detected, there is a car icon to the left of the current gap setting (as shown in Figure 25).

The driver controls the ACC with four buttons. The ACC is activated by the driver pushing the "on/off" button (the left side of the middle button on the steering wheel), as shown in Figure 25 and 26. The set speed is selected by toggling the top button down, and then toggling it up or down to increase or decrease the set speed. Short toggles produce changes of 1 mph in set speed, while holding the button in the up or down position for about one second produces a change of 5 mph in the corresponding direction. The bottom button ("Cancel") is used to interrupt the ACC action at any time the user chooses, analogous to hitting the brake pedal, but retaining the set speed value for the next time the system action is resumed by toggling the top button up.

3.2.3.2 CACC Driver-Vehicle Interface

From a driver's perspective, the CACC operation is identical to that of the original factory-installed ACC. Therefore, the existing ACC driver interface (described above) has been adapted for the CACC with minor changes on the display. The primary differences between the two systems lie in the number of available gap settings and the location of the display. On the copper-colored FX-45, which is used for the CACC driving experiments, this display is located on an additional larger LCD screen, mounted to the right of the steering wheel as shown in Figure 27. This display was provided for experimental convenience and will not be a topic for evaluation in the experiments.

This display allows both the driver and the experimenter to see the CACC system status and current gap settings during the experiment. One additional icon was added to the CACC display, resembling a radio transmitter icon. The presence or absence of this icon indicates whether or not the vehicle-vehicle communication is operational.

Figure 27: CACC display (right of steering wheel)

Note that in Figure 27 there is also a small video camera mounted by this display, pointed at the driver's face. This camera is used to verify that the correct person is driving the vehicle, and that it has not been driven by an unauthorized driver who is not part of the experiment. (See the DAS section of this report for more details on data collection setup.)

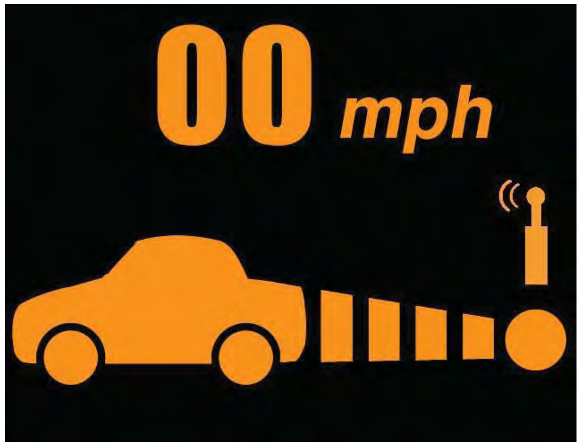


Figure 28: CACC Driver Vehicle Interface

Figure 28 shows a close-up of the CACC display with the set speed indication and lead vehicle icon (indicating that the system has identified the lead vehicle for possible following). The four bars behind the lead vehicle icon indicate that the driver has selected the largest following gap setting. As the driver toggles the gap setting switch (the right side of the middle button shown in Figure 26), this cycles through the three shorter gap settings in sequence, until only one bar remains. If the driver toggles it again, the system switches back to the longest gap setting. The CACC time gap settings are 1.1, 0.9, 0.7 and 0.6 seconds (compared to 2.2, 1.6 and 1.1 seconds for the ACC on these vehicles).

4 Data Acquisition System (DAS)

An identical data acquisition system is installed on both vehicles. The silver ACC vehicle will be used for establishing a baseline; i.e., observing the driver's following behavior without the use of any system, and also to collect data during the ACC familiarization. The test of CACC driving will be conducted with the participant driving the copper vehicle. The data collected on each vehicle will provide the opportunity to compute the parameters classically used for describing driver behavior, such as time gap or time to collision, describe the participant's control of the vehicle with either system, and characterize some of the driving environment conditions, making it possible to compare the driver behavior with the systems and the use of each system.

The data acquisition system records a variety of engineering variables to characterize the motions of the vehicles, the driver actions, and the functioning of the ACC and CACC systems. In addition, it records two channels of video data to provide additional information about the driving environment (forward and rear driving scenes, especially for cut-in and cut-out maneuvers that may be difficult to interpret from the lidar data) and three to record the driver's actions (four views are grouped on a four to one video splitter: use of pedals, hand motions for adjustment of speed and gap settings, driver's face for ensuring that the driver is indeed the experiment participant, and rear view of the traffic).

4.1 DAS Hardware

For each of the vehicles, the DAS package contains the following equipment:

- Video computer (PC 104 –Linux)
    - 5 video cameras
    - One "four-to-one" video splitter
    - 2 titlers (Horita)
- Engineering data computer (PC 104), connected to the C/ACC system computers to provide data about the vehicle controls use (e.g. steering wheel, pedals), system uses (C/ACC on/off, gap selected) and dynamics (speed, yaw rate)
- Accelerometer: longitudinal and lateral acceleration
- DGPS: latitude, longitude and UTC

The DAS is shown in Figure 29, which illustrates the connection between the ACC and CACC computers with the engineering computer already interfaced with the CAN bus (See Figure 4).

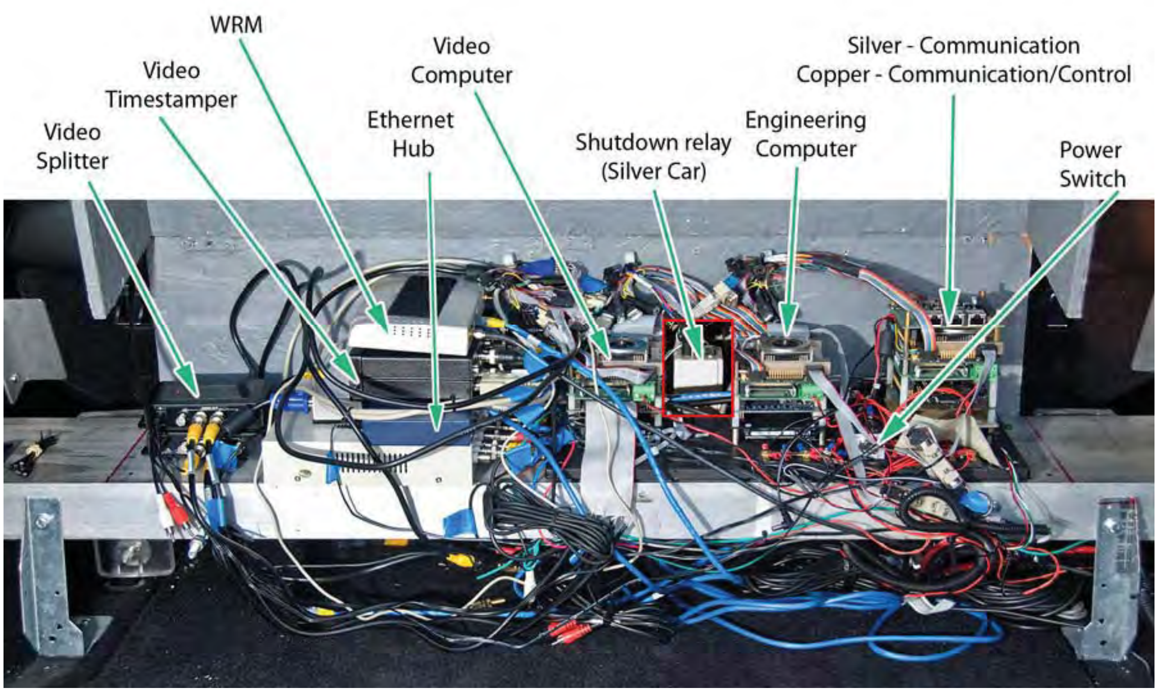


Figure 29: C/ACC DAS and Engineering Computer

Figure 30 shows the computer installation with the cover closed, as it will be seen by the test participants. The closed cover protects the equipment and leaves the participants with trunk space behind it for storing goods that they need to transport.

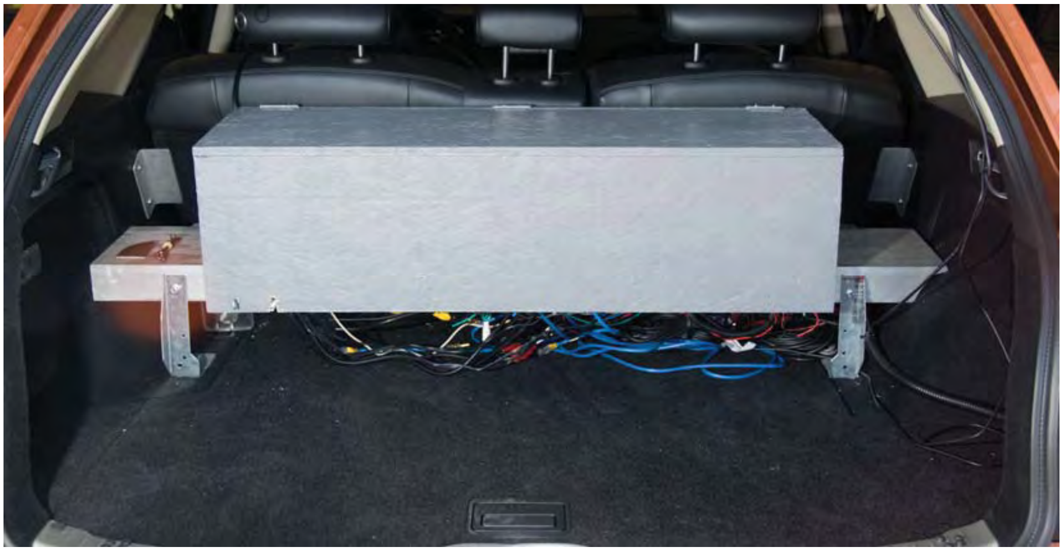


Figure 30: Computer enclosure in luggage compartment behind rear seat of vehicle, with cover closed

The DGPS system is used to provide continuous information about the location of the vehicle and the accurate time reference. It receives satellite signals from an antenna mounted on the roof of the vehicle, adjacent to the additional antenna used to receive the vehicle-vehicle DSRC communications, as shown in Figure 31.

Figure 31: DGPS Antenna (left) and DSRC Communication Antenna (right)

The locations of the video cameras in the front portion of the vehicle interior are shown in Figure 32. An additional video camera is mounted in the rear window of the vehicle, facing back, to capture images of the traffic scene behind the vehicle.

Figure 32: Vehicle Interior, Showing Locations of Video Cameras

4.2 DAS Software

The software architecture on the vehicles consists of a set of processes running on PC-104 computers and communicating through the *Publish/Subscribe database*. The software is written in C or C++ and runs either on the QNX 6.2 (engineering computer) or 6.3 (Communication and control computer) real-time operating system and Linux (video computer). Specific details of the software architecture, such a listing of processes and diagrams of how they interact, can be found in Appendix A, while a higher level description of the data flows can be found in Figure 33 and Figure 34. Figure 33 describes the data flow in the Silver Infiniti FX45 which only has the factory ACC enabled for vehicle control, but also serves as the lead vehicle for CACC testing. Figure 34 describes the data flow in the Copper Infiniti FX45 which has the CACC system enabled.

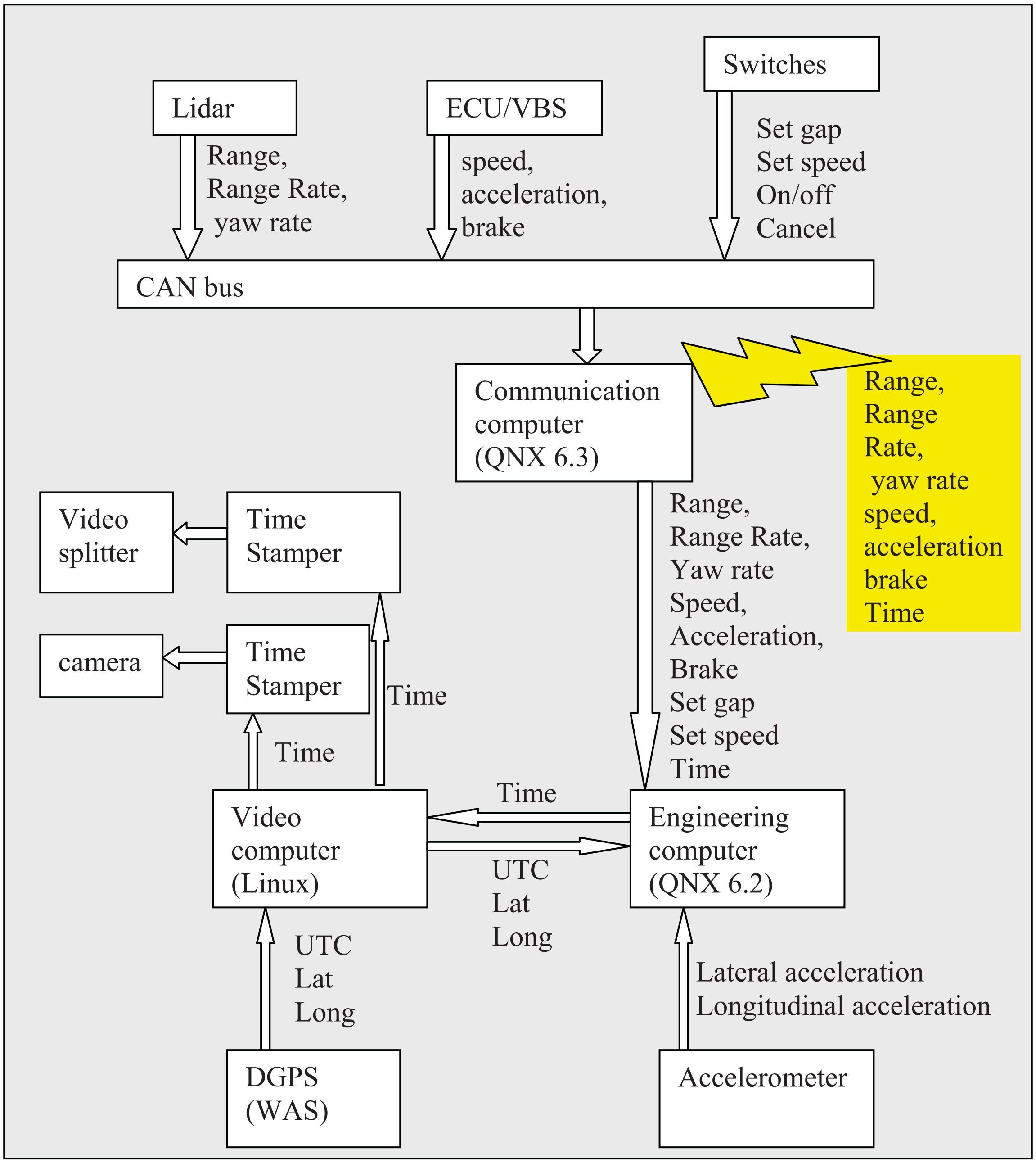


Figure 33: DAS Data Flow for Silver FX45 (ACC or lead vehicle for CACC)

The yellow boxes in Figure 33 and Figure 34 contain the information that is sent from the silver ACC vehicle to the copper CACC vehicle from the Communication Computers. The silver lead vehicle logs the information that it sends to the copper CACC equipped vehicle while the copper CACC vehicle logs the information that it receives from the silver lead vehicle.

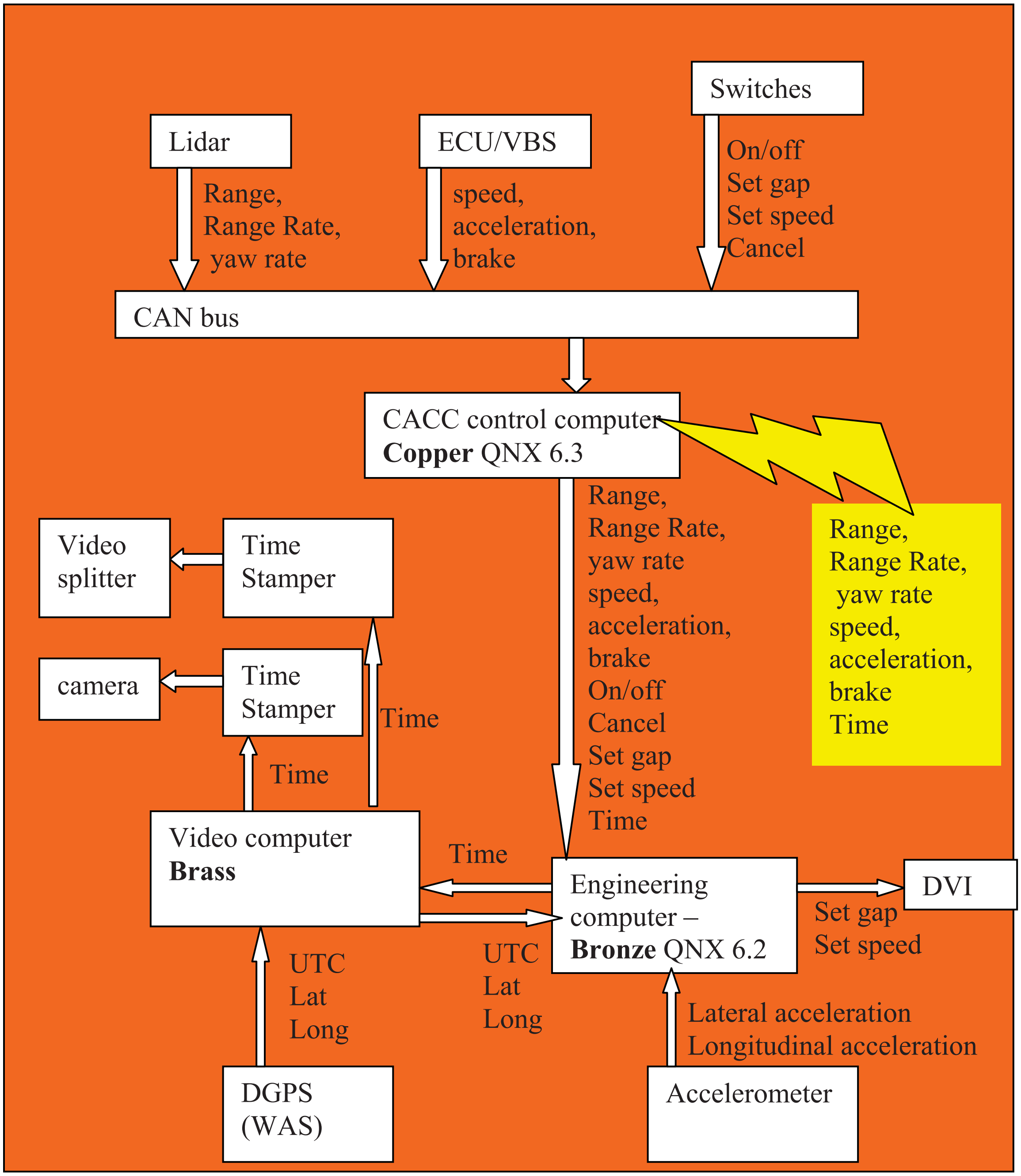


Figure 34: DAS Data flow for Copper (CACC) Vehicle

5 Experimental Protocol

The experimental protocol was designed to evaluate the perceived acceptability of shorter gap settings offered by the CACC system using an on-the-road, in real traffic, study design. Although the goal of the experiment was to test the shorter gaps provided by the CACC system, most drivers in the U.S. are unfamiliar even with the already available ACC systems that are currently on the market. At the time of this study, ACC systems were generally only available on high-end, luxury cars, and often as a fairly expensive option, and the market penetration of these systems was rather small. Thus, a protocol needed to be developed to first get the test participants acquainted with a standard ACC system, before the testing of a CACC system could begin.

