Measurement of Driver Preferences and Intervention Responses as Influenced by Adaptive Cruise Control Deceleration Characteristics

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(ABSTRACT)

In comparison to conventional cruise control, adaptive cruise control (ACC) vehicles are capable of sensing forward traffic and slowing to accommodate as necessary. When no forward vehicles are present, ACC function is the same as conventional cruise control. However, with ACC, when a slower vehicle is detected, the ACC system will decelerate and follow at a selected time-based distance. While slowing to follow, the driver will experience a system-controlled deceleration of the ACC vehicle. An experiment was conducted to evaluate driver preferences for the distance at which the primary deceleration occurs and the level of deceleration that is obtained. Driver intervention was required in one trial and driver response behavior was measured. Ten men and ten women in two age groups evaluated the decelerations from a cruise speed of 70mph to a following speed of 55mph behind a confederate lead vehicle on the highway. Evaluations can be made using four scales: Good vs. Bad, Comfortable vs. Uncomfortable, Jerky vs. Smooth, and Early vs. Late. Decelerations of approximately 0.06g which occur approximately 200ft to 250ft behind the lead vehicle were most preferred. Prior to intervention, foot position ranged from a point directly below the brake pedal to 16.4in from the brake pedal. Foot motion began between 21.12s time-to-collision (TTC) and 3.97s TTC. Eighty percent of the participants paused to "cover" the brake before final motion to activate the brake. The older age group intervened (braked) later than the younger age group. Driver braking after intervention ranged from 0.16g to 0.32g.

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Chapter 1 - Introduction

This report includes five sections: this introduction, a literature review, methodology, results, and conclusions. The introduction includes a brief history of cruise control, motivation for the research, a description of the technology being investigated, and an overview of the design issues. Following the introduction, a literature review provides a survey of previous related research and provides insight into gaps in the literature. The methodology describes the experimental methods that will be used in an attempt to fill in these gaps, first with a general description of method, describing the experimental design, followed by more detailed description of the procedures. The results section reports on the final methods used and reports the findings of the research. The last section draws conclusions from the results of the research.

Automatic maintenance of a set automobile speed was first introduced as a vehicle option in 1958 by Chrysler Corporation. The concept for this feature was developed from the recognition that on long open roads, drivers were inconsistent in their maintenance of speed. It was considered a safety feature by its inventor, Ralph Teator, because with speed control engaged, the system would monitor the speed of the vehicle, leaving the driver to focus on monitoring the road. Additionally, it was felt that the system permitted the driver to maintain a higher level of attention by allowing him or her to stretch and use different positions while driving (Callahan, 1992).

Following its introduction in 1958, cruise control was offered by other manufacturers under names including Speed Control, Cruise Control, Autopilot, Electro-Cruise, and Co-pilot (Ball, 1967). Over the years, cruise control has continued to grow in popularity as the specifics of the system and the interface have been shaped by the various manufacturers. In 1990, 70% of new US cars included cruise control (Callahan, 1992). Today's conventional cruise control (CCC) permits the selection of a desired speed setting (set speed), which is retained in memory. The cruise control system takes vehicle speed and engine load as inputs and outputs throttle commands to maintain the stored set speed. A driver interface permits control of the system, including adjustments to the set speed and cancellation of speed maintenance.

Since 1958, the nature of the driving environment, especially in terms of traffic density, has changed significantly. In 1958, there were 68.3 million registered vehicles on the road. In 1995, there were 201.5 million registered vehicles on the road. In 1958, approximately 77.3 billion miles were being driven by passenger cars annually. In 1995, approximately 321.5 billion miles were being driven in passenger cars annually on interstate highways alone (Federal Highway Administration Office of Highway Information Management, 1996). In 1995, there were 45,744 miles of interstate (DOT-BTS, 1996a), and Americans took almost 505 million trips of over 100 miles in their personal vehicles with a median round trip distance of 368 miles (DOT-BTS, 1997). The Department of Transportation reports that average daily vehicles per lane has increased approximately from 10,331 in 1985 to 13,306 in 1995, an increase of more than twenty-five percent. It is reported that at peak volume times, approximately 70 percent of urban interstate highways are operating at near saturation levels (DOT-OHIM, 1996b).

This increase in level of congestion makes it clear that periods of driving at constant speeds are becoming less frequent. This situation is clearly illustrated by overseas markets where conventional cruise control is of little utility because traffic densities rarely permit its use. As this trend continues in the United States, cruise control designed for maintenance of a constant speed will either gradually be degraded in usefulness, or drivers will attempt to make use of it in situations beyond what it was intended. For example, while waiting for an opening in the surrounding traffic which permits a pass without changing their speed, drivers may delay termination of cruise control and allow the range to the lead vehicle to become small (Fancher and Ervin, 1994).

Foreign and domestic automotive manufacturers are currently considering Adaptive Cruise Control (ACC) as an option that will benefit drivers on a micro and macro level. On a micro level, an adaptive speed control system will permit use of speed control in higher levels of traffic congestion. Driving in traffic of varying speeds will be made more convenient by a system that adjusts to lead vehicle speeds and therefore removes some of the workload from the driver. On a macro level, drivers will benefit from a system that contributes to the overall efficiency of the traffic flow by stabilizing speeds and following distances. The combination of these benefits makes ACC a stepping stone toward intelligent vehicle systems which are designed to improve the driver's task and throughput in future driving situations.

ACC is an extension of conventional cruise control which will control a vehicle's speed in response to the traffic in the vehicle's path of travel. ACC is a speed control system that uses forward-looking sensors to detect and respond to the presence of a lead vehicle. While ACC systems, sometimes referred to as intelligent cruise control, have been under development for some time, only recently have the capabilities of sensors and control systems been sufficient for construction of useable systems. ACC extends the usefulness of CCC into the increasingly frequent situations where vehicles must follow a lead vehicle while either waiting for a passing opportunity or while part of a platoon. These situations place additional demands on the driver to monitor the relative speeds between the vehicles, perform frequent control adjustments, and maintain heightened vigilance.

Use of ACC during open-road driving is indistinguishable from CCC. A desired cruising speed is selected by the driver and the system performs the necessary throttle commands to maintain this set speed. When slower moving traffic is overtaken, the system evaluates the speed of the lead vehicle and transitions to a following mode in which it attempts to maintain a specified headway behind the lead vehicle, issuing throttle, transmission, and/or brake commands. In this following mode, the ACC system switches from maintaining a set speed to maintaining a set distance (based on speed) behind a lead vehicle.

The subject of this investigation centers on the ACC-controlled transition from a state of open-road cruise at a set speed to a state of distance maintenance behind a lead vehicle. Issues central to this transition include driver performance in open-road driving, overtaking, and following situations, as well as preferences for automated system performance, deceleration thresholds, and operator supervision issues. *The primary objective of this research is to identify how drivers would like an ACC vehicle to decelerate from a cruise speed into following behind a* *slower vehicle. The second objective is to investigate the timing and nature of a driver's response when intervention is required.* This information, in turn, will allow designers of ACC algorithms to tune system performance in this situation according to the preference of drivers and to shape system performance to accommodate the needs of drivers when they are required to intervene.

In order to do this, an understanding of driver behavior during open-road, overtaking, and following driving, concentrating on the deceleration occurring during overtaking, must be developed. This understanding must first come from the evaluation of manual, or unassisted, performance of this overtaking deceleration. The dynamics of the deceleration must be understood so as to identify the variations that might or might not be preferred by the driver. Next, an understanding of how drivers might want an automated system to control this previously manual function must be identified. It becomes important to know how this automated deceleration impacts the driver's behavior and performance when overriding the ACC system deceleration. Thus, an understanding is desired of the impact of automation on the braking response time and braking application upon driver intervention.

Research Questions

The objectives of this research can be summarized in the following research questions:

In terms of preference, for an ACC system when transitioning from a state of open-road cruise at a set speed to a state of distance maintenance behind a lead vehicle,

1. How do drivers want the vehicle to decelerate behind a slower lead vehicle?
2. Do drivers want ACC deceleration to be like their own deceleration?
3. Does deceleration preference change with system experience?

Related to intervention behavior, for an ACC system when transitioning from a state of open-road cruise at a set speed to a state of distance maintenance behind a lead vehicle,

1. Where are drivers placing their driving foot while using ACC?
2. When do drivers choose to intervene?
3. What is the nature of driver control after taking over?

Chapter 2 - Literature Review

Driving Modes

As identified in the introduction, this investigation focuses on the deceleration characteristics of a system that will perform the transition from open-road driving to a state of following behind another vehicle. The initial driving mode being investigated here is a driver traveling at his/her preferred speed without the influence of vehicles in the road ahead. Forbes (1972) indicates that vehicles traveling with the path clear ahead up to 10 or 12 seconds can be considered to be operating in an open-road driving mode. In other words, when driving at 70 mph, vehicles traveling farther than about two-tenths of a mile (1,056 ft) ahead do not influence the speed of the driver. In this open-road mode, the driver is either manually controlling his/her speed using the accelerator pedal, or he/she has set the cruise control at his/her preferred speed and the cruise control system is maintaining the speed.

As a slower moving lead vehicle is approached, the driver of the following vehicle will begin making adjustments. This approach mode, called overtaking, is described as occurring as the driver of the overtaking vehicle closes to within approximately 9 seconds of the vehicle being overtaken (Forbes, 1972). At 70 mph, this transition begins at approximately 900 ft and continues to about 400 ft, or 4 seconds following time behind the lead vehicle. Forbes indicates that after the overtaking vehicle has approached to closer than 4 seconds, the driver can be considered to operate in a following mode. Following is considered to extend to about 0.5 seconds headway. A driver who is following a lead vehicle will attempt to match the speed of the lead vehicle. The figure below illustrates the three modes described and provides the associated headways in time and distance at various speeds.

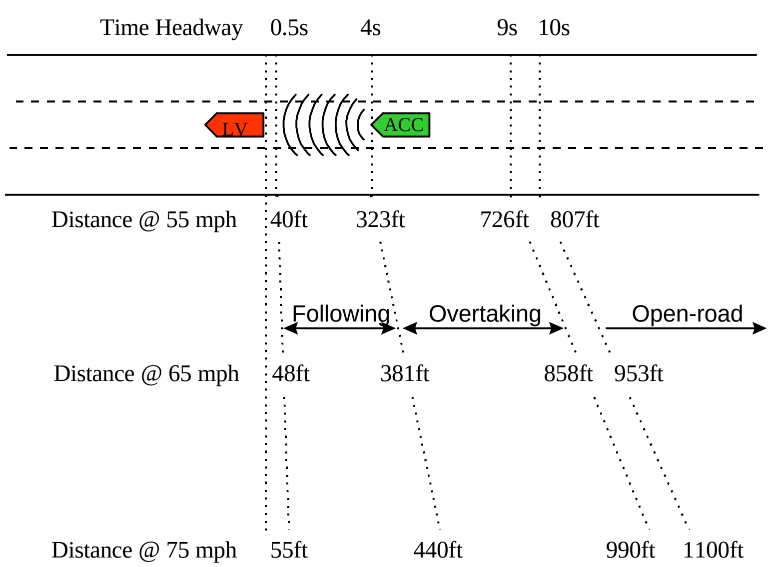


Figure 2-1. Driving Regimes and Headways (based on Forbes, 1972)

The deceleration, which is the interest of this investigation, occurs somewhere during the transition from open-road driving into an overtaking mode, and finally terminating with the following vehicle matching the speed of the lead vehicle for some period of time. Not all overtaking results in following. In many cases, where traffic densities permit, an overtaking driver performs a flying pass by changing lanes to pass the lead vehicle without significant deviation from his/her preferred speed. In designing ACC decelerations, profiles are being developed for overtaking maneuvers that result in some period of time in car-following. For this reason, an understanding of the perceptual factors and driver performance in the following mode are expected to be critical in designing acceptable decelerations.

Following

As discussed previously, following occurs at time headways between approximately 0.5 seconds and 4 seconds. Several components of driver performance related to following are discussed by Evans (1991). Perception of speed is described as being primarily related to movement in the visual field, but also related to auditory information. Our ability to judge relative speed is approximately inversely proportional to vehicle spacing. In other words, the greater the distance between vehicles, the worse our ability to judge speed differences. Amount of visible roadway (due to car size or hood shape) is important in estimating headway. When driving, more visible roadway causes larger estimation of distance. So, in a small car, a driver will estimate the distance as greater than when in a large car.

The effect of environmental factors on following was investigated using video observation of traffic on two freeways in Massachusetts (Shih-ken, Sheridan, Kusunoki, and Komoda, 1995). Environmental factors that were shown to influence car following behavior include wet road surfaces in congested flow, nighttime driving in congested flow, and the specific highway. In free flowing traffic, no effects were found for wet surfaces or nighttime.

In an investigation of car following behavior under manual, CCC, and ACC driving modes, Fancher, Bareket, Johnson, and Sayer (1995) use a frequency distribution analysis of range and range rate. By investigating the plots of the three modes, it is clear that "drivers frequently come surprisingly close (in both time and distance) to the preceding vehicle in either manual control or conventional cruise control driving" (p.1737).

In a description of driver strategies during car following, Saad (1997) indicates that driving requires continuous adaptation and reacting to variations identified as potential for collisions. The driver is continually making use of a safety margin while managing interactions with other vehicles. Ohta (1994) classified drivers according to three types based on their car following strategies: Type 1 – tries to maintain constant velocity, Type 2 – tries to maintain constant headway, and Type 3 – changes headway according to road type rather than speed. Allen, Magdaleno, Serafin, Eckert, and Sieja (1997) found that headway control is slow compared to other control inputs such as steering. Time delays, probably due to difficulty in perception of range and range rate, result in long (several seconds) delays in adjustment of headway and so limit the ability to maintain headway.

Headway

There has been considerable investigation of headway. Two headway guidelines are commonly found which drivers have obtained either through training or safety publications: (1) the two-second headway rule, and (2) the guideline of one car length for each 10 mph. Forbes (1972) reports that in low density traffic situations, drivers prefer not to car-follow and will either pass or fall farther than 4 seconds behind the lead vehicle. In higher density situations, drivers will operate at headways below each of the above guidelines. Forbes (1972) reports a previous study by Lee which found that headways of 0.8s are typical in high-density traffic, and can be as close as 0.5s.

Research has indicated that there are both intra- and inter-individual variances in preferred headway. Intra-individual differences in choice of headway can be influenced by external factors such as secondary tasks (e.g., mobile telephone use; Brookhuis, De Vries, and de Waard, 1991), fatigue (Fuller, 1984), and driving instructions (Ohta, 1994). Inter-individual differences have been attributed to internal personality traits such as sensation seeking (Zuckerman, 1979) and level of braking competence (i.e., skill in estimating time-to-collision; van Winsum and Heino, 1996). Evans and Wasilewski (1983) found that shorter headways are generally employed by younger drivers, drivers of newer cars, and vehicles with medium mass.

While there are guidelines and external and internal influences in selection of a desired headway, there are also perceptual factors that govern the establishment and maintenance of a headway. Change in distance headway necessary for detection has been identified as following Weber's law (Forbes, 1972) with

$$\Delta H = KH_i$$

where

ΔH is the distance headway change (i.e., change in range to lead vehicle),
K is a constant between 0.1 and 0.2, and
H_i is the initial distance headway (i.e., initial range).

So if the initial range is 100ft, a 10ft to 20ft change in the range will be required for the driver to detect the difference. Forbes goes on to say that estimation of headway is "woefully poor in most driving situations with errors ranging anywhere from 20 to 100 percent for various drivers" (p.138).

There is some confusion in the literature as to whether drivers use a set following distance at all speeds. Fuller (1986) found that they do: as speed increased, headway decreased. However, no effect of speed on headway was found by Ohta (1994) at speeds of 31, 37, or 50 mph (50, 60, or 80 km/h). van Winsum and Heino (1996) performed a simulator experiment that also indicated that a driver's preferred headway is constant over speed. They found that drivers adjust their following distance, following farther back at high speeds and closer at lower speeds, but maintaining an equal time-based headway.

In an ACC study by Fancher, Ervin, Sayer, Hagan, Bogard, and Bareket (1997), comparisons of ACC and manual driving indicate that ACC driving is characterized by longer headways. Headways measured during ACC driving are necessarily distributed around the allowable headway settings (1.0, 1.4, and 2.0 seconds) due to the successful system maintenance of headway. Manual driving headways were found to be shorter than these settings. It is proposed that when ACC is available, drivers use manual control when road type and traffic density require shorter headways.

Deceleration

As the driver makes the transition from open-road driving to following, he/she will experience some deceleration from his/her preferred speed into the following speed. Currently, if the driver has been manually maintaining speed, deceleration is controlled by either reducing throttle, applying brakes, or a combination of both. If the driver has been using conventional cruise control for maintaining speed, he/she will command the deceleration either by terminating cruise control and assuming manual control, or by using the cruise control decelerate command buttons.

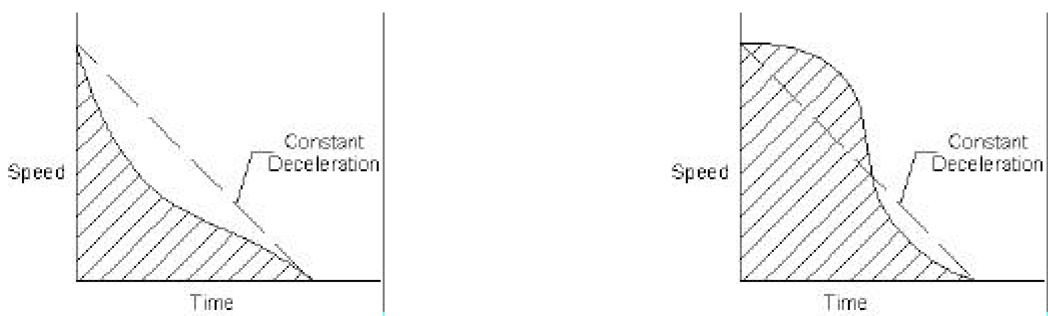
The driving situation in which cruise control is used, and especially situations for which ACC is being designed, is a dynamic one with many factors affecting driver performance and response. The driver's control of deceleration is based on many factors including his/her driving preference, perception of the distance to the lead vehicle, estimation or perception of the relative speed of the vehicles, vehicle deceleration or braking capabilities, and estimation of time-to-collision.

In decelerations from 50 mph to a stop at a specified point, Forbes (1972) reports that drivers perform the decelerations consistently, but that there is considerable variation in the deceleration profiles between drivers. In non-panic situations, decelerations of experienced drivers are reported as not exceeding 5 ft/s^2 (0.16 g). Novice drivers tend to begin with lower deceleration levels (3 ft/s^2 or 0.09 g), but soon increase to the deceleration levels of experienced drivers.

Driver behavior and capabilities when braking to a stop were also investigated in a number of different tests performed by Newcomb (1981). It was found that all drivers increased deceleration progressively during the first part of a stop. However, the level of deceleration was different for different drivers after the initial application. Some drivers maintained the initial level, while other drivers reduced the deceleration towards zero at the end of the stop, and yet other drivers braked later and harder. The maximum deceleration amplitude ranged from 0.25 g to 0.65 g in stops from 30 m/s (67 mph). Skilled drivers showed steady deceleration throughout the application without need for feedback. Unskilled drivers showed more oscillatory braking than experienced drivers. Experienced drivers were able to decelerate from 48 km/h (29 mph) without deviating considerably from 0.2 g. After training themselves to decelerate to a stop at 0.25 g in one car, experienced drivers were also able to achieve the same deceleration in a different car to within +/- 0.03 g.

Newcomb (1981) also investigated distraction during braking. Distraction caused drivers to brake gently. An investigation into initiation of braking showed that when surrounding references were removed (one light was used as a target on a runway on a moonless night), drivers were unable to stop at the target and always overshot. With two lamps separated, drivers began braking when the angular velocity of the second lamp exceeded a threshold value (0.003 rad/s) and stopped normally. Other tests with various target positions and visual conditions show that different orientations can alter deceleration behavior. Wide featureless roads are said to potentially make it difficult for a driver to adjust where and how hard to stop. Conversely, in high information situations, drivers slow down until information is received at an acceptable rate (Newcomb, 1981).

Wortman and Fox (1994) investigated vehicle decelerations to a stop at a traffic light. By analyzing each deceleration from an initial velocity using kinematic equations and comparing the calculated results to the measured decelerations, the deviation from a uniform or straight-line deceleration could be quantified. They found that 69% of the vehicles decelerated in some non-uniform profile. That is to say that the deceleration levels varied over time during the stop. The general nature of this variation in profiles can be approximated according to initial approach speeds. Wortman and Fox found that at higher initial approach speeds, drivers used higher initial deceleration rates. An example of what this profile might look like is presented in Figure 2-2(a). Conversely, when the initial approach speed was lower, drivers commanded lower initial decelerations. A typical profile of this type is shown in Figure 2-2(b).



(a) (b)

Figure 2-2. Deceleration Profiles (adapted from Wortman and Fox, 1994)

A three-state model of driver deceleration behavior in car following situations was proposed by Hattori, Asano, Iwama, and Shigematsu (1995). The model was designed around a deceleration of the lead car occurring during following. The lead vehicle was being driven between 50 mph (80 km/h) and 62 mph (100 km/h) when it executed a deceleration. They propose three states of following, standing, and braking. During deceleration, two transition paths are possible: (1) the driver may move directly from following into braking, or (2) the driver may include standing in his/her transition from following to braking. They also indicate that the driver has three perception thresholds based on either deceleration, relative speed, or headway deviation. Whichever measure exceeds its threshold first generates the driver's perception of closure on the leading vehicle. Perception of relative deceleration is described as the cue used for transition directly from the following state to the braking state or emergency braking. So when a driver becomes aware of a stronger deceleration by the lead vehicle than his/her own deceleration, he/she transitions directly to braking.

van Winsum and Heino (1996) found that the time-to-collision at the moment of lead vehicle braking influenced the following driver's initiation and control of deceleration (braking). The study investigated braking initiation differences and braking control differences between drivers with short headways and drivers with long headways. Short followers used larger decelerations, and their braking response depended more on the criticality of the deceleration than the braking response of long followers. That is, their braking response was more appropriate for the necessary braking than long followers. This indicates that initial necessary braking response is estimated based on perceived TTC and that short followers are better able to make this estimation.

The previous discussion applies only to the initiation of braking. Once the initial response is made, adjustments in control must be made according to the visual feedback of the lead vehicle's deceleration profile. A maximum in deceleration of the following vehicle was considered the point where the driver knew collision would be avoided. That is to say, deceleration will ramp up to a point where the driver knows the collision will not occur, at which time he/she relaxes braking. The closer the deceleration peak matches with the minimum TTC, the closer the driver is to matching deceleration with required deceleration. It was found that the time difference between these two peaks was small for short followers, indicating that they are better able to adjust their braking to the required braking.

For a given relative speed between the lead and following vehicles, the nature of deceleration may vary in two significant parameters: (1) amplitude or maximum deceleration as discussed in the Newcomb (1981) braking studies, and/or (2) time distribution, or the profile of the deceleration from beginning to end, as described in the Wortman and Fox (1994) research. A driver who begins the transition early and uses gradual reduction in throttle input to establish a steady headway behind a lead vehicle would experience a deceleration of low amplitude and constant deceleration with smooth onsets and offsets. Another driver might maintain cruise control until relatively close to a lead vehicle, then apply brakes and decelerate quickly to a speed that matches the lead vehicle. This driver would experience a higher maximum deceleration, and the deceleration would be distributed over a shorter period of time. Figure 2-3 illustrates these two different deceleration profiles. Both decelerations have an initial velocity of 70 mph and terminate in following at approximately 55 mph with similar headways. In Deceleration 1, deceleration is being controlled by the ACC system. In Deceleration 2, deceleration is being manually controlled. The differences in the profiles can be seen both in the shape of the curve and in the time over which the deceleration was executed. In Deceleration 1, the reduction in speed occurred over approximately 15 seconds. In Deceleration 2, speed was reduced over approximately 40 seconds. It is clear that Deceleration 1 would be stronger than Deceleration 2.

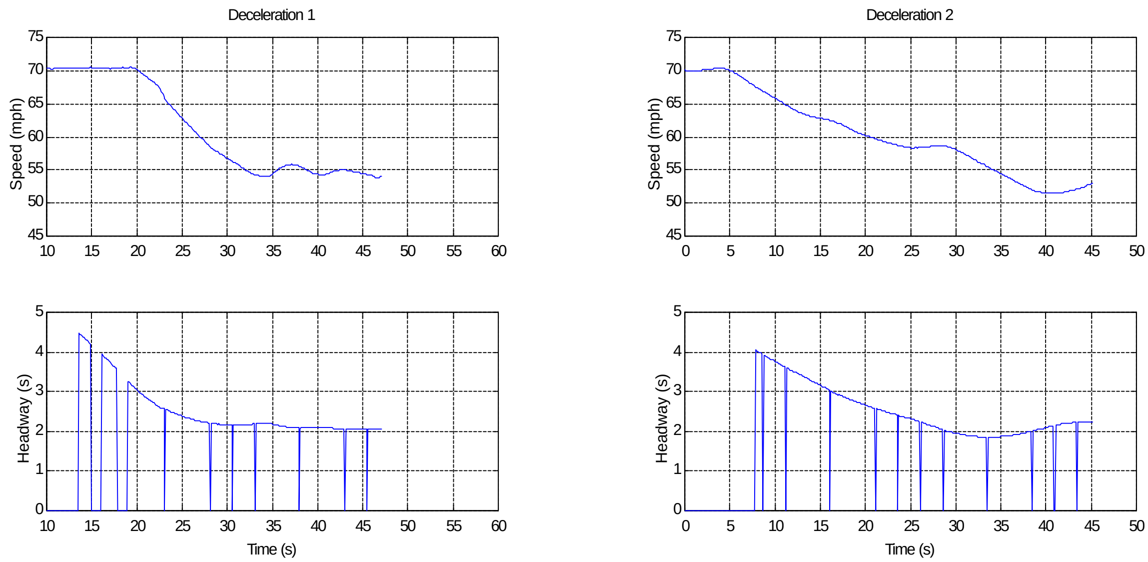


Figure 2-3. Deceleration and Headway Profiles

It is also valuable to recognize that the nature of the manually controlled deceleration is subject to the variables discussed previously, such as perception of differences in velocity, driver capabilities, driver distraction, etc.

Adaptive Cruise Control

Up to this point, issues of manual driving behavior and profiles have primarily been addressed. The following sections will address issues concerning automation within the driving environment, specifically ACC, and its influence upon driver behavior.

The design of ACC systems must follow a human-centered process to ensure that the driver's capabilities are maintained in the short term, in terms of attention and situation awareness, and in the long term, in terms of maintenance of longitudinal control and traffic monitoring skills. As with all automation, failure to appropriately design the automation for the human may negatively impact driver capabilities. Endsley and Kiris (1995) discuss the consequences of leaving the operator out-of-the-loop, and his/her ability to recover control when intervention is required. In a simulated automation of a navigation task, low situation awareness corresponded with longer decision time following failure of the system. This performance decrement is "attributed to a possible loss of skills and situation awareness arising from vigilance and complacency problems, a shift from active to passive information processing, and a change in feedback provided to the operator" (p.381). Moderation of loss of situation awareness can be achieved by adjusting the level of operator control. Decreased situation awareness under automation was most likely caused by the change from active to passive information processing.

In an investigation of the effect of ACC on comfort and situation awareness, Ward, Fairclough, and Humphreys (1995) measured comfort and situation awareness of individuals driving with and without a prototype ACC system. Comfort was measured using three different tools:

1. The UWIST Mood Adjective Checklist in terms of Energetic Arousal, Tense Arousal, and Hedonic Tone (Mathews et al., 1990);
2. Level of arousal was measured with the Modified Stanford Sleepiness Scale for Energy and Activation, and Sleepiness (MacLean et al., 1992); and
3. The NASA R-TLX was used to measure mental workload.

The first two tools were administered as pre-tests to develop baseline data. All three were then measured after each of the two sessions (ACC and no-ACC). Situation awareness was also measured using three methods:

1. A reaction time task to simulate reaction to brake lights;
2. A participant self-report questionnaire; and
3. An experimenter recorded driving errors based on observation of poor lane position, unsafe lane change/passing, failure to yield to others, following too closely, distraction, and confusion.

The first and second situation awareness measures indicated no effect of ACC vs. no-ACC conditions. The experimenter observation measure indicated that subjects in the ACC condition were more often in poor lane position, failed to yield to traffic more often, and were distracted more often. However, subjects were observed less often following too close in the ACC condition; high sensation seeking subjects were observed speeding less often when using ACC. Vehicle measures indicated that drivers selected a higher average set speed with ACC than their mean driven speed without ACC. Subjects varied their speed less when using ACC. Subjects also set a shorter headway with ACC than when they drove without ACC. Use of ACC also resulted in fewer periods of excessive high speed and short headways. The authors indicate that the use of ACC did not influence mood or overall mental workload. The observed reduction in lane maintenance and yielding to other traffic when using ACC was potentially attributed to a novel system and interface.

One investigation of on-road driver performance with a prototype ACC system was performed by Fancher et al. (1995). In this study, objective and subjective measurements were obtained for 36 naive drivers while driving manually, using CCC, and using ACC. Subjective responses were favorable towards ACC. Drivers felt that ACC provided safer following distances (i.e., longer headway), helped maintain posted speeds, and reduced driver workload. Subjects indicated that it was easy to learn when their intervention was necessary. Some subjects expressed concern for becoming over dependent on technology and for system reliability. Subjects were reported to state "...that automatic braking crossed the line that dictates who controls the vehicle..." (p.1735), and that ACC braking would need to consider vehicles following the ACC car.

In their investigation of manual, CCC, and ACC driving, Fancher and Ervin (1994) approximated that in manual highway driving, the driver is making accelerator pedal adjustments, or decisions, about once every three seconds, or 1200 decisions per hour. With CCC, the driver is required to evaluate traffic situations and decide whether to maintain continued use of cruise control. Drivers are required to adjust to the presence of other vehicles in their path, perform lane tracking, make steering corrections, apply braking, and later re-engage cruise control. The CCC driver may permit small following distances in anticipation of an opportunity to continue at speed without termination of cruise control.

Attention and Vigilance

A critical concern among human factors investigators is the level of supervision that will be maintained as drivers use ACC over time. As drivers learn that the ACC system will handle the longitudinal control of the vehicle, they may allocate their attention to other tasks. Vigilance can be negatively affected, which may result in failure to recognize obstacles or dangerous situations. In situations where the ACC system fails to handle a deceleration appropriately, the driver will be required to respond by taking manual control of the deceleration. The preparedness of the driver to make this intervention will affect the timeliness and appropriateness, or control, of the braking response.

The task of driving involves allocation of attention to the forward road scene and the many variables that it includes. Attention is essentially the focus that is given by an individual to a specific task. In this situation, appropriate allocation of attention among the many driving tasks, and potentially non-driving tasks, is of critical importance. Wickens (1992) describes three types of failure of attention:

1. Failures of selective attention: situations where an operator intentionally attends to, or selects, a stimuli that is perhaps more obvious, but that distracts from the actual important information.
2. Failures of focused attention: situations in which the operator is unable to focus on the critical information and ignore the unimportant secondary source, or distraction.
3. Failures of divided attention: situations in which the operator is unable to process information from more than one source, or perform more than one task simultaneously.

Vigilance tasks are those that require an operator to detect signals, or events, that are distributed infrequently, unpredictably, or intermittently over an extended period of time (Wickens, 1992). The less salient an event is, or the more uncertainty there is as to the time that a signal will occur, the worse maintenance of vigilance. Additionally, if background signals are frequent, vigilance will also suffer. For example, as traffic density increases, the frequency of longitudinal control tasks will increase, and the potential for vigilance decrement occurs. Consideration of these factors in the design of ACC can reduce the potential for decreased vigilance, or employ methods of maintaining vigilance.

Braking Response Time and Control

Simple reaction time data and movement time data have been shown to have low correlations with driving task reaction times (Vercruyssen, M., Folderberg, D., and Williams, G., 1996). For this reason, it is important to investigate reaction times in the context of driving due to the complexity of the task and environment. Returning to the second objective of this research, this investigation will consider the braking reactions of a driver who is intervening as an automated system insufficiently controls a transition from open-road driving into a following situation. Currently, there is very little research that addresses this specific topic.

Response time in driving is described as being composed of the time to decide on an action (reaction time) and the time to perform the action (movement time). Generally, these response times for braking fall between 1.5s and 4.0s (Evans, 1991). Various estimates of response time, including perception, decision, and response action, are presented below. Perception of the stimulus and reaction time to the stimulus are influenced by both expectancy (in this case, expectancy of the need to intervene) and the number of available response options. The driver must first perceive the stimulus. Within the context of this deceleration or transition from open-road driving into a following situation with an ACC vehicle, the stimulus may be: lead vehicle braking, the perception of lead vehicle deceleration without braking, the perception of relative velocities beyond what the driver is comfortable with or beyond what he/she feels the ACC system can handle, or the perception of a warning generated by the ACC system to indicate that manual intervention is required.

Once perception of the stimulus has occurred and the response alternative has been selected, the driver must perform the movement necessary to execute the response. In manual driving, this response might include reducing pressure on the accelerator, moving the foot from the accelerator to the brake, and application of brakes at some desired pressure. With the introduction of CCC, and now ACC, some additional variables are included. Because the cruise control system is maintaining speed, the driver’s foot is generally not on the accelerator pedal. The foot may still be located near the pedals, but may also be at rest in some location much farther from the pedals. There has been little investigation of driver foot position during cruise control use. In a discussion of issues for consideration in ACC, Sayer (1996) reports, "Drivers frequently position their feet away from the brake and accelerator pedals when driving in either the conventional cruise or ICC modes" (p.14). He goes on to say that knowing the placement of a driver's foot during system use would be useful both in predicting response times and potentially in setting headway times and adjusting system deceleration characteristics.

Movement times for foot-activated pedals have been investigated by applying Fitt's law-type modeling to foot controls. Dury (as cited in Sanders and McCormick, 1987) developed an adaptation of Fitt's law to predict movement time from one foot pedal to another. The modification uses an index of difficulty (ID) as follows:

$$ID = \log_2\left[\frac{A}{W+S} + 0.5\right]$$

where

A = movement amplitude (distance) to centerline of target,
W = target width, and
S = shoe sole width.

A reciprocal movement time (RMT) was developed as

$$RMT = 0.1874 + 0.0854(ID)$$

For a single movement time (SMT), an adjusted reciprocal of the RMT may be calculated as

$$SMT = \frac{RMT}{164}$$

These formulae are designed for coplanar movements. Movement time will be longer than predicted for more complex movements such as travel from a resting position on the floor board to the brake pedal.

In an investigation of foot movement accuracy and speed, Kroemer (as cited in Sanders and McCormick, 1987) employed an arrangement of targets to measure the capabilities of subjects to respond with foot controls. He found that subjects were capable of travel times averaging about 0.1s from various positions and that their forward movements were slightly faster than backward movements.

Kobayashi (1988) describes the progression from perception to judgment to braking onset. He found that this sequence can be approximated to be 2.5s in total and consists of 0.4s for perception and reaction (foot motion), 0.2s changing pedals, 0.1s of pressing the brake pedal and braking onset, and the remainder being judgment time. In an investigation of braking in manual and automated driving (CCC and ACC), subjects reported braking frequency to be lowest when using ACC, however, it was actually lowest when using manual control. A statistically significant difference ($p \leq 0.01$) was found for mean braking frequency between the three modes of longitudinal control. The mean number of brake applications in manual driving was 5.8, in ACC mode was 7.4, and in CCC mode was 11.3 (Fancher et al., 1995).

As stated earlier, the driver's response action includes both his/her initiation of a response, when he/she hits the brakes, and his/her control of this response, or how he/she applies the brakes. In an investigation of the role of TTC on brake response time, van Winsum and Heino (1996) found that the braking reaction time, or initiation of braking, is affected by TTC at the moment the lead vehicle begins braking. In other words, the driver uses his/her estimation of TTC at the instant of lead vehicle braking to decide when to start braking. The TTC is considered an important factor in when drivers initiate braking and also how they control their braking. Initiation of braking describes when a driver begins braking, and it includes the release of the accelerator pedal and time between release of the accelerator and activation of the brake. Control of braking describes the amplitude of the braking and the time from initial activation to maximum application. If initial TTC is high, it is expected that response time will be low.

ACC Deceleration Research

Forbes (1972) states that drivers are able to sense accelerations as low as 0.01 g. Design of systems that command decelerations that are intended to be detected by the driver should ensure that commanded decelerations remain above the 0.01 g threshold. While it is common for drivers to comment favorably on a "smooth," almost imperceptible deceleration, it may be important for the maintenance of situation awareness, and is necessary for haptic warnings, to use decelerations that are detectable by the driving population.

Fancher et al. (1995) indicate that during manual driving on US freeways, decelerations rarely exceed 0.1g . This value provides a reference point in that ACC-controlled decelerations stronger than 0.1g would be higher than typically experienced in manual driving and so may be undesirable and/or may attract the attention of a driver. However, the automated nature of ACC decelerations vs. Manually-controlled decelerations may generate different perceptions of the deceleration among drivers.

Deceleration limits proposed by Winner et al. (1996) include maximum decelerations of 2.5 m/s^2 (0.25g) and maximum deceleration rates of 1.0 m/s^3 (0.1g per second). These maximums are proposed to provide smooth braking that will not surprise the driver or make it difficult for him/her to intervene if necessary.

Semantic Differential Technique

Up to this point, the objective measures of the stimulus and response have been addressed. However, to measure the preference of the driver for the system deceleration characteristics, a subjective measurement method will be used. The use of a semantic differential technique provides a rapid method for querying users' evaluative judgments, and will provide recommendations for subsequent design of the profiles to adjust them to preferences. Use of the semantic differential technique also provides the capability to evaluate stimuli that influence a user's perception according to multiple dimensions. For example, from previous experience in this area, it has become clear that in describing a deceleration, a driver might consider the stimuli in terms of different phases of the deceleration, such as the onset or offset. The driver might also evaluate deceleration in terms of his/her comfort during the deceleration, or the degree to which the deceleration matched his/her expectations. The driver might also relate it to the strength of a deceleration at a point in time. Each of these components, and others, may contribute to the driver’s overall preference for a specific deceleration. In investigating driver deceleration preference, a tool must be developed that is capable of including these many dimensions of evaluation.

The Semantic Differential Technique was first developed by Charles Osgood and George Suci as a method that uses multiple dimensions to identify meaning of a concept. The same technique for evaluating what a concept means to an individual can be used to measure the meaning or interpretation of an object or stimulus. Application of the Semantic Differential Technique is useful for evaluating judgment-type perceptions of a stimulus. The technique uses scales that are first developed for use with a specific application and are then applied by querying subject responses to the scales. The semantic scales are anchored using bipolar terms, meaning that the terms are considered opposites by the population being surveyed.

Development of the scales is accomplished as an iterative process. Initially, a large set of adjectives and descriptors are developed related to the stimuli, product, or idea that is to be considered. The initial list of adjectives is intended to be as comprehensive as possible. The adjective list is developed using methods that facilitate elicitation of ideas. Because the list is developed using open-ended methods to elicit any description of the stimuli, it is expected that the list will include terms that provide evaluative judgment on several different axes. For example, one set of the adjectives may be related to good/bad type perception, while another group of terms may relate to some physical property such as large/small. These sets of adjectives generate an axis on which evaluation is made. In this example, there is an axis from good to bad and an axis from large to small, both of which independently describe the stimuli. Once a large list of adjectives is developed, the words are paired off into antonyms where possible, or antonyms are identified for the adjective. Terms that do not have clear antonyms are avoided.

At this stage, however, the degree to which the pairs are antonyms, or bipolar, has not been evaluated. Bipolarity can be investigated using a method that generates all possible combinations of the adjectives in the list. Cogliser and Schriesheim (1994) describe a method of evaluating terms which would potentially be used in scales to describe a coworker. Lists were developed that presented all possible combinations of the potential adjectives. Respondents were asked "to rate how nearly similar the two words were in the context of describing a coworker." The subjects used a scale from -100 to +100 to indicate the degree of similarity, with -100 indicating they had opposite meaning and +100 indicating they had identical meaning. Zero indicated that there was no predictable relationship between the two words.

The number of word combinations can be calculated as

$$\text{number of combinations} = \frac{(n_{pairs}\ x\ 2)^2 - (n_{pairs}\ x\ 2)}{2}$$

where n_{pairs} is the number of adjective pairs to be evaluated. For example, if there are sixteen pairs (thirty-two words) to be evaluated for bipolarity and orthogonality, the survey would include 496 combinations.

The evaluation generates a set of word pairs that are acceptable in terms of bipolarity for use in evaluation of the stimuli. From this set, a subset may be selected for use during evaluation. Osgood (1972) describes a factor analysis method to identify what factors are used to describe a stimulus and to judge a stimulus. This analysis involves elicitation of a number of terms that describe the stimulus. Osgood originally developed a list of 50 word pairs such as good-bad, sweet-sour, etc. The development of additional pairs is possible through content analysis such as focus groups, oral protocols, word association, and discussion among experts.

The semantic differential technique has been used as a measurement method in many different applications. Mindak (1972) reports using the technique for measurement of marketing "images" of six beers. Among the advantages he reports in using the method is its quick and efficient means for measuring opinions in both direction and intensity. He reports that it is easily repeatable and so can be used in longitudinal investigations, that it avoids stereotyped responses, and that it encourages quick, "top-of-the-mind" responses. The responses to the scales can provide researchers with more than just an accept-reject tool for evaluating a stimuli. By considering the intensity and direction of the responses, the stimuli (or in this research, the deceleration) can be shaped and redesigned according to specific dimensions of the responses.

In a human factors context, Whitaker and Sommer (1986) used the semantic differential technique to evaluate viewers' perceptions of traffic signs in which a symbol, such as a logo, conflicts with the direction indication in the sign. The procedure used six five-point scales to investigate the viewer's perceptual conflict and sign meaning. The six scales used were clear/unclear, unified/separate, relaxed/tense, valuable/worthless, strong/weak, and active/passive. Signs in which the directional indication of the sign was concordant with the directional indication of an image in the sign were found to receive higher ratings than signs in which the symbols and sign disagreed. Higher ratings were considered as clear, unified, relaxed, valuable, strong, and active.

Automobile interiors were investigated using a semantic differential technique by Shimizu, Yanagishima and Nagamachi (1989). Their research involved five steps: (1) compilation and determination of adjective pairs, (2) evaluation of photos of 21 car interiors using 160 adjective pairs, (3) factor analysis to reduce the 160 pairs to 80 pairs, (4) evaluation of 21 interiors using the 80 pairs, and (5) classification of the vehicles by interior design elements.

In a related study (Jindo, Yanagishima, Shimizu, 1990), physical dimensions of vehicle interiors were related to subjective assessment of comfort. A large set of measurements were made to identify the dimensions of the interiors of 40 vehicles. Next, 46 subjects rated thirteen automobiles using twenty-two adjective pairs. Factor analysis was then performed on their ratings to identify the principal factors involved in their judgments regarding the interiors. This generated three factors, which are described as spatial atmosphere (space), spatial volume (shape), and spatial style (artistic sense), based on the general meaning of pairs that make up the factors. In the final step, the dimensional elements of the vehicles were related to the judgments based on adjective pairs. In this way, during design, the dimensions that strongly correlate with the subjective judgments can be adjusted appropriately.

The semantic differential technique was applied to the design of headlight beam patterns by Jack, O'Day, and Bhise (1994). Development of adjectives involved three focus groups, review of internal reports regarding drive evaluations, and brainstorming sessions. Using a sample of beam patterns which covered the range of those available, 56 respondents evaluated the beam pattern using a survey that included 58 word pairs. This large set of pairs was then reduced using four criteria: (1) pairs showing small standard deviation across the beams did not discriminate well and so were eliminated, (2) pairs in which the center of the scale was used more than 50% of the time were eliminated, (3) pairs with skewed histograms were eliminated because one of the adjectives was not meaningful to the respondents, and (4) judgment calls were made to maintain pairs that reflected important aspects of evaluation. This process reduced the set of pairs to twenty-five. This subset was then tested on eight different vehicles to identify the discrimination capability of the pairs. Eighty-one percent of the pairs were found to have a standard deviation of less than 1.0. Ninety-one percent of the pairs had less than 50% of the responses in the center, or non-discriminating region of the scale. Sixty-six percent of the pairs were skewed less than 3:1. Using this shortened list of pairs, designers are able to rapidly evaluate a potential design and focus design efforts on characteristics of the beam pattern that contribute to positive customer evaluations.

In a continuation of their previous work, Jack, O'Day, and Bhise (1995) describe the reduction of the previously mentioned 25 word pairs to a smaller set for use in evaluation of viewing zones on the roadway. Factor analysis applied to the twenty-five word pairs identified two factors. The word pairs “smooth/choppy” and “aimed/misaimed” were used to describe these factors. Two additional word pairs were added to evaluate the perceived light output (bright/dim) and subjective impression (secure/insecure) of the beam pattern in the different zones. This smaller questionnaire was then correlated with the larger questionnaire which included twenty-five word pairs and was shown to have a strong correlation (0.94), indicating that the two questionnaires could be substituted for one another depending on the needs of the situation.

In a later study (O'Day, Stone, Jack, and Bhise, 1997), five factors were identified from the scales and related to physical properties of the beam pattern to explore potential models relating the objective measures to subjective measures. The twenty-five word pairs were grouped according to the following factors: uniformity, aim, power, shape, and comfort. Scores were developed for each of the factors, and these scores were then correlated with the physical measures of the beam pattern. Regression models were identified which relate the physical beam characteristics to the subjective ratings.

Selection of Variables

For the present study, selection of independent and dependent variables is influenced by previous research and the desire to make informed design decisions related to deceleration characteristics of ACC vehicles. The independent variables of age and gender are of interest in any research related to transportation and vehicle design. Age becomes particularly important in the investigation of ACC due to issues related to response time, acceptance of technology, and all issues related to older drivers. An independent variable encompassing the deceleration behavior of the vehicle as it approaches the lead vehicle will be referred to as the deceleration profile and will primarily be investigated using the peak deceleration that is attained and the distance at which this peak deceleration occurs from the lead vehicle. These two measures provide a straightforward reference by which to gauge the deceleration. Dependent variables for the study were selected to investigate driver preferences for deceleration and to provide objective information about the behavior of drivers while taking control from the vehicle. Preference will be measured using semantic differential techniques as described in the previous section. The semantic differential technique permits evaluation of users’ judgments both in direction and magnitude on multiple concepts or criteria. Foot position, movement time, and time-to-collision will be incorporated because these are behavioral measures that have been frequently applied to manual driving, but that have not been fully investigated in the automated driving context. These variables provide valuable information about the driver’s expectancy, response, and thresholds for response. The manual braking deceleration will be measured after taking control using the same measures that are applied to the ACC decelerations to develop an understanding of driver braking when intervening. Driver performance during this phase will also be investigated using time-to-collision and headway information.

Chapter 3 - Methods

General Approach

The methods used in this investigation are designed to manipulate characteristics of the ACC system response, in terms of the nature of the deceleration profile (i.e., the shape of the velocity curve or acceleration curve), as the ACC vehicle approaches a slower moving lead vehicle. The deceleration profile can be looked at as the onset and offset of the deceleration. In this study, the shape was measured by the peak deceleration and the range to the lead vehicle at which this peak deceleration occurred. Figure 3-1 below presents an example of what is meant by a deceleration profile.

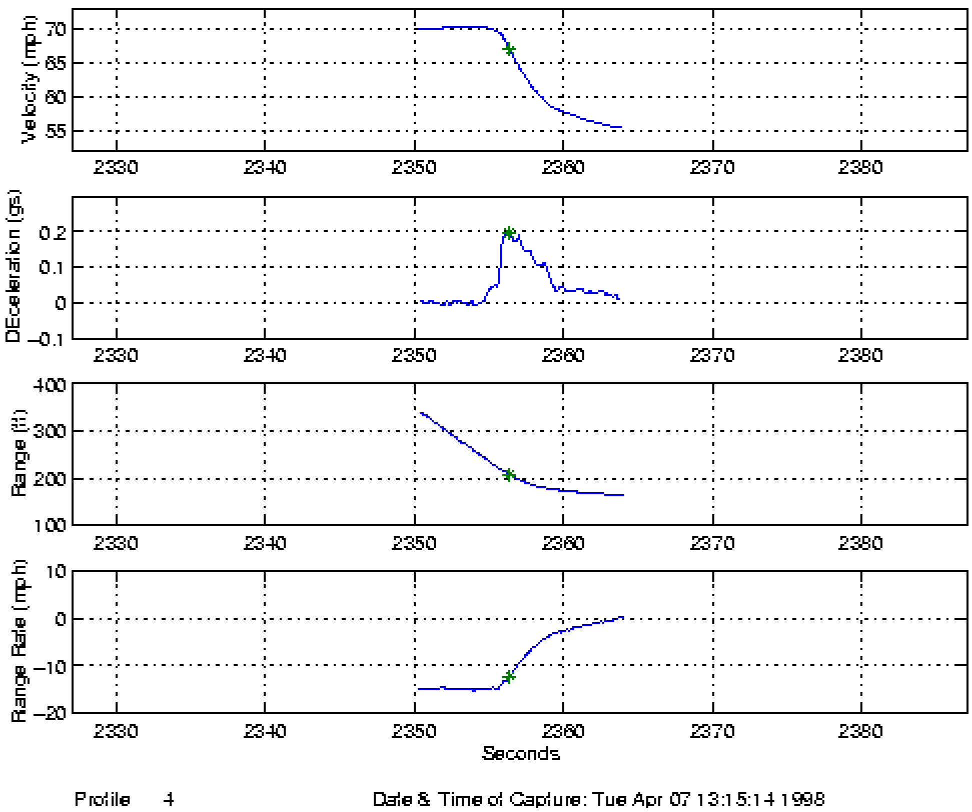


Figure 3-1. Deceleration Profile Example

In the figure, the shape of the velocity or acceleration traces describe the profile. A relatively hard deceleration like the one shown will have a steep drop in velocity and a defined high peak in deceleration. Lighter decelerations will show as a long low constant deceleration and a gradual decline in velocity. Each of the plots portrays a different piece of information about the vehicle performance during a specific deceleration trial. In the top plot, the vehicle's velocity is shown. In the second plot, the deceleration of the ACC vehicle is portrayed. In the third plot, the range from the ACC vehicle to the lead vehicle is shown. In the bottom figure, the difference in speed (DV) between the ACC vehicle and the lead vehicle is shown. The asterisk in each of the plots denotes the point where peak deceleration occurred during the trial. One can see from the top plot in Figure 3-1 that the ACC vehicle is initially traveling at a set speed of 70 mph. The bottom figure shows that there is a 15mph speed difference between the two vehicles during this phase. At approximately 240ft, the ACC car begins a deceleration which peaks 200ft from the lead vehicle at 0.2g. As the vehicle slows to match the 55mph of the lead vehicle, range rate goes to zero.

The driver's preferences for how the vehicle performs this deceleration behind a lead vehicle will be evaluated by creating situations that generate the various profiles, or levels of system response, and subsequently measuring the driver preference for that type of response. Two phases were required: the first to develop the tool to measure the preferences, and the second is to measure the preferences using the tool. Figure 3-2 below provides a flowchart of the steps used for development of the evaluation surveys, measurement of preferences, and consideration of the subset of scale dimensions.