The experimental protocol was split into two phases (See Table 1). In the first phase, the test participants were given the silver Infiniti FX45 with the ACC system to drive as their own (without an experiment present) for a period of about 11 days. During that period, there were roughly 7 week days where the subject would be commuting to and from work with the vehicle and 4 weekends.

The second phase of the experiment lasted for two days, immediately following the last day of the first phase. In this phase, the test participant drove the copper Infiniti FX45 with the CACC system for their morning and evening commutes. During these four trips an experimenter was present in the vehicle with the test participant, and the silver Infiniti FX45 was driven by a confederate to play the role of the lead vehicle during the commute.

Table 1: Summary of testing condition per day

	Wednesday	Thursday	Friday	Saturday	Sunday	Monday	Tuesday
Week 1	Vehicle delivered	Day 1 No ACC	Day 2 ACC	Day 3 ACC	Day 4 ACC	Day 5 ACC	Day 6 ACC
Week 2	Day 7 ACC	Day 8 No ACC	Day 9 ACC	Day 10 ACC	Day 11 ACC	Day 12 CACC	Day 13 CACC

The driving sessions took place on public highways on the route that the participant usually follows for his/her commute. The subjects were informed that they could stop at any moment or choose any route that they desired, but they were asked to drive in accordance with all state and local driving laws.

5.1 Participant Recruitment

To be eligible to participate in the study, potential candidates needed to meet the following criteria:

- Have a valid California driver’s license
- Have a clean driving record with no moving violations within in the last 3 years and no DUIs
- Commute daily with 25 or more minutes spent travelling at freeway speeds each way
- Have relatively secure parking at both home and work
- Be between the ages of 25 and 55 years of age

The initial test participants were recruiting using the U.C. Berkeley and U.C. San Francisco Research Subject Volunteer Program, which is a basically a website bulletin board where potential participants can browse studies which are currently seeking volunteers. After an experimenter validated a candidate participant’s eligibility, either through a phone call or email, a participant packet was mailed to the participant. (See Appendix B) The packet contained a cover letter, study consent forms, and a DMV records release from (to verify the candidate’s eligibility to participate).

There were actually three consent forms. The first detailed the study providing the participants with enough information to make an informed decision about whether or not they still wanted to participate in the study. Consent on this form was mandatory for participation. The second consent form was a video and photographic image release form. This was not mandatory for participation. Finally, there was a fuel card user agreement, which was only required if the participant wished to use a University provided fuel card to purchase gas for the vehicle. It was not required if the participant wished to purchase fuel on his or her own, and submit receipts for reimbursement at the end of the study. The participants generally had several weeks to review the consent materials and ask questions, as the forms were not signed until the day that the vehicle was dropped off to the participant.

5.2 Phase 1: Gaining Experience with ACC Systems

The goal of the first phase of the experiment was to allow the driver to acclimate to the test vehicle and to gain experience with a typical ACC system, since it was assumed that most drivers in the US would be unfamiliar with such a system. The first phase also allowed for the collection of baseline driver behavior data during two days when the test participant was asked to drive the vehicle without using the ACC system. This phase of the protocol could further be broken into five steps over 11 days.

5.2.1 Step 1: Vehicle Delivery

After a potential participant's eligibility to participate in the experiment was verified, a testing date was scheduled, and the vehicle was delivered at the participant's place of residence or work by an experimenter on either a Wednesday or a Thursday. At the time of delivery, the experimenter trained the test participant in the features of the vehicle and the use of the ACC system following the vehicle checkout checklist found in Appendix C.

The first part of the training took place when the vehicle was parked. The experimenter explained the ACC functions, how to activate them, and how to turn them off. The test participant was invited to ask questions throughout this step.

The second part of the training involved taking the vehicle on a highway for a short trip with the experimenter in the passenger seat. The participant was then instructed to turn the ACC system on whenever he or she felt comfortable to do so. The experimenter then talked the participant through the features of the system and answered any additional questions that the driver had about the system. The experimenter also stressed the following important parts of the experimental protocol to the test participant.

- The participant was the only person allowed to drive or ride in the vehicle.
- The participant was to try to use this vehicle as he/she would use their personal vehicle.
- The participant should try to use the ACC when conditions allowed (highway driving with relative free flow traffic) as much as possible on the non-baseline days of the protocol.
- The participant was encouraged to try the different gap settings until finding one with which they were comfortable.

- The participant was reminded to fill out a logbook entry for each trip taken in the vehicle. (See Appendix C for a copy of a typical logbook entry.)

5.2.2 Step 2: One Baseline (Non-ACC) Driving Day

On Day 1, the first full day with the ACC equipped vehicle (which was typically a Thursday), the test participant was instructed to drive the vehicle without using the ACC system. Although the participant was not actively using the ACC system, the DAS was still recording all of the data that would normally be collected when the ACC system was active. The data collected from this day was then used as a baseline to characterize the test participant's normal driving behavior.

5.2.3 Step 3: Six ACC Driving Days

After the baseline driving day, the participant was allowed to drive the vehicle for the next six days while freely using the ACC system. This would include four days of commutes and two weekend days of experience with the ACC system. Data from the vehicle's DAS was typically downloaded on day 6 while the test participant was at work.

5.2.4 Step 4: One Second Baseline (Non-ACC) Driving Day

At this point, the test participant has had the ACC equipped vehicle for about a week. On Day 7, the second Thursday, the participant was again instructed to drive the vehicle without using the ACC system. This day served as a second baseline to allow for comparisons to be made between the participant's behavior before using the system and the participant's behavior after using the system to see whether or not the system had an influence on the participant's typical behavior.

5.2.5 Step 5: Three More ACC Driving Days

On Days 8 through 11, the test participant was again allowed to drive the vehicle using the ACC system. This would include one commute day and two weekend days. During this period of time, the participants were instructed to fill out the first survey on their experiences with the ACC system.

5.3 Phase 2: Using the CACC system

In the second phase of the experimental protocol, the experimenter and a confederate, lead-vehicle driver met the test participant at his or her residence or place of work with the CACC equipped vehicle. The test participant then drove the CACC-enabled copper-colored FX45 with the experimenter present in the passenger seat, while the silver-colored FX45 was driven by the confederate driver to serve as the lead vehicle. The protocol provided the driver with four trips using the CACC system.

Although an experimenter was present during this phase of testing, the participant still scheduled the times of departures, routes taken, and even the lane of travel. All of this was communicated to the lead vehicle driver via two-way radio. The experimenter also served as a safety observer since the CACC system was a prototype, and was only reliably capable of following the communication-enabled, silver-colored FX45. If the CACC system misbehaved or other vehicles cut in-between the two test vehicles, the experimenter was able to turn the system off with a panic button which, in effect, mimicked the functionality of the CACC on/off switch.

At the end of the second day, the participant was asked their general impressions of the CACC system and given a survey on their experiences with both the ACC and CACC system to be completed and mailed back. The participants were thanked and paid $100 for their participation in the experiment, and they were also reimbursed for any fuel expenses occurred while in possession of the ACC equipped vehicle (see participant payment receipt form in Appendix C). The vehicles were then inspected and readied for the next participant using the vehicle return checklist found in Appendix C.

6 Data Files

There were two types of data files generated by the ACC/CACC vehicle's Data Acquisition System (DAS). First, the vehicles generated engineering files, collected and stored on the engineering computer installed each vehicle. Second, the vehicles generated two digital video files from the five onboard cameras, which were stored on a separate video collection computer. Two paper questionnaires were also administered during the experiment regarding driving practice and ACC/CACC usage.

6.1 Engineering and Video Files Created by the DAS

6.1.1 Engineering files

The engineering files are essentially text files containing rows and columns of numeric vehicle data such as speed, distance, latitude, longitude, etc. Data was recorded every 50 ms (20 Hz sampling rate) and the files were saved every two minutes. There were three types of engineering files that were recorded by the DAS and their contents are described in Tables 6 through 8. Although it may seem trivial, much effort was put into creating a file naming method that would insure that each file contained a unique name, thus avoiding any potential to accidently overwrite data when it is copied or moved. The engineering filenames were constructed using the following convention:

[V][F][MMDD][TTTT][SSS].dat

Where:

- [V] is a single character representing the vehicle on which the data is collected:
    'c' is used for data from the copper car, equipped with the CACC prototype
    's' is used for data from the silver car, with the commercial ACC
- [F] is a single character representing the type of data that will be contained within the file:
    'a' is used for C/ACC data
    'c' is used for communication from the lead vehicle data
    'd' is used for driver behavior and target data
- [MMDD] is the date with 2 characters for month and 2 characters for the day of the month

- [TTTT] is a 4-digit Trip ID number which is incremented each time the vehicle is started
- [SSS] is a 3-digit sequence number which starts at 000 and increments every 2 minutes

When the engineering files are downloaded from the vehicle, they are grouped into the concept of a trip, where a trip corresponds to each time the vehicle ignition was switched on. The files are copied into a single trip directory which is named using the following convention:

e[YYMMDD][TTTT]

Where:

- 'e' is the indication that the directory contains engineering (instead of video) data
- [YYMMDD] is the trip date with 2 digits representing year, month, and day
- [TTTT] is a 4-digit Trip ID which matches the trip ID number of the enclosed files

Table 2: Contents of the 'a' File (CACC Data)

Column		Description	Unit/Range
1	A	Time of day this entry was recorded	hh:mm:ss.sss
2	B	Number of seconds since start of process	sec
3	C	Virtual pedal position (from driver, ACC or CACC)	percent
4	D	Engine RPM	rpm
5	E	Mean effective torque	Nm
6	F	During shift (no/yes)	0/1
7	G	Current gear	0-7
8	H	Front right wheel speed	rpm
9	I	Brake pressure	bar
10	J	Change counter	0-7
11	K	Output Shaft revolution rate	rpm
12	L	Turbine revolution rate	rpm
13	M	Target engine torque	Nm
14	N	Target lock	0/1
15	O	Virtual distance (CACC output command)	m
16	P	Virtual speed (CACC output command)	m/s

Table 3: Contents of the 'c' File (Communication Data)

Column		Parameter	Units
1	A	Time of day this entry was recorded	hh:mm:ss.sss
2	B	Number of seconds since start of process	sec
3	C	Time wireless comm message sent	sec
4	D	Time wireless comm message received	sec
5	E	Time engineering message sent	sec
6	F	Time engineering message received	sec
7	G	Message count	0-255
8	H	My time	msec
9	I	Accelerator pedal position (from driver)	percent
10	J	Virtual pedal position (from driver, ACC or CACC)	percent
11	K	Engine RPM	rpm
12	L	Mean effective torque	Nm
13	M	During shift (no/yes)	0/1
14	N	Current gear	0-7
15	O	Front right wheel speed	rpm
16	P	Driver braking (no/yes)	1/0
17	Q	Target lock	0/1
18	R	Car space (ACC gap selection)	1-3
19	S	Set speed	km/h
20	T	Brake pressure	bar
21	U	Distance from silver Nissan to target vehicle	m
22	V	Relative speed (between silver Nissan and its ACC target vehicle)	m/s
23	W	Yaw rate	deg/s
24	X	Vehicle Speed	km/h

Table 4: Contents of the 'd' File (Driver Behavior Data)

Column		Parameter	Units
1	A	Timestamp of file write	hh:mm:ss.sss
2	B	Number of seconds since start of process	sec
3	C	Time wireless comm message was sent	sec
4	D	Time wireless comm message was received	sec
5	E	Time engineering message was sent	sec
6	F	Time engineering message was received	sec
7	G	Yaw rate	deg/s
8	H	X-Acceleration	g
9	I	Y -Acceleration	g
10	J	ACC Active (off/on)	0/1
11	K	Car Space (ACC or CACC Gap Setting)	2-3-4-5 for copper 1-2-3 for silver
12	L	Target Approach Warning (false/true)	0/1
13	M	MainSW – ACC powered on (off/on)	0/1
14	N	ACC Buzzer - Master Alarm (off/on)	0/127
15	O	ACCBuzzer2nd - Target Approach Warning (off/on)	0/1
16	P	ACCBuzzer3rd	0/1
17	Q	ACC/CACC Set speed	km/h
18	R	Accel. PedalPosition (from driver)	percent
19	S	VirtualPedalPosition (from driver, ACC or CACC)	percent
20	T	Driver Braking (off/on)	1/0
21	U	ACCMainSW – ACC powered on (off/on)	0/1
22	V	Brake pressure	bar
23	W	Vehicle Speed	km/h
24	X	UTC Time	HHMMSS:ss
25	Y	Longitude	degree
26	Z	Latitude	degree
27	AA	Altitude	m
28	AB	GPS Speed Over Ground	km/h
29	AC	Numsats (number of GPS satellites available)	-
30	AD	Date	ddmmyy
31	AE	Change Counter	-
32	AF	Distance to Lead Vehicle	m
33	AG	Relative Speed Compared to Lead Vehicle (+ if closing gap / - if opening gap)	m/s

6.1.2 Video Files

Video data was recorded continuously from five cameras into two divx digital video files at a rate of 500 kbps. The files were roughly two minutes long such that the ends of the video files were synchronized with the ends of the corresponding engineering files. Unfortunately, due to technical constraints and some level of randomness with the time it takes to open a new video file in real time, the beginnings of the video files are not necessarily synchronized with the beginnings of the engineering files. The video files typically contain an additional 1 to 2 seconds of video at the beginning to avoid the possibility of a loss of video.

Figure 35 illustrates the views provided by each of the two video file types. The image on the left is the front scene from a single forward looking camera. At the bottom of the image is the time, in hours, minutes, seconds and milliseconds and the date. The image on the right is a composite of 4 cameras using a video quad splitter. In the top left corner is the rear view. In the top right corner is a view of the steering wheel. In the bottom left corner is a view of the driver's right foot above the accelerator and brake pedals, and finally, in the bottom right corner is a view of the driver's face.

Figure 35: Example of video file content (left is front view, right is quad view)

As with the engineering filenames, care was taken to ensure unique video filenames which followed the following naming convention:

[V][F][MMDD][TTTT][SSS].avi

where:

- [V] is a single character representing the vehicle on which the data is collected.
    's' is used for the silver car.
    'c' is used for the copper car.
- [F] is a single character representing the video file type or channel
    'f' represents the file containing the single video looking out of the front window
    'q' represents the file containing the four (quad) video images
- [TTTT] is a 4-digit Trip ID number which is incremented each time the vehicle is started
- [SSS] is a 3-digit sequence number which starts at 000 and increments every 2 minutes

Similar to the engineering files, the video data files were organized and copied into video trip directories. The video trip directories were named using the following convention:

v[YYMMDD][TTTT]

where:

- 'v' is the indication that the directory contains video data.
- [YYMMDD] is the trip date with 2 digits representing year, month, and day
- [TTTT] is a 4-digit Trip ID which matches the trip ID number of the enclosed files

6.2 Questionnaires

6.2.1 Drivers' characteristics files

Information that might allow a subject to be identified is always kept confidential; however, there are some attributes that get coded each participant. This information is entered manually by an experimenter in either Excel or SPSS, and then coded to a random participant number assigned to each participant.

The driver characteristics that are typically coded for each participant include the following:

- Age
- Gender
- Typical Annual Mileage Driven
- Prior ACC use
- Daily Commute Miles Driven One Way & Round Trip

6.2.2 ACC and CACC comfort assessment questionnaire

Two questionnaires were administered during this experiment, and copies of them can be found in Appendix D. The first questionnaire was administered after the participant had about a week's worth of experience with the ACC system, but before the participant had a chance to experience the CACC system. Thus, the first questionnaire focused on comparing the ACC system to both conventional cruise control and manual driving. The second questionnaire was administered at the end of the study, after the participant had experienced both the ACC and CACC systems, and more or less repeated many of the questions found on the first questionnaire. This allowed for a more direct comparison of the ACC and CACC systems.

The questionnaires covered four basic topics:

1. Comfort and Convenience
2. Safety
3. Driving with the System
4. Road and Traffic Conditions

6.3 Data Organization and Processing

6.3.1 Data Downloading and Validation

For each test participant, somewhere between 8 and 11 GB worth of data is collected across two DAS computers. There are a number of both automatic and manual steps or procedures that are required to retrieve the data from the vehicles DAS computers, verify its integrity, and move it to a raid storage device where it can be archived and analyzed. On the vehicle DAS computers themselves, when a new trip is generated (each time the vehicle is started), the files for the last completed trip are automatically copied to a directory on the DAS video computer and put into a queue to be downloaded. When an external drive is attached to the video computer via USB, a script can be activated which will copy all of the data in the download queue to the external drive.

To assist in uploading the data from the USB drive to the raid storage device, a data importing tool was written in the RealBasic programming language. The data import tool serves three functions and a screenshot is provided in Figure 36:

1. It displays the list of trips recorded by the DAS in a table that can be easily read by an analyst. The analyst can then cross-reference the trips that were downloaded from the vehicles with the paper trip logs kept by the test participants to determine whether or not data for any of the trips made by the participant were missing.
2. It allows the analyst to filter out or skip the importing of inconsequential trips, such as short trips where the vehicle is simply moved, or trips where there was no opportunity for freeway travel and ACC use.
3. It allows the analyst to assign a Driver ID number to the trips.
4. It copies or imports the files from the USB drive to the raid storage device, while both restructuring and renaming the files to make subsequent data processing easier.
5. It verifies the integrity of the data being copied by reporting any expected, but missing files, and by checking for potential sensor failures on the vehicles.
6. It creates and archives an import log file of all operations performed and errors encountered.