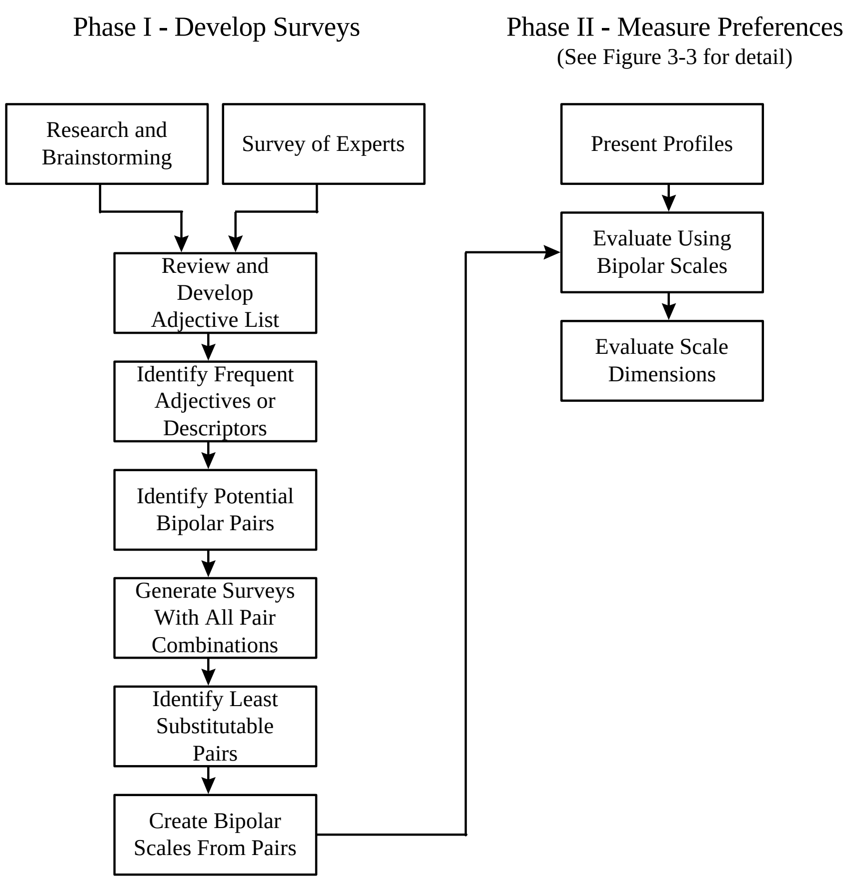


Figure 3-2. Survey Development and Preference Measurement Procedure

The following section describes Phase I, which was the development of a deceleration preference measurement tool. In Phase II, the ACC deceleration profiles were presented to participants for evaluation.

Phase I - Develop Surveys

Drivers' preferences for deceleration profiles were obtained through the use of a semantic differential technique. Before preference could be measured, a set of stimuli-appropriate scales had to be developed. Two methods were employed in developing the potential list of adjectives for use as anchors in the semantic differential scales: subject expert research and brainstorming, and survey of experts.

Research and Brainstorming

The initial activity used for identifying possible adjectives that could be used in the semantic differential scales was to review the semantic differential literature and previous ACC experiments for possible applicable descriptors for the measurement of ACC decelerations. Adjectives and descriptors that are considered of potential value in measuring driver perceptions of deceleration were identified and recorded. From Osgood's literature, a list of fifteen possible bipolar pairs were selected that might be applicable to the measurement of ACC decelerations. This list is shown below.

fast/slow
rough/smooth
nice/awful
long/short
relaxed/tense
heavy/light
ferocious/peaceful
sharp/dull
pleasant/unpleasant
valuable/worthless
calm/agitated
strong/weak
hard/soft
beautiful/ugly
good/bad

Additionally, from previous experience investigating ACC accelerations and review of the literature, another fourteen possible pairs of adjectives were developed for possible use and are shown below.

uncomfortable/comfortable
unsafe/safe
jerky/smooth
startling/expected
reckless/cautious
appropriate/inappropriate
early/late
natural/unnatural
expected/unexpected
even/uneven
inaccurate/accurate
close/far
normal/abnormal
aggressive/docile

Survey of Experts

To obtain a more detailed and current list of terms, a survey was distributed to individuals involved in this research field. A survey of eight questions related to both ACC deceleration and deceleration in general was developed (see Appendix A). Questions related to both ACC deceleration and deceleration in general were developed and distributed to seventeen individuals who have experience with ACC, ranging from engineers completely involved in the field and on-road ACC studies to individuals who have driven ACC cars and are generally familiar with ACC issues. The individuals included human factors engineers at Ford and UMTRI, sensor suppliers, vehicle engineers, software engineers, and program managers. Twelve of the surveys were returned.

These responses were reviewed, and descriptors and adjectives were identified and tallied. From the review of the twelve returned surveys, 91 different words were identified as possible descriptors of decelerations. The list below identifies descriptors that were used by two or more of the respondents. A complete list of descriptors may be found in Appendix B.

Descriptor	**Frequency**	**Descriptor**	**Frequency**
smooth	11	rough	3
jerky	9	soon	3
comfortable	8	sudden	3
late	8	aggressive	2
like me (or mine)	8	constant	2
abrupt	7	firm	2
harsh	5	heavy	2
uncomfortable	5	high	2
close	4	inadequate	2
early	4	insufficient	2
enough	4	little	2
hard	4	responsive	2
confident	3	right	2
good	3	sluggish	2
gradual	3		

Eleven of the twelve respondents used the word "Smooth." Nine of the twelve included "Jerky." "Comfortable" and "Late" were used by eight of the respondents. Some description comparing a deceleration to how they would decelerate, termed "Like me," was also used by eight of the respondents. "Abrupt" was used by seven respondents. "Uncomfortable" and "Harsh" were used by five of the respondents. The remaining words were used by four or fewer of the respondents. Terms that occurred in a large number of the returned surveys were considered common and valuable for potential inclusion as scale anchors for evaluation of deceleration. Additionally, words that were mentioned infrequently, but that were considered of potential use for design decisions, were also considered.

Investigation of Term Bipolarity

Semantic differential scales are anchored with terms that are bipolar, or opposites, on a dimension describing a concept or stimulus. From the research, brainstorming, and survey of experts, a list of word pairs was developed for testing as potential word pairs for bipolarity. Having selected a set of words that showed potential for evaluation of decelerations, it was necessary to investigate the degree to which the terms were antonyms. A survey was developed which was used to investigate bipolarity of the adjectives in semantic space. The list of eight pairs that were investigated is as follows:

1. bad/good
2. jerky/smooth
3. comfortable/uncomfortable
4. early/late
5. safe/unsafe
6. like me/unlike me
7. natural/unnatural
8. hard/soft

Pairs #1 (bad/good) and #8 (hard/soft) are original bipolar pairs referenced in Osgood (1972). The remaining six pairs were developed during the adjective elicitation phase of the research. The sixteen words or phrases (i.e., like me/unlike me) were presented to respondents so that each word was paired with each of the other sixteen words, generating 120 pairs. A presentation technique used by Cogliser and Schriesheim (1994) was used for the following evaluation of the adjectives. Each of the ten surveys was unique, with the 120 pairs presented in random order on each survey. Table 3-1 below provides an example from the first twelve pairs presented on one survey.

Table 3-1. Example of Bipolarity Survey

	Similarity (-100 to +100)
safe <==> like me	
unlike me <==> soft	
unsafe <==> hard	
comfortable <==> late	
unnatural <==> hard	
smooth <==> natural	
uncomfortable <==> hard	
uncomfortable <==> like me	
safe <==> natural	
jerky <==> smooth	
bad <==> good	
jerky <==> uncomfortable	

Respondents were required to indicate, using a rating from -100 to +100, the degree to which the words were similar or could be substituted for each other in a sentence. Pairs that were perfect substitutes should be scored with a +100. Pairs that would completely change the meaning, considered opposites, would receive a -100. Two words that were unrelated would receive a score near zero. Ten surveys were completed by five males and five females. An example of an entire returned survey and instructions to the respondents may be found in Appendix C.

Multivariate clustering of the surveys with respondents identified as variables (10) and each potential pair as an observation (120) was performed after standardizing the respondent data. Using a simple requirement of five separate clusters divided the data generally into clusters representing strong opposites, strong substitutability, weaker opposites, weaker substitutability, and finally a group of two pairs for which it is difficult to identify a relationship. Ten pairs of words were included in the cluster that included strong opposites. While this clustering does not provide rigorous evaluation of the biploarity of the pairs, it provides a useful reference to consider the level of anonymity of the pairs. The ten pairs included the original eight described above, with the addition of “bad” and “safe” being considered as opposites, as well as “good” and “uncomfortable.” Table 3-2 below lists these ten pairs. The right hand column provides the average rating for each pair across all ten survey respondents.

Table 3-2. Word Pair Substitutability Averages

Pair	Average
comfortable <==> uncomfortable	-99.5
early <==> late	-99.5
safe <==> unsafe	-99.5
bad <==> good	-99
like me <==> unlike me	-99
jerky <==> smooth	-96
hard <==> soft	-89.5
natural <==> unnatural	-89.5
bad <==> safe	-79.5
good <==> uncomfortable	-57

The first eight of these pairs were maintained for use in the scales that would be used for evaluating driver preferences for deceleration profiles. The presence of the last two pairs in the list, bad vs. safe and good vs. uncomfortable, indicates that there may be some congruency or lack of orthogonality in the evaluation of a deceleration where good-bad, safe-unsafe, and comfortable-uncomfortable may overlap. However, the utility of including these scales precluded their elimination from the scales that were used. Additionally, factor analysis after the collection of data could be used to evaluate the orthogonality of the pairs.

The scales developed in Phase I were used in Phase II to measure driver preferences for different deceleration profiles. The application of the scales occured following the demonstration of each profile.

Phase II - Measure Preferences

In the initial portion of the experiment (see Figure 3-3 - Block 1), participants were required to drive for approximately one-half hour on the freeway. During this segment, vehicle information was collected to develop driver-specific behavior such as headway maintenance, braking behavior, following behavior, range rates, accelerator use, brake application, and level of maximum braking. At the end of the natural driving segment, the driver's manual deceleration was recorded for inclusion in later measurements. After this natural driving data collection was completed, preferences for automated braking behavior were investigated.

The preference measurement portion of the experiment began by presenting two examples, or demonstrations, of braking profiles (Figure 3-3 - Block 3) . The participant was introduced to the scale anchors during these two initial deceleration demonstrations, but was not required to respond. Following these two examples, thirteen braking profiles were presented to the participant for evaluation. The first and last presentations (Figure 3-3 - Blocks 4 and 7) are used as standard measures which were compared to investigate any change in preference from the beginning to the end of the preference evaluation segment. Ten presentations (Figure 3-3 - Block 5) were used to evaluate the driver's preference for the deceleration profile. These ten presentations included five general profiles that were presented twice. Finally, a deceleration was used which required the driver to brake (Figure 3-3 - Block 6). As described earlier, the final presentation was the same as the first of the thirteen evaluated profiles.

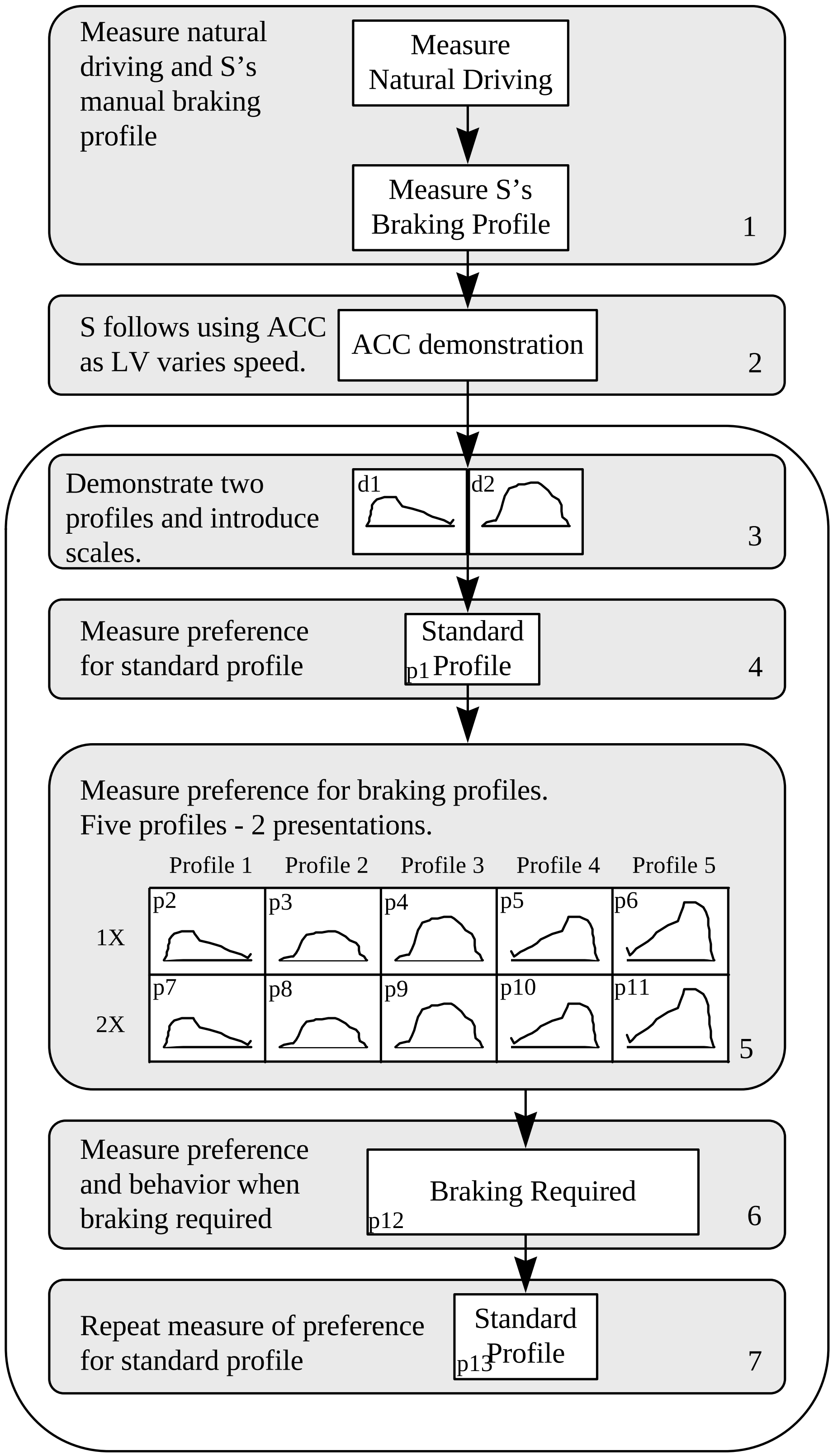


Figure 3-3. Experimental Procedure

Experimental Design

The experiment was a mixed-factor design with age and gender as between-subject independent variables. The within-subject independent variable was the deceleration profile. Dependent variables were preference, movement time, manual braking profile, and foot position. These variables are discussed in more detail below.

Independent Variables

Between-Subjects Variables

Age (2)

Younger (21-30 yrs), Older (40-50 yrs)

The older age group was set at 40-50 years, which is younger than is generally used for an older age group in human factors transportation studies. This was done for two reasons. First, it is not difficult to fill a typical older age group (e.g. 65 years and above) using Ford Motor Company employees. Second, it is expected that vehicles that are initially marketed with ACC will be purchased by individuals in or near the 40-50-year age range. The younger age range was also selected to accommodate the ages available in the participant pool.

Gender

Within-Subjects Variables

Profile (5)

By manipulation of the vehicle control algorithm, different deceleration profiles were presented to elicit participant responses during the deceleration behind the lead vehicle. The algorithm inputs and final target deceleration levels were developed before the experiment to fit the cells of the experimental design. It was not possible to obtain identical profiles from one trial to another, but the variable was controlled to within certain ranges. The deceleration levels and distances listed in Table 3-3 describe the profiles achieved during the study.

Table 3-3. Profile Parameters

Profile	Approximate Maximum Deceleration	Approximate Range at Maximum Deceleration
Standard	0.16g	270
Profile 1	0.06g	300 ft
Profile 2	0.10g	190 ft
Profile 3	0.20g	250 ft
Profile 4	0.21g	200 ft
Profile 5	0.29g	175 ft
Intervention	0.06g	----

Deceleration levels were desired that would both include the deceleration levels that were expected to be desirable, and to cover the range of decelerations possible in the vehicle. The vehicle used for the study was capable of decelerations up to approximately 0.30g. Additionally, decelerations occurring at various ranges were desired. These deceleration ranges were generated through adjustment of primary variables (gains) in the control algorithm. The experimental profiles were developed according to both the described experimental motivations and within the capabilities of the control algorithm.

Experimental Design Matrix

The experimental design matrix for the 2X2X5 mixed-factor design is provided in Table 3-4. Five subjects were used per cell for a total of twenty subjects.

Table 3-4. Experimental Design Matrix

Between		Within				
Gender	Age	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5
Male	Young	s1 - s5	s1 - s5	s1 - s5	s1 - s5	s1 - s5
	Old	s6 - s10	s6 - s10	s6 - s10	s6 - s10	s6 - s10
Female	Young	s11 - s15	s11 - s15	s11 - s15	s11 - s15	s11 - s15
	Old	s16 - s20	s16 - s20	s16 - s20	s16 - s20	s16 - s20

Dependent Variables

Some of these indicators, such as movement time, may be directly used to evaluate the performance of the driver. Other behaviors are selected because they are considered indicators of less direct measures of performance such as level of attention, expectancy, or the driver's mental model of the system. The following section describes the measures that were used, why they were used, and how they were measured.

Preference

Measurement of preference was performed using the semantic differential scales described previously. After each deceleration profile was demonstrated, the participant verbally responded to the scales presented by the experimenter. The measurement of preference for the profiles and the preferences measured according to the various dimensions represented by the scales will be useful in the design and analysis of system deceleration.

Foot Position

The closer that a driver's foot is to the brake pedal, the faster he/she will be able to apply the brake. Shorter brake response time translates to more situations avoided or reduced damage or injury. Additionally, foot position can indicate the driver's awareness and possible anticipation. A driver who has low anticipation of needing to intervene may position his/her foot farther from the pedal. A driver who is anticipating a manual braking situation may move the foot closer or even cover the brake pedal. Participant foot position was measured using video analysis. During the driving segments, an infrared video camera placed above the participant's feet recorded foot position in the area from the pedals to the front of the driver's seat. Prior to the start of the study, a grid pattern was laid out on the floorboard of the test vehicle. The grid origin was placed at a point directly below the right lower corner of the brake pedal. The grid was video taped and this tape was then played on a large monitor and the grid was transferred to an overlaid transparency. During review of the driver's intervention, the transparency was placed on the monitor and the location of the ball of the driver's right foot was identified in two coordinates using the overlaid grid pattern. These two coordinates were then used to identify the distance from the ball of the foot to the brake pedal.

Movement Time

During the braking-required trial (Figure 3-3 - Block 6), the foot movement time of the driver was measured. Movement time was measured (1) when the participant changed his/her foot position from a resting position, (2) at the point of readiness, or "covering" the brake, and (3) when the participant activated the brake pedal.

Time-to-Collision

The TTC at intervention during the braking-required trial (Figure 3-3 - Block 6) was measured using the range and range rate information from the ACC sensor.

Manual (Intervention) Braking Profile

In the development of ACC, it is important to develop an understanding of the nature of a driver's response beyond simple reaction (activation of the brake). Measurement of the automated plus driver decelerations will provide data for approximating the potential for automated braking systems in mitigating damage and injury in front-to-rear end collisions. Measurement of the driver's braking profile following intervention was performed using vehicle velocity and acceleration data.

Participants

Twenty participants were included in the study. All twenty participants were Ford Motor Company employees. Participants were recruited using e-mail lists (see Appendix D) within Ford Motor Company and by word of mouth. Individuals who had driven ACC vehicles or collision avoidance vehicles were not permitted to participate. Participants were licensed drivers with more than two years experience, and were selected from two age groups, 21-30 years and 40-50 years. Eighteen of the participants reported driving a Ford or Mercury vehicle as their primary vehicle. The two remaining participants drove a Honda and a Saturn. Eight participants reported being engineers, four were analysts, three were coordinators, two were clerks, two were administrative assistants, and one was a CAD data manager. The annual mileage reported by participants as being driven in their two primary vehicles ranged from 12,000 miles to 45,000 miles with a mean of 20,510 miles. Nineteen of the participants reported that they drive daily. One participant indicated driving a few times a week. Nine of the participants reported using conventional cruise control every day. Ten of the participants reported using conventional cruise control a few times a week. The remaining individual reported using cruise control a few times a month. Nineteen of the participants indicated that highways are a type of road on which they drive the most. Sixteen of the participants indicated that they drive on the section of I-275 used for the study a few times a year. The remaining four indicated that they never drive on the test section of I-275. All of the participants indicated that they use cruise control on highways. Eight of the participants indicated that they use the steering wheel buttons frequently to increase and decrease their set cruise speed. Six reported that they do this occasionally. Four indicated that they use the buttons sometimes, and two indicated that they rarely use the buttons. Twelve of the participants indicated that they had never heard of Intelligent or Adaptive Cruise Control. The remaining eight participants had heard of it in magazines, around work, in class, or on TV.

Research Vehicles

ACC Vehicle

The ACC vehicle is a four-door 1994 Ford Taurus SHO. The vehicle uses a forward-looking sensor and is controlled using a headway maintenance algorithm written by Ford Motor Company. Acceleration is controlled by throttle commands, and deceleration is achieved through throttle commands and commanded braking.

The ACC system is controlled by the driver using steering wheel controls located on the steering wheel web area. The standard Ford Motor Company On, Off, Cancel, Resume, Accelerate, and Decelerate buttons are used.

With cruise control active, application of the brake cancels cruise control and retains the driver's set speed (cruise speed) in memory. Application of the accelerator with cruise control active allows manual control of acceleration. In this situation, the driver's set speed is returned to automatically after release of the accelerator pedal.

The test vehicle records data at 10 Hz. Recorded vehicle parameters include longitudinal acceleration, velocity, range, range rate, system state (e.g., cruise, driver override), throttle position, and brake cylinder pressure. Video recording was made of the forward road scene using a lipstick camera located below the rear view mirror. Driver foot position was recorded using an infrared CCD camera attached to the brake pedal bracket. An audio channel was included for recording participant comments and discussion. The two video views were digitally synchronized with the vehicle data stream.

A laptop computer networked with the vehicle control computer was used to monitor system performance and to select the profiles for presentation. The laptop display permits monitoring of information including system state (e.g., cruising without a target, following a target, manual control), set speed, acceleration, range to target, current headway, and current speed.

Lead Vehicle

A 1998 Lincoln Continental was used as the lead vehicle. The experimenter and lead vehicle driver were able to communicate using hand-held two-way radios. The lead vehicle driver used the vehicle's conventional cruise control to maintain the 55mph lead vehicle speed used throughout the study.

Roadway Description

The initial natural driving segment was performed on the Southfield Freeway North to I-96 West to I-275 South. This section of road consists of three and four lanes. The posted speed on these roads varies from 55 mph to 70 mph. The preference measurement portion of the study was performed on I-275. In this section, I-275 South is a three-lane section of road with minimal roadway appurtenances and has an average traffic volume of 43,200 vehicles per day (MDOT, 1996) and a posted speed of 70 mph. The highways and driving portions of the route are shown in Figure 3-4.

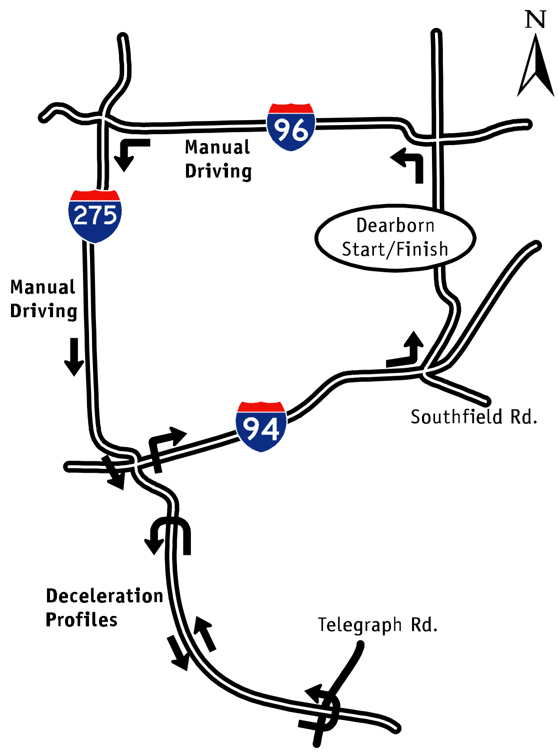


Figure 3-4. Map of Experiment Route and Driving Segments

Initially, a-six mile segment was used to perform the trials, but construction on the roadway (which began approximately half-way through the study) reduced the length of usable roadway to an approximately 1.5-mile segment between two exits. The roadway geometry was without visible vertical curvature and included some gentle horizontal curves and straight sections.   Performance of the trials involved driving South on I-275 to Telegraph Road, where the highway was exited and re-entered in the opposite direction. This test section was used repeatedly as needed by reversing direction at each end.

Procedure

Prior to driving, time was taken to orient the driver with the experiment, the vehicle, and procedures; to administer pre-experimental surveys; and to introduce the driver to the scales and how they would be used. The driving portion of the session can be considered as six blocks (see Figure 3-3): measurement of baseline driving behavior, an ACC braking demonstration, measurement of preference for a standard profile, measurement of profile preference, measurement of preference and behavior when braking was required, and finally, post-treatment measurement of the standard profile. Following the driving portion of the session, the participant was debriefed and questions were answered by the experimenter. A copy of the script and procedure steps used by the experimenter can be found in Appendix E.

Table 3-5 identifies each of the profiles in order of presentation and provides a brief explanation of each. Further description of the profiles and their purpose can be found in the following sections.

Table 3-5. Order of Deceleration Profiles

Profile	Block Name	Profile Description	Explanation
d1-d2	Block 3 - Braking Demonstrations	Demonstration Profiles	Two examples of profiles served as a basis for preference measurements.
p1	Block 4 - Preference Measurement	Standard Profile	A standard profile was administered to develop a preference baseline.
p2-p11	Block 5 - Preference Measurement	Preference Measurement	These ten demonstrations included the five profiles presented twice.
p12	Block 6 - Braking Required	Braking Required	A deceleration that required the driver to intervene was presented. Preference and response behavior were measured.
p13	Block 7 - Standard Profile	Standard Profile	The standard profile was re-administered.

Pre-Driving

The purpose of this pre-driving segment was to orient the participant to the vehicle and procedures of the study, and to collect preliminary information about the participants. All but two of the participants were met at their building by the experimenter in the ACC car. Two participants opted to meet the experimenter at his building for convenience. The participant was provided with a letter describing the study (see Appendix F) and read and signed two Informed Consent Forms (see Appendix G and Appendix H). The participant then competed the pre-experiment Participant Background Form (see Appendix I) which investigated driving behavior including the participant's use of conventional cruise control, annual mileage, etc. Next, the participant was assisted in orienting himself/herself to the ACC vehicle: seats and mirrors were adjusted, and ACC controls were pointed out and explained. The experimenter then provided additional verbal description of the procedures the participant could expect and responded to any questions. When the participant was familiarized and ready, the natural driving segment began.

Block 1 - Natural Driving

The purpose of this first driving segment was to record driving data that describe the participant's natural driving behavior. This information can provide a baseline to which ACC deceleration preferences may be compared. During this natural driving segment, the participant drove the Ford Taurus ACC car in traffic without using ACC. The participant drove for approximately 30 minutes consisting of freeway driving (e.g. Southfield Freeway North to I-96 West to I-275 South). At a designated point (e.g., after passing I-94), the natural driving segment ended.

Upon completion of the natural driving segment, the participant slowed and the compatriot vehicle assumed the lead and established a large gap between the vehicles. During this segment, the participant was instructed to maintain his/her current (center) lane and drive at 70 mph under manual control. The lead vehicle was driving at a speed of 55 mph using conventional cruise control. As the participant approached the lead vehicle and slowed, his/her deceleration profile was recorded.

Block 2 - ACC Demonstration

Once the participant had stabilized at a following distance behind the lead vehicle, the participant continued following the lead vehicle and ACC was engaged with a set speed of 70mph. The two vehicles continued traveling in this manner while the lead vehicle drove at various speeds between 55mph and 70mph, thereby permitting the participant to experience the ACC vehicle adjusting speed to match the speed of the lead vehicle. One deceleration of the lead vehicle included deceleration with braking. The ACC demonstration continued until the participant indicated that he/she was comfortable with how the system worked and had no questions about its operation.

Block 3 - Braking Demonstration

After the participant was familiarized with ACC, two deceleration demonstrations (d1 and d2 in Table 3-5) were provided. In these demonstrations, the deceleration was controlled by ACC. As in Block 1, the LV was traveling at 55 mph. The participant engaged ACC with a set speed of 70 mph. As the ACC vehicle approached the lead vehicle, the ACC system controlled deceleration. This was repeated once more with a different deceleration profile. After each of these demonstrations, the experimenter read the scales. Participants were permitted to practice responding to the scales or to simply listen to them.

Block 4 - Standard Profile - First Presentation

The first deceleration that was evaluated by the participant was the first presentation of the Standard Profile.

Block 5 - Preference Measurement

Next, the ten profiles (p2 - p11 in Table 3-5) were presented for measurement of preference. The ten profiles included the five profiles presented twice. After presentation of each profile, the driver verbally responded to a set of nine scales, and his/her response was recorded by the experimenter. Appendix J provides the table used by the experimenter to order profile presentations and record participant responses.

Block 6 - Intervention

Following the evaluation of the profiles for investigation of preference, a trial was presented that appeared to provide insufficient braking, and so required the driver to intervene. No indication was given to the driver that this profile would be insufficient for the situation.

Block 7 - Standard Profile - Second Presentation

The last profile that was presented to the participant was the second presentation of the standard profile that was presented at the beginning of the set of thirteen trials.

Post Experiment

Following the completion of the preference measurement segment, the participant drove back to his/her building while the experimenter reviewed the various parts of the experiment with the participant and responded to questions.

Chapter 4 - Results

Manual Deceleration

Maximum Deceleration

Before activating ACC, subjects approached the lead vehicle in a situation similar to the conditions under which ACC was used later in the study. The lead vehicle was traveling in the center lane maintaining a speed of 55mph, and the participant was instructed to maintain approximately 70mph and approach and follow the lead vehicle. During this manually-controlled deceleration, vehicle data including range and range rate to the lead vehicle were collected. Decelerations measured ranged from 0.04g to 0.14g. The mean deceleration was 0.07g and the median was 0.06g. The standard deviation was 0.03g. Figure 4-1 below presents the frequency distribution of maximum driver-controlled decelerations measured for eighteen participants.

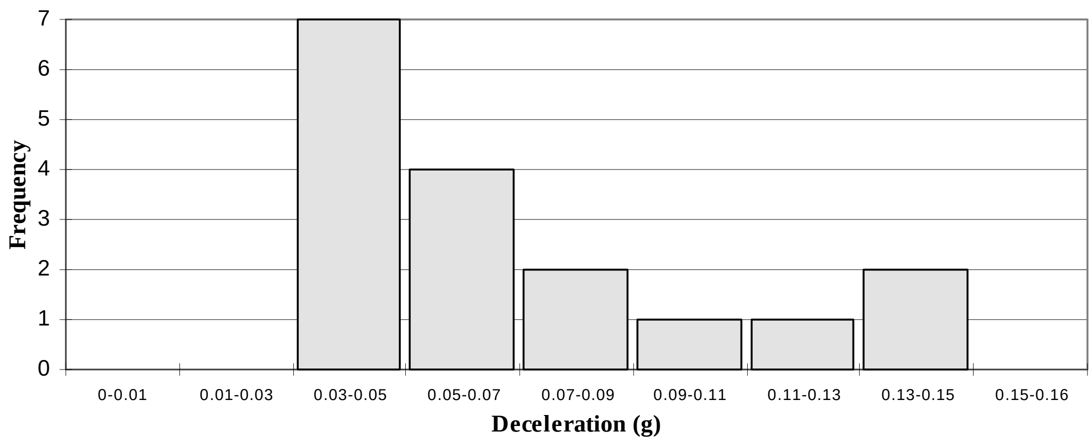


Figure 4-1. Maximum Driver-Controlled Decelerations

Range at Maximum Deceleration

At the time of maximum deceleration, the range to the lead vehicle varied from 336ft to 53ft. The mean range was 179ft and the median was 164ft. Standard deviation for the range was 94ft. Figure 4-2 below portrays a frequency distribution for the eighteen participants for which the data were successfully collected.

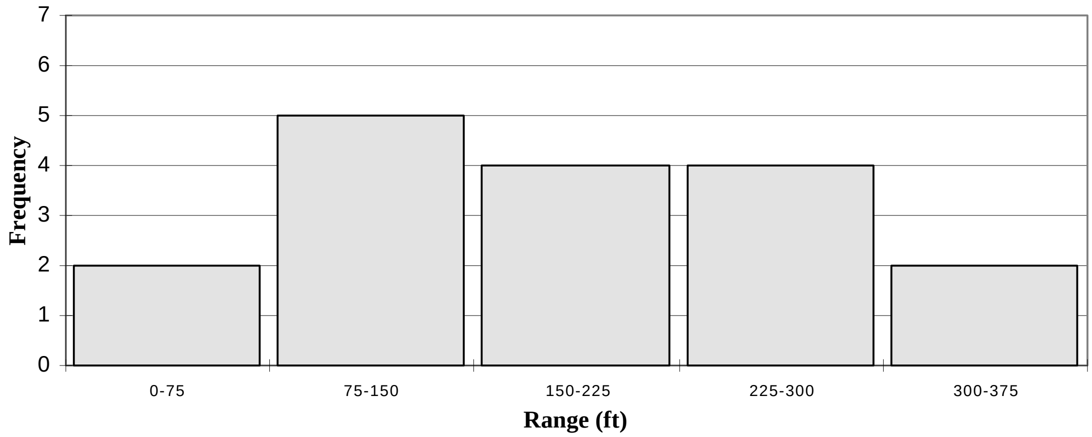


Figure 4-2. Range at Maximum Driver-Controlled Deceleration

An ANOVA investigating the range at which maximum deceleration occurred during the manually-controlled deceleration was performed and generated no significant differences at the α=0.05 level. The ANOVA table can be found in Appendix K.

Scales

Nine scales were used in this study, eight of which were developed and evaluated as semantic differential scales. The ninth scale, Alarming vs. Imperceptible, was included during the study as a lead into future research. This scale was not evaluated for bipolarity prior to its use in the study. Throughout the data analysis, where the scales were evaluated independently, the ninth scale is analyzed similar to the other eight scales. Where the bipolar scales were analyzed as a group, the ninth scale was omitted from the analysis.

Factor analysis was performed on the responses to the eight scales to identify the axes on which participants were evaluating the decelerations and how the scales are related. Principal component analysis and VARIMAX rotation were used to reduce and group the scales into factors, thereby identifying scales that are related and identifying the principle issues, or axes, that are contributing to the evaluation of the profiles. Table 4-1 below indicates the results of the factor analysis and the correlation between scales and factors.

Table 4-1. Factor Analysis Results

Variable	Factor1	Factor2	Factor3	Factor4	Communality
S3 - Safe vs. Unsafe	0.804	-0.317	-0.281	0.3	0.916
S1 - Comfortable vs. Uncomfortable	0.748	-0.435	-0.28	0.323	0.932
S5 - Like me vs. Unlike me	0.714	-0.456	-0.256	0.22	0.832
S6 - Smooth vs. Jerky	0.455	-0.802	-0.143	0.245	0.931
S7 - Soft vs. Hard	0.323	-0.782	-0.253	0.395	0.936
S8 - Natural vs. Unnatural	0.625	-0.661	-0.198	0.196	0.905
S2 - Early vs. Late	0.279	-0.19	-0.923	0.18	0.998
S4 - Good vs. Bad	0.336	-0.347	-0.216	0.843	0.991
Variance	2.6088	2.3462	1.2456	1.2407	7.4413
% Var	0.326	0.293	0.156	0.155	0.93

Scales that are grouped together indicate the tendency of responses on those scales to be in agreement with one another. Scales that are separate after factor analysis indicate that they are considered distinct from the other evaluation scales. From the eight scales, four factors were identified that can be considered separate in the evaluation of the profiles. By looking at the general meaning of the scales that the factors encompass, it is possible to attribute a meaning to the axes that the factors represent. Factor 1 could be described as a well being scale. Factor 2 could be considered to indicate the mechanics of the deceleration. Factor 3 describes the timing of the deceleration, and Factor 4 is an overall evaluative measure.

Preference Ratings

Age

Investigation of differences between the older and younger age groups was performed using a Mann-Whitney test for unrelated samples to compare the eight scale responses between the two groups. In considering all of the profiles, on the Bad vs. Good scale, the older group tended to indicate that the profiles were more towards the bad side than the younger group indicated ($p=0.0065$). Although not significant at the $\alpha=0.05$ level, it is interesting to note that on the Early vs. Late scale, the older group indicated that the profiles were later than indicated by the younger group ($p=0.0597$).

Gender

Investigation of gender differences for all eight of the scales was performed. The following five differences were found at a significance level of $\alpha=0.05$ in the participant response to the scales:

- Females said that profiles were later than the males said they were; Mann-Whitney run on Males vs. Females ($p=0.0016$)

- Males said that profiles were more jerky than the females said they were; Mann-Whitney run on Males vs. Females ($p=0.0016$)

- Males said that profiles were harder than the females said they were; Mann-Whitney run on Males vs. Females ($p=0.0002$)

- Males said that profiles were more unnatural than the females said they were; Mann-Whitney run on Males vs. Females ($p=0.0034$)

- Males said that profiles were more alarming than the females said they were; Mann-Whitney run on Males vs. Females ($p=0.0005$)

Effect of Experience on Ratings

Comparison of scale responses to the first presentation compared to the second presentation of the standard profile was performed. The scale responses from one to seven were first converted to a -3 to +3 scale. Next, for each of the scales, the first evaluation was subtracted from the second evaluation to generate a difference score between the two presentations for each question (e.g., S1R2 - S1R1 = D1, S2R2 - S2R1 = D2, etc). No change between the first and second evaluations would generate a zero difference. A lower score on the second presentation would generate a negative difference, while a higher score on the second presentation would generate a positive difference score. A Wilcoxon Signed Rank test for related samples was performed on the difference score for each of the scales to evaluate whether there was a consistent change from the participant's first evaluations of the standard presentation to his/her second evaluations. In performing this analysis, it is possible to identify changes in the participant's perception or evaluation from the beginning to the end of the experiment. Table 4-2 below lists the p-values for each of the nine scales.

Table 4-2. Comparison of First and Second Standard Profile Responses

Test of median = 0.000000 versus median not = 0.000000						
	Scale	N	N for Test	Wilcoxon Statistic	P	Estimated Median
D1	Comfortable/Uncomfortable	20	17	94.5	0.407	0.5
D2	Early/Late	20	17	113	0.088	0.5
D3	Safe/Unsafe	20	13	29	0.263	-0.5
D4	Bad/Good	20	16	75.5	0.717	0.5
D5	Like me/Unlike me	20	14	63	0.53	0.25
D6	Jerky/Smooth	20	14	64.5	0.47	0.5
D7	Hard/Soft	20	15	49.5	0.57	0.00E+00
D8	Natural/Unnatural	20	14	63.5	0.51	0.5
D9	Alarming/Imperceptible	20	17	89	0.57	0.25

None of the scales showed a significant change in the participants' evaluations at the α=0.05 level. The second scale, Early vs. Late, showed some potential for a change, with a p-value of 0.088. The estimated median indicates a positive 0.5 response. On the Early vs. Late scale, this difference would indicate that the second presentation was rated as earlier than the first presentation.

Scale Evaluation of Profiles

Investigation of the five profiles was performed using a Friedman test for related samples. The Friedman test ranks the response within each subject rather than across the responses of all subjects. The responses for the first and second presentation of each profile were first averaged into one score. A Friedman test was performed to test for differences among all of the five profiles for each scale. This test also generated an estimated median for each profile. Significant differences in responses between profiles were investigated by comparing each profile to each of the other profiles on each scale. The p-values obtained for each of the comparisons may be found in Appendix M.

Comfortable vs. Uncomfortable

Significant differences were found in all of the comparisons except for where Profile 3 was compared to Profile 4. Figure 4-3 below provides the estimated median response values for each of the profiles as calculated in the Friedman test comparing all five profiles. Median values that are bridged by a solid line in the figure cannot be distinguished from one another at the α=0.05 level based on the participant responses.

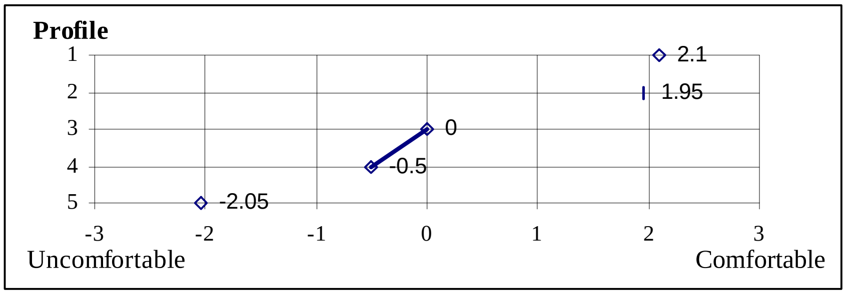


Figure 4-3. Profile Comparison - Comfortable vs. Uncomfortable

Profile 1 and Profile 2 were described as comfortable, with Profile 1 being slightly more comfortable. Profile 3 is neither comfortable nor uncomfortable. Profile 4 is more comfortable than Profile 5, and less comfortable than Profiles 1 and 2. Profile 5 decelerations are considered uncomfortable.

Early vs. Late

Comparison of the deceleration profiles using the Early vs. Late scale (Figure 4-4) indicated differences between all of the profiles except where Profile 2 was compared to Profile 3. Profile 1 is considered slightly early. Profile 2 is closer to the line, neither early nor late. Profile 3 is considered slightly late. Profile 4 is more late than the lower number profiles, and Profile 5 is considered the latest of all of the decelerations.

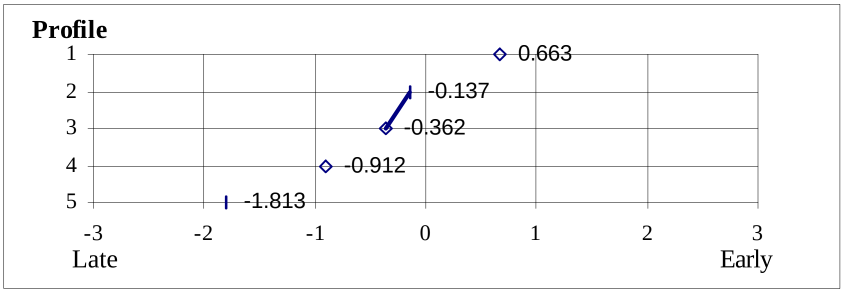


Figure 4-4. Profile Comparison - Early vs. Late

Safe vs. Unsafe

In the comparison of the decelerations using the Safe vs. Unsafe scales (Figure 4-5), all of the comparisons showed significant differences except when comparing Profile 3 and Profile 4. Profiles 1 and 2 were perceived as being safe. Responses indicated that Profile 3 seemed neither safe nor unsafe. Profile 4 was perceived as slightly unsafe, while Profile 5 was perceived as unsafe.

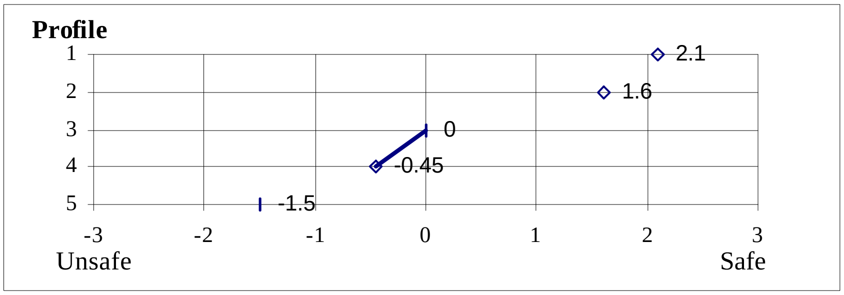


Figure 4-5. Profile Comparison - Safe vs. Unsafe

Good vs. Bad

Profile 1 and Profile 2 could not be distinguished by the responses to the Good vs. Bad scale (Figure 4-6). Similarly, Profile 3 and Profile 4 showed no significant differences in the responses on the scale. In comparisons to other profiles, Profiles 1 and 2 both tended to be evaluated as on the good side of the scale. Profile 5 was considered the worst of the five profiles. Profile 3 and Profile 4 were also on the bad side of the scale.

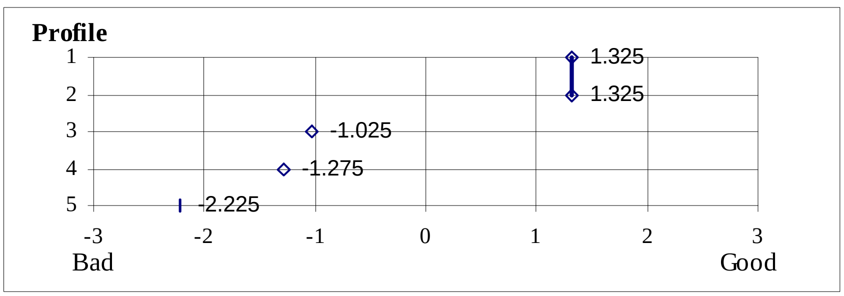


Figure 4-6. Profile Comparison - Good vs. Bad

Like Me vs. Unlike Me

In the analysis of the participant reports of whether the automatic deceleration of the ACC vehicle was like their own deceleration (Figure 4-7), Profiles 1 and 2 and Profiles 3 and 4 could not be distinguished from each other. Profile 5 was reported the least similar to how the participants would perform the deceleration. Both Profile 1 and Profile 2 were considered more like the participants would decelerate than Profiles 3, 4, and 5.

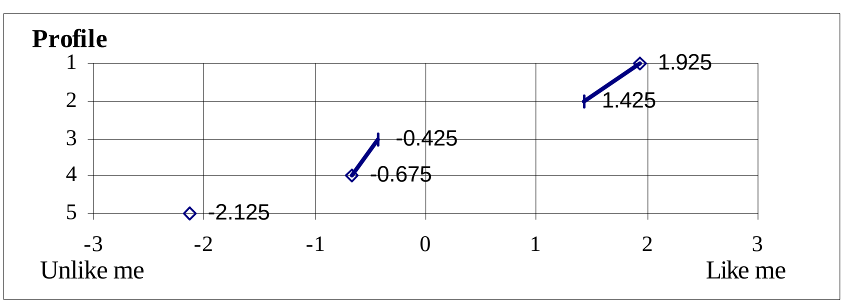


Figure 4-7. Profile Comparison - Like Me vs. Unlike Me

Smooth vs. Jerky

Comparison of the profiles using the Smooth vs. Jerky scale (Figure 4-8) indicated differences in each of the comparisons except Profile 3 versus Profile 4. Profile 1 was considered the smoothest of the profiles. Profile 2 was also considered smooth. Profiles 3 and 4 were considered somewhat jerky, while Profile 5 was considered the most jerky.

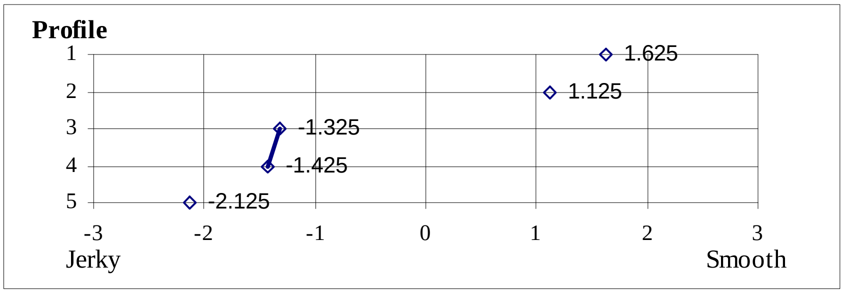


Figure 4-8. Profile Comparison - Smooth vs. Jerky

Soft vs. Hard

Profile 3 and Profile 4 showed no significant differences when evaluated on a Soft vs. Hard scale (Figure 4-9). Comparisons of the other scales showed significant differences. Profile 1 was considered the most soft of the profiles. Profile 2 was also considered soft, but less so than Profile 1. Profiles 3, 4, and 5 were considered hard, with Profile 5 being the hardest of all the decelerations.

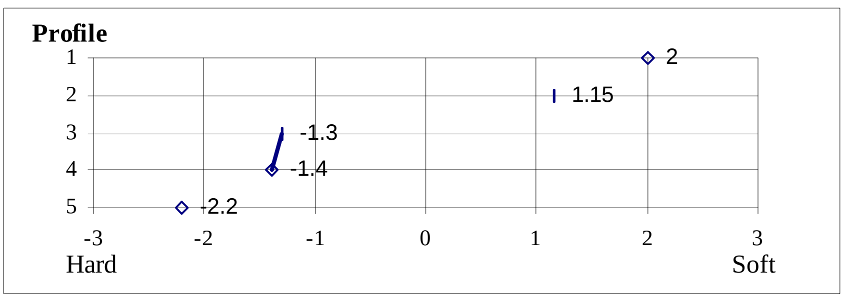


Figure 4-9. Profile Comparison - Hard vs. Soft

Natural vs. Unnatural

On the Natural vs. Unnatural scale (Figure 4-10), comparisons of the profiles all indicated differences except Profile 3 compared to Profile 4. Profiles 1 and 2 were considered natural, with Profile 1 being slightly more natural. Profile 3 and Profile 4 were considered somewhat unnatural, while Profile 5 was considered the most unnatural of the profiles.

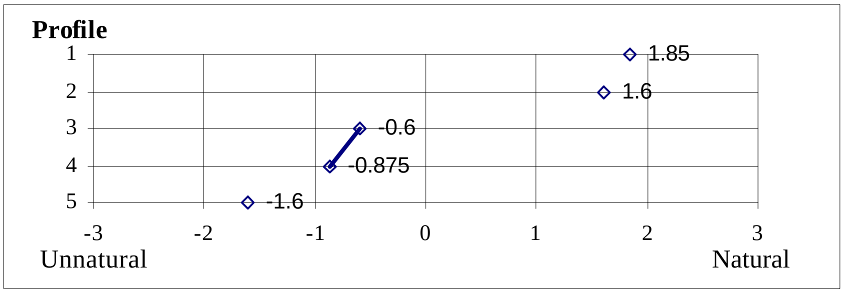


Figure 4-10. Profile Comparison - Natural vs. Unnatural

Imperceptible vs. Alarming

In considering the decelerations as ranging from alarming towards imperceptible (Figure 4-11), responses indicated differences between all of the profiles except Profile 3 and Profile 4. None of the profiles were described as imperceptible. Profiles 1 and 2 were identified as being towards the imperceptible side of the scale. Profiles 3, 4, and 5 are considered somewhat alarming.

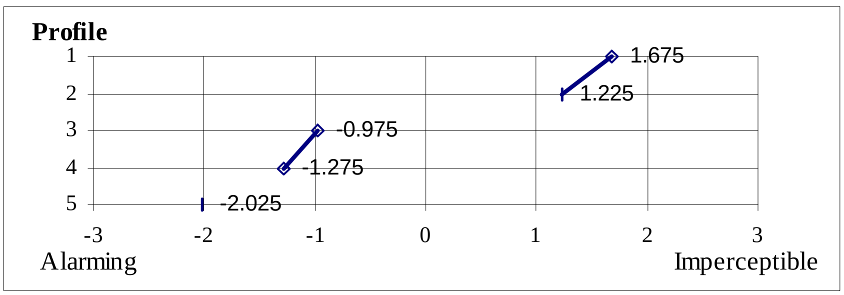


Figure 4-11. Profile Comparison - Imperceptible vs. Alarming

Individual Deceleration Preference

Identification of the most preferred profile for each participant was accomplished using a combination of the participant responses on the Good vs. Bad, Comfortable vs. Uncomfortable, and Early vs. Late semantic scales. These three scales were selected to cover three of the four dimensions on which evaluations were made, as discussed previously. The fourth dimension, referred to as the "Mechanics" dimension, could not be attributed to preference for all subjects. For example, one individual might prefer a hard, distinct deceleration, whereas another might desire a soft deceleration. Once the scores were adjusted to the +3 to -3 scale, the rating for each trial on the Good vs. Bad (S4) and Comfortable vs. Uncomfortable (S1) scales were summed and the absolute value of the Early vs. Late (S2) rating was subtracted. This generated a sum for each trial. The most preferred trial was the trial with the greatest number. If two trials tied for the greatest sum and they were both the same profile, that profile was selected as the participant's most preferred. If two sums were tied as the highest and they included more than one profile, both profiles were recorded as most preferred. An example is provided in Table 4-3 below. In this example, Profile 1 and Profile 2 tied with a value of 4. If the second presentation of Profile 1 had also summed to 4, it would have been selected solely as the most preferred profile.