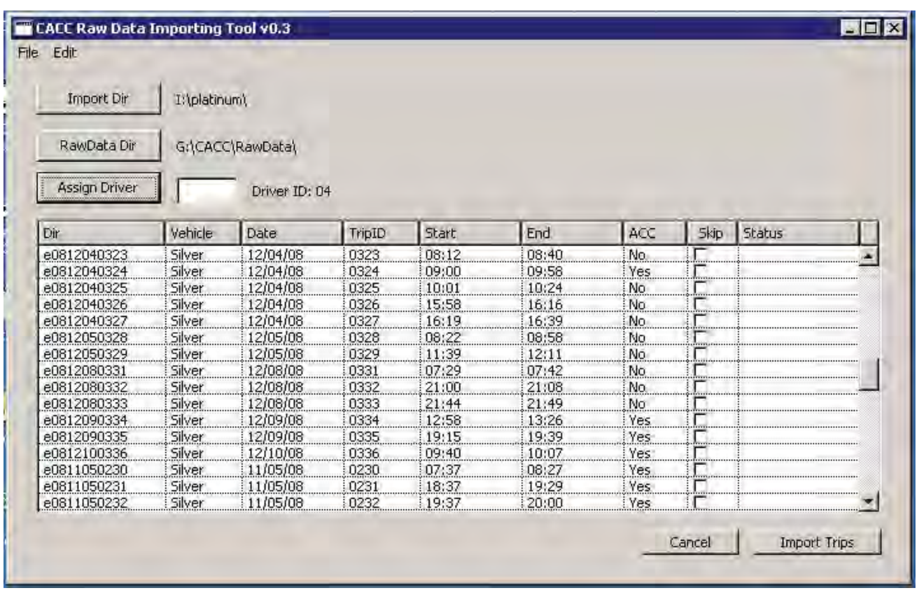


Figure 36: Sample screenshot of the CACC data import and validation tool

While the file naming conventions used on the vehicles were optimized to prevent the possibility of duplicate file names, the resulting filenames are a bit unwieldy for a person or analyst to visually parse and comprehend. As the files were imported to the raid storage device, the directory structure and files names were changed to match the following conventions:

- Driver[XX]
  - [Vehicle]
    - Date[YYMMDD]
      - Trip[TTTT]
        - [SSS]
          - [V][F][TTTT][SSS].[EXT]

Where:

- [XX] is a two-digit test participant ID number
- [Vehicle] is the name of the vehicle from which the data was collected
  'Silver' is used for the silver ACC-enabled car
  'Copper' is used for the copper CACC-enabled car
- [YYMMDD] is the trip date with 2 digits representing year, month, and day
- [TTTT] is a 4-digit Trip ID number which incremented each time the vehicle was started
- [SSS] is a 3-digit sequence number which started at 000 and incremented every 2 minutes
- [V] is a single character representing the vehicle on which the data is collected.
  's' is used for the silver car.
  'c' is used for the copper car.
- [F] is a single character representing the data file type
  'a' is used for C/ACC data
  'c' is used for communication from the lead vehicle data
  'd' is used for driver behavior and target data
  'f' represents the file containing the single video looking out of the front window
  'q' represents the file containing the four (quad) video images
- [EXT] is a 3-letter file extension, either .dat or .avi for data or video files, respectively

6.3.2 Data Analysis Plan

In order to describe the data organization, we will start by a summary of the testing condition as there will be a need to compare the three following conditions:

- Baseline driving, when the driver is not using either the ACC or CACC. This condition will be used in order to categorize the driving style in terms of vehicle following control.
- ACC use
- CACC use

Table 1 in Section 5 summarized the test condition for each day. Of special interest is the data collected on days 1, 2, 5, 6, 7, 8, 9, 12 and 13, or the days on which the test participant will be commuting to and from work. Because days 3, 4, 10 and 11 are weekends, we do not expect the participants to go to work, however, California being California, it will be worthwhile to double-check this assumption with the data.

In summary:

- Baseline Driving: Days 1 and 8
- ACC use: Days 2, 5, 6, 7, 8, 9
- CACC use: Days 12 and 13

Only Days 1 and 8 are considered to contain baseline data. Any data that is collected during the days where the ACC or CACC *can* be used, but either system is *not* being used, cannot be considered baseline data, because one of our goals is to understand the conditions of use of the system. For example, if the ACC system is not used when traffic is fairly dense we would skew our data into having shorter time gaps for the baseline than if we used data from trips driven when there is no possibility to use the system.

For each of the Baseline, ACC and CACC days, a further distinction will be made between the morning and evening commute trips. The focus on commute trips can be justified by the desire to "block" additional sources of variability, since the "main" variation among trips will be caused by traffic conditions, and eventually by the driver (if the level of fatigue varies from day to day), although the latter is not information that we will have access to.

For this study, the focus is on highway driving, so the trips will be further divided into the following sections:

- On-ramp: when the participant enters the highway
- Cruising: longer highway sections where the participant mostly regulates speed and distance
- Merge: sections where the participant favors being in specific lanes in order to follow a direction
- Split: same as above
- Exit: when the participant exits the highway.

The main question to answer is whether drivers are comfortable with the shorter gaps provided by the CACC. In order to do so, both opinions and more "objective" data were gathered to observe:

- Their use of the systems
- The influence of the system on their driving

The part of their driving that will be focused on is essentially:

- Gap regulation with a lead vehicle
- Lane changes, in terms of number and location, along the commute trip

The data analysis activities will proceed in roughly six steps or phases:

1. Each section of each trip must be described in terms of the time where the driver is following a vehicle versus the times where the driver is driving "alone", i.e. no targets are sensed. Each trip may have a number of vehicle following episodes or epochs of varying duration. Furthermore, this description must be examined from two perspectives:

    - First, from the chronological time perspective,
    - Second, from the location or distance perspective as there may be certain locations where the ACC/CACC is systematically used/not used

2. Each following epoch will then be characterize along the following dimensions:

   - Duration
   - Initiation condition (e.g. SV catches up with slower POV, SV changes lane, POV changes lane)
   - Time gap at ACC initiation
   - Average time gap
   - Number of braking events
   - Max braking level
   - SV speed
   - End condition (SV changes lane, POV changes lane, POV distances SV)

3. For each following epoch, there are a number of graphs and metrics which will be examined including, but not limited to, the following:

   - Lead vehicle speed and speed variability over the duration of the epoch
   - ACC vehicle speed and speed variability
   - Time gap to lead vehicle
   - Time To Collision (TTC)

4. Lane changes will be identified, and the causes for each lane change will be identified and categorized as best as possible. This must be done to distinguish between lane changes for overtaking and lane change for following a route.

5. ACC/CACC system use will be characterized along the following dimensions:

   - For each trip using one of the ACC/CACC systems
     - Number of episodes when the system is used
     - Length of each of these episodes
     - Sections when the system is engaged/disengaged.
   - For each system use episode within a trip
     - Initial set speed
     - Conditions of disengagement of the system (brake pedal vs. button on steering wheel)
     - Elapsed time between disengagement and next engagement
     - Setting used, for speed and gap, and conditions for changes

6. ACC/CACC comparison

   - Comparison of system engagement and use, e.g., is the ACC or CACC typically disabled by the driver under conditions when the other variant would normally be used?
   - How and when is each of the systems disengaged by the driver and is there a difference for these disengagements for which the system type might account, e.g., does the closer gap maintained by the CACC system cause the driver to brake (thereby disengaging the system) more often?
   - Comparison of typical system gap settings used.

6.3.3 Data Analysis Tools

The amount of data collected during this study is quite daunting to both process and analyze. For each driver there is approximately 10 GB of data and video files. That equates to roughly 15 to 18 hours of commute time video that must be analyzed based on the discussions in the previous section. The sheer amount of data that needs to be processed requires a number of tools to be created to both efficiently access, search, processes, and view the data.

Several architectures and data processing tools for both storing and accessing the data were evaluated, and the decision came down to two leading candidates. The first candidate was to create a database with data. While this method holds some promise for the future, the issues in building and maintaining this type of system provided too much challenge for the resources of this project. The second candidate architecture was to store the data in flat files using the standardized conventions previously discussed in Section 6.3.1. While this architecture was simple to implement, it necessitates the use of a number of tools to efficiently locate and access the data.

The chief tool that was selected to process the data files is the MatLab interactive programming environment. A number of loosely linked basic utilities were written to load and synchronize data files, to search for events, to graph parameters that were recorded, and to save various types of output files for analysis in other tools such as Excel or other statistics packages. Although the bulk of the analysis tools had not been completed at the time of this report, an architecture and data processing plan were being developed and are detailed below:

- Applications or functions written in MatLab are to be used to open the original data files, and then apply any filters needed in memory before any data processing commences.
- MatLab can then be used to provide output in the forms of copies of selected data, summaries of data, graphs, or event files.
- Event files are time-coded lists of when certain things happened in the data, such as the time when buttons were pressed. Event files will have a standard format so that they can be both opened by and saved by different applications.
- Event files will be used to guide analysts on where they need to look to examine the video surrounding a certain event during a trip. Ideally, although not yet developed, a video playback tool will read in the event file and automatically play the sections of video near the events, allowing the analysts to code additional information, which could not be captured by the sensors on the vehicle, into the event files based on watching the incidents.
- The event files can then be re-imported into MatLab and used with the original data to generate graphs or summaries.

Although the tools to facilitate the proposed analysis had not been completed at the time of this report, much of the proposed analysis could still be done, as evident in Section 7, but they were done using more tedious and time consuming manual methods.

7 Pilot Experiment Results

This report covers the initial results of the human factors experiment rather than producing final conclusions about the entire experiment because that experiment is being completed under another project. Progress was slower than planned for a variety of reasons; including problems with getting potential test participant DMV records checked and last minute equipment failures which interrupted the testing of the first pilot participant. While improvements to the vehicles are still ongoing, and there is still some random data loss during one or two trips, the data collection is proceeding. At the time of this report, a total of one pilot participant and three test participants had completed the experiment.

This section of the report is composed of three parts. In the first part, a description of the sample at the time the report was written is discussed. In the second part, the responses to the ACC and CACC questionnaire are presented, and in the final part, the interactions of the pilot participant with the systems are discussed.

7.1 Description of participants sample

The sample at the time of this report was composed of one pilot participant and three test participants. Table 5 below provides the participants' characteristics.

Table 5: Test Participants characteristics

Participant #	Age	Gender	Miles Driven Annually	Commute miles one way (home to work)
Pilot	51	M	25,000 m/y	36 miles/72 miles round trip
1	32	F	10,000 m/y	24 miles/48 miles round trip
2	36	M	15,000-16,000 m/y	28 miles/56 miles round trip
3	38	F	15,000 m/y	37 miles/74 miles round trip

As a reminder, the test plan aims to reach a total of 20 participants, equally balanced on gender and part of one age group ranging from 30 to 45 years of age.

7.2 Questionnaires

The participants were given two questionnaires. The first was given to them after about eight days of driving the ACC vehicle. The second was given to them at the end of the test, after they had driven both the ACC and CACC vehicles. The questionnaire covered four basic topics:

1. Comfort and Convenience
2. Safety
3. Driving with the System
4. Road and Traffic Conditions

The preliminary results from the questionnaires were examined for the four participants who had completed the testing at the time of this report. All of the four participants were conventional cruise control users, from ten months for the shortest exposure to ten years for the longest exposure. Only one of the participants had used an ACC prior to the test, for a period of two months, and he rated himself as in-between a novice and expert user.

It should be noted that the data presentation below illustrates, to some extent, how the data will be processed, but cannot be used to conduct any statistical tests or draw any conclusions because the sample size is still too small at this stage.

7.2.1 Comfort and Convenience

Overall, the participants were comfortable using both the ACC and CACC systems. Only one participant rated their comfort with the CACC system as less than that with the ACC system. This may possibly be indicative of an order or learning effect, since all of the participants started off with the ACC system before using the CACC system. This supposition could also be supported by the fact that the drivers were generally not as comfortable with the ACC system's shortest gap, but they were all comfortable with the CACC system's longest gap (and these two gap settings were identical).

One participant was not comfortable with any of the shorter gaps offered by the CACC system. The other participants were generally comfortable with the shorter gaps offered by the CACC system, but that did not generally extend all the way down to the shortest gap (0.6 sec.) offered by the system.

The fact that the CACC system was a prototype may have influenced the pilot participant's perception of the system, as this participant consistently ranked the CACC system below the ACC system, while the other participants did not seem to have the same reaction.

Please refer to Table 6 for a full presentation of the results.

7.2.2 Safety

Participants moderately agreed that ACC and CACC systems are going to increase driving safety. When the participants compared the safety of operating an ACC relative to manual driving, they considered the ACC as safer. When the CACC mode was added to the comparison the ACC system remained the mode seen as the safest. This trend followed when asked which mode of operation brought them to their destination the safest.

Participants indicated that, when they where driving with either the ACC or CACC systems, they were moderately more aware of the actions of vehicles around them. Participants felt that they sometimes got into situations of relying too heavily on the ACC or CACC systems, letting the system get into situations in which it might not be best to rely on the system.

Participants indicated that it did not take much effort or was fairly easy to keep a safe following distance across all the modes of operation; however, conventional cruise control was rated as a slightly more difficult mode for keeping a safe following distance. Participants stated that they rarely experienced unsafe following distance when using the ACC and CACC systems.

Participants thought that they were moderately more responsive to the actions of the vehicles around them when driving in manual mode than when relying on either the ACC or CACC systems. Participants thought that there were a few times when one of the systems failed to detect a vehicle that they were approaching or following. However, overall, participants felt moderately safe using both the ACC and CACC systems.

Please refer to Table 7 for a full presentation of the results.

7.2.3 Driving with the system

Participants seemed to feel that manual driving was the slowest mode of operation, and that the use of ACC was the fastest mode of operation. When the questionnaire was administered during the ACC testing, the participants ranked manual driving as the mode that required them to brake the most often, followed by ACC, and then by conventional cruise control. Interestingly, after using the CACC testing, the responses for the same question became more distributed among the different modes. In the second questionnaire both ACC and CACC were ranked as the systems requiring the driver to apply the brakes most often, while conventional cruise control and manual were rated as the modes of operation requiring the least braking. Two possible explanations for this reversal of ranking could be that either the drivers had become more familiar with the ACC system by the time they filled the second questionnaire or that the CACC experience influenced their perception of the ACC system.

The participants thought the acceleration employed by the ACC system when pulling into empty lanes ranged from acceptable to moderately too fast. The deceleration employed by the ACC system when following another vehicle was reported as being just about right. However, the opinions on the deceleration employed by the CACC system, ranged the spectrum from too hard to too gentle.

As participants got used to both the ACC and CACC systems they felt more confident with them than upon initial use. With both systems, the participants indicated that they either rarely or very infrequently did not understand how the system was behaving.

The participants felt that they reached their destinations with less stress while using either of the ACC or CACC system, with manual driving being the more stressful mode. Possibly due to driving more cautiously in a loaned vehicle, participants indicated they drove slightly slower or about normal with both the ACC and CACC systems.

Please refer to Table 8 for a full presentation of the results.

7.2.4 Road and Traffic

When using the ACC over the range of traffic conditions (heavy to light), the participants indicated that they followed at about the same distance or slightly further away than they would have during manual driving. When using the CACC system, the participants indicated that they followed either slightly closer or about the same as they would have during manual driving.

Under light traffic conditions, the participants indicated that they were very comfortable using the ACC system and moderately comfortable using the CACC system. However, under heavy traffic conditions, the participants responded that they were slightly to moderately uncomfortable using both the ACC and CACC systems.

Participants generally indicated their speed in relation to other vehicles over the range of traffic conditions was about right. Two of the participants did not have commutes that took them over hilly roads, while the other two participants indicated that using both the ACC and CACC on hilly roads was very comfortable.

Please refer to Table 9 for a full presentation of the results.

Table 6: Questionnaire responses about comfort and convenience using the ACC and CACC systems

Questions (as the questions were identical for both system, they are merged for simpler presentation, the merge takes the form of C/ACC for questions pertaining to the ACC and CACC system, and when CACC functions are presented, they are added in italics, as they did not appear in the ACC questionnaire.)	ACC Response	CACC Response
Overall, how comfortable did you feel driving the car using the C/ACC system? Uncomfortable 1 2 3 4 5 6 7 Comfortable	All participants: 5	P 98:4 All others: 6
How easy was it to drive using the C/ACC system? Easy 1 2 3 4 5 6 7 Difficult	P98:2 P1:1 P2:6 P1:1	P98: 6 P1: 2 P2:1 P2:1
What was your level of comfort for each of these gaps with the ACC? [CC] Long gap Uncomfortable 1 2 3 4 5 6 7 Comfortable Medium gap Uncomfortable 1 2 3 4 5 6 7 Comfortable Short gap Uncomfortable 1 2 3 4 5 6 7 Comfortable *Shortest gap* *Uncomfortable 1 2 3 4 5 6 7 Comfortable*	All participants were comfortable with long and medium For short: P98:5 P1:4 P2:6 P3:6	P98, 2 and 3 rated all gaps 7, except for P98 and 3 who rated shortest 6 P1: M:5 S:3 Shortest: 1
How long did it take you to be comfortable using the ACC system?	2 days for all participant except P3, 1 day	No answer
How comfortable were you driving the C/ACC system in comparison to the manual driving? Uncomfortable 1 2 3 4 5 6 7 More comfortable	P98: 5 P01: 6 P02: 5 P03:7	P98: 2 P01: 5 P02: 5 P03: 7

How likely is it that you would have become more comfortable using the ACC system given more time? Not likely 1 2 3 4 5 6 7 Very likely	All participants 7	P98: 3 P01: 4 P02: 7 P03: 7
Compare (rank) these operation modes for comfort (from 1 most comfortable to 3*/4* least comfortable) __ Manual driving (no ACC) __ Cruise Control (speed only) __ Adaptive Cruise Control (speed and distance) __ *Cooperative Adaptive Cruise Control (speed and shorter distance)*	All participants rank ACC 1, P98 and P1 rank M2 and CC3 P2 and P3 rank M3 and CC2	P98, 1 and 2 ranked ACC 1, P03 ranked CACC 1 and ACC 2 P1 and 2 ranked CACC 2 and P98 ranked it 3
Compare (rank) these operation modes for convenience (from 1 most convenient to 3*/4* least convenient) __ Manual driving (no ACC) __ Cruise Control (speed only) __ Adaptive Cruise Control (speed and distance) __ *Cooperative Adaptive Cruise Control (speed and shorter distance)*	All participants rank ACC 1, All but P1 rank CC2 and M3, P1 ranks CC 3 and M2	All participants rank ACC 1 P01 and 02 rank CACC 2, while P98 ranks it 3
Compare (rank) these operation modes for driving enjoyment (from 1 most enjoyable to 3 least enjoyable) */4* __ Manual driving (no ACC) __ Cruise Control (speed only) __ Adaptive Cruise Control (speed and distance) __ *Cooperative Adaptive Cruise Control (speed and shorter distance)*	All participants rank ACC 1, All but P1 rank CC2 and M3, P1 ranks CC 3 and M2	P03 considers both system as enjoyable, The other 3 ranked ACC 1 and P01 and 02 rank CACC 2, while P98 ranks it 3

Would you rather have: ☐ An ACC ☐ a (speed only) cruise control ☐ no system *☐ A CACC*	All participants 1	P98 and P1: ACC P2 and P3: CACC
Rank, in order of preference, the following modes of operation for personal use. (Rank 1 most desirable to 3/*4* least desirable) __ Manual driving (no ACC) __ Cruise Control (speed only) __ Adaptive Cruise Control (speed and distance) __ *Cooperative Adaptive Cruise Control (speed and shorter distance)*	All participants rank ACC 1, All but P1 rank CC2 and M3, P1 ranks CC 3 and M2	P98 and P1 ranked ACC 1, P98 ranked CACC 4 and P1 ranked CACC 2 P2 and P3 ranked CACC 1 and ACC 2