Table 4-3. Individual Preference Example

	S1 +	S4 -	|S2|	= Sum	
Profile	S1	S4	S2	Sum	
1	2	2	0	4	Preferred
1	2	2	1	3	
2	2	2	0	4	Preferred
2	2	2	1	3	
3	0	1	0	1	
3	0	0	-1	-1	
4	-1	1	0	0	
4	-1	-1	-1	-3	
5	-1	1	-1	-1	
5	-1	-1	-1	-3	

Using this method, ten individuals (50%) selected Profile 1 as their most preferred. Seven individuals (35%) selected Profile 2 as their most preferred. Two individuals (10%) had a two-way tie between Profile 1 and Profile 2. One individual (5%) had a three-way tie between Profiles 1, 3, and 4. A Wilcoxon signed rank test indicates that the greater number of individuals selecting Profile 1 as their most preferred is not an adequate majority to indicate Profile 1 as most preferred of these two profiles (p=0.538).

Preference and Gender

Investigation of the most preferred profile by gender was performed using the Mann-Whitney non-parametric test for unrelated samples. Individuals with ties for most preferred profile were dropped from the calculation, leaving seven females and ten males in the analysis. Comparison of the most preferred profile for males vs. the most preferred profile for females indicated no significant differences in preference between the groups (p=0.3121).

Preference and Age

A Mann-Whitney non-parametric test was also performed to investigate age differences in preference. Ties between profiles were again dropped from the analysis, leaving nine individuals in the older group and eight individuals in the younger group. No significant difference was found between the older and younger age groups for the preferred profile (p=0.2449).

Preferred Profile vs. Manual Deceleration Behavior

Each individual had the opportunity to evaluate the five profiles twice. Not including the standard profile, this generated ten decelerations in the car which were evaluated by the individual. In the Individual Deceleration Preferences section, the method for identifying which of these ten decelerations were most preferred by the participant was described. Once the deceleration was found, it can be described by both the commanded profile number, such as 1 through 5, or using the actual measured characteristics of that specific deceleration. Having identified the most preferred profiles for each individual, it was possible to use both the measured deceleration data for investigating the relationship between the participant's most preferred ACC deceleration profile and his/her own manual deceleration behavior.

First, the commanded profiles were investigated. A correlation was run between the preferred ACC-controlled deceleration profile for each individual and his/her own maximum deceleration during his/her manual deceleration behind the lead vehicle. In this analysis, the nominal value (i.e., 1-5) for the commanded profile preferred was used. Tied values and individuals with data missing for the manual deceleration were eliminated from the calculations, leaving fifteen pairs for calculation of a correlation. At an α=0.05 level, the correlation was not significant (r=-0.102). Similar evaluation was performed of the individual's preferred ACC-controlled deceleration and the range at which maximum deceleration occurred during the driver's manual deceleration. This correlation (r=0.212) was also not significant at the α=0.05 level.

Next, the actual deceleration values were used. Two evaluations were performed using the actual measured maximum deceleration and range at maximum deceleration of the most preferred deceleration rather than the nominal value. For example, rather than correlating a 2 for Profile 2 with the maximum deceleration during manual deceleration, the actual maximum deceleration of the participant's most preferred deceleration was used. If the participant's most preferred profile had an actual deceleration of 0.08 at a range of 260ft due to variability in the vehicle, this actual value was related to the level of deceleration and range in the individual's manual deceleration. In this correlation, where more than one deceleration tied for the participant's most preferred, the measured values for the two (or more) decelerations were averaged. These values, both for maximum deceleration and range at maximum deceleration, were then correlated with the values of the participant's own manual deceleration. The correlation between the individual's maximum deceleration during manual control and maximum deceleration of the preferred ACC-controlled deceleration was r=-0.077. The correlation between the individual's range at maximum deceleration during manual control and range at maximum deceleration of the preferred ACC-controlled deceleration was r=0.112. Both of these values were calculated using eighteen pairs and were not significant.

Intervention Response Behavior

Video and braking data were investigated for the braking scenario. For one of the participants, incorrect system settings generated a unique response by the vehicle, so his data are not included in this summary. In general, as the ACC vehicle approached the lead vehicle, the participant would be driving with his/her foot at some location removed from the brake pedal. In general, participants began with their brake foot in a "rest" position, which ranged from being near the accelerator pedal to being near the front of their seat. As the ACC car closed on the lead vehicle, some participants responded by moving towards the brake and covering it, while others moved directly to applying the brake. Of the nineteen participants, two never applied the brakes during the brake intervention scenario. All but one of the seventeen who intervened solely used braking as a response. One of the seventeen employed steering as well as braking to respond to the scenario. This subject steered around the lead vehicle by changing into the left lane. Details of the behaviors are provided below.

Description of the Data

For the nineteen subjects who had useable data, four pieces of time information related to their response behavior were collected from the video:

1) Time at which the participant moved his/her foot from a rest position towards the brake pedal
2) Time and duration of any pauses in motion
3) Time of maximum brake pedal deflection
4) Time when the participant began releasing the brake pedal (pedal return motion)

For the subjects who activated the brake, two pieces of time information related to their activation of the brake pedal were identified from the electronic data:

1) Time at which the participant activated the brake pedal
2) Time when the participant removed his/her foot from the brake pedal.

Each of these times were used in combination with the electronic data to identify vehicle information surrounding the instance including velocity, range to the lead vehicle, range rate to the lead vehicle, deceleration of the ACC vehicle, and TTC. Additionally, the times were used to calculate duration of events. A summary table of the data for each of the twenty participants can be found in Appendix K.

Figure 4-12 below presents a graphical summary of one participant's behavior during intervention, and provides an example of the behavior of the ACC car and interaction of the two vehicles during the scenario. The information obtained is from the electronic data surrounding the application of the brake. From the top plot to the bottom, the line on the plots portrays the ACC vehicle's velocity and deceleration, range to the lead vehicle, and range rate between the two vehicles. Time in seconds is shown horizontally. Initially, in the velocity plot, one can see the ACC vehicle maintaining a speed of 70mph. ACC-controlled deceleration can be identified where the velocity begins slowing from 70mph. At this point, in the deceleration plot, the level of ACC deceleration can be identified (e.g., approximately 0.05g in this figure). By identifying this same time on the lower plots, the range and range rate at this instance can also be identified. The asterisk indicates the maximum point of the ACC-controlled deceleration (e.g, 0.05g in this example). The "X" on the plot indicates the point where the driver activated the brake pedal. On all four plots, the trace to the right of the "X" is driver-controlled deceleration. The "+" symbol denotes the peak of the driver-controlled deceleration, which is 0.32g in this example. Termination of the trace indicates the point at which the driver released the brake pedal.

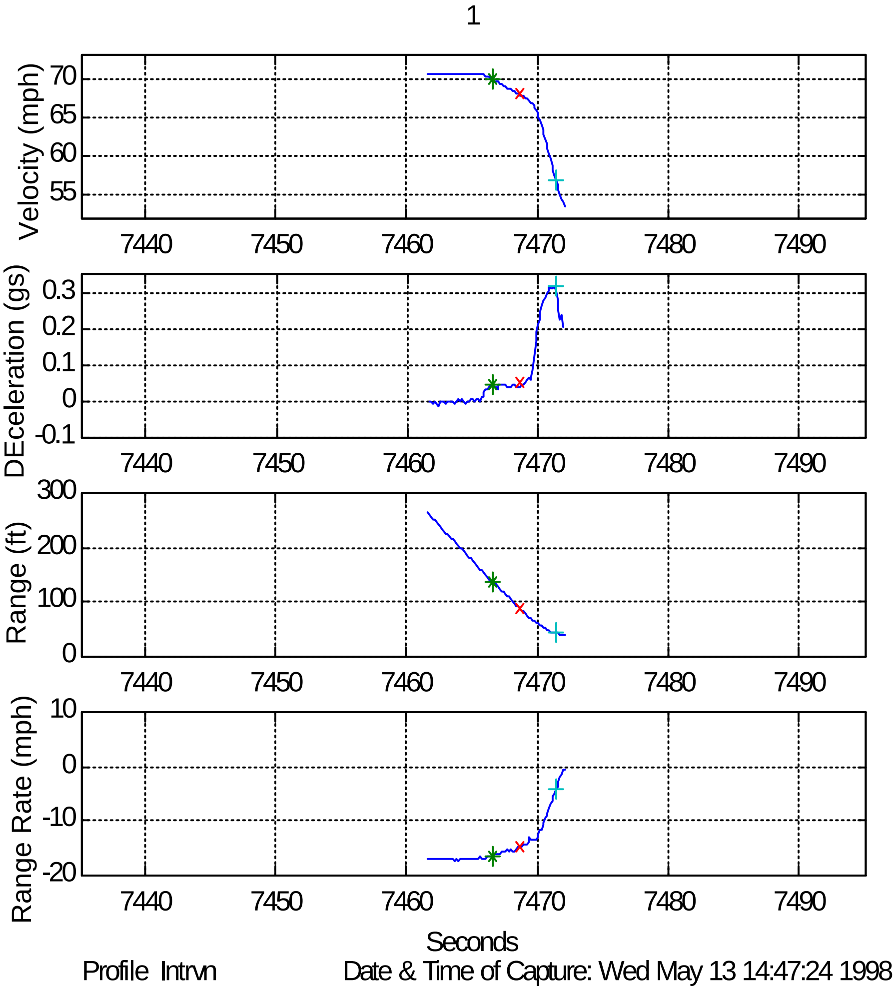


Figure 4-12. Intervention Plots

The following numerical data were identified during each of the ACC-controlled decelerations:

```
t of Max Decel = 7466.53 seconds
Max Decel = 0.05 g
Velocity at Max Decel = 69.91 mph
Range at Max Decel = 137.64 ft
Range Rate at Max Decel = -16.33 mph
```

The following information regarding the driver's intervention (i.e., pressing the brake) was also collected:

```
Brake pressed at 7468.62 s.  Brake released at 7472.10 s
Time span = 3.49 s
TTC at Intervention = -4.07
Intervention: Decel at Intervention = 0.04 g
Intervention: Velocity at Intervention = 67.93 mph
Intervention: Range at Intervention = 88.95 ft
Intervention: Range Rate at Intervention = -14.54 mph
Intervention: t of Max Decel = 7471.41 seconds
Intervention: Max Decel = 0.32 g
Intervention: Velocity at Max Decel = 56.86 mph
Intervention: Range at Max Decel = 42.85 ft
Intervention: Range Rate at Max Decel = -4.25 mph
Max Brake Pressure = 44
Max Brake Pressure t = 2.8 s
```

Resting Foot Position

Foot position or rest position prior to response was approximated from the video as described in the Methods section. The distance is measured from the ball of the right foot to a position directly below the right edge of the brake pedal. Figure 4-13 below presents a frequency distribution of the horizontal distance in inches, or rest distance, prior to response.

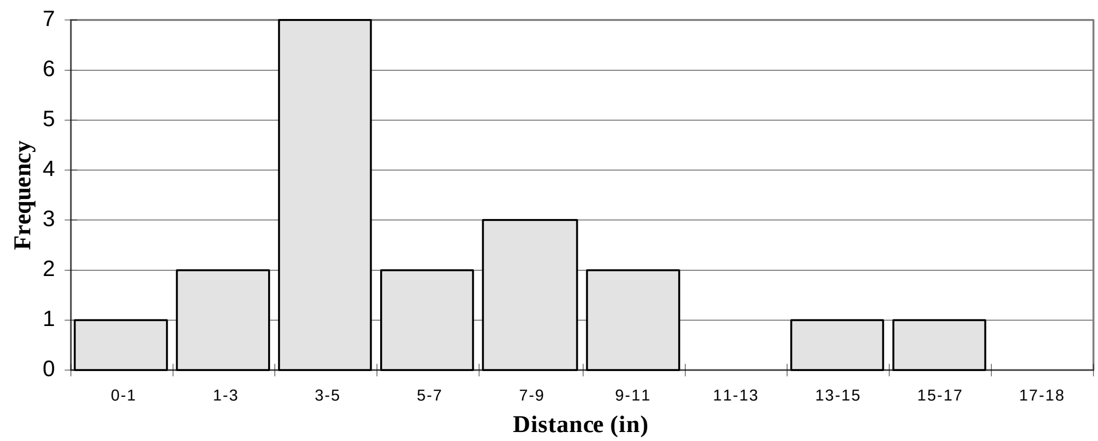


Figure 4-13. Resting Foot Distance to Brake

Actual distribution of foot rest positions is portrayed in Figure 4-14 below. The foot position prior to movement during the intervention scenario is represented by a circle in the figure.

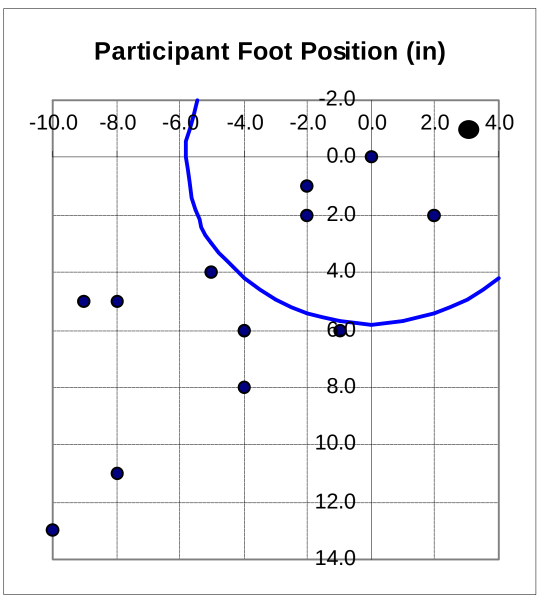


Figure 4-14. Resting Foot Positions

The right corner of the brake pedal is shown as the origin of the coordinate system. Horizontal position shows left to right foot position, with -10in being near the driver's door.

Fore-aft foot position is shown vertically, with 14in being near the front of the driver's seat. The image in Figure 4-15 is taken from the video and illustrates the resting position at -10in, 13in.

Figure 4-15. Distant Foot Position

In Figure 4-14, the circle at position 3in, -1in maps to the accelerator pedal position. This point represents the foot positions of seven different participants as described further below. A video frame representing this foot position is shown in Figure 4-16.

Figure 4-16. Accelerator Foot Position

Following engagement of ACC, during the initial approach to the lead vehicle, twelve individuals placed their foot somewhere in the floor area. The posture of the foot in these instances included being flat on the floor, rotated to rest on the outside of the foot, and resting in some position behind the left foot. Seven individuals maintained a position covering the accelerator pedal with the heal of the foot planted. Nine individuals rested the foot at a distance further than the accelerator pedal. Four rested the foot at a distance closer than the accelerator position. Horizontal distances from the foot to the brake pedal ranged from 0in to 16.4in. The mean distance prior to response was 5.8in and the median was 3.2in, which is the approximate distance when the foot is over the accelerator pedal. Standard deviation was 4.2in.

A balanced ANOVA performed on the resting position for all twenty subjects showed no significant differences (see Appendix L) for Age, Gender, or Age X Gender interaction.

Foot Movement Before Brake Activation

Although two of the participants never intervened by pressing the brake pedal, all participants exhibited a response to the approach situation. Of the nineteen correct presentations, fifteen of the participants (79%) moved to and maintained a "covering" position over the brake for some period of time before final motion terminating in brake activation. For the purposes of this investigation, "covering" is defined as maintaining a foot position that permits activation of the brake without significant side-to-side translation or rotation of the foot. The video frame in Figure 4-17 is representative of a covering position used prior to activation of the brake.

Figure 4-17. Covering Foot Position

Distance from the brake pedal during this pause is not considered. One individual paused twice while moving toward the brake, both pauses without her foot covering the brake pedal. This individual's final movement was directly toward the brake pedal. Three of the nineteen participants (15.8%) moved directly from a resting position to activation of the brake with no visible pause in motion. Four of the individuals (21.1%) paused at a closer intermediate position between their rest position and either applying or covering the brake.

Conditions at Initiation of Response

Time-to-collision at the time of motion from a rest position towards the brake pedal is presented in Figure 4-18.

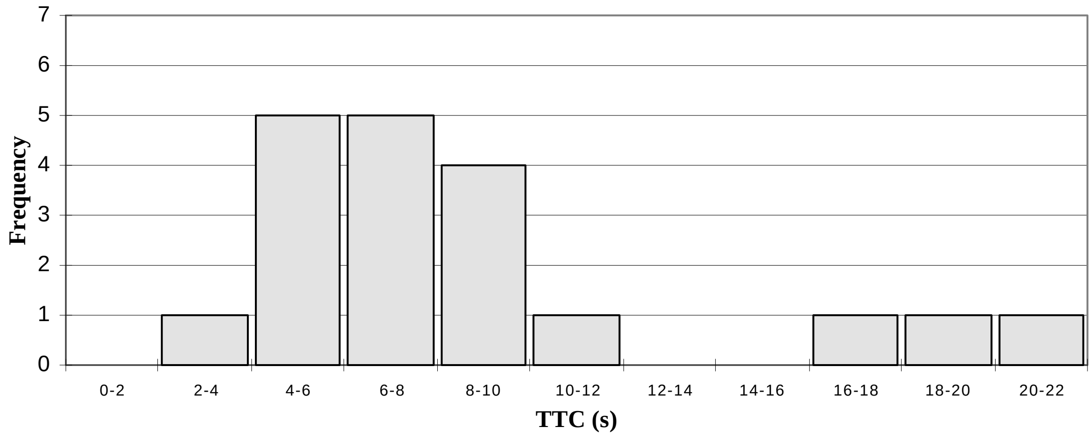


Figure 4-18. Time-to-Collision at Start of Movement

The earliest movement from rest occurred at a TTC of 21.12s. The latest response was at a TTC of 3.97s. The mean initiation of response was at 8.7s and the median was 7.4s. Standard deviation for TTC at time of movement from a rest position was 5.1s. Thirteen of the individuals moved from a rest position to a position closer to the brake pedal prior to any ACC braking. These individuals comprise the movements that occurred at 6.7s TTC and 152ft or greater. The remaining six individuals began movement at some time after ACC braking had begun at a level between 0.03g and 0.05g. These individuals represent the responses occurring at 5.2s TTC and 109ft or less. No significant differences (α=0.05) were found in the TTC at the time the participants moved from a rest position toward the brake pedal (see Appendix L).

Looking at this same data in terms of headway, the earliest response occurred at 4.9s headway and the latest occurred at 0.8s headway. At the time of response, the mean headway for nineteen participants was 1.9s and the median was 1.6s. The standard deviation was 1.1s.

Foot Movement Time

A frequency distribution of the time interval between beginning motion and activation of the brake pedal is presented in Figure 4-19.

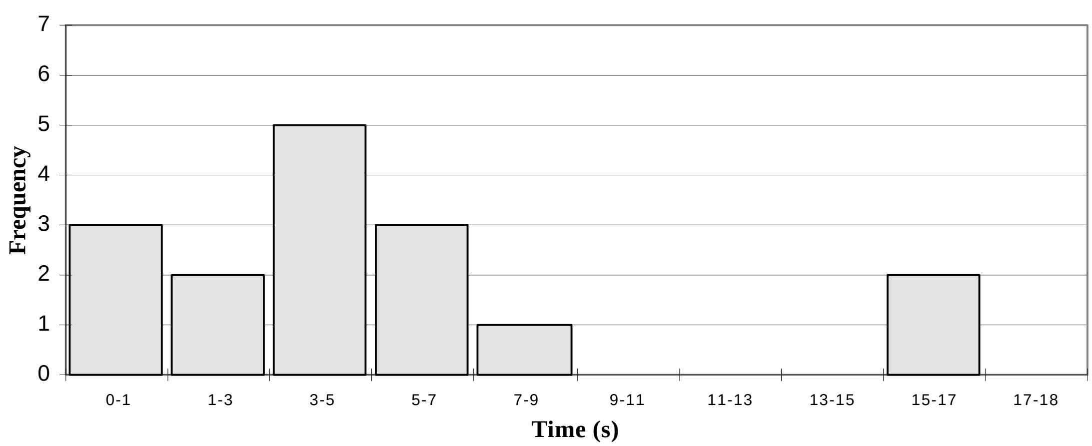


Figure 4-19. Rest Position to Brake Pedal Motion Time

Movement from a rest position ranged in time from 0.8s to 16.1s prior to contacting the brake pedal. Mean time was 4.6s and the median was 3.9s.

Investigation of the relationship between the resting distance and the time at which the driver began his/her response is summarized in Figure 4-20.

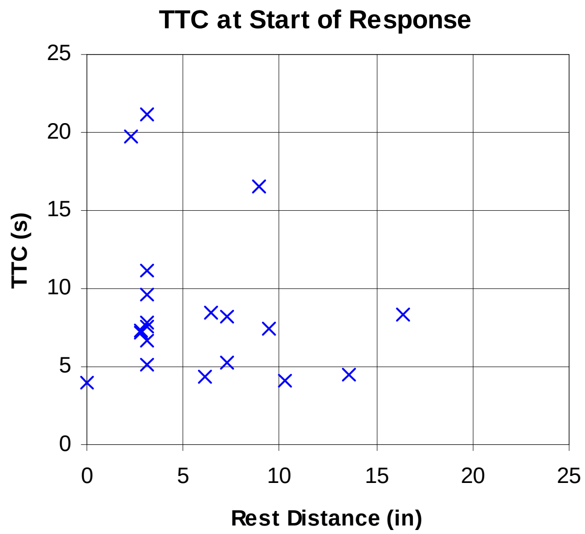


Figure 4-20. TTC at Start of Response vs. Resting Distance

TTC is shown in seconds plotted against the distance of the foot from the brake pedal at the initiation of the response movement.

Covering Behavior

The fifteen subjects who covered the brake included the two individuals who never intervened. Times for covering the brake were calculated from the point in time at which motion stopped in a position over the brake pedal to the point in time where motion began that terminated in brake activation. Figure 4-21 below presents the times of the thirteen individuals who were found to cover the brake pedal and subsequently activate the brake pedal.

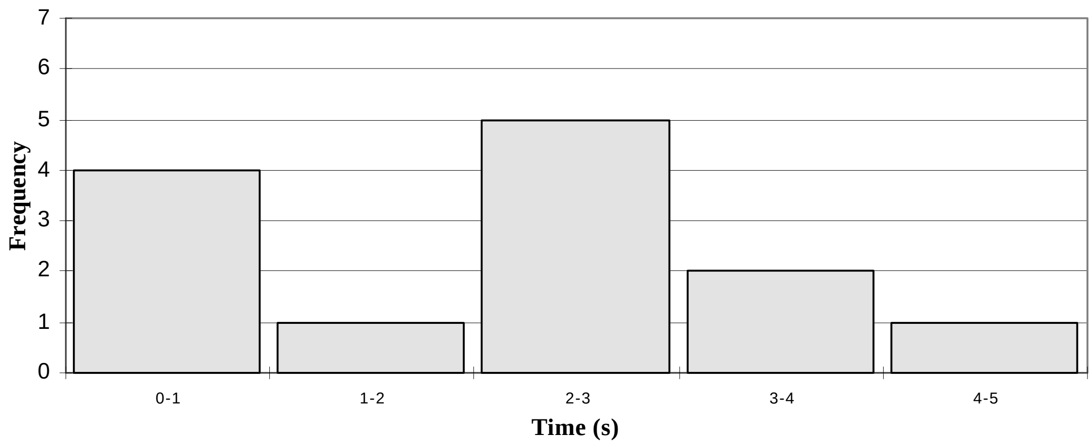


Figure 4-21. Time in Covering Position

The time spent with the foot in a brake covering position ranged from a minimum of 0.4s to a maximum of 4.8s. The mean time covering the brake was 2.1s and the median time was 2.3s.

Intervention

When considering the group of subjects as a whole, the TTC at the time of intervention (Figure 4-22) for participants who intervened ranged from 3.7s to 6.1s. The two individuals who did not intervene are not included in this analysis. The mean TTC at intervention was 4.4s and the median was 4.2s. The standard deviation was 0.7s.

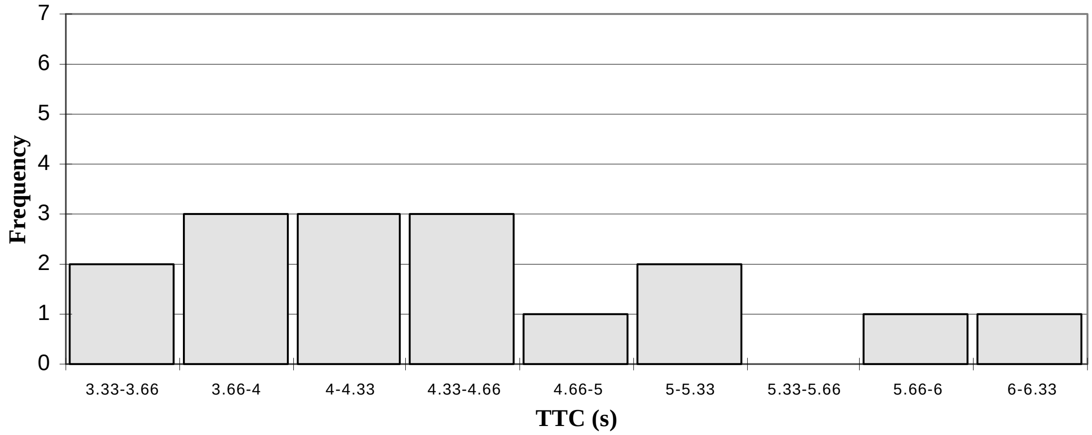


Figure 4-22. Time-to-Collision at Intervention

An ANOVA performed on the TTC at intervention showed a significant difference (p=0.050) between the older and younger age groups. The ANOVA table is shown in Table 4-4.

Table 4-4. ANOVA - Time-to-Collision at Intervention

Analysis of Variance for IntvTTC

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Age	1	2.0621	2.0032	2.0032	4.66	0.050*
Gender	1	0.0663	0.0828	0.0828	0.19	0.668
Age*Gender	1	0.3414	0.3414	0.3414	0.79	0.389
Error	13	5.5835	5.5835	0.4295		
Total	16	8.0533				

The mean TTC at the time of pressing the brake was 4.1s for the older age group with a 0.4s standard deviation. For the younger age group, the mean TTC was 4.8s with a standard deviation of 0.8s.