Table 7: Questionnaire responses about safety when using the ACC and CACC systems

Questions (as the questions were identical for both system, they are merged for simpler presentation, the merge takes the form of C/ACC for questions pertaining to the ACC and CACC system, and when CACC functions are presented, they are added in italics, as they did not appear in the ACC questionnaire.)	ACC Response	CACC Response
Do you think ACC is going to increase driving safety? Strongly disagree 1 2 3 4 5 6 7 Strongly agree	All participants rated 5.	P98 & P03: 5 P01 & P02: 4

Compare safety under these operation modes (from 1 most safe to 3 least safe) __ Manual driving (no ACC) __ Cruise Control (speed only) __ Adaptive Cruise Control (speed and distance) __ *Cooperative Adaptive Cruise Control (speed and shorter distance)*	3 participants ranked M.D as 1, CC as 3, ACC 2. One participant ranked M.D & CC as equal 2, with ACC 1.	3 Participants ranked MD as 2, the other a 1. CC had two 4's, a 3 and a 2. 3 Participants ranked ACC as 1, with a 2 (opposite as MD). CACC had two 3's, a 4, a 1.
Under which mode of operation did you feel you reached your destination most safely? (from 1 most safely to 3 least safely) __ Manual driving (no ACC) __ Cruise Control (speed only) __ Adaptive Cruise Control (speed and distance) __ *Cooperative Adaptive Cruise Control (speed and shorter distance)*	All participants ranked MD as 1, with one participant rating all as an equal 1. 3 Participants had CC as 3, with ACC 2.	One participant ranked MD & CC equal at 2, as well as ACC & CACC equal at 1. P98: 1, 2, 3, 4, P01: 2,4,1,3 P02:3,4,1,2. With 3 participants rating ACC as 1.
When driving the ACC system, compared to manual driving, were you more or less aware of the actions of vehicles around you than you normally are? Less aware 1 2 3 4 5 6 7 More aware	Two participants marked 4, with P98: 6 P01:5	P98: 7 P01: 6 P02 & P03: 4

How frequently did you get into situations when you relied too heavily on the ACC to handle situations that it could not handle? Frequently 1 2 3 4 5 6 7 Never	P98: no answer P02: 5 2 participants 6.	P98: no answer P01: 4 P02: 5 P03: 7
How much effort did it take to maintain a safe following distance when using each of the following modes of operation? Manual driving (no ACC) Difficult 1 2 3 4 5 6 7 Very easy Cruise Control (speed control only) Difficult 1 2 3 4 5 6 7 Very easy Adaptive Cruise Control (speed and distance) Difficult 1 2 3 4 5 6 7 Very easy	MD: P98: 7 P 01 &P02: 6 P03: 3 CC P98 & P02: 5 P01:3 P03: 2 ACC P98:5 All others 6.	MD P98: 7 P01: 5 P02 &P03: 4 CC P98: 5 All others 3. ACC P01: 7 All others 6 CACC P03: 7 All others 6.
How often, if ever, did you experience "unsafe" following distances when using the ACC system? Frequently 1 2 3 4 5 6 7 Never	P98 & P03: 5 P01: 3 P02:6	P01: 3 All others 6
Driving the ACC system, compared to manual driving, did you find yourself more or less responsive to actions of vehicles around you? Less responsive 1 2 3 4 5 6 7 More responsive	P98: 6 P01:5 P02 & P03: 4	P98 & P01: 6 P02 &P03: 4
While using the ACC system, how often, if ever, did the system fail to detect a vehicle that you were approaching or following? Often 1 2 3 4 5 6 7 Never	P98: 4 P01: 6 P02: 7 P03: 5	No equivalent question in the CACC part.

How safe did you feel using the ACC system? Not safe 1 2 3 4 5 6 7 Very safe	P98: 4 P01:5 P02 & P03: 6	P98: 3 P01: 5 P02 &P03: 6

Table 8: Questionnaire responses about driving with the ACC and CACC systems

Questions (as the questions were identical for both system, they are merged for simpler presentation, the merge takes the form of C/ACC for questions pertaining to the ACC and CACC system, and when CACC functions are presented, they are added in italics, as they did not appear in the ACC questionnaire.)	ACC Response	CACC Response
In general, under which mode of operation did you feel like you reached your destination fastest? (Rank 1 fastest to 3 slowest) __ Manual driving (no ACC) __ Cruise Control (speed only) __ Adaptive Cruise Control (speed and distance)	P02: did not answer any MD P98: 3 P01:1 P03:2 CC P98 &P03: 2 P01: 3 ACC P98: 1 P1 &P03: 2	MD P98: 4 P01: 1 P02 &P03: 3 CC P98 &P03: 3 P01: 4 P02: 2 ACC P98 &P03: 02 P01: 3 P02:1 CACC P98:1 P01 &P03: 2 P02: 4
Do you feel the following distance adjustment function is useful? Strongly disagree 1 2 3 4 5 6 7 Strongly agree	P98: 6 All others 7.	Does not appear on CACC.

Which mode of operation (Manual, Conventional Cruise, ACC) required you to apply the brakes most often? (Rank 1 least braking to 3 most braking) __ Manual driving (no ACC) __ Cruise Control (speed only) __ Adaptive Cruise Control (speed and distance)	MD All rated 1. CC P03: 1 All others 3 ACC P03:1 All others 2.	MD P01: 3 All others 4. CC P98 &P03: 3 P01 &P02: 1 ACC P98: 1 P01: 4 P02 &P03: 2 CACC P98 &P01: 2 P02:3 P03:1
What did you think of the acceleration provided by the ACC system when pulling into an empty adjacent lane to pass other vehicles? Too slow 1 2 3 4 5 6 7 Too fast	P98 &P03: 6 P01 &P02: 4	NA as in order to use the CACC the participant had to follow the confederate vehicle
What did you think of the deceleration rate provided by the ACC system when following a vehicle? Too gentle 1 2 3 4 5 6 7 Too hard	P98:5 P01 &P03: 4 P02: 3	P98 &P01: 6 P02: 3 P03: 1
Did you feel more comfortable performing additional tasks, (e.g., adjusting the climate control or the radio) while using the ACC system as compared to driving under manual control? Strongly disagree 1 2 3 4 5 6 7 Strongly agree	P98 &P03: 5 P01: 4 P02: 7	P98: 2 P01 &P02: 4 P03: 6

As you got used to the ACC system, how would you rate the change of your level of confidence in the system? (circle 4 if your level of confidence remained the same) More confident 1 2 3 4 5 6 7 Less confident	P98 &P01: 3 P02 &P03: 2	P98: 5 P01: 3 P02: 2 P03: 1
When using the ACC system, did you ever feel that you didn't understand what the system was doing, what was taking place, or how the ACC system might behave? Very frequently 1 2 3 4 5 6 7 Very infrequently	P 02: 7 All others 6	P98: 3 P01 &P02: 6 P03: 7
In general, under which mode of operation did you feel like you reached your destination with the least stress related to driving? (Rank 1 least stress to 3 most stress) __ Manual driving (no ACC) __ Cruise Control (speed only) __ Adaptive Cruise Control (speed and distance)	MD P98, 02, 03: 3 P1: 2 CC P98, 02,03: 2 P01: 3 ACC All rated 1.	MD P98 &P01: 3 P02 &P03: 4 CC P98: 1 P01:4 P02 &P03: 3 ACC P98 &P03: 2 P01 &P02: 1 CACC P98: 4 P01 &P02: 2 P03: 1
While driving with the ACC, how confident did you feel about the system? Very confident 1 2 3 4 5 6 7 Not confident	P98 &P03: 2 P01: 1 P02: 6	Did not appear on the CACC.

When you were driving with the ACC, were you driving slower or faster than you normally drive? Heavy traffic Slower 1 2 3 4 5 6 7 Faster Medium traffic Slower 1 2 3 4 5 6 7 Faster Light traffic Slower 1 2 3 4 5 6 7 Faster	HT P98 & P02: 4 P01 &P03: 3 MT P98: 6 All others 4 LT P98: 6 P01: 5 P02 &P03: 4	HT P98: 5 P01: 6 P02 &P03: 3 MT P98: 6 P01: 4 P02 &P03: 3 LT P98: 6 P01 &P03: 4 P02: 3

Table 9: Questionnaire responses about road and traffic conditions influence on using the ACC and CACC

Questions (as the questions were identical for both system, they are merged for simpler presentation, the merge takes the form of C/ACC for questions pertaining to the ACC and CACC system, and when CACC functions are presented, they are added in italics, as they did not appear in the ACC questionnaire.)	ACC Response	CACC Response
When using the ACC system in each of the following traffic conditions, did you follow other vehicles closer or further than you normally do? Heavy traffic Closer 1 2 3 4 5 6 7 Further Moderate traffic Closer 1 2 3 4 5 6 7 Further Light traffic Closer 1 2 3 4 5 6 7 Further	HT P98: 4 P01 &P03: 5 P02: 3 MT P98: 4 P01 &P03: 5 P02: 2 LT P98: 3 P01 &P03: 5 P02: 2	HT P98: 5 P01: 4 P02: 2 P03: 3 MT P98: 5 P01: 3 P02 &P03: 2 LT P98: 4 P01,02,03: 2

How comfortable were you using the ACC system when driving in the following traffic environments? Heavy traffic Uncomfortable 1 2 3 4 5 6 7 Very comfortable Moderate traffic Uncomfortable 1 2 3 4 5 6 7 Very comfortable Light traffic Uncomfortable 1 2 3 4 5 6 7 Very comfortable	HT P98: 1 P01: 3 P02:4 P03: 6 MT P98:3 P01,02,03: 6 LT P98: 6 P01,02,03: 7	HT P98: 1 P01: 3 P02: 5 P03: 6 MT P98: 3 P01: 5 P02 &P03: 7 LT P98: 5 P01: 3 P02 &P03: 7
When you were driving with the ACC, was your speed generally slower or faster than the speeds of neighboring vehicles? Heavy traffic Slower 1 2 3 4 5 6 7 Faster Medium traffic Slower 1 2 3 4 5 6 7 Faster Light traffic Slower 1 2 3 4 5 6 7 Faster	HT P98: 5 P01 &P03: 4 P02: 4 MT P98 &P02: 5 P 01: 4 P03: 3 LT P98 & P02: 6 P01 &P03: 4	HT P98, 02, 03: 4 P01: 6 MT P98 & P03: 4 P01 & P02: 5 LT P98: 6 P01: 2 P02: 5 P03: 4
25 - How comfortable were you using the ACC system on hilly roads? Uncomfortable 1 2 3 4 5 6 7 Very comfortable	Two participants had a N/A, P98 &P01: 7	Two participants had a N/A. P98 &P01: 6

7.3 Driving data supporting the analysis of comfort with the systems

In this section, the data presented focuses on the trips made by the pilot participant, as the treatment of the engineering data is more time consuming than the processing of the questionnaire data. In this section, the goal is to illustrate some of the aspects of the data that will be analyzed in order to support the determination of whether or not drivers would be willing to use the shorter gaps offered by a CACC system. This section first presents the data set gathered for this participant, followed by a description of the driver's interactions with the systems. It concludes with a summary of the results gathered for this participant, with an emphasis on the similarities between the results obtained via the questionnaire and the observation of the driver's use of the systems.

7.3.1 Data set presentation

The final data set gathered for participant 98[1] is composed of 13 commutes between residence and workplace detailed in Table 10. Of these commutes, 11 were completed with the silver FX and use of the ACC at the participant's discretion, and three were completed with the CACC. One of the CACC tests has been excluded because traffic was too dense for use of the CACC on that day (evening commute of Day 8). The trip characteristics are presented in the table below, as well as other names used in order to refer to the trip for the presentation of the results.

Table 10: Test pilot participant's commute trip description

Trip	Date	Commute	Mode	Other names used in the report	
45	07/24/2008	Evening	ACC	A	Day 1
47	07/25/2008	Morning	ACC	B	Day 2
56	07/25/2008	Evening	ACC	C	Day 2
65	07/28/2008	Evening	ACC	D	Day 3
68	07/29/2008	Morning	ACC	E	Day 4
71	07/29/2008	Evening	ACC	F	Day 4
72	07/30/2008	Morning	ACC	G	Day 5
76	07/31/2008	Morning	ACC	H	Day 6
89	08/01/2008	Evening	ACC	I	Day 7
104	08/06/2008	Morning	ACC	J	Day 10
220	08/04/2008	Morning	CACC		Day 8
226	08/05/2008	Morning	CACC		Day 9
233	08/05/2008	Evening	CACC		Day 9

A few commutes were not available to be analyzed due to DAS malfunctions, as was the case for the mornings of the 28th of July and the 1st of August, and the evening of the 30th of July.

For each of the commutes for which we had valid data, the sections of highway driving have been extracted from the data set and only these sections have been subjected to the data

[1] This participant has been attributed the number 98 as he was part of the pilot for the verification of the protocol and DAS behavior, as well as supporting the development of tools for analyzing the engineering data.

processing that will be presented in the next section. This extraction was conducted by watching video and identifying the beginning and end of the highway driving.

Although it has not been used yet, the use of the GPS data for this purpose will be further investigated. Figure 37 shows an example of how the trips can be reconstructed from the GPS data and overlaid on a map using Google Earth.

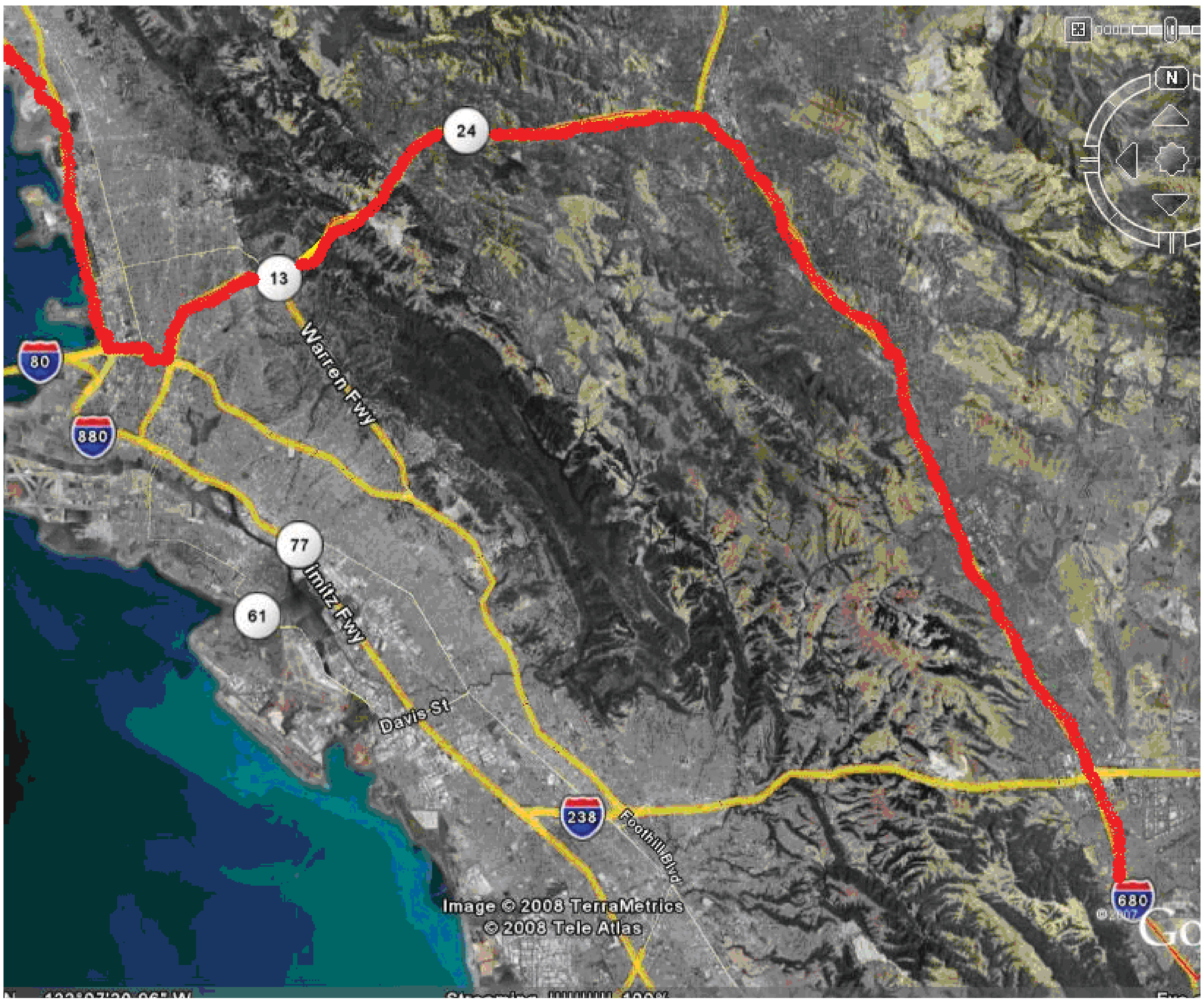


Figure 37: Top view of Trip 47 using GPS data and Google Earth

The red line on top of HWY 680 to 24 to 13 and 80 illustrates the morning commute. In order to protect the privacy of the participant, the urban sections are not integrated to this view. By plotting the trips, it is easy to identify the highway on which the driving was conducted. A possible benefit from this identification is the matching of this data with the level of congestion for the day and time the test drive took place, which could support the understanding of the driver's choice to use the system or choice of the settings used. It also permits identification of the different routes that the participant chose for the morning commute, as illustrated in Figure 38.