The headway for the interventions for the group of participants ranged from a minimum of 0.7s to a maximum of 1.3s. The mean and median headways at the time of intervention were 0.9s. The standard deviation for headway was 0.2s. Figure 4-23 below presents the frequency distribution for headway at intervention.

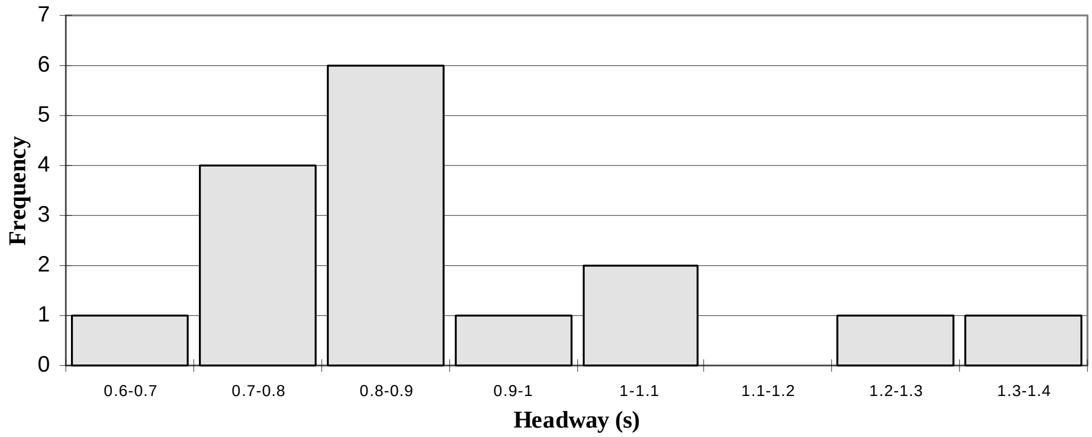


Figure 4-23. Headway at Intervention

Investigation of the two age groups and two gender groups using an ANOVA again identified differences between the age groups (p=0.016). The ANOVA table for age is shown in Table 4-5.

Table 4-5. ANOVA - Headway at Intervention

Analysis of Variance for IntvHDW

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Age	1	0.20318	0.19736	0.19736	7.59	0.016*
Gender	1	0.00129	0.00186	0.00186	0.07	0.793
Age*Gender	1	0.01862	0.01862	0.01862	0.72	0.413
Error	13	0.33793	0.33793	0.02599		
Total	16	0.56102				

The mean headway at the time of intervention was 0.8s for the older age group with a standard deviation of 0.1s. The mean headway at the time of intervention for the younger age group was 1.0s with a standard deviation of 0.2s.

Driver-Controlled Deceleration After Intervention

After taking over control of the vehicle's deceleration, driver intervention deceleration ranged from 0.16g to 0.32g. The mean deceleration was 0.24g and the median was 0.24g. Standard deviation was 0.05g. The frequency distribution in Figure 4-24 portrays the deceleration levels identified for the seventeen participants who intervened.

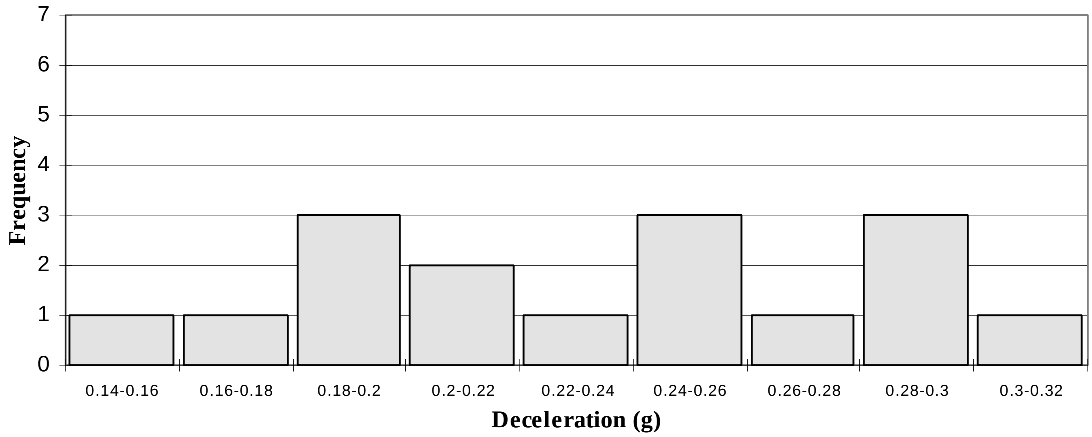


Figure 4-24. Maximum Deceleration During Driver Intervention

An ANOVA performed on the maximum driver-controlled deceleration after intervention showed no significant differences between groups (see Appendix L).

During the driver-controlled deceleration after intervention, the peak decelerations occurred between the ranges of 106ft and 34ft. The median of the decelerations was a range of 49.8ft. Figure 4-25 below provides a frequency distribution for the range at which maximum deceleration occurred.

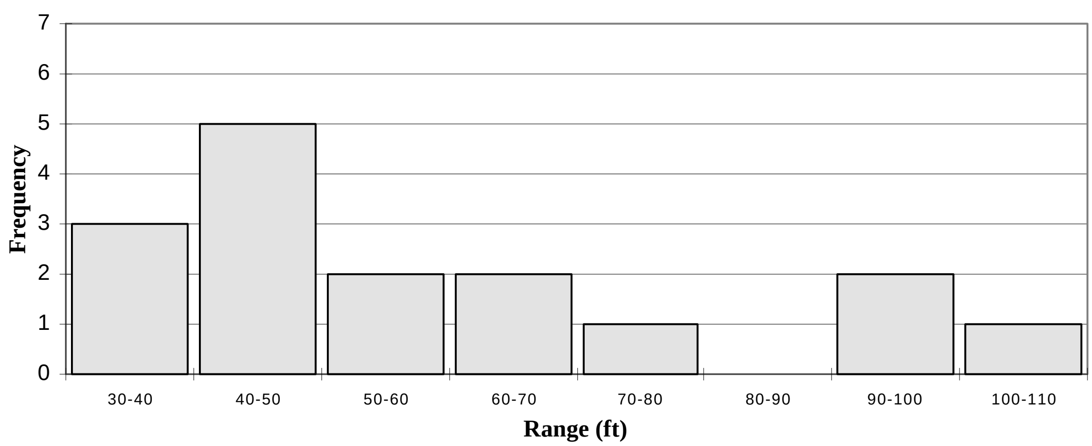


Figure 4-25. Range at Maximum Deceleration During Driver Intervention

An ANOVA performed on the range at maximum driver-controlled deceleration after intervention showed no significant differences between groups (see Appendix L).

For each of the intervention scenarios, the minimum TTC was also identified. Minimum TTCs during the approach to the lead vehicle ranged from 5.9s to 2.3s. The mean minimum TTC was 3.9s with a standard deviation of 0.9s. The median value was 3.6s. Figure 4-26 below presents the distribution of minimum TTC values that occurred during the intervention trials.

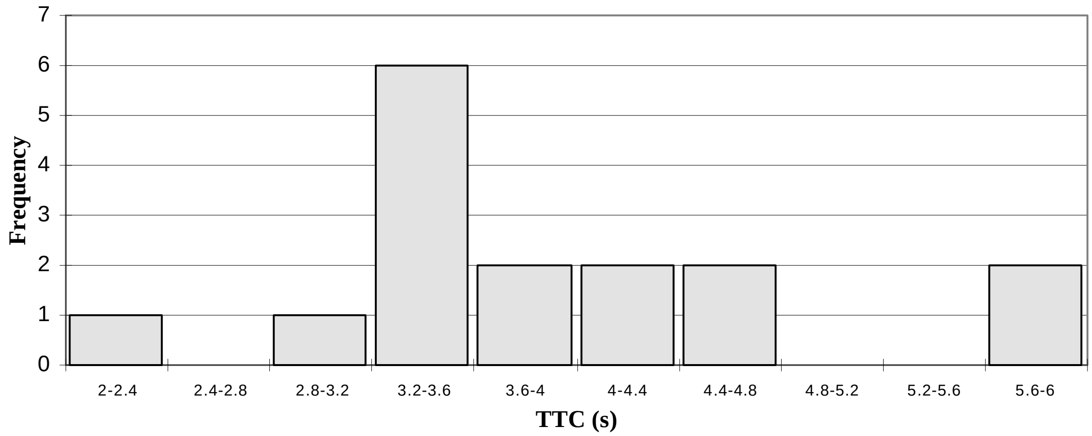


Figure 4-26. Minimum TTC During Intervention

An ANOVA conducted on the minimum TTC that drivers obtained while approaching the lead vehicle showed no significant differences between the groups (see Appendix L).

The time at which this peak TTC occurred was compared to the time at which the maximum deceleration occurred. In Figure 4-27, the velocity, deceleration, and TTC as the driver applies the brakes are plotted. The minimum TTC, shown in the bottom plot, occurred at 8855.3s. The driver's peak deceleration in this case occurred 1.0s later at 8856.3s, as shown in the middle plot. The difference between these to values provides the time separation between the time where the TTC switches from decreasing to increasing, to where the driver reduced the amount of deceleration.

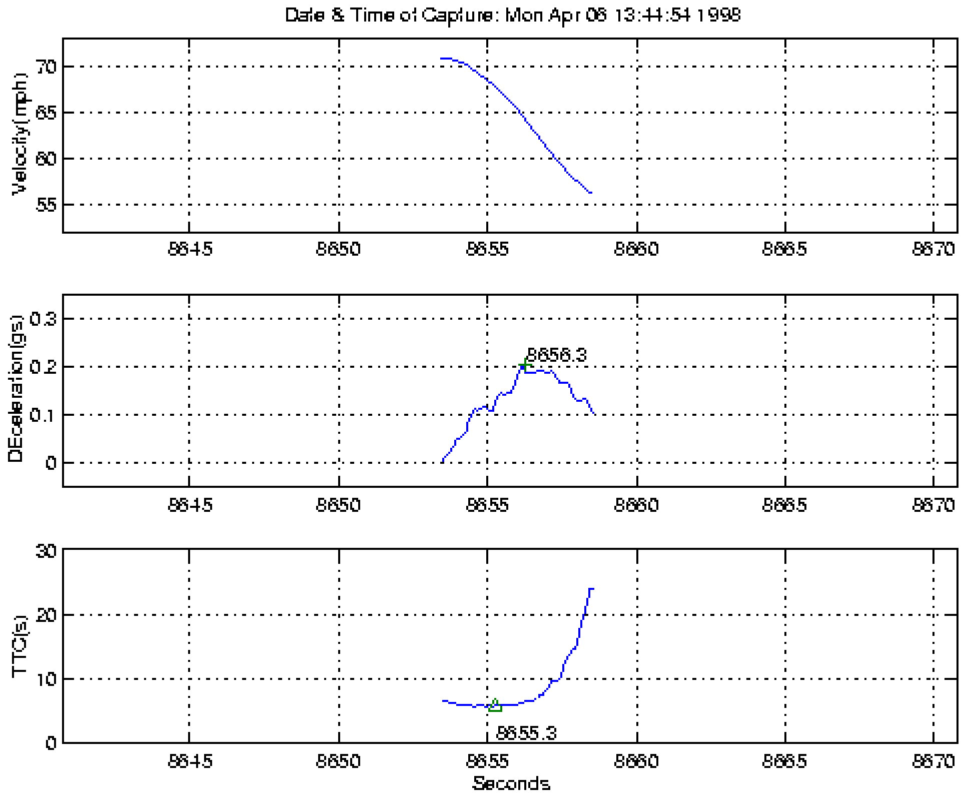


Figure 4-27. Separation Between Minimum TTC and Peak Deceleration

The minimum TTC occurred from 2.7s to 0.1s before the peak driver-controlled deceleration. Figure 8-28 below describes the distribution of these time differences.

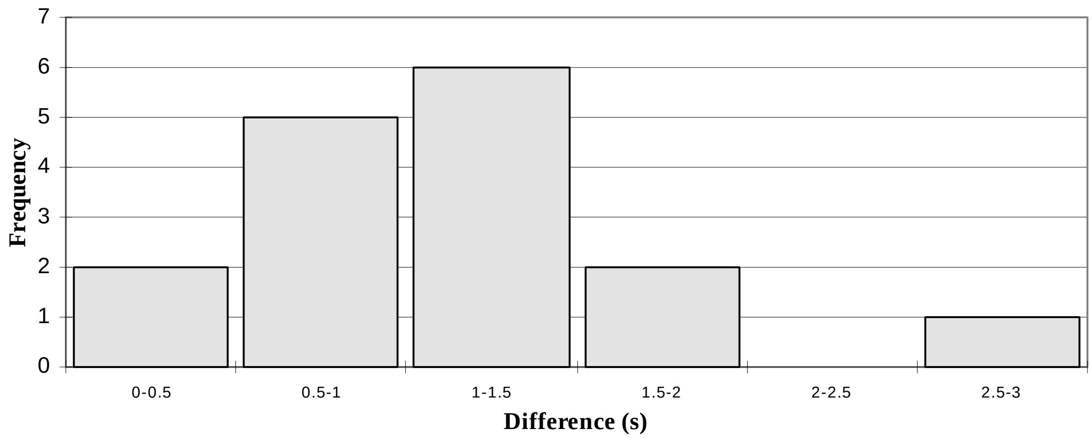


Figure 4-28. Time Separation Between Minimum TTC and Peak Deceleration

The mean separation between the two values was 1.1s with a standard deviation of 0.63s. The median was 1.0s. An ANOVA performed on the time separation between the minimum TTC and the peak deceleration showed no significant differences between groups (see Appendix L).

Chapter 5 - Conclusions

Responses to Research Questions - Preference

The following section presents the three research questions proposed in the Introduction regarding driver preference. Sub-sections under the questions provide supplementary findings related to the research question.

How do drivers want the vehicle to decelerate behind a slower lead vehicle?

Of the five deceleration profiles presented to participants in this study, Profile 1, which decelerated the vehicle at approximately 0.06g and had a maximum deceleration approximately 300ft behind the lead vehicle, and Profile 2, which had decelerations between 0.06 and 0.14g and which occurred between 145ft and 220ft behind the lead vehicle, were the most preferred. It is inconclusive which of these two profiles is most preferred. No differences were found for the different groups as to a most preferred profile.

Response Scales

Following the experiment, it was possible to reduce the eight scales used to a set of four factors. The scales for Safe vs. Unsafe, Comfortable vs. Uncomfortable, and Like Me vs. Unlike Me grouped together into a factor. This factor can be considered to describe the general well being that an individual perceives in the vehicle performance. A second factor was composed of the scales Jerky vs. Smooth, Hard vs. Soft, and Natural vs. Unnatural. These scales seem to make up a general description of the mechanics of the deceleration. The Early vs. Late scale remained separate and can be considered to describe the overall timing of the deceleration. Finally, the Good vs. Bad scale also remained separate and might be understood as an independent evaluative factor. Having evaluated the components of drivers' evaluations, it is now feasible to reduce the number of scales, thereby increasing efficiency in data collection without loss of information.

Discussion of Profiles

Profile 1 was considered the most comfortable, most safe, most good, most like people would perform a deceleration, smoothest, softest, and most natural of the profiles. Profile 1 was also considered as occurring slightly early. This suggests that when transitioning from a cruise state with a set speed of 70mph to a follow state behind a slower lead vehicle traveling at 55mph, participants prefer a deceleration level of approximately 0.06g.

Profile 2 followed the same scale directions as Profile 1, but generated slightly more moderate responses on most scales. Profile 2 was considered neither early nor late. Based on this information, levels of deceleration of approximately 0.06g, occurring at a range more similar to the 140ft to 240ft of Profile 2 and Profile 3, may be acceptable to drivers.

Profile 1 and Profile 2 were considered safe. Profile 3 was perceived as neither safe nor unsafe. Based on this information, decelerations of 0.06g between ranges of 350ft to 250ft are perceived as safe by the drivers in this study.

Preference - All Profiles Combined

Consideration of all the profiles combined may be valuable as an indicator of the preference for the system as a whole or the aspects of the ACC system of which people are most critical, and conversely where the most return on improvements might be realized. The 40-50-year age group indicated that the ACC decelerations in general were worse (i.e, more bad) than the 21-30-year age group indicated. The males in this study indicated that the profiles in general were worse on the scales that compose the Mechanics factor. That is to say, males indicated that in general, the profiles were more jerky, hard, and unnatural than the females indicated. The males also said the profiles were more alarming than the females indicated. The evaluation of the profiles by females indicated that the decelerations occurred later than was indicated by the males.

Preference - Most Preferred by Individual

Ten individuals preferred Profile 1. Seven individuals preferred Profile 2. Two individuals had two-way ties between Profiles 1 and 2. One individual had a three-way tie between Profiles 1, 3, and 4.

Do drivers want ACC deceleration to be like their own deceleration?

No relationship could be found between an individual's preferred profile and his/her own deceleration behavior. The following information was obtained regarding how drivers controlled their deceleration while slowing behind a lead vehicle. While driving at 70mph under manual control, and approaching a vehicle traveling 55mph (lead vehicle speed was unknown to the participant), maximum decelerations ranged from 0.04g to 0.14g with a median of 0.06g. The mean distance to the lead vehicle at maximum deceleration was 179ft. Six participants used the brake during this deceleration. No significant differences were found for Age, Gender, or Age by Gender interaction.

Does deceleration preference change with system experience?

During the course of this study, the participant experienced a total of fifteen decelerations behind a lead vehicle. Presentation of two standard ACC-controlled decelerations separated by eleven intervening ACC-controlled decelerations failed to indicate any significant differences in how drivers perceived the deceleration after the intervening experience. While the drivers in the study obtained very limited experience and can still be considered novices with the system, preliminary investigation of possible learning effects can be obtained.

Based on an analysis of the presentation of two profiles with eleven intervening experiences with ACC deceleration, individuals did not change their evaluation of system performance over time. The second presentation of the Standard Profile showed some potential ($p=0.088$) for being considered earlier than the first presentation. The Standard Profile peak deceleration occurred at about 270ft. Nine of the eleven intervening ACC decelerations occurred at distances shorter than 270ft. For this reason, the second time the standard was presented, individuals may have considered it as being earlier (or farther) because it was earlier than nine of the profiles they had just experienced.

Some participants commented that they felt they were adjusting their evaluation during the study. These comments seemed to be either related to additional experience with vehicle deceleration capabilities or related to better understanding of how to use the scales. An individual who experienced several low decelerations first, then a high deceleration, might comment that what they previously reported as "Hard" was now not considered so hard. Or, after a few trials, individuals might comment that they felt like they were just getting used to using the scales. Although these learning effects probably were eliminated by the balanced design, the comments indicate value in introducing individuals to the scales as well as the range of the stimuli prior to obtaining evaluations. This experiment used one discussion of the scales and two demonstrations of the stimuli, each with further discussion of or practice with the scales.

Responses to Research Questions - Intervention Behavior

The following section presents the three research questions proposed in the Introduction regarding driver intervention behavior. Sub-sections under the questions provide supplementary findings related to the research question.

Where are drivers placing their driving foot while using ACC?

For the twenty participants in this study, while driving with ACC engaged in cruise, resting foot positions ranged from partially under the brake pedal to as far back against the seat as possible and sometimes behind the left foot. Although no trials prior to the intervention scenario required intervention, some anticipation of the need to brake is expected because each trial ended with the participant tapping the brake to cancel cruise control. The distance from the portion of the foot which is typically used for braking and the brake pedal was found to range between 0.0in and 16.4in. The mean distance was 5.8in with a standard deviation of 4.2in. The resting foot distance is limited by the distance between the front of the driver's seat and the brake pedal. This distance also varies with the driver's selection of a seat position. No significant differences were found to describe placement of the foot by the different groups.

When do drivers choose to intervene?

<u>Initiation of Response</u>

While approaching the slower moving lead vehicle, drivers began moving towards the brake between 16.1s and 0.8s prior to activating the brake pedal. The time-to-collision was typically about 7.4s and ranged from 21.12s to 3.97s, and the headway was about 4s at this initiation of foot movement (response). Use of a covering position prior to activating the brake was common among participants (80%) and lasted between 0.4s and 4.8s. Some individuals did move directly from rest to braking. More than half (thirteen) of the participants began moving their foot towards the brake prior to the start of the ACC-controlled deceleration. Six individuals moved at some time after ACC had started deceleration at a 0.05g level. The TTC for these individuals at the time they began moving their foot ranged from 5.2s to 3.97s. No differences were found to describe differences in TTC or headway when the groups began movement toward the brake.

Intervention Timing

The TTC at which the participants finally activated the brake ranged from 6.1s to 3.7s. The headway at intervention ranged from 1.3s to 0.7s. The younger age group was found to intervene at a longer (earlier) TTC and headway and with greater variability in times than the older group. At intervention, the mean TTC of 4.1s for the older age group was 0.7s later than the 4.8s mean TTC for the younger group. The headway at intervention for the older age group was also significantly different than the headway at intervention for the younger group. Mean headway at intervention for the older group was 0.8s with a standard deviation of 0.1s, while for the younger group, the mean was 1.0s with a standard deviation of 0.2s.

What is the nature of driver control after taking over?

Intervention Braking

After the driver had taken control of the ACC vehicle during an approach with an insufficient ACC deceleration of 0.05g, drivers in this study employed a deceleration level between 0.16g and 0.32g to handle the situation, with a mean of 0.24g. The range at peak occurred close to the lead vehicle, with most occurring closer than 60ft from the lead vehicle. Minimum TTC ranged from 5.9s to 2.3s. These minimums in TTC occurred between 2.7s and 0.1s before the peak in deceleration.

Implications of the Research

While evaluating potential deceleration characteristics of ACC vehicles, evaluations can be made using four scales: Good vs. Bad, Comfortable vs. Uncomfortable, Jerky vs. Smooth, and Early vs. Late. Based on the preference data from this study, in a deceleration situation similar to the one presented in the experiment, designers should configure a system for a deceleration of approximately 0.06g occurring approximately 200ft to 250ft behind the lead vehicle. The older group in this study generally was more critical of the entire set of system decelerations. This may indicate that individuals in the 40-50yr age group will be more critical of system performance overall than those in the 21-30yr age group. Strong system-commanded decelerations, as might be found in collision avoidance systems, may need to consider the drivers' readiness to brace themselves while feet are in various positions. Also, if foot position could be tracked by a system, deceleration levels or warning thresholds could potentially be adjusted accordingly. Intervention timing difference between the age groups in this study could be attributed to either different reaction times or different levels of trust in the system. If slower reaction times are the cause of later interventions, the individuals in the older age group would realize greater benefit from the additional early braking provided by an ACC system than the younger group. It is expected that if this is the case, the elderly driver would recognize even greater benefit than the older age group in this study. If trust in the system causes the delay found in intervention, then issues surrounding the appropriateness and value of that trust should be investigated.

Generalizability of the Research

Presentation of a single scenario, specifically the ACC vehicle traveling at 70mph and closing on the lead vehicle traveling at 55mph, is an obviously narrow area of investigation when considering the range of deceleration situations that could potentially occur on the highway. While it is important to recognize that only one scenario was investigated, the research does contribute understanding to the larger context. Approaching a vehicle with a speed difference of 15mph below the set speed presents large speed difference but still realistic difference in velocity when considering highway traffic. It is reasonable to expect that drivers would desire at least equal or more comfortable and smooth performance for decelerations over smaller ΔVs.

Measurement of the manual deceleration profile was performed using participant instructions which attempted to minimize the participant's expectations in the situation. Although the speed difference was not known to the participant, awareness that the lead vehicle was a compatriot vehicle and the surrounding setup for the trial seemed to generate earlier awareness in some participants of the need to decelerate than might be found in actual conditions. The results are therefore considered useful in terms of developing a range of behaviors and for investigating group differences in this situation, but mean values should be considered within the constraints of the study.

From observation and participant comments, presentation of the intervention scenario seemed to successfully generate an unexpected intervention. The participants had become accustomed to the ACC vehicle handling the decelerations and so their response, including their initial resting foot position, movement toward the pedal, and covering while evaluating the need to intervene, is considered indicative of what could be expected during actual use of the system. A somewhat different intervention scenario is one where the driver has become familiar with the capabilities and limitations of the system in a given situation and so has a higher, or earlier, expectancy of the need to intervene. The response in this recognized scenario, including subsequent driver braking levels, may be different from the unexpected intervention scenario presented in this study.

Future Research

Research that continues the work presented here is currently underway. Consideration is being made of different ΔVs and different deceleration scenarios, including lead vehicle braking during overtaking and following. Manual deceleration behavior at highway speeds will also be investigated further. The preference of drivers regarding the trade-off between the need to intervene and vehicle braking capabilities is also being investigated.

There are numerous other related research needs in the area of ACC deceleration and related driver response. These include: the relationship between system deceleration levels and driver intervention performance, the influence of warning timing and modes on the driver's behavior, and net deceleration results in situations where ACC provides braking earlier than the response of the driver. Investigation of the driver's ability to learn the limitations of the system and recognize when the system’s response will be insufficient is also important. Also, issues such as driver supervision of the system, vigilance, situation awareness, and the capabilities of the driver when taking over control are important issues in implementation of this system.

Glossary of Terms

Deceleration profile: The deceleration of a vehicle considered over a period of time so as to consider the onset, peak, and offset of the deceleration and range to the lead vehicle at the time of peak deceleration.

Flying pass: A following vehicle overtakes and passes a lead vehicle without significantly adjusting speed during the pass.

Following: A vehicle traveling in the same direction behind another while the driver of the rear vehicle attempts to match the speed of the lead vehicle. Following is described as occurring between 4 and 0.5 seconds following time (Forbes, 1972).

Headway: The amount of time the following driver has to reach the same level of deceleration as the lead vehicle. The time interval between two vehicles in car-following is calculated as the range between the two vehicles divided by the speed of the following vehicle:

$$\text{Headway} = \frac{\text{Range}}{V_F}$$

Movement time: Interval of time between initiation of response movement and associated control input.

Open-road driving: A vehicle traveling without presence of a lead vehicle within approximately 10 to 12 seconds of headway (Forbes, 1972).