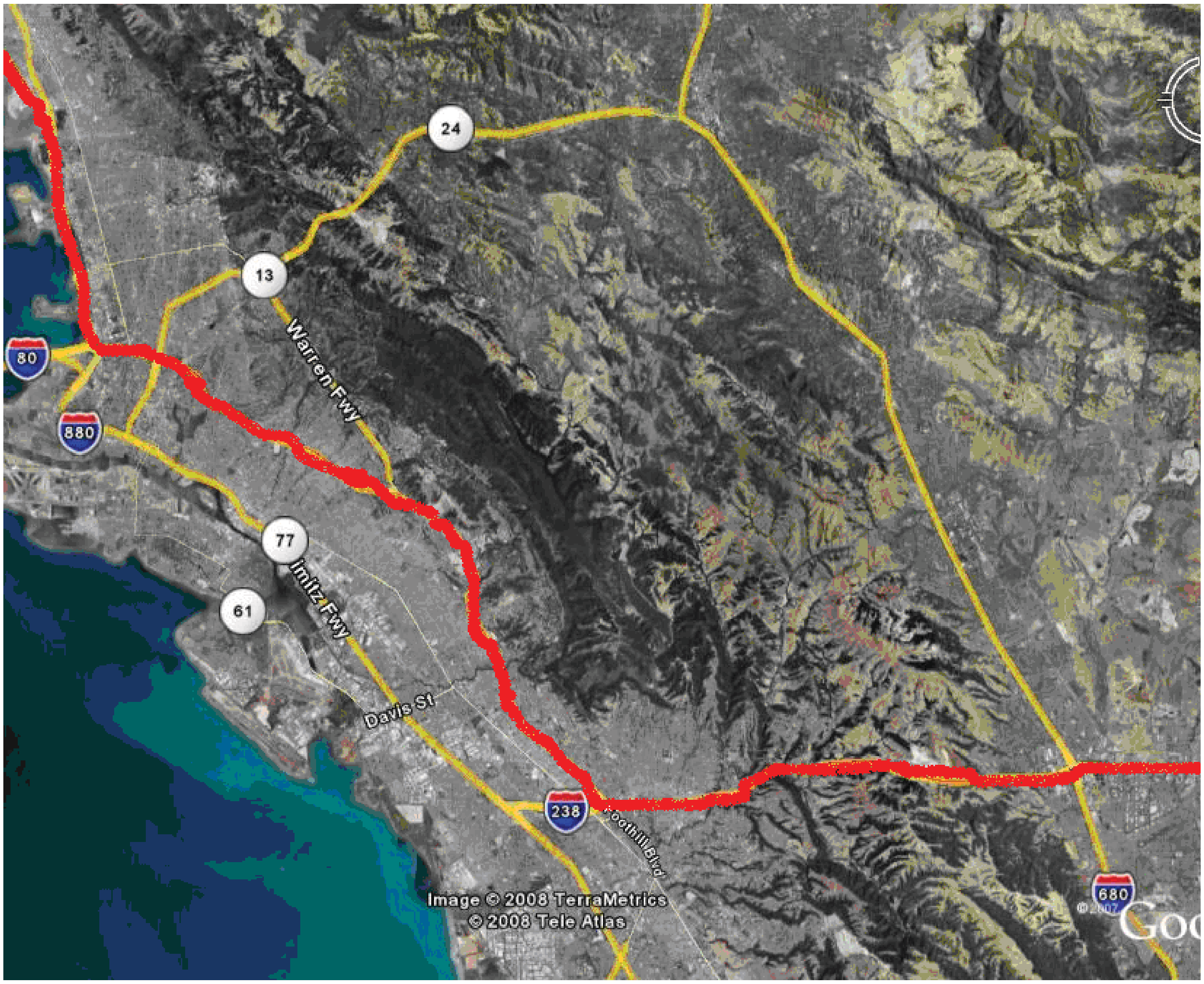


Figure 38: Top view of Trip 72 using GPS data and Google Earth

7.3.2 Driver's interactions with the ACC and CACC

The interactions with the system are described in terms of percentage of time the system is activated when the participant drives on a highway, and the evolution of the choice of gap settings, as demonstrated by the amount of time each of the settings was selected during each trip. No baseline of manual driving could be accomplished for this participant, so in order to have an insight about this participant's driving style, a summary of the average time gap was computed for each trip when the systems were not activated. It is important to note that characterization of the driver's manual driving in terms of average time gap will be conducted for all the other participants, using the four baseline trips in the protocol.

Figure 39 illustrates the percentage of time the system was activated when the participant was driving on the highway. The system seems to have been activated more consistently in the morning, when, with the exception of the last morning, the system seems to have been used for at least 70% of the highway driving time. Mornings 8 and 9 as well as evening 9 represent commutes conducted using the CACC system. A possible reason, not verified at the moment of writing the report, for explaining the decreased use of the ACC system during the evening commutes is that the average speed and density of traffic might have deterred the participant from using the system. This assumption seems to also be supported when looking at the average speed per trip as presented in Figure 40.

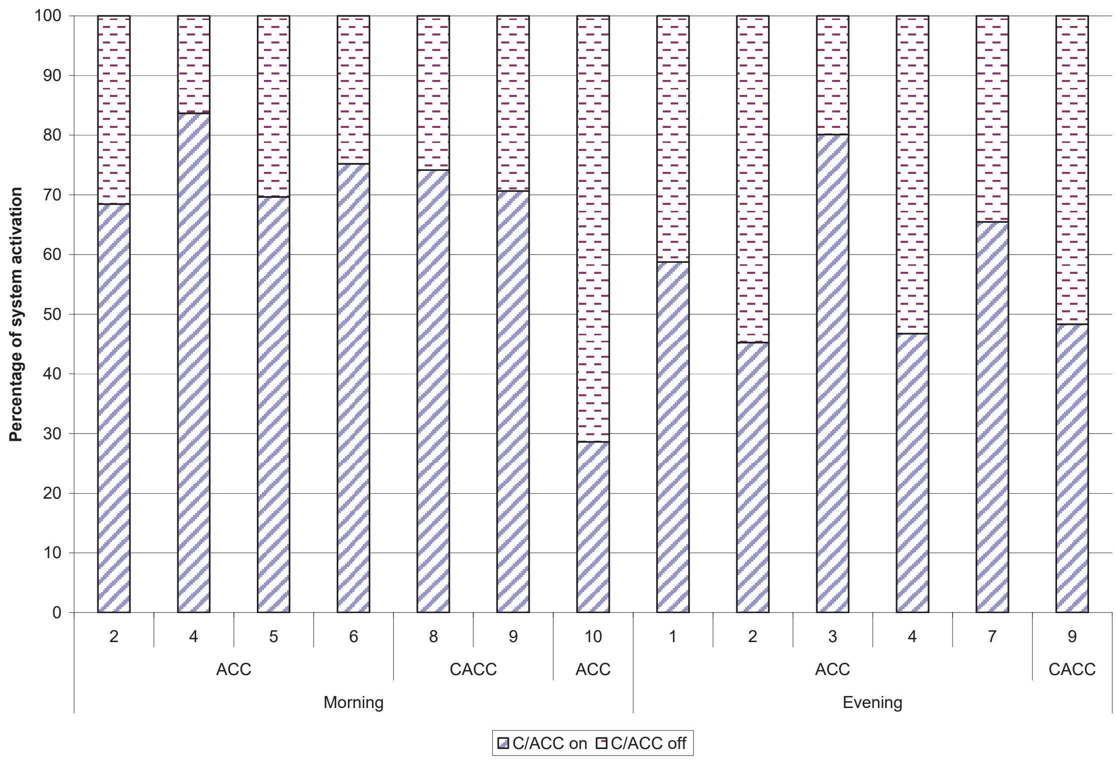


Figure 39: Percentage of systems' activation during the test for Participant 98

Figure 40 displays the average speed for each trip when the systems were activated and when they were not activated. The speeds travelled when the systems were not engaged are lower than when the systems were engaged, and this difference is even more pronounced for the evening commutes. Additionally, it should be noted that the system was not designed for stop and go traffic, and the system will not engage if the speed is below about 16 m/s. Thus, on days where the average speed was less than 16 m/s, it would be impossible for the system to be used reliably without the system constantly disengaging when the speed fell too low. This graph certainly supports the assumption that traffic conditions will influence the driver's decision to use the system. It also seems to indicate that the driver used the system relatively systematically whenever the conditions were right for the system to make the trip more comfortable.

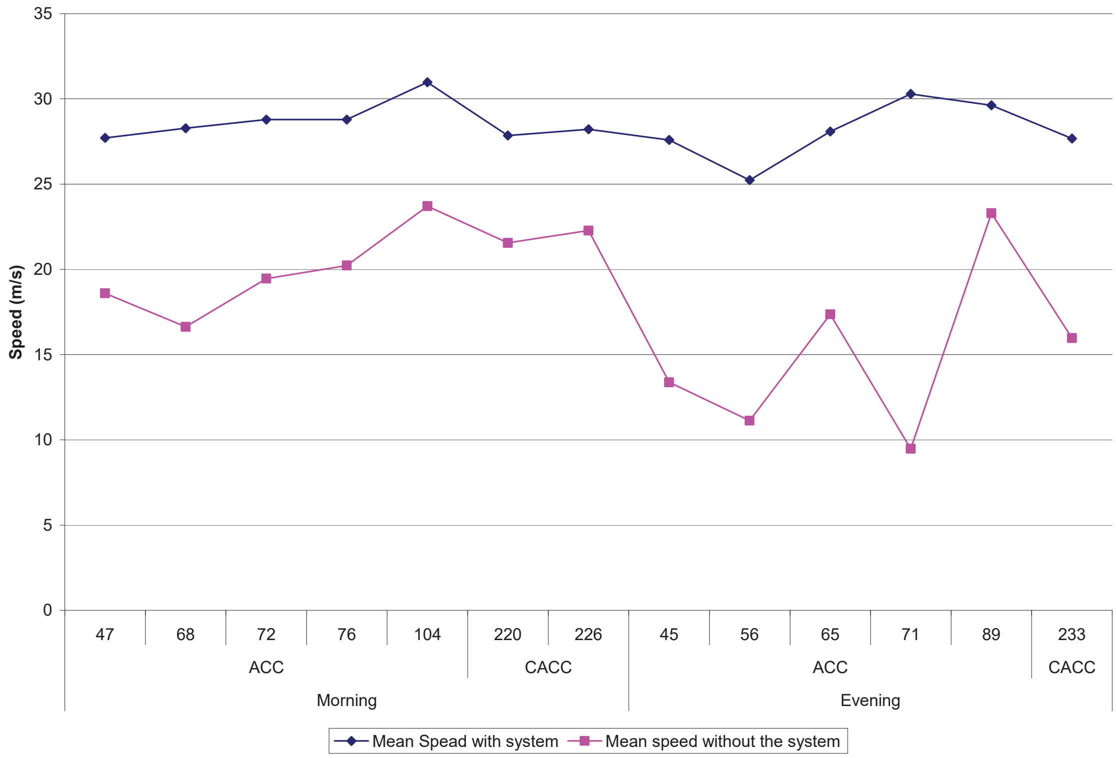


Figure 40: Average speed per trip, system activated vs. disabled system

In Figure 41, the trips are presented in chronological order for a better rendering of the evolution of the setting selection as the participant became more familiar with the system. The letter in parenthesis indicates whether the trip was an evening (E) or morning commute (M). The shortest setting was not used during the first three trips (A, B, and C). Use of the shortest gap setting began gradually, starting from the fourth trip. It was then used most frequently for the next several trips (F through G) and the last trip (J). During trips H and I, the pilot participant appeared to experiment with other gap settings again. The trip (J) was made by the participant after the CACC trials, but even though the shortest setting was the most used, it is necessary to keep in mind that the ACC was still used for a little less than 30% of the time during that trip (See Figure 39).

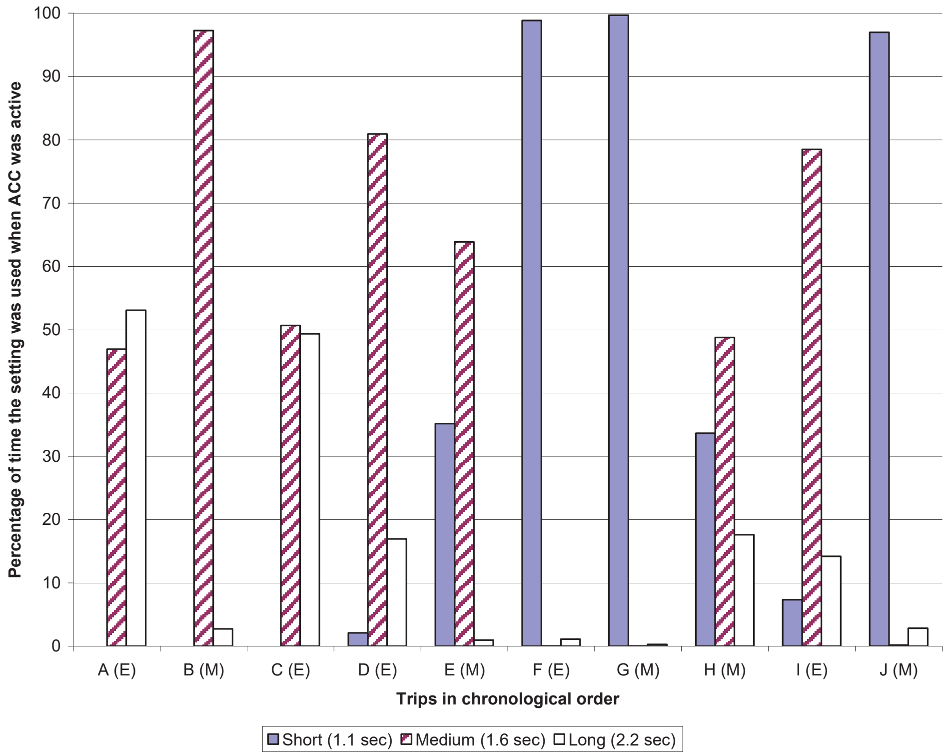


Figure 41: Percentage of time for each gap setting per trip – ACC

Figure 42 illustrates the gap setting choices while the participant used the CACC system. On the first trip with the system, the participant used mostly the longest gap provided by the CACC system (which equates to the shortest gap setting provided by the ACC system), but did try each of the three shorter gap settings provided by the CACC system. On the next day, this participant again mostly used the longest gap setting, but seemed willing to explore the next lower gap setting (0.9 s). On the third trip, this participant settled on using the 0.9 s gap setting for the majority of the trip.

It is possible that this driver might have benefited from a longer exposure to the CACC system in order to have a chance to gain comfort at each of the decreased gap settings offered by the system. Based on this participant's ACC driving, he needed between two to three trips of about 45 minutes of highway driving, in order to gain enough confidence with a gap setting before moving on to experiment with a shorter gap setting. One of the aspects to explore with the rest of the participants will be to determine if other drivers exhibit a similar learning pattern, which will be indicative of the exposure time needed to gain comfort with such a new system. This information will support setting a testing period for a new system evaluation in future studies.

It should also be noted that no baseline driving, in terms of car following behavior, was available for this driver, as all of the trips for which data have been recorded are trips that include a use of the system. In order to frame the driver's style, the average time gap when no system was used was computed. It is to be noted that this measure should be interpreted with caution as the methodology is not as strong as having a true baseline measure of manual driving (as we will have with the other participants).

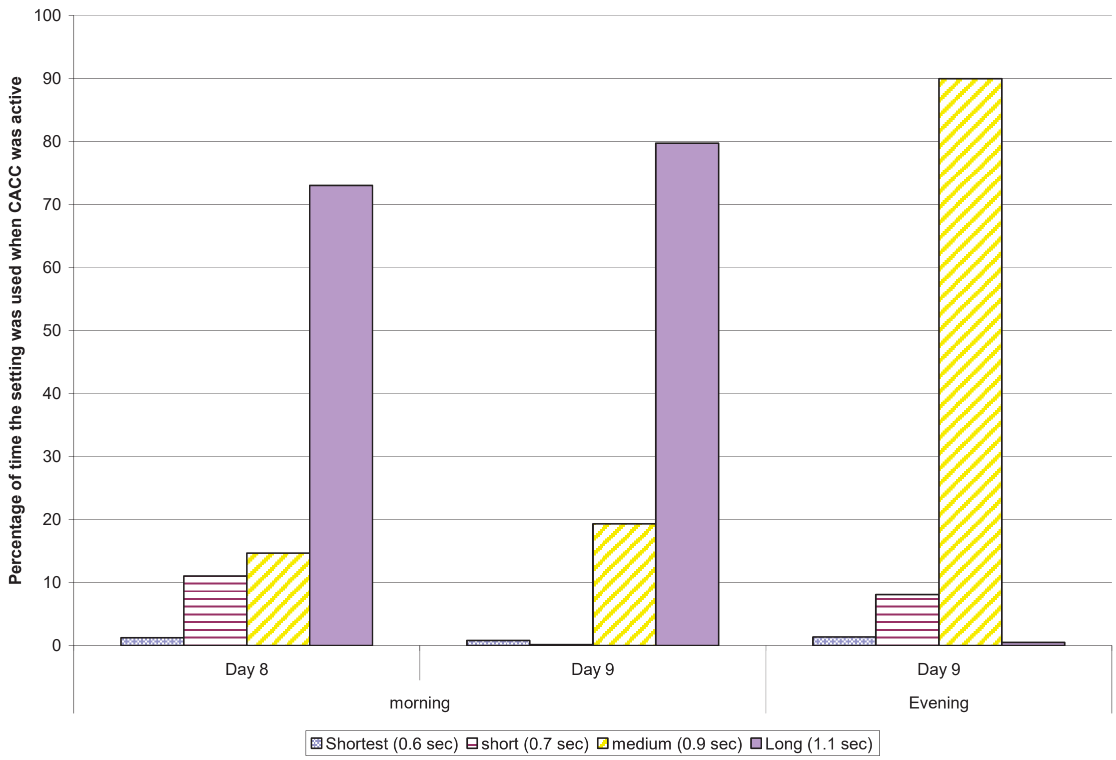


Figure 42: Percentage of time for each gap settings per trip – CACC

Figure 43 seems to confirm that that driver was experimenting with the system during the first trips, as the mean time gap when the system was engaged is higher than the time settings of the system, in other words, even though the driver was engaging the ACC, the speed selection was most likely slower than traffic for some of the epochs during which the system was enabled. Further analysis of these epochs will be needed to confirm this assumption. It is also interesting to note that for these two instances where the average time gap is higher than the ACC gap setting when the system is enabled, the average time gap under manual control are shorter than with the system. A possible explanation is that the driver is more actively engaged in the gap change when directly controlling the speed than using the ACC.

It also seems that this driver favored longer gaps when driving under manual control than the gaps provided by the CACC system, as shown in Figure 44. (The standard deviations range from 0.5 sec to 1 sec.) Without a true baseline driving measure, it is impossible to establish whether or not the use of the ACC or CACC systems influenced of the sizes of the gaps that were typically chosen by this participant when under manual control of the vehicle.