Overtaking: A vehicle traveling at a given speed encounters and approaches a slower moving vehicle. Forbes (1972) describes overtaking as occurring in the range between 9 and 4 seconds following time.

Passing: A following vehicle becomes the lead vehicle.

Range: Measurement from the front bumper of the following vehicle to the rear bumper of the lead vehicle. In this discussion, it is often measured as distance from the ACC car to the lead vehicle.

Range-rate: The rate at which the range between the lead and following vehicles is changing. Synonymous with relative velocity (see next entry).

Relative velocity (ΔV): The difference between the velocity of a lead vehicle and the velocity of the following vehicle:

$$\Delta V = V_L - V_F$$

where V_L is the velocity of the lead vehicle and V_F is the velocity of the following vehicle.

Reaction time: Interval of time between presentation of a stimulus and the initiation of response movement.

Response time: Interval between presentation of a stimulus and the associated control input. Response time is the sum of reaction time and movement time.

Set speed: The speed retained in the cruise control memory which the driver has input as their desired speed.

Time-to-collision (TTC): Time required for two vehicles to collide if they continue at their present speed and path. The TTC is calculated as the range between the two vehicles divided by their relative velocity:

$$TTC = \frac{Range}{\Delta V}$$

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Appendices

Appendix A - Survey of Experts Questionnaire

Name: ______________________________

This questionnaire takes about 15 minutes to complete. The questions are intended to generate as many descriptions, or descriptors, of ACC decelerations as possible. Many of the questions will sound similar. They are re-phrased in several ways to provide alternative ways of considering the issues. You don't need to respond to all of them, but please read each carefully and place yourself in the situation to see if it generates any new ideas or descriptions.

List all the terms or phrases which you can think of which you or other people might use to describe a specific deceleration in an ACC car. e.g., "That deceleration was …" or "That deceleration seemed …" etc.

If you wanted to tell someone what you <u>liked</u> about a specific deceleration in an ACC car, what might you tell them? e.g., "It was …" or "That seemed …", etc

If you wanted to tell someone what you <u>disliked</u> about a specific deceleration in an ACC car, what might you tell them?

What things might make you uncomfortable during a deceleration in an ACC car or a regular car?

In your own car, if you were telling someone how you like to control your speed as you decelerate to follow a slower car, what might you tell them?

When you are a passenger in a regular car and the driver is approaching another vehicle from behind, what makes you nervous?

When another person is driving in a regular car, what aspects of their driving make you trust their skills?

When another person is driving in a regular car, what aspects of their driving make you feel comfortable with their skills?

Thanks for your time.

Appendix B - Descriptors from Expert Questionnaire

Descriptor	Frequency
smooth	11
jerky	9
comfortable	8
late	8
like me (or mine)	8
abrupt	7
harsh	5
uncomfortable	5
close	4
early	4
enough	4
hard	4
confident	3
good	3
gradual	3
rough	3
soon	3
sudden	3
aggressive	2
constant	2
firm	2
heavy	2
high	2
inadequate	2
insufficient	2
little	2
responsive	2
right	2
sluggish	2
acceptable	1
adequate	1
appropriate	1
assertive	1
attention	1
certain	1
confidence building	1
controlled	1
crappy	1
desired	1
erratic	1
even	1
excessive	1
expected	1
extreme	1
far	1
fast	1
gentle	1
inconsistent	1

Descriptor	Frequency
light	1
low	1
lumpy	1
mild	1
moderate	1
much	1
nasty	1
natural	1
nauseating	1
necessary	1
nervous	1
nice	1
normal	1
optimal	1
oscillatory	1
passive	1
progressive	1
prompt	1
rapid	1
refined	1
reasonable	1
safe	1
scary	1
secure	1
severe	1
sharp	1
short	1
slinky	1
slow	1
soft	1
solid	1
startle	1
subtle	1
sufficient	1
trusted	1
unacceptable	1
unexpected	1
unnatural	1
unnecessary	1
unrefined	1
unresponsive	1
weak	1
wrong	1

Appendix C - Bipolarity Survey

Appearing on these pages in random order are 120 paired sets of words. Your task is to tell how similar the two words are when they are used to describe something. This is to be done by indicating the proportion of times that one word could be substituted for the other and the meaning of a sentence is not substantially altered. Thus, for each pair of words you are to assign a number which may range from -100 through 0 to +100.

For example, if two words were perfectly interchangeable (substituting one for the other would never alter the meaning of a sentence in which they are used), you would assign the number +100. On the other hand, if changing one of the words for the other would result in reversing the meaning of all sentences, the number -100 should be assigned. Finally, a value of 0 would be warranted when the pair of words are not related to each other (i.e., when substituting one word for the other would produce no predictable effect on the meaning of a sentence)

For example, for the following pairs, you might indicate values as shown below.

	Similarity (-100 to +100)
sharp <==> dull	*-95*
sharp <==> dark	*0*
sharp <==> crisp	*60*

If you become confused, please refer back to the directions and example. While a large amount of consideration is not required for each, the survey does take some time. The survey doesn't have to be completed in one sitting.

Feel free to provide responses either in electronic or paper format to

shane@vt.edu
smclaugh@ford.com

or

Shane McLaughlin
Address

Since each person gets a different form, if you know of other people who might be interested in completing the survey, please request another form from me rather than giving them a copy of yours.

Thanks very much for your time.

SHANE

	Similarity (-100 to +100)
smooth <==> like me	0
late <==> unlike me	-50
jerky <==> unlike me	0
jerky <==> unsafe	70
jerky <==> uncomfortable	90
smooth <==> unnatural	20
unnatural <==> soft	20
comfortable <==> uncomfortable	-100
good <==> early	50
unsafe <==> like me	-70
unlike me <==> unnatural	90
smooth <==> early	0
bad <==> jerky	90
like me <==> soft	20
bad <==> comfortable	-50
smooth <==> unlike me	-20
bad <==> uncomfortable	90
late <==> unsafe	50
early <==> soft	0
bad <==> like me	20
jerky <==> soft	-80
smooth <==> late	0
uncomfortable <==> like me	20
good <==> natural	80
early <==> like me	70
jerky <==> natural	-20
unlike me <==> hard	20
natural <==> unnatural	-100
bad <==> good	-100
unsafe <==> natural	-50
good <==> uncomfortable	60
jerky <==> early	0
comfortable <==> natural	90
good <==> unlike me	-20
safe <==> soft	0
uncomfortable <==> unlike me	0
jerky <==> smooth	-100
bad <==> late	90
like me <==> unlike me	-100
jerky <==> comfortable	-100
comfortable <==> unlike me	0
bad <==> unnatural	60
smooth <==> uncomfortable	-80
uncomfortable <==> safe	60

	Similarity (-100 to +100)
late <==> unnatural	0
bad <==> smooth	-80
late <==> natural	0
smooth <==> hard	50
good <==> safe	100
comfortable <==> unsafe	-60
comfortable <==> hard	-40
safe <==> unnatural	0
uncomfortable <==> unsafe	0
uncomfortable <==> soft	-80
safe <==> like me	70
uncomfortable <==> natural	-90
safe <==> natural	0
natural <==> soft	80
early <==> unlike me	50
jerky <==> unnatural	90
jerky <==> safe	0
bad <==> safe	-90
smooth <==> unsafe	-80
uncomfortable <==> early	0
good <==> hard	50
comfortable <==> safe	90
jerky <==> like me	0
good <==> like me	80
late <==> like me	70
late <==> soft	0
good <==> smooth	80
safe <==> hard	0
early <==> late	-100
uncomfortable <==> unnatural	90
late <==> safe	0
comfortable <==> like me	80
uncomfortable <==> late	0
good <==> unnatural	0
bad <==> unlike me	50
jerky <==> hard	20
good <==> soft	80
good <==> unsafe	-90
like me <==> natural	90
unsafe <==> unlike me	80
early <==> natural	0
smooth <==> comfortable	90
uncomfortable <==> hard	80
early <==> hard	0
unlike me <==> natural	-80

	Similarity (-100 to +100)
unlike me <==> soft	0
bad <==> natural	-20
bad <==> early	-70
comfortable <==> early	0
early <==> unnatural	0
bad <==> soft	-80
hard <==> soft	-50
good <==> comfortable	90
like me <==> unnatural	-80
jerky <==> late	20
unsafe <==> hard	20
early <==> safe	20
smooth <==> soft	80
smooth <==> safe	50
good <==> jerky	-90
comfortable <==> unnatural	-90
unsafe <==> unnatural	0
safe <==> unlike me	-50
comfortable <==> soft	30
like me <==> hard	0
comfortable <==> late	0
smooth <==> natural	40
early <==> unsafe	20
safe <==> unsafe	-100
bad <==> unsafe	90
late <==> hard	0
bad <==> hard	20
good <==> late	-10
unnatural <==> hard	10
unsafe <==> soft	0
natural <==> hard	10

Appendix D - E-mail List Request for Participants

From: ETCEMAIL--DRBN007 Date and time 04/07/98 12:22:31
To: All PC and UNIX users in ETC

FROM: Colleen Serafin USAET(UTC -04:00)
Subject: cruise control study

Cruise Control Evaluation

The Automotive Safety Office would like to invite you to participate in an evaluation of an advanced cruise control system. The purpose of the evaluation is to obtain driver impressions of the system so that we can develop a system that is safe, easy, and enjoyable to use.

As a participant in this evaluation, you will drive a vehicle equipped with an advanced cruise control system around a test route in Wayne and Monroe Counties. A Ford test engineer will be in the test vehicle with you and will ask for your observations

The evaluations will take approximately three hours and are planned for April 6-24. Evaluations will take place at 8:30 AM and 12:30 PM Monday through Friday.

For more information and/or to schedule an appointment, please contact Colleen Serafin (Profs: CSERAFIN).

We are interested in participants who use cruise control on a weekly basis and who are in the following age ranges (21-30 years and 40-50 years), so please let me know which group you are in when you reply.

Regards,
Colleen Serafin
tel:313 31 77288
fax:313 32 21830______________________________cserafin@ford.com
Regards,
E Tcemail

Appendix E - Experimenter Script and Procedure List

Checklist

1. Laptop
2. Delete previous files
3. Gas
4. Video tape
5. Sunglasses
6. Pens
7. Forms
8. Radios
9. LV keys
10. Phone

Experimental Procedure

Get car working

Start DSP
Run Cockpit
Check boxes, cushion, headway
Run Trace
Acquisition mode 0402m1.idf

Familiarize subject with car, seats, mirrors, controls
Familiarize with procedure

During this session, we will be driving on the Soutfield, I-96 West (Lansing) to I-275 South (Toledo). We'll be conducting most of the experiment on a section of I-275. After reaching the section of 275 we'll be using, I'll have you drive a little using ACC. We'll follow a lead vehicle and let you get a general feel for how ACC works. I'll be telling you what you need to do, such as when to press what buttons, when to cancel, etc. Once you are comfortable with how ACC works, we'll begin the main part of the study, which is to look at decelerations.

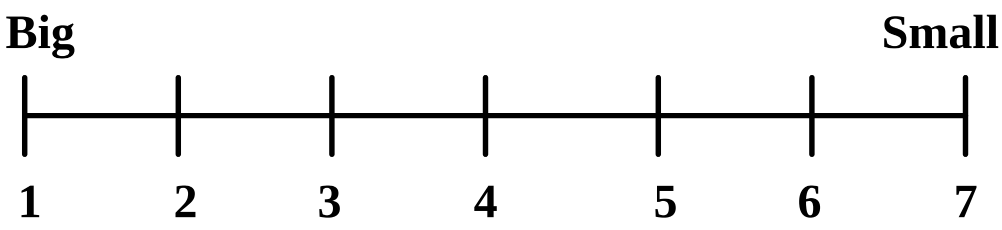
During this segment, we'll set up situations where you are approaching a slower moving car, and the ACC car, this car, will automatically slow behind it.

As you'll read in just a second in the written material, while these decelerations are controlled by ACC, some situations may not be handled completely, so if you feel uncomfortable with the way the car is handling it or not handling it, you should override the system by taking over braking just like with normal cruise control.

Stop while participant reads material and completes forms and questionnaires.

During and after the deceleration, you can comment on any aspects of the deceleration. After deceleration, I'll ask you to respond to a set of scales.

The scales we will be using are seven point scale just like you've probably seen in many other places. The difference will be that I'll be reading you the scales and you'll be responding to them verbally. I'll read the scale and you just give me your answer from 1 to 7. The following is an example



If you were evaluating an object using this scale, and you felt it was Big, you would respond with a 1. If you thought it was small, you would respond with a 7. If it was neither big nor small, or if the scale didn't really apply, you would respond with a 4. Any questions?

During the drive, we will be recording video and audio to record you comments regarding the decelerations and to track the traffic and road situation.

At all times, you are the driver and in charge of the vehicle. Because we are on the road, sometimes slowing quickly, it is important to monitor the other traffic, and especially anyone behind you. If during the drive anyone is following closely or approaching rapidly from behind, just tap the brake to assume manual control. I will remind you of this while we are out there.

Do you have any questions?

Manual Driving

1. Start video recording
2. Turn on microphone
3. Disable Cruise&Follow
4. Start data recording
5. Depart building with ACC car leading
6. ACC vehicle leads as we drive to 275
7. LV sets cruise at 55 while on the way to 275
8. ACC driver sets cruise at 70 mph while on the way to 275
9. LV will take the lead as we enter 275
10. Stop data recording

Driver's Manual Decel

1. Start new trace file 02202m2.idf
2. ACC car will go 60mph while LV gets far ahead in center lane - difficult because of traffic intervention in long space.
3. LV will initiate cruise at 55 mph
4. ACC car will accelerate and drive manually at 70mph and fall in behind LV
5. After ACC car falls in behind and stabilizes

6. Stop trace file

Demonstrate ACC

1. Start trace file 02202b1.idf
2. LV will vary speed between 55 and 70, holding speed at different levels.
3. After a period of doing this, performance of decel starts

Your in charge. If during the drive anyone is following closely or approaching rapidly from behind, please tap the brake to assume manual control. Also remember that in some situations, you may need to take over braking.

Decelerations

1. LV goes 70 to extend gap
2. ACC car goes 55-60 to fall back
3. LV notifies when at 55 mph (double-click)
4. ACC car accelerates to 70 mph
5. Subject presses resume
6. ACC car closes and stabilizes behind LV
7. ACC subject taps brakes
8. Experimenter double-clicks to notify LV to accelerate to about 70 mph
9. Experimenter queries participant responses about decel (2X for free responses, 2X for scales)
10. Experimenter changes gain settings
11. Experimenter double-clicks to notify LV that cars are extending gap - ACC will slow.
12. Return to Step 1

General Procedure

1. Manual Drive
2. Record Manual Deceleration
3. Demonstrate ACC
4. Demo Decel 1
5. Read Scales
6. Demo Decel 2
7. Read Scales

8. Standard Decel - Presentation 1
9. Ask scales

10. Perform Decels (10X)
11. Remind participant (1) Keep an eye on mirrors, (2) Don't hesitate to intervene if you are uncomfortable.
12. Ask scales (10X)

13. Braking Decel
14. Ask scales

15. Standard Decel - Presentation 2
16. Save Data file

Return Trip

1. Start new trace file 0401h1.idf
2. Activate Cruise and Follow lights.
3. Debrief - Scales for preference, response behavior, manual data, intervention trial, etc.
4. Drop off subject
5. Stop Data
6. Turn off Microphone
7. Eject video

Appendix F - Ford Information Letter

Subject Information Letter
Adaptive Cruise Control System Study

Dear Driver:

We would like to invite you to participate in a study of a new feature known as adaptive cruise control (ACC). During the study, you will be using an ACC system while driving on a test route. Since this is a new system that is still under development, we are very interested in getting your input as you drive the test vehicle. We invite you to discuss the things you like and dislike about this system freely throughout the study.

Adaptive cruise control is a system that allows you to maintain a fixed distance between the vehicle you are driving and the vehicle you are following. It uses a sensor to detect the speed of and distance to the car in front of you. When turned on and set, ACC will automatically control the vehicle acceleration and deceleration. The level of automatic braking will be mild and you will be required to add additional brake force as necessary.

Participants will help us evaluate elements of the ACC system design so that we can develop a system that is safe, easy, and enjoyable to use. As a participant in this study, you will drive a vehicle equipped with ACC around a test route in Wayne and Monroe Counties. Throughout the study, a Ford test engineer will be in the test vehicle with you. The engineer will assist you in learning to use the ACC system and give instructions. If you have any questions during the study, the test engineer can answer them for you.

While driving in this study, you will not be asked to perform any unsafe driving actions and you must obey all traffic laws.

Risks: While driving, you will be subject to all risks normally present during driving. The scenarios examined in this study will involve using a new prototype system to control following, passing, acceleration and deceleration at various freeway speeds while in normal traffic. Caution should be exercised when operating equipment with which you are not familiar. Be aware that accidents can happen at any time while driving.

The system is intended to maintain a certain distance between your vehicle and the vehicle you are following depending on your speed: the faster you go, the greater the following distance. You will experience acceleration and deceleration of the vehicle by the ACC system to maintain the following distance. The level of acceleration you will experience will be similar to that which you would experience when driving a car with a conventional cruise control system. The maximum level of deceleration produced by the ACC system that you will experience will be mild and similar to the level of braking you might use to come to a normal stop at a traffic light. You may have to provide additional braking as needed depending on the traffic situation and which test is being conducted.

You should be aware that this prototype sensing system can sometimes select targets other than the vehicle in front of you or not recognize a vehicle in your path. In these situations, the car may maintain speed or automatically accelerate or decelerate inappropriately. If any of these situations occur, you should override the system using whichever pedal is appropriate or by pressing Off, Cancel, or the middle console switch.

Benefits: The results of this study will provide guidance for the development of ACC systems that are easy and safe to use. By participating in this study, you will be lending your observations and driving experience to support research regarding the future development of ACC systems.

Confidentiality: We are gathering information on ACC system use. We are not testing you. If you agree to participate in this study, your name will not be released to anyone not working on this project. Your name will not appear in any reports or papers written about the project.

After the test engineer has answered any questions that you may have, please let him/her know whether or not you are interested in participating in this study. If you are willing to participate, the test engineer will ask you to read and sign a Subject Informed Consent Form before you can participate in the study. Please note your participation in this study is voluntary. You may withdraw from this study at any time and for any reason.

Sincerely,

Eugene Farber
Principal Investigator, NHTSA ACC Project
Advanced Vehicle Safety and Regulations

Appendix G - Virginia Tech Informed Consent Form

Informed Consent for Participant of Investigative Project
Virginia Polytechnic Institute and State University

Title of Project: Measurement of Driver Preferences and Intervention Responses as Influenced by Adaptive Cruise Control Deceleration Characteristics

Principal Investigators: Shane McLaughlin, Dr. Thomas Dingus

I. THE PURPOSE OF THIS RESEARCH/PROJECT

The purpose of this study is to investigate, driver preferences and best design characteristics for the automatic control of deceleration in adaptive cruise control (ACC) vehicles. Adaptive cruise control is an evolution of current cruise control which will adjust your speed to accommodate slower moving vehicles in your path, thereby reducing decision making demands and also increasing the number of situations in which cruise control may be used beyond what is possible with current cruise control. The results of this study will aid in the design of adaptive cruise control systems for user comfort and acceptance.

II. PROCEDURES

During the course of this study you will be driving a vehicle both manually and with the assistance of the adaptive cruise control system. Your role in this drive is that of evaluator, to experience different types of decelerations, and provide your perceptions. The experimenter will be adjusting different parameters of the adaptive cruise control system during each trial. It is important that you understand that we are not evaluating you or your performance in any way. In each trial, you are helping us to evaluate various characteristics of the adaptive cruise control system.

This experiment entails driving the research vehicle and evaluating how the automated system controls deceleration of the vehicle when slowing from open road cruising to following behind a slower moving vehicle. During the experiment, you will be following a slower moving lead vehicle that is driven by a second experimenter. Presence of the slower vehicle ahead of the research vehicle will cause the research vehicle to decelerate. This situation will be presented to you numerous times during the experiment. After each, you will respond to questions which investigate your perception of the deceleration.

In some situations, as you close on the lead vehicle, the gap between the vehicles will reduce beyond what you desire while driving. In these situations, simply apply the brakes and begin manual control of the vehicle. In these trials, the adaptive cruise control system is configured such that its deceleration capability is less than is required to automatically decelerate the vehicle appropriately.

All information that you help us attain will remain anonymous. Your actions may be noted and you will be asked to verbally describe your impressions of the system.

The session will last approximately 3 hours. You are welcome to take rest breaks as needed.

III. RISKS

While driving, you will be subject to all the risks normally present during driving. The scenarios examined in this study will involve using a new prototype system to control following, acceleration, and deceleration at various freeway speeds while in normal traffic. Caution should be exercised when operating equipment with which you are not familiar. Be aware that accidents can happen at any time while driving.

IV. BENEFITS OF THIS PROJECT

There are no direct benefits to you. You may, however, find the experiment interesting. No promise or guarantee of benefits has been made to encourage you to participate. Your participation in this study will contribute to the improvement of the adaptive cruise control system. Improvements in the design of adaptive cruise control may have a significant impact on driving safety, system usability, and consumer satisfaction.

You are requested to refrain from discussing the evaluation with other people who might be in the candidate pool from which other participants might be drawn.

V. EXTENT OF ANONYMITY AND CONFIDENTIALITY

The data gathered in this study will be kept strictly confidential. Your written consent is required for the researchers to release any data identified with you as an individual to anyone other than personnel working on the project. The information you provide will have your name removed and only a subject number will identify you during analyses and any written reports of the research.

VI. COMPENSATION

There will be no compensation for participating in this study.

VII. FREEDOM TO WITHDRAW

You are free to withdraw from this study at any time for any reason. Furthermore, you are free to not answer any questions or respond to any research situations without penalty.

VIII. APPROVAL OF RESEARCH

This research has been approved, as required, by the Institutional Review Board for projects involving human subjects at Virginia Polytechnic Institute and State University, and by the Department of Industrial and Systems Engineering.

IX. SUBJECTS RESPONSIBILITIES AND PERMISSION

I voluntarily agree to participate in this study, and I know of no reason I cannot participate. I have read and understand the informed consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project. If I participate, I may withdraw at any time without penalty. I agree to abide by the rules of this project.

____ ____________________
Signature Date

____
Name (please print)

Should I have any questions about this research or its conduct, I may contact:

Shane McLaughlin, Principal Investigator	Phone: (313) 317-9141
Dr. Tom Dingus, Director, Center for Transportation Research	Phone: (540) 231-8831
T. H. Hurd, Director of Sponsored Programs	Phone: (540) 231-5281

Appendix H - Ford Informed Consent Form

Subject Informed Consent Form
Adaptive Cruise Control System Study

I, ____, agree to participate in a study of an adaptive cruise control system.

I understand that:

1) The purpose of this study is to obtain driver impressions as part of an evaluation of a new cruise control technology called adaptive cruise control (ACC).

2) I must possess a valid, unrestricted driver's license and have a minimum of two years of driving experience.

3) I must not be under the influence of alcohol, drugs, or any other substances which may impair my ability to drive.

4) As a participant, I will drive a Ford Taurus on public roads in Southeast Michigan while using the prototype ACC system to follow a lead vehicle. I understand that the experiment will last about 3 hours. I will not drive for longer than 60 minutes without receiving a 5 minute rest break.

5) During the experiment, a ride-along test engineer will be in the test vehicle with me. The test engineer will assist me in learning to use the prototype ACC system, will give me instructions for driving, and will ensure that no inadvertent safety risks are taken. At the conclusion of the experiment, I will be asked to complete a post-drive questionnaire regarding my impressions of driving the prototype vehicle and a background questionnaire providing information about my driving habits (e.g., annual mileage, cruise control usage).

6) While driving for this study, I will not be asked to perform any unsafe driving actions and agree to obey all traffic laws.

7) While driving, I will be subject to all risks normally present during driving. The use of ACC in general is intended to make driving more convenient and comfortable than normal. However, caution should be exercised when operating a prototype vehicle with equipment with which I am not familiar. I should not become over reliant on the prototype ACC system and I am aware that accidents can happen at any time while driving. I understand that the existence of the prototype ACC system on the test vehicle will not eliminate the possibility of an accident occurring.

8) While riding in the test vehicle and using the prototype ACC system, I will experience acceleration and deceleration of the vehicle produced by the prototype ACC system to maintain a certain following distance between my vehicle and the vehicle I am following. The following distance will depend on my speed: the faster I go, the greater the following distance. I understand that the level of acceleration I will experience will be similar to that which I may have experienced when driving a car with a conventional cruise control system. The maximum level of deceleration I will experience will be mild and similar to the level of braking I might use to come to a normal stop at a traffic light. I may have to provide additional braking as needed depending on the traffic situation and the test being conducted.

9) I am aware that the prototype sensing system can sometimes select targets other than the vehicle in front of me or not recognize a vehicle in my path. In these situations, the car may maintain a speed or

automatically accelerate or decelerate inappropriately. If any of these situations occur, I should override the system using whichever pedal is appropriate or by pressing Off, Cancel, or the middle console switch.

10) The results of this study will provide guidance for the development of ACC systems. By participating in this study, I am supporting research regarding the future development of ACC systems. I understand that I will not be informed as to the results of this study.

11) Ford is gathering information on prototype ACC system use. Ford is not testing me. My name will not be voluntarily released to anyone not working on the project. My name will not appear in any reports or papers written about the project. It is possible that, should I be involved in an accident during testing, Ford will have to release data on my driving in response to a court order.

The data gathered in this experiment will be treated with anonymity. Shortly after I have participated, my name will be separated from my data. Videotapes will be kept in a locked room and will be erased when no longer needed.

12) Ford employees will answer any questions that I may have about this study. The employee in charge of testing is:

Eugene Farber
NHTSA Project Principal Investigator
Automotive Safety and Engineering Standards Office
phone (313) 845-5305

13) My participation in this study is voluntary and I understand that I may withdraw from this testing at any time, for any reason, without penalty or loss of benefits to which I am entitled.

I certify that, to the best of my knowledge, I have no physical ailments or conditions which could either be further aggravated or adversely affected by participating in this study.

I, ____, HAVE READ AND UNDERSTOOD THE TERMS OF THIS AGREEMENT. I VOLUNTARILY CONSENT TO PARTICIPATE IN THIS STUDY.