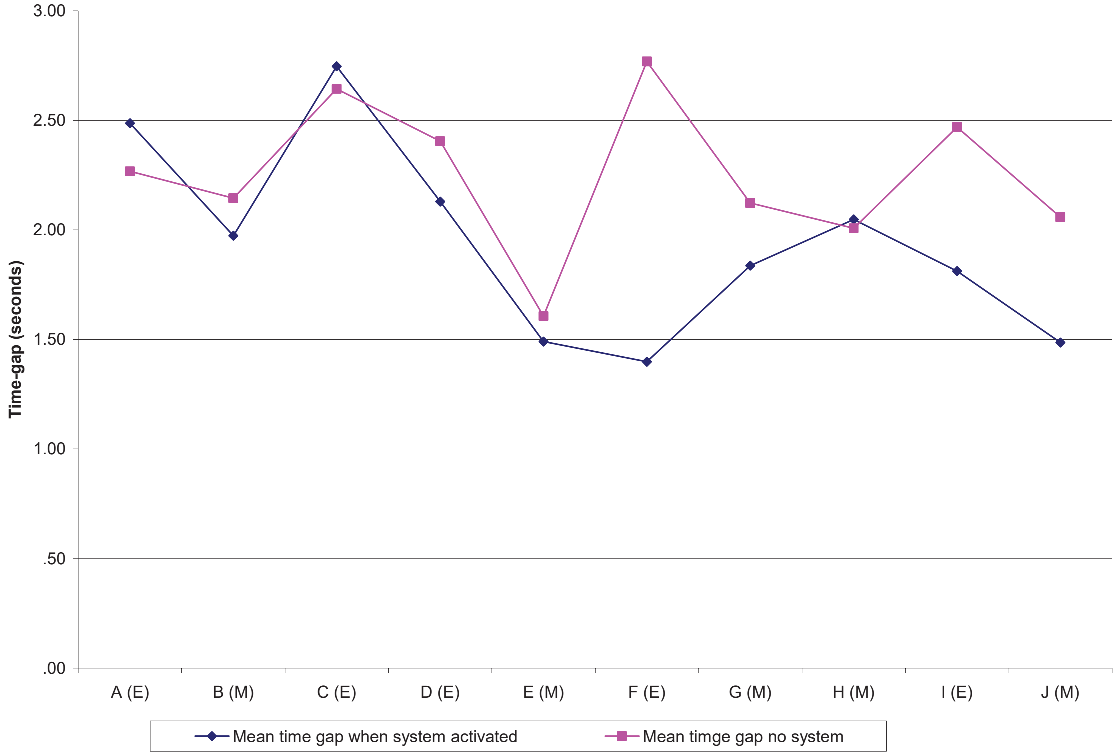


Figure 43: Average time-gap per trip under manual and ACC driving

It is interesting to note that for the trips involving the CACC testing, the average time gap for manual driving during each trip was below two seconds, and much less than the gaps chosen a few days earlier when driving the ACC vehicle under manual control. This difference may not be as much a result of any influence of driving with the CACC system, as it may be an artifact of other traffic or experiment related factors. As an example, when the system was not in use, the driver might have been keeping a shorter than normal gap with the lead vehicle to prevent cut-ins from other vehicles, which would have prevented the CACC system from being re-engaged as soon as traffic conditions permitted.

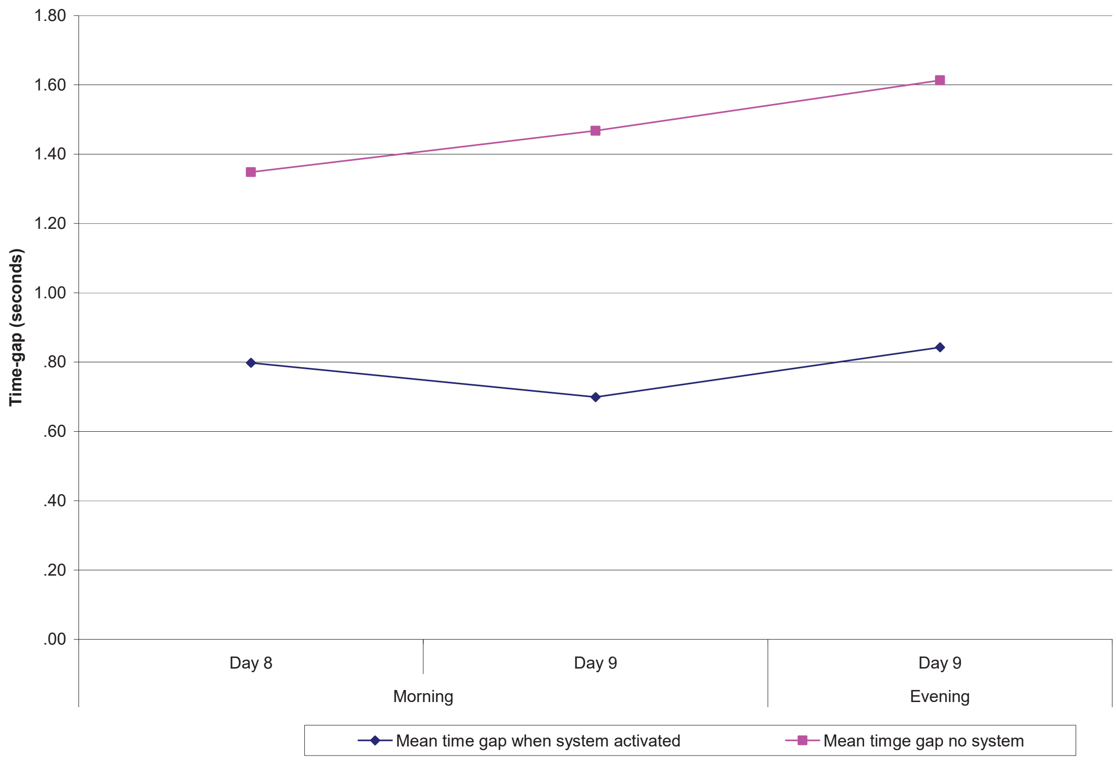


Figure 44: Average time-gap per trip under manual and CACC driving

7.3.3 Results summary

The ACC and CACC questionnaires filled out by this participant indicated that this participant was comfortable with the ACC, but that some aspects of the CACC behavior, notably its control of gap, made him less comfortable with the CACC system. This can also be seen in terms of choice of gap with the lead vehicle when using the CACC. The driver did not feel comfortable with the shorter gaps offered by the CACC. This also illustrates the difficult trade-offs faced when running a data collection. Although it appears that this driver would not be willing to use the shortest gap provided by a CACC, this conclusion has to be modulated by the other apparent result that the CACC testing phase was too short for this participant. The determination of the appropriate duration for a testing phase of a system such as CACC will be an interesting aspect to explore further when the data collection is completed.

8 Conclusions

This report has described the design and implementation of Cooperative Adaptive Cruise Control (CACC) system on two Infiniti FX-45 test vehicles, as well as the data acquisition system that has been installed to measure how drivers might use the system. The CACC system is intended to enhance the vehicle-following capabilities beyond those of a conventional ACC system, thus, allowing for shorter gaps to be safely maintained. Such a system might offer a significant opportunity to increase traffic flow density and efficiency without compromising safety or expanding roadway infrastructure. However, this largely depends on whether or not drivers would be willing to accept the shorter following distances the could be offered by a CACC system.

This report also describes an experimental protocol and the preliminary results of pilot testing for an on-the-road experiment using the CACC system. The experiment is expected to show how willing drivers will be to take advantage of the shorter time gaps that the CACC enables. Since most drivers are unfamiliar with conventional ACC systems, the protocol includes both ACC and CACC testing phases, along with baseline driving data to compare how drivers drive under normal traffic conditions both without the ACC or CACC systems. Although the testing is far from complete and will be covered more thoroughly in a subsequent report, the pilot testing provided promising results. After the completion of the testing, it should become possible to estimate the extent to which the CACC capability will produce shorter gaps in highway traffic, potentially leading to significant increases in the capacity per lane compared to today's manual driving.

References

1. J. VanderWerf, S.E. Shladover and M.A. Miller, "Conceptual Development and Performance Assessment for the Deployment Staging of Advanced Vehicle Control and Safety Systems", California PATH Research Report No. UCB-ITS-PRR-2004-22.

2. S.E. Shladover, J. VanderWerf, M. Miller, N. Kourjanskaia and H. Krishnan, "Development and Performance Evaluation of AVCSS Deployment Sequences to Advance from Today's Driving Environment to Full Automation", California PATH Research Report No. UCB-ITS-PRR-2001-18.

Appendix A – DAS Software Architecture

List of processes for the communication (**silver**) computer on the silver Nissan:

1. database server (script file start_q including qserve, nserve, datahub)
2. CAN driver (can_man)
3. CAN message interpretation (veh_nissan2)
4. wireless communication (wrmsnd)
5. send info to "**stainless**" computer (sndengmsg)

List of processes for the **copper** computer on the copper Nissan:

1. database server (script file start_q including qserve, nserve, datahub)
2. CAN driver (can_man)
3. CAN message interpretation (veh_nissan2)
4. wireless communication (wrmrcv)
5. CACC control (vi_control1)
6. send info to "bronze" computer (sndengmsg)
7. send command to CAN bus (sendtest)

List of processes for the **bronze** computer on the copper Nissan and the **stainless** computer on the silver Nissan:

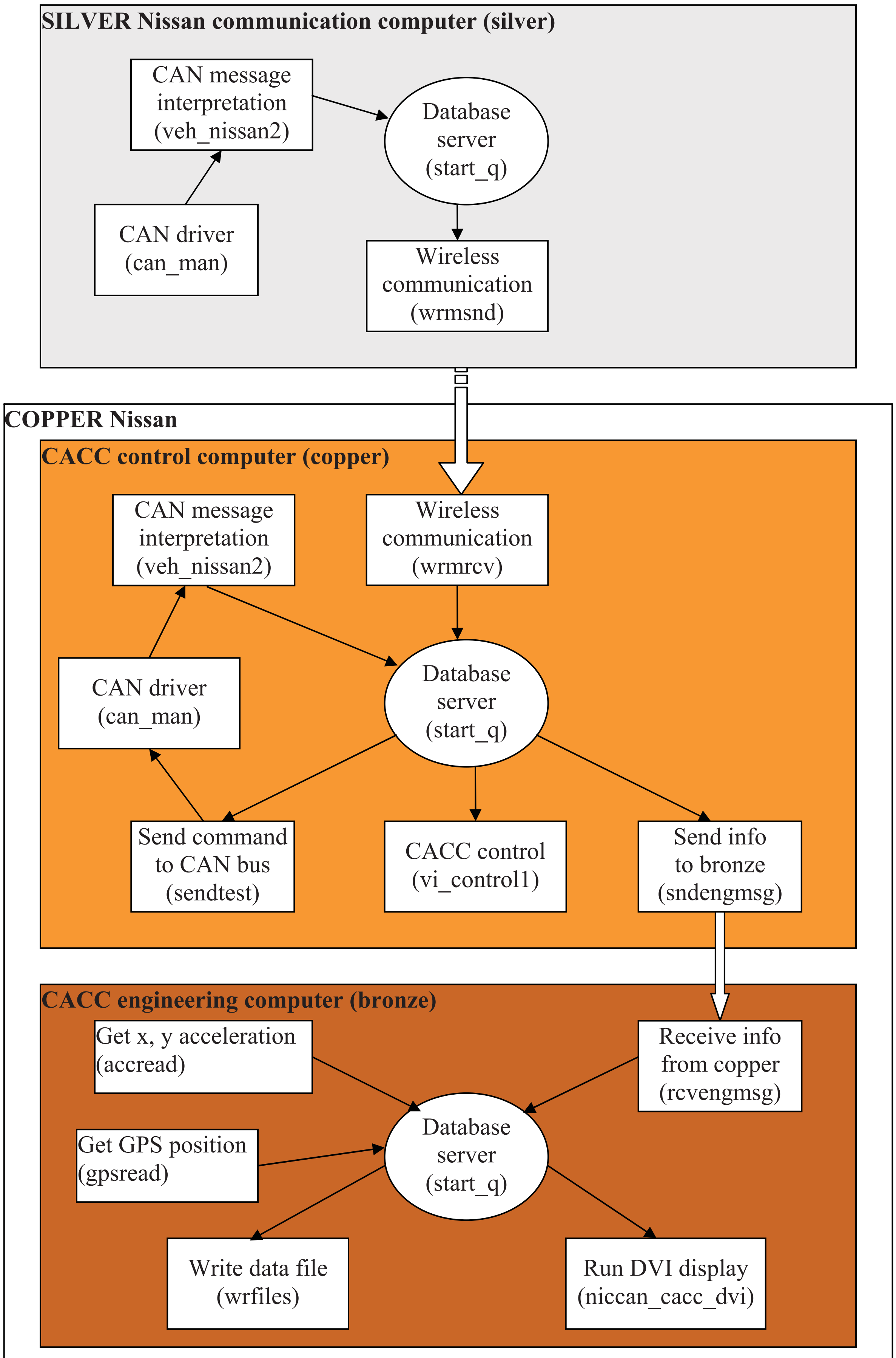
1. database server (script file start_q including qserve, nserve, datahub)
2. receive info from "copper" computer (rcvengmsg)
3. run the DVI display (nissan_cacc_dvi)
4. write data file (wrfiles)
5. read GPS position (gpsread)
6. read x and y acceleration (accread)

The interactions among these processes are shown schematically in the diagrams on the following pages.

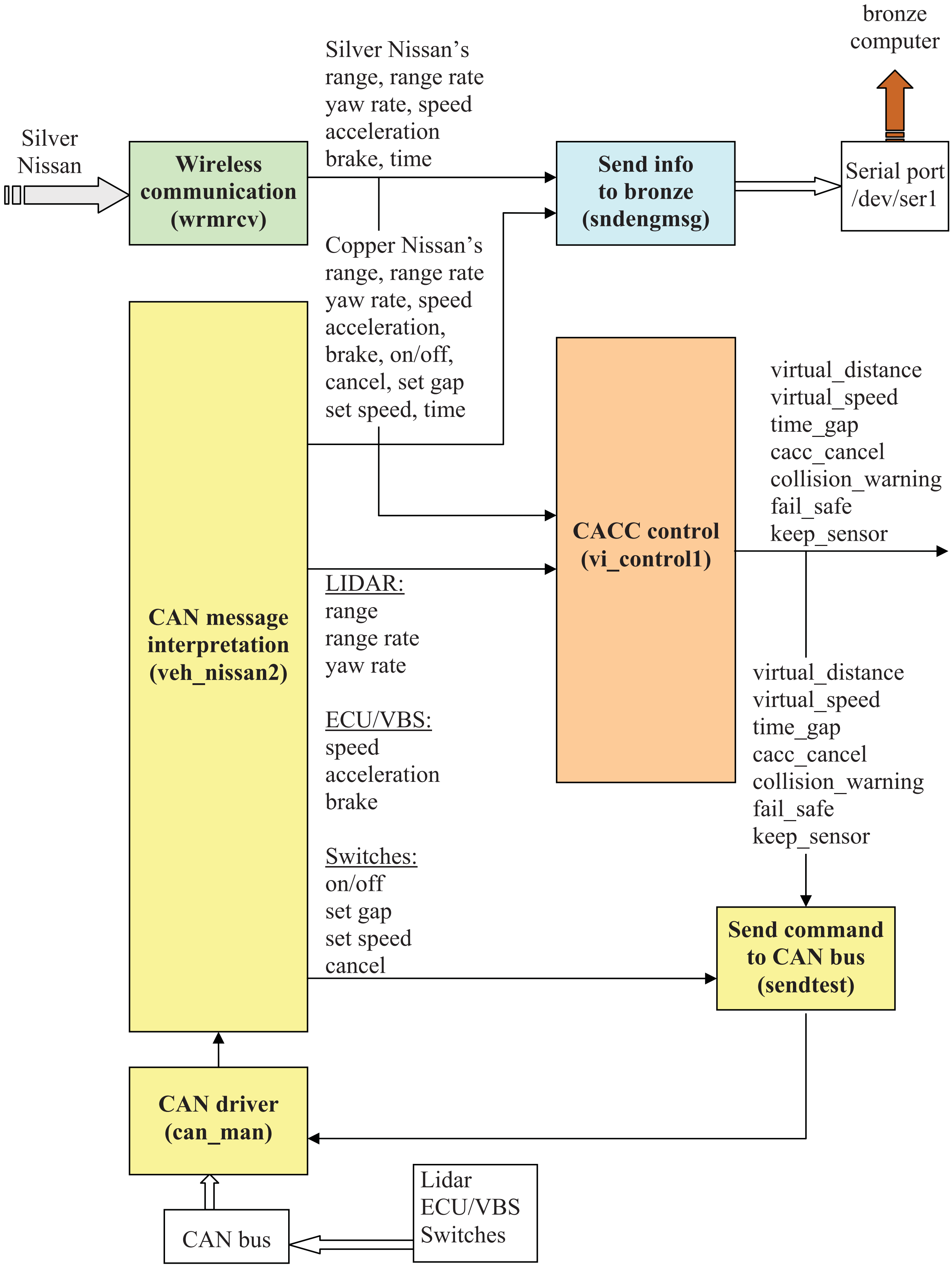
The CACC control process writes the structure DB_CACC_CONTROL to the database every 20 msec:

- virtual distance
- virtual speed
- time gap
- cacc cancel
- collision warning
- fail safe

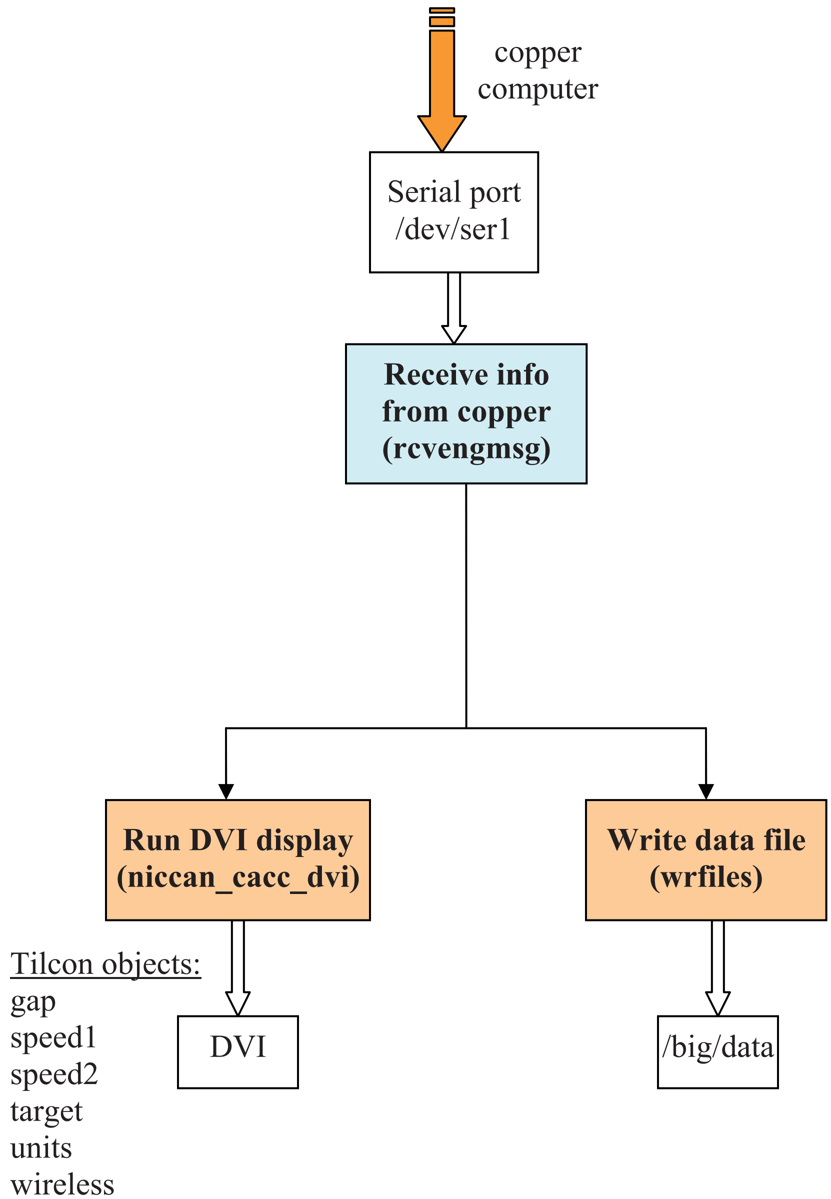
- keep sensor


SILVER Nissan communication computer (silver)
CAN message interpretation (veh_nissan2)
Database server (start_q)
CAN driver (can_man)
Wireless communication (wrmsnd)
COPPER Nissan
CACC control computer (copper)
CAN message interpretation (veh_nissan2)
Wireless communication (wrmrcv)
CAN driver (can_man)
Database server (start_q)
Send command to CAN bus (sendtest)
CACC control (vi_control1)
Send info to bronze (sndengmsg)
CACC engineering computer (bronze)
Get x, y acceleration (accread)
Receive info from copper (rcvengmsg)
Database server (start_q)
Get GPS position (gpsread)
Write data file (wrfiles)
Run DVI display (niccan_cacc_dvi)

Processes on the Copper Nissan **copper** computer (CAN Message contents):



Processes on the Copper Nissan **bronze** computer:



Appendix B: Participant Packet

Current Date

Subject: Information Packet for Participation in Driving Behavior study using two forms of Cruise Control

Dear Participant:

Thank you for your interest in the study. Enclosed in this packet you will find 4 items:

(1) Consent Forms: These are included so you may have time to read over the specifics of the study. You will be asked to sign these forms before participation in the study begins. If you have questions or concerns, feel free to contact us.