SIGNATURE ____

DATE ____

ADDRESS ____

____

____

TELEPHONE ____

Appendix I - Participant Background Form

Participant No. _________

Date ______________

Participant Background Form
Adaptive Cruise Control System Study

Name: ____ Profs ID: ____________________

Job Title: ____

Gender: M F Age Range: 21-30 40-50

Make and model year of vehicle(s) you currently drive:

1)____
Cruise control? N Y
If yes, how often use it? daily a few times a week a few times a month a few times a year

2)____
Cruise control? N Y
If yes, how often use it? daily a few times a week a few times a month a few times a year

Annual Mileage you drive in each: Vehicle 1: ______________ Vehicle 2: ______________

How often do you drive?
daily a few times a week a few times a month a few times a year

Type of road you drive on the most (circle two if you drive two equally often):
rural two-lane suburban city highways

How often do you drive on the section of I-275 between Eureka Rd and Telegraph Rd?
daily a few times a week a few times a month a few times a year never

Type of roads on which you use cruise control (circle all that apply):
rural two-lane suburban city highways

How often do you increase/decrease the set cruise speed using the system controls only (not using the pedals)?
frequently occasionally sometimes rarely never

Have you ever heard of Intelligent Cruise Control (ICC) or Adaptive Cruise Control (ACC)?
N Y -> Where? ____

THANK YOU FOR YOUR PARTICIPATION AND INTEREST IN THIS STUDY!

Appendix J - Participant Response Sheet

		1	Comfortable	Early	Safe	Bad	Like me	Jerky	Hard	Natural	Alarming
		7	Uncomfortable	Late	Unsafe	Good	Unlike me	Smooth	Soft	Unnatural	Imperceptible
Order	**rep**	**Profile**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**
4	1	**1**	1	1	1	7	1	7	7	1	7
9	2	**1**	1	3	1	7	1	7	7	1	7
6	1	**2**	1	3	1	7	1	7	7	1	7
11	2	**2**	1	3	1	7	1	7	7	1	7
5	1	**3**	3	5	3	6	2	6	3	3	5
10	2	**3**	3	3	3	5	3	6	5	3	6
3	1	**4**	5	6	6	5	6	4	5	5	2
8	2	**4**	5	5	5	3	5	4	3	5	4
2	1	**5**	5	4	5	5	6	3	4	5	3
7	2	**5**	6	5	5	4	6	3	4	6	3
11	2	**Brk**	7	7	7	1	7	6	6	7	1
1	1	**Stand1**	6	5	5	4	5	2	4	5	3
13	2	**Stand2**	3	4	5	5	6	5	5	6	3

Appendix K - Summary of Participant Data

Control ===>																								
Response ===>									Rest Position				<---- Moving - Data from start of movement ---->								Stopped - Data from when mo			
Data Source ===>					File				From Video					File							Video	File		
Subject	**Age**	**Gender**	**Date**	**Data File**	**maxd**	**V**	**R**	**RR**	**Area**	**Xpos**	**Ypos**	**distance**	**From Rest**	**Index**	**Range**	**RR**	**Decel**	**Velocity**	**Headway**	**TTCRst**	**At pos1**	**Index**	**Range**	**RR**
1	O	F	0406am	0406a8	0.07	67.04	71.62	-12.75	floor	-2.0	2.0	2.8	7738.0	993.0	168.5	-16.1	0.003	70.3	1.6	7.1				
2	Y	M	0406pm	0406a6	0.10	69.72	130.94	-15.66	accel	3.0	-1.0	3.2	8649.1	1057.0	265.9	-16.3	-0.003	70.9	2.6	11.1				
3	O	F	0407am	0407a9	0.05	69.25	115.23	-14.54	accel	3.0	-1.0	3.2	6621.0	1091.0	183.4	-16.1	0.013	70.6	1.8	7.8	6623.3	1114.0	129.1	-15.2
4	Y	F	0407pm	0407a8	0.06	67.59	117.62	-14.09	accel	3.0	-1.0	3.2	3412.3	3653.0	151.9	-15.4	-0.010	70.3	1.5	6.7				
5	O	M	0415pm	0415a6	0.06	59.10	79.60	-12.08	floor	-2.0	1.0	2.2	5536.6	4044.0	419.4	-14.5	0.016	70.4	4.1	19.7	5539.1	4069.0	364.7	-14.8
6	Y	M	0417am	0417a12	0.06	69.59	116.64	-14.76	floor	-4.0	6.0	7.2	6997.3	1483.0	191.7	-15.9	-0.017	70.9	1.8	8.2				
7	*Y*	*F*	*0422pm*	*0422a10*	*0.16*	*62.91*	*42.10*	*-8.72*	*floor*	*-9.0*	*5.0*	*10.3*	*8255.2*	*1813.0*	*77.3*	*-13.0*	*0.046*	*66.9*	0.8	4.1				
8	O	M	0423am	0423a9	0.05	67.38	73.72	-12.75	floor	-4.0	6.0	7.2	6410.3	1690.0	109.0	-14.3	0.040	69.1	1.1	5.2				
9	O	M	0423pm	0423a10	0.05	68.98	117.53	-15.44	floor	-8.0	11.0	13.6	4614.9	1475.0	96.6	-14.5	0.030	68.1	1.0	4.5				
10	Y	M	0424am	0424a7	0.05	69.30	120.97	-15.21	floor	2.0	2.0	2.8	6714.0	4343.0	169.3	-15.9	-0.020	70.4	1.6	7.3				
11	O	M	0424pm	0424a6	0.06	66.84	65.59	-11.86	accel	3.0	-1.0	3.2	6398.4	1685.0	214.2	-15.2	-0.003	70.3	2.1	9.6				
12	O	M	0428am	0428a8	0.05	67.86	85.80	-13.42	accel	3.0	-1.0	3.2	6041.4	2192.0	107.3	-14.3	0.039	68.6	1.1	5.1				
13	*O*	*F*	*0428pm*	*0428a8*	~~*BRAKE*~~	~~*BRAKE*~~	~~*BRAKE*~~	~~*BRAKE*~~	*floor*	*0.0*	*0.0*	*0.0*	*7139.6*	*1160.0*	*84.5*	*-14.5*	*0.022*	*68.3*	0.8	4.0				
14	Y	F	0501pm	0501a8	0.09	69.72	120.54	-14.76	floor	-4.0	8.0	8.9	7284.9	3038.0	326.0	-13.4	-0.010	70.5	3.2	16.6				
16	Y	M	0506pm	0506a6	0.06	69.08	109.82	-14.09	accel	3.0	-1.0	3.2	7321.6	4047.0	169.9	-15.2	0.015	70.5	1.6	7.6				
17	O	F	0507pm	0507a8	0.07	67.60	90.85	-12.30	floor	-8.0	5.0	9.4	8325.2	4321.0	160.3	-14.8	-0.010	70.0	1.6	7.4				
18	O	F	0511am	0511a8	0.05	69.23	110.34	-14.54	floor	-10.0	13.0	16.4	7445.8	2071.0	196.1	-16.1	0.003	70.8	1.9	8.3	7447.0	2083.0	165.3	-16.3
19	Y	F	0511pm	0511a7	0.05	69.12	107.42	-15.88	floor	-1.0	6.0	6.1	7861.5	3965.0	100.2	-15.9	0.049	68.7	1.0	4.3				
20	Y	M	0513am	0513a8	Lost	Lost	Lost	Lost	floor	-5.0	4.0	6.4	7860.2	4502.0	184.3	-14.8	-0.028	70.5	1.8	8.5				
21	Y	F	0513pm	0513a7	0.05	69.91	137.64	-16.33	accel	3.0	-1.0	3.2	7452.7	1808.0	505.0	-16.3	-0.018	70.4	4.9	21.1	7455.4	1835.0	423.7	-16.3

Control ===>				ACC Controlled																			
Response ===>				tion stops		<---- Moving - Data from start of movement ---->						Stopped - Data from when motion stops						<---- Moving - Data from start of movement ---->					
Data Source ===>						Video	File					Video	File					Video	File				
Subject	**Age**	**Gender**	**Date**	**Decel**	**Velocity**	**from pos1**	**Index**	**Range**	**RR**	**Decel**	**Velocity**	**Atcover**	**Index**	**Range**	**RR**	**Decel**	**Velocity**	**From cover**	**Index**	**Range**	**RR**	**Decel**	**Velocity**
1	O	F	0406am									7740.5	1017.0	111.2	-14.5	0.028	68.8	7741.3	1026.0	91.1	-13.6	0.050	68.0
2	Y	M	0406pm									8649.9	1065.0	244.9	-16.3	-0.016	70.9	8653.0	1096.0	171.3	-16.3	-0.008	70.7
3	O	F	0407am	0.033	69.8	6623.6	1117.0	122.0	-14.9	0.039	69.5	6624.1	1122.0	112.9	-14.5	0.043	69.1	6624.6	1127.0	100.7	-14.1	0.052	68.5
4	Y	F	0407pm									3413.0	3660.0	135.5	-15.0	0.035	69.8	3415.1	3681.0	92.2	-13.0	0.054	67.9
5	O	M	0415pm	0.017	70.4	5551.0	4189.0	104.2	-13.2	0.047	68.6	5552.1	4200.0	83.3	-12.1	0.058	67.5	5552.5	4203.0	76.0	-11.8	0.047	67.1
6	Y	M	0417am									6998.3	1493.0	169.5	-16.1	0.017	70.9	7002.0	1531.0	84.4	-12.7	0.048	67.7
7	*Y*	*F*	*0422pm*									*8255.7*	*1818.0*	*67.5*	*-12.7*	*0.035*	*66.4*						
8	O	M	0423am									6411.1	1698.0	93.6	-13.4	0.048	68.2	6411.7	1704.0	81.5	-13.0	0.058	67.7
9	O	M	0423pm																				
10	Y	M	0424am									6714.8	4351.0	149.5	-15.9	0.013	70.3	6716.0	4363.0	123.1	-15.2	0.046	69.3
11	O	M	0424pm									6399.5	1696.0	188.4	-15.2	0.004	70.3	6404.3	1744.0	84.7	-13.0	0.044	67.8
12	O	M	0428am																				
13	*O*	*F*	*0428pm*									*7140.5*	*1169.0*	*67.7*	*-13.6*	*0.079*	*67.3*						
14	Y	F	0501pm									7286.0	3049.0	301.6	-14.1	0.002	70.5	7288.7	3076.0	238.5	-16.1	-0.005	70.6
16	Y	M	0506pm									7322.1	4052.0	158.0	-15.2	-0.011	70.5	7324.4	4075.0	107.4	-13.9	0.025	68.8
17	O	F	0507pm									8326.2	4331.0	137.2	-14.8	0.046	69.9	8328.5	4355.0	89.0	-12.3	0.047	67.4
18	O	F	0511am	-0.010	70.8	7449.8	2111.0	103.5	-14.5	0.044	68.7												
19	Y	F	0511pm			7862.8	3978.0	70.0	-13.6	0.068	67.1												
20	Y	M	0513am																				
21	Y	F	0513pm	0.004	70.2	7464.1	1923.0	199.4	-17.0	-0.003	70.5	7465.8	1940.0	155.4	-16.8	-0.003	70.4	7468.4	1966.0	93.7	-15.2	-0.060	68.0

Control ===>					Driver																		
Response ===>							At Brake Press						Driver pressing brake pedal										
Data Source ===>				File	Video		File												Video		File	Video	
Subject	**Age**	**Gender**	**Date**	**Brake**	**Brake**	**brkdiff**	**TTC**	**Headway**	**d**	**V**	**R**	**RR**	**maxd**	**V**	**R**	**RR**	**HdwPeak**	**TTCPeak**	**fullp**	**Release**	**Off**	**Off**	**offdiff**
1	O	F	0406am	7742.4	7742.3	-0.1	-3.83	0.75	0.05	67.19	73.72	-12.97	0.24	66.61	33.70	-12.30	0.3	1.9	7744.1	7745.1	7742.6	7746.1	3.5
2	Y	M	0406pm	8654.5	8653.1	-1.4	-5.70	1.30	0.09	69.94	133.27	-15.88	0.2	64.59	98.23	-10.51	1.0	6.4	8654.5	8658.6	8658.7		-8658.7
3	O	F	0407am	6624.9	6625.0	0.1	-4.46	0.94	0.04	68.36	94.39	-14.09	0.22	61.89	63.82	-8.05	0.7	5.4	6625.5	6627.1	6627.5	6627.6	0.1
4	Y	F	0407pm	3415.5	3415.4	-0.1	-4.47	0.85	0.04	67.61	84.29	-12.53	0.25	59.16	51.28	-4.92	0.6	7.1	3416.5	3418.1	3418.5	3418.8	0.3
5	O	M	0415pm	5552.7	5552.7	0.0	-4.22	0.74	0.05	67.03	72.38	-11.41	0.19	64.20	57.45	-8.95	0.6	4.4	5553.2	5555.4	5555.7	5555.9	0.2
6	Y	M	0417am	7002.3	7002.3	0.1	-4.14	0.81	0.04	67.64	80.65	-12.97	0.27	55.32	39.14	-0.45	0.5	59.3	7003.5	7005.4	7005.8	7006.5	0.7
7	*Y*	*F*	*0422pm*			*0.0*			*0.05*	*55.82*	*20.05*	*-2.01*		*62.91*		*-8.72*							*0.0*
8	O	M	0423am	6412.2	6412.1	-0.1	-3.87	0.73	0.05	67.27	71.92	-12.53	0.21	54.97	35.04	-0.22	0.4	108.6	6412.9	6415.2	6416.7	6416.9	0.2
9	O	M	0423pm	4615.8	4615.8	0.0	-3.87	0.80	0.04	67.43	79.20	-13.65	0.25	57.02	40.88	-3.80	0.5	7.3	4616.3	4618.6	4619.0	4619.0	0.0
10	Y	M	0424am	6716.5	6716.4	-0.1	-5.11	1.10	0.04	68.93	111.49	-14.76	0.23	59.60	68.47	-5.59	0.8	8.4	6717.2	6719.2	6719.4	6719.5	0.1
11	O	M	0424pm	6405.2	6404.8	-0.4	-3.77	0.69	0.04	66.97	67.29	-12.08	0.3	58.21	44.85	-3.80	0.5	8.0	6406.1	6407.1	6407.6	6407.6	0.0
12	O	M	0428am	6042.2	6042.4	0.2	-4.36	0.90	0.04	67.98	89.87	-13.65	0.29	67.61	49.77	-12.97	0.5	2.6	6043.8	6045.2	6042.6	6046.7	4.1
13	*O*	*F*	*0428pm*	~~*BRAKE*~~	~~*BRAKE*~~	~~*BRAKE*~~			~~*BRAKE*~~	~~*BRAKE*~~	~~*BRAKE*~~	~~*BRAKE*~~		~~*BRAKE*~~		~~*BRAKE*~~							*0.0*
14	Y	F	0501pm	7293.2	7292.2	-1.0	-6.07	1.31	0.08	69.93	133.86	-14.99	0.18	66.13	106.04	-11.41	1.1	6.3	7293.3	7295.1	7298.0	7298.3	0.3
16	Y	M	0506pm	7324.7	7324.6	-0.1	-5.02	1.01	0.05	68.58	101.38	-13.65	0.19	64.67	71.43	-10.29	0.8	4.7	7325.9	7326.0	7327.9	7328.4	0.5
17	O	F	0507pm	8328.8	8328.9	0.1	-4.70	0.85	0.03	67.30	83.60	-11.63	0.26	67.60	90.85	-12.30	0.9	5.0	8330.5	8331.1	8329.0	8331.5	2.5
18	O	F	0511am	7451.2	7451.1	-0.1	-3.66	0.73	0.05	67.54	72.74	-13.42	0.29	58.97	44.92	-5.37	0.5	5.7	7452.0	7453.2	7454.4	7454.7	0.3
19	Y	F	0511pm	7862.3	7862.3	0.0	-3.66	0.82	0.04	67.94	81.80	-14.99	0.16	67.71	37.43	-14.76	0.4	1.7	7864.1	7864.3	7862.5	7864.7	2.2
20	Y	M	0513am	Lost	7860.9	#VALUE!			Lost	Lost	Lost	Lost		Lost		Lost			7861.8	7863.0		7864.6	7864.6
21	Y	F	0513pm	7468.6	7468.6	0.0	-4.07	0.89	0.04	67.93	88.95	-14.54	0.32	56.86	42.85	-4.25	0.5	6.9	7470.2	7471.4	7472.1	7472.5	0.4

Control ===>
Response ===>

Data Source ===>				vid->data	Video				video->data	data > video	Video	Video	Data			
Subject	**Age**	**Gender**	**Date**	**rst -> brk**	**rst -> P1**	**onP1**	**p1->cover**	**on cover**	**cover -> brk**	**brk->fullp**	**on fullp**	**rel -> off**	**Peakat**	**PeakTTC**	**MinTTCt**	**Diff**
1	O	F	0406am	4.4		0.0		0.8	1.1	1.8	1.0	1.0	7640.4	2.9	7744	-0.9
2	Y	M	0406pm	5.4		0.0		3.1	1.5	0.0	4.1	-8658.6	8656.3	5.7	8655.3	-1
3	O	F	0407am	3.9	2.3	-0.3	0.5	0.5	0.3	0.6	1.6	0.5	6626.7	4.2	6625.8	-0.9
4	Y	F	0407pm	3.2		0.0		2.1	0.4	1.0	1.6	0.7	3417.8	3.84	3416.4	-1.4
5	O	M	0415pm	16.1	2.5	-11.9	1.1	0.4	0.2	0.5	2.2	0.5	5553.7	4.02	5553.4	-0.3
6	Y	M	0417am	4.9		0.0		3.7	0.3	1.3	1.9	1.1	7005.5	3.44	7003.6	-1.8
7	*Y*	*F*	*0422pm*			*0.0*			*0.0*	*0.0*	*0.0*	*0.0*				
8	O	M	0423am	1.9		0.0		0.6	0.5	0.7	2.3	1.7	6415.6	3.52	6413	-2.7
9	O	M	0423pm	0.9		0.0	0.0		4615.8	0.5	2.3	0.4	4618.5	3.13	4617.2	-1.3
10	Y	M	0424am	2.5		0.0		1.2	0.5	0.7	2.0	0.3	6719.1	4.7	6717.4	-1.7
11	O	M	0424pm	6.8		0.0		4.8	0.9	0.9	1.0	0.5	6407	3.6	6405.7	-1.3
12	O	M	0428am	0.8		0.0	0.0		6042.2	1.6	1.4	1.5	6044.6	3.59	6043.7	-0.9
13	*O*	*F*	*0428pm*			*0.0*					*0.0*	*0.0*				
14	Y	F	0501pm	8.3		0.0		2.7	4.5	0.1	1.8	3.2	7294.5	5.93	7293.9	-0.6
16	Y	M	0506pm	3.1		0.0		2.3	0.3	1.2	0.1	2.4	7326.3	4.43	7325.8	-0.5
17	O	F	0507pm	3.6		0.0		2.3	0.3	1.7	0.6	0.4	8331	3.84	8330.4	-0.6
18	O	F	0511am	5.4	1.2	-2.8			7451.2	0.8	1.2	1.5	7453.1	3.22	7452.1	-1
19	Y	F	0511pm	0.8		-7862.8			7862.3	1.8	0.2	0.4	7864.6	2.31	7864.5	-0.1
20	Y	M	0513am			0.0					1.2	1.6				
21	Y	F	0513pm	15.9	2.7	-8.7	1.7	2.6	0.2	1.6	1.2	1.1	7471.4	3.24	7470.1	-1.3

Appendix L - ANOVA Tables

ANOVA (GLM) for maximum deceleration during manually control deceleration.

Analysis of Variance for ManualD

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Age	1	0.000840	0.000347	0.000347	0.30	0.591
Gender	1	0.000858	0.001239	0.001239	1.08	0.316
Age*Gender	1	0.001890	0.001890	0.001890	1.65	0.220
Error	14	0.016040	0.016040	0.001146		
Total	17	0.019628				

ANOVA (GLM) for distance at which maximum deceleration occurred during manual deceleration.

Analysis of Variance for MDRange

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Age	1	27593	27108	27108	3.08	0.101
Gender	1	23	7	7	0.00	0.978
Age*Gender	1	220	220	220	0.02	0.877
Error	14	123162	123162	8797		
Total	17	150997				

ANOVA (Balanced) for foot rest distance prior to movement toward the brake pedal.

Analysis of Variance for RestDist

Source	DF	SS	MS	F	P
Age	1	2.24	2.24	0.11	0.743
Gender	1	6.38	6.38	0.32	0.581
Age*Gender	1	2.11	2.11	0.11	0.750
Error	16	321.56	20.10		
Total	19	332.31			

ANOVA (GLM) for TTC when the driver moves from a rest position toward the brake pedal.

Analysis of Variance for RestTTC

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Age	1	15.29	13.36	13.36	0.47	0.504
Gender	1	0.02	0.01	0.01	0.00	0.982
Age*Gender	1	17.99	17.99	17.99	0.63	0.440
Error	15	428.54	428.54	28.57		
Total	18	461.83				

ANOVA for TTC at intervention.

Analysis of Variance for IntvTTC

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Age	1	2.0621	2.0032	2.0032	4.66	0.050
Gender	1	0.0663	0.0828	0.0828	0.19	0.668
Age*Gender	1	0.3414	0.3414	0.3414	0.79	0.389
Error	13	5.5835	5.5835	0.4295		
Total	16	8.0533				

ANOVA for maximum driver controlled deceleration after intervention.

Analysis of Variance for IntrvBrk

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Age	1	0.002647	0.002684	0.002684	1.10	0.313
Gender	1	0.000095	0.000095	0.000095	0.04	0.847
Age*Gender	1	0.000000	0.000000	0.000000	0.00	0.992
Error	13	0.031705	0.031705	0.002439		
Total	16	0.034447				

ANOVA for range at maximum driver controlled deceleration after intervention.

Analysis of Variance for IntvRng

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Age	1	727.4	647.3	647.3	1.22	0.290
Gender	1	16.9	8.3	8.3	0.02	0.903
Age*Gender	1	539.6	539.6	539.6	1.01	0.332
Error	13	6915.9	6915.9	532.0		
Total	16	8199.9				

ANOVA for minimum TTC during driver controlled deceleration after intervention.

Analysis of Variance for MinTTC

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Age	1	1.7401	1.7395	1.7395	2.04	0.177
Gender	1	0.5662	0.6233	0.6233	0.73	0.408
Age*Gender	1	0.5239	0.5239	0.5239	0.61	0.447
Error	13	11.0964	11.0964	0.8536		
Total	16	13.9265				

ANOVA on time difference between peak deceleration and minimum TTC during intervention.

Analysis of Variance for PeakDiff

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Age	1	0.0106	0.0026	0.0026	0.01	0.938
Gender	1	0.7674	0.7605	0.7605	1.81	0.202
Age*Gender	1	0.0026	0.0026	0.0026	0.01	0.938
Error	13	5.4700	5.4700	0.4208		
Total	16	6.2506				

Appendix M - Profile Comparison Tables

The tables below presents the comparisons of each of the five profiles for the scales. The cell entries indicate p-values for the comparison obtained during the Friedman test for two samples. Significant differences are denoted with an asterisk (*).

S1 - Comfortable vs. Uncomfortable					
	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5
Profile 1		0.020*	<0.001*	<0.001*	<0.001*
Profile 2			<0.001*	<0.001*	<0.001*
Profile 3				0.225	<0.001*
Profile 4					<0.001*
Profile 5					

S2 - Early vs. Late					
	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5
Profile 1		0.002*	0.001*	<0.001*	<0.001*
Profile 2			0.617	0.018*	<0.001*
Profile 3				0.029*	<0.001*
Profile 4					0.003*
Profile 5					

S3 - Safe vs. Unsafe					
	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5
Profile 1		0.052*	<0.001*	<0.001*	<0.001*
Profile 2			<0.001*	<0.001*	<0.001*
Profile 3				0.346	<0.001*
Profile 4					<0.001*
Profile 5					

S4 - Good vs. Bad					
	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5
Profile 1		0.808	<0.001*	<0.001*	<0.001*
Profile 2			<0.001*	<0.001*	<0.001*
Profile 3				0.317	<0.001*
Profile 4					0.002*
Profile 5					

S5 - Like me vs. Unlike me					
	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5
Profile 1		0.157	<0.001*	<0.001*	<0.001*
Profile 2			<0.001*	<0.001*	<0.001*
Profile 3				0.405	<0.001*
Profile 4					<0.001*
Profile 5					

S6 - Smooth vs. Jerky					
	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5
Profile 1		0.046*	<0.001*	<0.001*	<0.001*
Profile 2			<0.001*	<0.001*	<0.001*
Profile 3				0.285	0.003*
Profile 4					0.003*
Profile 5					

S7 - Soft vs. Hard					
	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5
Profile 1		0.029*	<0.001*	<0.001*	<0.001*
Profile 2			<0.001*	<0.001*	<0.001*
Profile 3				0.109	<0.001*
Profile 4					0.001*
Profile 5					

S8 - Natural vs. Unnatural					
	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5
Profile 1		0.029*	<0.001*	<0.001*	<0.001*
Profile 2			0.001*	<0.001*	<0.001*
Profile 3				0.808	0.002*
Profile 4					<0.001*
Profile 5					

S9 - Imperceptible vs. Alarming					
	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5
Profile 1		0.059*	<0.001*	<0.001*	<0.001*
Profile 2			<0.001*	<0.001*	<0.001*
Profile 3				1.000	<0.001*
Profile 4					0.002*
Profile 5					

Vita

Shane B. McLaughlin is currently a Human Factors Engineer at Ford Motor Company, where he is continuing research related to implementation of adaptive cruise control. While earning his M.S. in Human Factors Engineering, he was a Graduate Research Associate at Virginia Tech's Center for Transportation Research. During the summer of 1997, he was a Ford Intern working on adaptive cruise control modeling in the Automotive Safety Office and with the Advanced Vehicle Technology Division designing and conducting on-road experiments. He received a B.S. in Engineering Science and Mechanics from Virginia Tech in 1994. Prior to coming to Virginia Tech, Shane earned a B.S. in Business Administration and Management from Virginia Commonwealth University. He is a certified Engineer-in-Training in the State of Virginia and a Private Pilot.