(2) A DMV Personal Record Request Form: We are required by the University to verify your driving record before allowing your participation in the study. Please fill out the top portion of the left side of this form. Be sure to sign the form, and fill in boxes A & B. Cut along the centerline, and mail the left portion to the DMV in the provided envelope. The right portion can be kept for your records.

(3) A Money Order: The $5 money order is included to pay the DMV record request fee. Please add your driver license number to the front of the money order.

(4) Preaddressed Envelope: Please use this preaddressed and prepaid envelope to mail the DMV record request form and money order and the money order to the DMV.

Best regards,

Jessica O'Connell
Associate Development Engineer
California PATH, UC Berkeley
(510) 665-3623

Enclosures (4)

Informed Consent for Testing Drivers' On-Road Behavior and their Choices of Following Distance when using Two New Cruise Control Systems

Welcome to the California PATH Research Program. PATH stands for Partners for Advanced Transit and Highways. We are part of the University of California at Berkeley and this project is under the direction of Professor Alex Skabardonis who is a Professor of Civil Engineering. I would appreciate your participation in my research study on driving behavior. In this research study, we wish to collect data about the way people drive when using new cruise control systems for automobiles. We are studying systems that are called Adaptive Cruise Control and Cooperative Adaptive Cruise Control systems. Both of these systems regulate your speed while driving just like the usual cruise control systems with which you may be familiar. These new systems regulate the distance of your car relative to the car directly in front of you (this distance is called gap). You are able to make some choices about the size of the gap between you and the vehicle ahead. The Adaptive Cruise Control is a system existing on the market. The Cooperative Adaptive Cruise Control is an experimental prototype not yet on the market.

We are examining the impact of these devices on driving safety, comfort and convenience. We are particularly interested in how the use of the prototype Adaptive Cruise Control and Cooperative Adaptive Cruise Control might modify driver behavior. We believe this is important research that will contribute to enhancing automobile safety and comfort, but we want to ensure that these devices are designed with the driver in mind.

While participating in this study, you will be driving an Infiniti FX 45 on local roadways. This vehicle is equipped with a market version of an Adaptive Cruise Control and a prototype version of an Adaptive Cruise Control called a Cooperative Adaptive Cruise Control. At no time during this study will you be asked to perform any unsafe driving actions. If you agree to take part in the research, I will ask permission to inspect your driving record. Your record will be obtained by having you fill out and mail a record request form to the California DMV listing California PATH as the recipient. I will look only for information about moving violations less than three years old and Driving Under the Influence (DUI). The driving records will be destroyed after the screening procedure regardless of whether or not you are selected (or choose) to participate in the research.

This vehicle will be delivered to your residence on a Wednesday evening. This is the schedule that we will follow for the test:

Phase 1:

- Wednesday evening: learning how to use the ACC with experimenter in the car, possibly driving back from work, ½ an hour of experimenter presence at your residence.
- Thursday to Wednesday: use the vehicle as you would use your own.
- Wednesday morning or evening: assessment of ACC use: possibly drive your commute with experimenter on board.
- Thursday to Sunday: use the vehicle as you would use your own.

Phase 2:

- Monday, Tuesday, and Wednesday (if needed), test of the CACC vehicle with experimenter on-board during your morning and evening commute.

While using the Infiniti, you will:

1. be the only person to drive the vehicle
2. not carry any passenger other than the experimenter
3. operate the vehicle in accordance with all traffic laws
4. not drive the research vehicle while impaired by alcohol or any controlled substance
5. not take the vehicle outside of the continental United States
6. be the sole individual responsible for all tickets and violations for the duration which the research vehicle is assigned to you
7. report as early as possible to PATH any problems, mechanical malfunctions

While using the Infiniti with the experimenter, you will

1. be asked to drive on a route that is usually the one you take for your commute
2. you will ***not*** be asked to drive:
    a. at dusk,
    b. at night,
    c. in heavy traffic,
    d. during inclement weather

An informational package describing the ACC and CACC systems and detailing the test procedure will be sent to your address 2 weeks before the tests.

Vehicle insurance coverage will be provided by the University of California as long as the vehicle is used as described above. If you violate any of the laws of California or the terms outlined above while driving the Infiniti, the University's vehicle insurance coverage will not be in effect and you will be held liable for any damages. Passengers other than the experimenter will not be covered, which means that you cannot carry any passenger other than the experimenter.

Video cameras will record the front and rear scene as well as your face at all times. We will use these video recordings in order to assess the type of traffic you were in, and to make sure that you are the driver using the vehicle during the days the vehicle will be under your care. You have the right to restrict the use of the video recording and to change your mind about the how restricted or limited use may be of the tape. You can specify the use of the video by filling out the video release form attached to this form.

There is no direct benefit to you from the research. I hope that the research will benefit society by improving our knowledge about driver behavior and using this knowledge to improve the development of advanced transportation concepts and prototypes.

All of the information that I obtain about you during the research will be kept confidential. I will not use your name or identifying information in any reports of my research. I will protect your identity and the information I collect from you to the full extent of the law (this does not include subpoena). Should you be involved in an accident while driving the study car, the videotapes taken may be subpoenaed as evidence.

After this project is completed, I may make the data collected during your participation available to other researchers or use the data in other research projects of my own. If so, I will continue to take the same precautions to preserve your identity from disclosure. Your identity will not be released to other researchers.

You will be paid a total of $100 for your participation. If you decide to withdraw from the study before the completion, you will be paid a prorated amount based on the number of days of participation. Fuel costs will either be reimbursed at the end of your participation with receipts, or you may be provided with the option to use a fuel card. If you choose this option, you will be asked to sign an additional fuel card user agreement.

If you are injured as a result of taking part in this study, care will be available to you. The costs of this care may be covered by the University of California depending on a number of factors. If you have any questions regarding this assurance, you may consult the Committee for Protection of Human Subjects, University of California, 2150 Shattuck Avenue, Rm. 318, Berkeley, CA 94704-5940, 510-642-7461.

Your participation in this research is voluntary. You are free to refuse to take part, and you may stop taking part at any time. If you have any questions about the research, you may contact the lead investigator, Christopher Nowakowski, at (510) 665-3673.

I have read this consent form. I agree to take part in the research.

__________________________________ _______________

Signature Date

PHOTOGRAPHIC, AUDIO, AND/OR VIDEO RECORDS RELEASE CONSENT FORM

As part of this project we have made a photographic, audio, and/or video recording of you while you participated in the research.

We would like you to indicate below what uses of these records you are willing to consent to. This is completely up to you. We will only use the records in ways that you agree to. In any use of these records, your name will not be identified.

1. The records can be studied by the research team for use in the research project.

Photo __________ Audio __________ Video __________

initials initials initials

2. The records can be shown to subjects in other experiments.

Photo __________ Audio __________ Video __________

initials initials initials

3. The records can be used for scientific publications.

Photo __________ Audio __________ Video __________

initials initials initials

4. The records can be shown at meetings of scientists interested in the study of ***driving behavior***

Photo __________ Audio __________ Video __________

initials initials initials

5. The records can be shown in classrooms to students.

Photo __________ Audio __________ Video __________

initials initials initials

6. The records can be shown in public presentations to nonscientific groups.

Photo __________ Audio __________ Video __________

initials initials initials

7. The records can be used on television and radio.

Photo __________ Audio __________ Video __________

initials initials initials

I have read the above description and give my consent for the use of the records as indicated above.

Signature ______________________________________ Date _________________

University of California, Berkeley

Fuel Card Agreement Form

For the purpose of the data collection that you agreed to participate in, you are entrusted with the use of a Fuel Card. The conditions of use and your role as a card user are detailed below.

Fuel Card User

The Fuel Card User assumes responsibility for the physical security of a State of California Fuel Card (Voyager Card) and its PIN (Personal Identification Number). The Fuel Card User assumes responsibility for all card transactions during the time frame when the card is in their possession. These transactions can be audited for appropriate use. If there are improper charges, see below, the participant is financially responsible to repay PATH for those charges.

The Fuel Card User shall:

- Ensure physical security of Fuel Card. The card may **not** be left in the custody of a vendor.
- Do **not** record the PIN on the fuel card, card jackets, or other documents stored with the card.
- Ensure all transaction receipts are kept and provided with the return of the card.
- Report if the card is lost or stolen immediately (within 24 hours).

A Voyager Fuel Card can be used to purchase:

- Fuel, oil, coolant, and other fluids
- **In out-of-area emergencies only:** parts and labor for towing, road service, and mechanical repairs. (If possible, verify with PATH researchers first.)

A Voyager Fuel Card should **not** be used to purchase:

- Food or beverages.
- Parts and labor for towing, road service, and mechanical repairs within range of our local vendors (Berkeley, Oakland, Albany, Emeryville). In these situations, please use the agreements with our local vendors. Details are provide in the vehicle handbook located in the vehicle's glovebox.
- Other goods or services.

Agreement

In reference to the card listed below, I agree with the responsibilities and guidelines outlined above and as stated on the Fuel Card Control/Transaction Limit information sheet.

Card Number: ______________________________

Card Fuel User (Print & Sign) Date | Fuel Card Custodian (Print & Sign) Date

DMV Record Request Form

A Public Service Agency

REQUEST FOR YOUR OWN DRIVER LICENSE/IDENTIFICATION CARD (DL/ID) OR VEHICLE/VESSEL REGISTRATION (VR) INFORMATION RECORD

FEE: $5.00 FOR EACH CURRENT RECORD

Write your DL/ID number or plate or VIN on the front or the back of your check.

DO NOT COMPLETE THIS FORM UNLESS YOU ARE REQUESTING YOUR OWN DL/ID RECORD OR YOU ARE THE CURRENT VR REGISTERED OWNER ON FILE WITH THE DEPARTMENT.

REQUESTER'S INFORMATION ***PLEASE PRINT CLEARLY***

FULL LEGAL NAME *(FIRST, MI, LAST)*

ADDRESS

CITY | STATE | ZIP CODE

DAYTIME TELEPHONE
(   )

SIGNATURE | DATE
X

Check box(es) for type of record(s) you are requesting.

☐ **DRIVER LICENSE/ID RECORD** ***(Complete boxes A & B)***
A. CALIF. DRIVER LICENSE/ID NUMBER
B. BIRTH DATE (MO/DAY/YR)

☐ **VEHICLE/VESSEL REGISTRATION RECORD** ***(Complete boxes C & D)***
C. CALIF. LICENSE/CF NUMBER
D. VEHICLE/VESSEL ID NUMBER

DMV USE ONLY
ID Verified by Cashier Line Date

This request may be presented in person to your local DMV office or mailed to DMV Headquarters:

Department of Motor Vehicles
P. O. Box 944247 MS G199
Sacramento, CA 94244-2470

INF 1125 (REV. 11/2000) WWW

Complete if mailing.
Send information to: *(Print your name and address clearly in the box.)*

NAME
ADDRESS
CITY | STATE | ZIP CODE

INF 1125 (REV. 11/2000) WWW — También disponible en español —

CUT ON LINE AND KEEP THIS PART FOR YOUR RECORDS

A Public Service Agency

REQUEST FOR YOUR OWN DRIVER LICENSE/IDENTIFICATION CARD (DL/ID) OR VEHICLE/VESSEL REGISTRATION (VR) INFORMATION RECORD

FEE: $5.00 FOR EACH CURRENT RECORD

Write your DL/ID number or plate or VIN on the front or the back of your check.

DO NOT COMPLETE THIS FORM UNLESS YOU ARE REQUESTING YOUR OWN DL/ID RECORD OR YOU ARE THE CURRENT VR REGISTERED OWNER ON FILE WITH THE DEPARTMENT.

REQUESTER'S INFORMATION PLEASE PRINT CLEARLY

FULL LEGAL NAME (FIRST, MI, LAST)

ADDRESS

CITY | STATE | ZIP CODE

DAYTIME TELEPHONE
(   )

SIGNATURE | DATE
X

Check box(es) for type of record(s) you are requesting.

☐ DRIVER LICENSE/ID RECORD (Complete boxes A & B)
A. CALIF. DRIVER LICENSE/ID NUMBER
B. BIRTH DATE (MO/DAY/YR)

☐ VEHICLE/VESSEL REGISTRATION RECORD (Complete boxes C & D)
C. CALIF. LICENSE/CF NUMBER
D. VEHICLE/VESSEL ID NUMBER

DMV USE ONLY
ID Verified by Cashier Line Date

This request may be presented in person to your local DMV office or mailed to DMV Headquarters:

Department of Motor Vehicles
P. O. Box 944247 MS G199
Sacramento, CA 94244-2470

INF 1125 (REV. 11/2000) WWW

Complete if mailing.
Send information to: (Print your name and address clearly in the box.)

NAME
ADDRESS
CITY | STATE | ZIP CODE

INF 1125 (REV. 11/2000) WWW — También disponible en español —

Vehicle Checkout Checklist

Silver Nissan FX45

Date Loaned	Vehicle Mileage	Subject #

☐ Walk around vehicle to inspect for damage. Show subject how to open gas cap.

☐ Explain proximity key (for entry and starting the vehicle).

☐ Have subject start vehicle, adjust the seat, and adjust the mirrors.

☐ Show subject the location in the glove box where the owner's manual, vehicle registration, insurance card, accident instruction kit, and PATH contact info are kept.

☐ Show subject where lights and wiper controls are located.

☐ Show basic radio, climate controls, and navigation system use.

☐ Program subject's home and work addresses into the navigation system.

☐ Go over ACC controls and displays while parked.

- Use only during highway driving with free flowing traffic conditions.
- The ACC system has limited braking capabilities. It will not stop the vehicle.
- Like regular CC, it should not be used in wet weather.

☐ Let the subject do a test drive to experiment with the ACC system.

- Turn on and off with controls
- Turn off with brake & resume
- Adjust following distance settings
- Warn driver of freeway exit hazard

☐ After returning from the test drive, remind the test participant of the following:

- The test participant is the only one authorized to drive this vehicle.
- The test participant should not have any passengers.
- Use the car as they would use their own vehicle normally.
- Use the ACC system as much as possible when conditions permit.
- Try out all the following distance settings.
- Fill in the provided logbook after each trip.

____
Test Participant

____
Experimenter

CACC Participant Silver Vehicle Log Book

Trip Date: Start Time: Fuel Costs:

From: To: ACC Use: *Yes* *No*

1. How familiar is this trip to you?

   Familiar *1* *2* *3* *4* *5* *Unfamiliar*

2. How frequently do you perform this trip?

   Daily *Weekly* *Monthly* *A Few Time a Year* *First Time*

3. Did you have to be at your destination at a specific time? *Yes* *No*

   3a. If yes, did you make it on time? *Yes* *No*

   3b. If no, how late were you? ______________________________

4. Events worth noting or other comments during this trip (continue on back if necessary):

Trip Date: Start Time: Fuel Costs:

From: To: ACC Use: *Yes* *No*

1. How familiar is this trip to you?

   Familiar *1* *2* *3* *4* *5* *Unfamiliar*

2. How frequently do you perform this trip?

   Daily *Weekly* *Monthly* *A Few Time a Year* *First Time*

3. Did you have to be at your destination at a specific time? *Yes* *No*

   3a. If yes, did you make it on time? *Yes* *No*

   3b. If no, how late were you? ______________________________

Events worth noting or other comments during this trip (continue on back if necessary):

Vehicle Return Checklist

Silver Nissan FX45

Date Returned	Vehicle Mileage	Returning Subject #

- [ ] ________ Initial — Download data and clear drive space if necessary.
- [ ] ________ Initial — Visual inspection for vehicle damage.
- [ ] ________ Initial — Check and charge battery if necessary.
- [ ] ________ Initial — Check tires pressures and inflate if necessary.
- [ ] ________ Initial — Check oil, coolant, etc.
- [ ] ________ Initial — Top off windshield washer fluid.
- [ ] ________ Initial — Verify that headlights, tail lights, and turn signals are all working.
- [ ] ________ Initial — Verify that insurance card and vehicle registration are *current* and in the glove box.
- [ ] ________ Initial — Verify that PATH accident kit and contact info are all in the glove
- [ ] ________ Initial — Clear navigation system address book (except for RFS) and previous destination list.
- [ ] ________ Initial — Wash & vacuum car.
- [ ] ________ Initial — Fill car with gas.

Test Participant Payment Receipt

Date: ______________________ Fund Number: 15980

Name: ____
Test Participant (Please Print)

Address: ____

____

Amount of payment for study participation: $ ____________________ *Note: payment using this form cannot exceed $600*

Was a fuel card issued to the participant during this study? ☐ Yes ☐ No

If **Yes**,

Disposition of the Card: ☐ Returned ☐ Lost ☐ Stolen

Fuel Receipts: ☐ All Receipts Attached ☐ (See Explanation)

If **No** or if purchases were made without using the fuel card,

Amount of payment for fuel expense reimbursement: $ ____________________ ☐ Receipts Attached

Fuel Usage: __________ miles / __________ gal = __________ mpg (~ 14 mpg)

Your signature below indicates that you were paid the amount listed above for your participation in the Cooperative Adaptive Cruise Control Project. Your signature also certifies that all fuel expenses detailed above were incurred for the test vehicle during your participation in the project.

____
Test Participant Signature

____
PATH Researcher Approving Payment

Appendix D: ACC & CACC Participant Questionnaires

Adaptive Cruise Control Survey

The questions in this survey address your driving experience with the Adaptive Cruise Control (ACC) system. You will find three types of questions:

- Questions on a scale from 1 to 7, where you will indicate the side to which you feel closest by circling a number, for example:

  I liked driving this car.

  Strongly disagree 1 2 3 4 5 6 7 Strongly agree

  You would circle 7 if you strongly agree with the statement.

- Rank order items from 1 to 3, where the ranking is explained at the end of the question.

- Open ended questions, for which you will write answers.

Feel free to add comments around questions if you think it helps better express your opinion.

The information gathered through this questionnaire is confidential. The use of this information will respect your privacy and no names will ever be mentioned when using this data.

Turn the page and proceed when you are ready.

1 - Are you familiar with cruise control (speed only) systems?

☐ yes ☐ no

If yes, for approximately how long have you been using one? ________

Please rate your level of expertise

Novice 1 2 3 4 5 6 7 Expert

2 - Are you familiar with ACC systems?

☐ yes ☐ no

If yes, for approximately how long have you been using one? ________

Please rate your level of expertise

Novice 1 2 3 4 5 6 7 Expert

3 - Please describe the ACC system and how it works, in the way that you would describe it to another driver who has not yet seen or used the system.

4 - Overall, how comfortable did you feel driving the car using the ACC system?

Uncomfortable 1 2 3 4 5 6 7 Comfortable

5 - Do you think ACC is going to increase driving safety?

Strongly disagree 1 2 3 4 5 6 7 Strongly agree

6 - When using the ACC system in each of the following traffic conditions, did you follow other vehicles closer or further than you normally do?

Heavy traffic

Closer 1 2 3 4 5 6 7 Further

Moderate traffic

Closer 1 2 3 4 5 6 7 Further

Light traffic

Closer 1 2 3 4 5 6 7 Further

7 - In general, under which mode of operation did you feel like you reached your destination fastest? (Rank 1 fastest to 3 slowest)

__ Manual driving (no ACC)

__ Cruise Control (speed only)

__ Adaptive Cruise Control (speed and distance)

8 - How easy was it to drive using the ACC system?

Easy 1 2 3 4 5 6 7 Difficult

9 - Compare safety under these operation modes (from 1 most safe to 3 least safe)

__ Manual driving (no ACC)

__ Cruise Control (speed only)

__ Adaptive Cruise Control (speed and distance)

10 - Do you feel the following distance adjustment function is useful?

Strongly disagree 1 2 3 4 5 6 7 Strongly agree

11 - Were there times when the system became uncomfortable or inconvenient, causing you to manually disengage the system? (If so, please describe)

12 - What was your level of comfort for each of these gaps with the ACC?

Long gap
Uncomfortable 1 2 3 4 5 6 7 Comfortable

Medium gap
Uncomfortable 1 2 3 4 5 6 7 Comfortable

Short gap
Uncomfortable 1 2 3 4 5 6 7 Comfortable

13 - Under which mode of operation did you feel you reached your destination most safely? (from 1 most safely to 3 least safely)

__ Manual driving (no ACC)

__ Cruise Control (speed only)

__ Adaptive Cruise Control (speed and distance)

14 - How comfortable were you using the ACC system when driving in the following traffic environments?

Heavy traffic

Uncomfortable	1	2	3	4	5	6	7	Very comfortable

Moderate traffic

Uncomfortable	1	2	3	4	5	6	7	Very comfortable

Light traffic

Uncomfortable	1	2	3	4	5	6	7	Very comfortable

15 - Which mode of operation (Manual, Conventional Cruise, ACC) required you to apply the brakes most often? (Rank 1 least braking to 3 most braking)

__ Manual driving (no ACC)

__ Cruise Control (speed only)

__ Adaptive Cruise Control (speed and distance)

16 - How long did it take you to be comfortable using the ACC system?

____

17 - When driving the ACC system, compared to manual driving, were you more or less aware of the actions of vehicles around you than you normally are?

Less aware	1	2	3	4	5	6	7	More aware

18 - How comfortable were you driving the ACC system in comparison to the manual driving?

Uncomfortable	1	2	3	4	5	6	7	More comfortable

19 - How frequently did you get into situations when you relied too heavily on the ACC to handle situations that it could not handle? [SD or S]

Frequently 1 2 3 4 5 6 7 Never

20 - When you were driving with the ACC, was your speed generally slower or faster than the speeds of neighboring vehicles?

Heavy traffic
Slower 1 2 3 4 5 6 7 Faster

Medium traffic
Slower 1 2 3 4 5 6 7 Faster

Light traffic
Slower 1 2 3 4 5 6 7 Faster

21 - Did the system ever surprise you? (If so, please describe)

22 - How comfortable would you feel if your driving-age child, spouse, parents or other loved ones drove a vehicle equipped with ACC? (*Some of the cases may not apply to you; in this case, please mark the N/A box*)

Driving-age child (☐ N/A)
Uncomfortable 1 2 3 4 5 6 7 Very comfortable

Spouse (☐ N/A)
Uncomfortable 1 2 3 4 5 6 7 Very comfortable

Parents (☐ N/A)
Uncomfortable 1 2 3 4 5 6 7 Very comfortable

23 - What did you think of the acceleration provided by the ACC system when pulling into an empty adjacent lane to pass other vehicles?

Too slow 1 2 3 4 5 6 7 Too fast

24 - What did you think of the deceleration rate provided by the ACC system when following a vehicle?

Too gentle 1 2 3 4 5 6 7 Too hard

25 - How much effort did it take to maintain a safe following distance when using each of the following modes of operation?

Manual driving (no ACC)

Difficult 1 2 3 4 5 6 7 Very easy

Cruise Control (speed control only)

Difficult 1 2 3 4 5 6 7 Very easy

Adaptive Cruise Control (speed and distance)

Difficult 1 2 3 4 5 6 7 Very easy

26 - How likely is it that you would have become more comfortable using the ACC system given more time?

Not likely 1 2 3 4 5 6 7 Very likely

27 - How comfortable were you using the ACC system on hilly roads?

Uncomfortable 1 2 3 4 5 6 7 Very comfortable

28 - How often, if ever, did you experience "unsafe" following distances when using the ACC system?

Frequently 1 2 3 4 5 6 7 Never

29 - Driving the ACC system, compared to manual driving, did you find yourself more or less responsive to actions of vehicles around you?

Less responsive 1 2 3 4 5 6 7 More responsive

30 - Compare (rank) these operation modes for comfort (from 1 most comfortable to 3 least comfortable)

__ Manual driving (no ACC)

__ Cruise Control (speed only)

__ Adaptive Cruise Control (speed and distance)

31 - If you could add one feature to the system, what would it be and why?

32 - Did you feel more comfortable performing additional tasks, (e.g., adjusting the climate control or the radio) while using the ACC system as compared to driving under manual control?

Strongly disagree 1 2 3 4 5 6 7 Strongly agree

33 - Compare (rank) these operation modes for convenience (from 1 most convenient to 3 least convenient)

__ Manual driving (no ACC)

__ Cruise Control (speed only)

__ Adaptive Cruise Control (speed and distance)

34 - While using the ACC system, how often, if ever, did the system fail to detect a vehicle that you were approaching or following?

Often 1 2 3 4 5 6 7 Never

35 - As you got used to the ACC system, how would you rate the change of your level of confidence in the system? (circle 4 if your level of confidence remained the same)

More confident 1 2 3 4 5 6 7 Less confident

36 - Compare (rank) these operation modes for driving enjoyment (from 1 most enjoyable to 3 least enjoyable)

__ Manual driving (no ACC)

__ Cruise Control (speed only)

__ Adaptive Cruise Control (speed and distance)

37 - How safe did you feel using the ACC system?

Not safe 1 2 3 4 5 6 7 Very safe

38 - If you could remove one feature/display method, what would it be and why?

39 - When using the ACC system, did you ever feel that you didn't understand what the system was doing, what was taking place, or how the ACC system might behave?

Very frequently 1 2 3 4 5 6 7 Very infrequently

40 - Would you rather have:

☐ An ACC ☐ a (speed only) cruise control ☐ no system

41 - In general, under which mode of operation did you feel like you reached your destination with the least stress related to driving? (Rank 1 least stress to 3 most stress)

__ Manual driving (no ACC)

__ Cruise Control (speed only)

__ Adaptive Cruise Control (speed and distance)

42 - While driving with the ACC, how confident did you feel about the system?

Very confident 1 2 3 4 5 6 7 Not confident

43 - Did the system ever distract you or lead you to make an inappropriate maneuver or error in judgment? (If so please describe)

44 - Rank, in order of preference, the following modes of operation for personal use. (Rank 1 most desirable to 3 least desirable)

__ Manual driving (no ACC)

__ Cruise Control (speed only)

__ Adaptive Cruise Control (speed and distance)

45 - When you were driving with the ACC, were you driving slower or faster than you normally drive?

Heavy traffic

Slower	1	2	3	4	5	6	7	Faster

Medium traffic

Slower	1	2	3	4	5	6	7	Faster

Light traffic

Slower	1	2	3	4	5	6	7	Faster

Cooperative Adaptive Cruise Control Survey

The questions in this survey address your driving experience with the Cooperative Adaptive Cruise Control (CACC) system. You will find three types of questions:

- Questions on a scale from 1 to 7, where you will indicate the side to which you feel closest by circling a number, for example:

  I liked driving this car.

  Strongly disagree 1 2 3 4 5 6 7 Strongly agree

  You would circle 7 if you strongly agree with the statement.

- Rank order items from 1 to 3, where the ranking is explained at the end of the question.

- Open ended questions, for which you will write answers.

Feel free to add comments around questions if you think it helps better express your opinion.

The information gathered through this questionnaire is confidential. The use of this information will respect your privacy and no names will ever be mentioned when using this data.

Turn the page and proceed when you are ready.

1 - Please describe the CACC system and how it works, in the way that you would describe it to another driver who has not yet seen or used the system.

2 - Overall, how comfortable did you feel driving the car using the CACC system?

Uncomfortable	1	2	3	4	5	6	7	Comfortable

3 - Do you think CACC is going to increase driving safety?

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

4 - When using the CACC system in each of the following traffic conditions, did you follow the preceding vehicle closer or further than you normally do?

Heavy traffic

Closer	1	2	3	4	5	6	7	Further

Moderate traffic

Closer	1	2	3	4	5	6	7	Further

Light traffic

Closer	1	2	3	4	5	6	7	Further

5 - In general, under which mode of operation did you feel like you reached your destination fastest? (Rank 1 fastest to 4 slowest)

__ Manual driving (no ACC)

__ Cruise Control (speed only)

__ Adaptive Cruise Control (speed and distance)

__ Cooperative Adaptive Cruise Control (speed and shorter distance)

6 - How easy was it to drive using the CACC system?

Easy	1	2	3	4	5	6	7	Difficult

7 - Compare safety under these operation modes (from 1 most safe to 4 least safe)

__ Manual driving (no ACC)

__ Cruise Control (speed only)

__ Adaptive Cruise Control (speed and distance)

__ Cooperative Adaptive Cruise Control (speed and shorter distance)

8 - While driving with the CACC, how confident did you feel about the system?

Very confident 1 2 3 4 5 6 7 Not confident

9 - Under which mode of operation did you feel you reached your destination most safely? (from 1 most safely to 4 least safely)

__ Manual driving (no ACC)

__ Cruise Control (speed only)

__ Adaptive Cruise Control (speed and distance)

__ Cooperative Adaptive Cruise Control (speed and shorter distance)

10 - Were there times when the system became uncomfortable or inconvenient, causing you to manually disengage the system? (If so, please describe)

12 - What was your level of comfort for each of these gaps with the CACC?

Long gap
Uncomfortable 1 2 3 4 5 6 7 Comfortable

Medium gap
Uncomfortable 1 2 3 4 5 6 7 Comfortable

Short gap
Uncomfortable 1 2 3 4 5 6 7 Comfortable

Shortest gap
Uncomfortable 1 2 3 4 5 6 7 Comfortable

13 - How comfortable were you using the CACC system when driving in the following traffic environments?

Heavy traffic

Uncomfortable 1 2 3 4 5 6 7 Very comfortable

Moderate traffic

Uncomfortable 1 2 3 4 5 6 7 Very comfortable

Light traffic

Uncomfortable 1 2 3 4 5 6 7 Very comfortable

14 - Which mode of operation (Manual, Conventional Cruise Control, ACC, CACC) required you to apply the brakes most often? (Rank 1 least braking to 4 most braking)

__ Manual driving (no ACC)

__ Cruise Control (speed only)

__ Adaptive Cruise Control (speed and distance)

__ Cooperative Adaptive Cruise Control (speed and shorter distance)

15 - How long did it take you to be comfortable using the CACC system?

____

16 - When driving the CACC system, compared to manual driving, were you more or less aware of the actions of vehicles around you than you normally are?

Less aware 1 2 3 4 5 6 7 More aware

17 - How comfortable were you driving the CACC system in comparison to the manual driving?

Uncomfortable 1 2 3 4 5 6 7 More comfortable

18 - When you were driving with the CACC, was your speed generally slower or faster than the speeds of neighboring vehicles?

Heavy traffic

Slower 1 2 3 4 5 6 7 Faster

Medium traffic

Slower 1 2 3 4 5 6 7 Faster

Light traffic

Slower 1 2 3 4 5 6 7 Faster

19 - How comfortable would you feel if your driving-age child, spouse, parents or other loved ones drove a vehicle equipped with CACC? *(Some of the cases may not apply to you; in this case, please mark the N/A box)*

Driving-age child (☐ N/A)

Uncomfortable 1 2 3 4 5 6 7 Very comfortable

Spouse (☐ N/A)

Uncomfortable 1 2 3 4 5 6 7 Very comfortable

Parents (☐ N/A)

Uncomfortable 1 2 3 4 5 6 7 Very comfortable

20 - Did the system ever surprise you? (If so, please describe)

21 - When driving the CACC system, compared to ACC driving, were you more or less aware of the actions of vehicles around you than you normally are?

Less aware 1 2 3 4 5 6 7 More aware

22 - How frequently did you get into situations when you relied too heavily on the CACC to handle situations that it could not handle? [SD or S]

Frequently 1 2 3 4 5 6 7 Never

23 - What did you think of the deceleration rate provided by the CACC system when following the lead vehicle?

Too gentle 1 2 3 4 5 6 7 Too hard

24 - How much effort did it take to maintain a safe following distance when using each of the following modes of operation?

Manual driving (no ACC)

Difficult 1 2 3 4 5 6 7 Very easy

Cruise Control (speed control only)

Difficult 1 2 3 4 5 6 7 Very easy

Adaptive Cruise Control (speed and distance)

Difficult 1 2 3 4 5 6 7 Very easy

Cooperative Adaptive Cruise Control (speed and shorter distance)

Difficult 1 2 3 4 5 6 7 Very easy

25 - How likely is it that you would have become more comfortable using the CACC system given more time?

Not likely 1 2 3 4 5 6 7 Very likely

26 - Compare (rank) these operation modes for convenience (from 1 most convenient to 4 least convenient)

__ Manual driving (no ACC)

__ Cruise Control (speed only)

__ Adaptive Cruise Control (speed and distance)

__ Cooperative Adaptive Cruise Control (speed and shorter distance)

27 - Driving the CACC system, compared to manual driving, did you find yourself more or less responsive to actions of vehicles around you?

Less responsive 1 2 3 4 5 6 7 More responsive

28 - How comfortable were you using the CACC system on hilly roads?

Uncomfortable 1 2 3 4 5 6 7 Very comfortable

Between the ACC and CACC system, did you prefer one of the systems?

☐ yes ☐ no

If yes, which system and why?

29 - How often, if ever, did you experience “unsafe” following distances when using the **C**ACC system?

Frequently	1	2	3	4	5	6	7	Never

30 - Compare (rank) these operation modes for comfort (from 1 most comfortable to 4 least comfortable)

__ Manual driving (no ACC)

__ Cruise Control (speed only)

__ Adaptive Cruise Control (speed and distance)

__ Cooperative Adaptive Cruise Control (speed and shorter distance)

31 - Did you feel more comfortable performing additional tasks, (e.g., adjusting the climate control or the radio) while using the CACC system as compared to driving under manual control?

Strongly disagree	1	2	3	4	5	6	7	Strongly agree

32 - How comfortable were you driving the CACC system in comparison to the ACC driving?

Less comfortable	1	2	3	4	5	6	7	More comfortable

33 - If you could add one feature to the system, what would it be and why?

34 - As you got used to the CACC system, how would you rate the change of your level of confidence in the system? (circle 4 if your level of confidence remained the same)

More confident 1 2 3 4 5 6 7 Less confident

35 - How likely is it that you would have become more comfortable using the CACC system if you could have used it to follow any vehicle?

Not likely 1 2 3 4 5 6 7 Very likely

36 - Compare (rank) these operation modes for driving enjoyment (from 1 most enjoyable to 4 least enjoyable)

__ Manual driving (no ACC)

__ Cruise Control (speed only)

__ Adaptive Cruise Control (Speed and distance)

__ Cooperative Adaptive Cruise Control (Speed and shorter distance)

37 - How safe did you feel using the CACC system?

Not safe 1 2 3 4 5 6 7 Very safe

38 - Did you feel more comfortable performing additional tasks, (e.g., adjusting the climate control or the radio) while using the CACC system as compared to driving with the ACC system?

More comfortable 1 2 3 4 5 6 7 Less comfortable

39 - When using the CACC system, did you ever feel that you didn't understand what the system was doing, what was taking place, or how the CACC system might behave?

Very frequently 1 2 3 4 5 6 7 Very infrequently

40 - Would you rather have:

☐ An ACC ☐ a cruise control ☐ no system ☐ A CACC

41 - Driving the CACC system, compared to driving the ACC system, did you find yourself more or less responsive to actions of vehicles around you?

Less responsive 1 2 3 4 5 6 7 More responsive

42 - If you could remove one feature/display method, what would it be and why?

43 - In general, under which mode of operation did you feel like you reached your destination with the least stress related to driving? (Rank 1 least stress to 4 most stress)

__ Manual driving (no ACC)

__ Cruise Control (speed only)

__ Adaptive Cruise Control (speed and distance)

__ Cooperative Adaptive Cruise Control (speed and shorter distance)

44 - Do you feel the following distance adjustment function is useful?

Strongly disagree 1 2 3 4 5 6 7 Strongly agree

45 - How likely is it that you would have become more comfortable using the CACC if you could have set your own speed?

Not likely 1 2 3 4 5 6 7 Very likely

46 - Did the system ever distract you or lead you to make an inappropriate maneuver or error in judgment? (If so please describe)

47 - Rank, in order of preference, the following modes of operation for personal use. (Rank 1 most desirable to 4 least desirable)

__ Manual driving (no ACC)

__ Cruise Control (speed only)

__ Adaptive Cruise Control (speed and distance)

__ Cooperative Adaptive Cruise Control (speed and shortest distance)

48 - When you were driving with the CACC, were you driving slower or faster than you normally drive?

Heavy traffic

Slower 1 2 3 4 5 6 7 Faster

Medium traffic

Slower 1 2 3 4 5 6 7 Faster

Light traffic

Slower 1 2 3 4 5 6 7 Faster