Driver Acceptance of Connected, Automation-Assisted Cruise Control—Experiment 1

PUBLICATION NO. FHWA-HRT-18-041

JULY 2018

U.S. Department of Transportation
Federal Highway Administration

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

FOREWORD

This report documents the results and conclusions of an initial experiment that examined human-factors issues in the use of adaptive cruise control (ACC) and a hypothetical cooperative ACC (CACC), which is an ACC system enhanced with vehicle-to-vehicle (V2V) communications to share information on speed, brake position, and distance between vehicles. In this driving simulator–based experiment, the CACC system was modeled to accelerate and decelerate less aggressively when the ACC radar lost track of the vehicle ahead on a curve. In addition to testing driver responses to two cruise-control systems, three cruise-control displays were tested. One display showed only whether cruise control was turned on or off. A second display showed not only whether the display was on or off, but also whether the system was tracking another vehicle. A third display showed which vehicle was being tracked. Drivers of the CACC-equipped vehicle rated their trust in cruise control higher than drivers of the ACC-equipped vehicle did.

It was concluded that supplementing ACC with V2V communications may increase the use of CACC relative to ACC and enhance attendant safety benefits. Providing CACC tracking information similar to that provided in this study does not appear to distract drivers; however, additional testing in more complex driving environments is recommended. This research should be of interest to developers of Level 1–automated systems and to safety professionals seeking to understand the benefits and opportunities of this technology to improve roadway safety.

Monique R. Evans, P.E., CPM
Director, Office of Safety
Research and Development

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. FHWA-HRT-18-041	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle Driver Acceptance of Connected, Automation-Assisted Cruise Control—Experiment 1	5. Report Date July 2018
	6. Performing Organization Code: HRDS-30
7. Author(s) Vaughan W. Inman, Steven Jackson, and Peter Chou	8. Performing Organization Report No.
9. Performing Organization Name and Address Leidos, Inc. 6300 Georgetown Pike McLean, VA 22101	10. Work Unit No.
	11. Contract or Grant No. DTFH61-13-D-00024
12. Sponsoring Agency Name and Address Office of Safety Research and Development Federal Highway Administration 6300 Georgetown Pike McLean, VA 22101-2296	13. Type of Report and Period Covered Technical report; March 2016–June 2017
	14. Sponsoring Agency Code FHWA ITS JPO

15. Supplementary Notes
The Federal Highway Administration Task Manager was Brian H. Philips (HRDS-30).

16. Abstract

The results and conclusions of an initial experiment that examined human-factors issues in the use of adaptive cruise control (ACC) and a hypothetical cooperative ACC (CACC) in which ACC supplemented with vehicle-to-vehicle (V2V) communications to extend ACC capabilities. In this driving simulator–based experiment, the CACC system was modeled to accelerate and decelerate less aggressively when the ACC radar lost track of the vehicle ahead on a curve. In addition to testing driver responses to two cruise-control systems, three cruise-control displays were tested. One display showed only whether cruise control was turned on or off. A second display showed not only whether the display was on or off, but also whether the system was tracking another vehicle. A third display incorporated a video of the road ahead with the second display and indicated which vehicle was being tracked. Drivers of the CACC-equipped vehicle rated their trust in cruise control higher than drivers of the ACC-equipped vehicle did. Drivers looked at the second and third display types about 2 percent of the time. However, no glance longer than 0.73 s to any cruise-control display was observed. It was concluded that supplementing ACC with V2V communications may increase system use relative to ACC and provide additional safety benefits. Providing ACC tracking information similar to that provided in this study does not appear to distract drivers; however, additional testing in more complex driving environments is recommended. This research should be of interest to researchers and developers of Level 1–automated systems.

17. Key Words Level-1 automation, adaptive cruise control, ACC, cooperative adaptive cruise control, CACC, cruise-control display, trust, glance behavior	18. Distribution Statement No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161. http://www.ntis.gov

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 39	22. Price N/A

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized.

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^{o}F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^{o}C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^{o}C	Celsius	1.8C+32	Fahrenheit	^{o}F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ACC	adaptive cruise control
CACC	cooperative adaptive cruise control
GEE	generalized estimating equation
HDS	highway driving simulator
ID	identification
LIDAR	light detection and ranging
NASA	National Aeronautics and Space Administration
NHTSA	National Highway Traffic Safety Administration
SAE	Society of Automotive Engineers
SSQ	simulator-sickness questionnaire
TLX	Task Load Index
V2V	vehicle-to-vehicle

INTRODUCTION

This report is the first of a series of experiments focusing on human-factors issues of Level-1 vehicle automation.

The goals of this project are threefold:

1. Improve the general understanding of the human-factors issues related to vehicle automation.
2. Perform experiments to support research on Level-1 vehicle automation.
3. Publish information to support the development of standards and performance requirements for Level 1–vehicle automation.

At the time this project was initiated, the National Highway Traffic Safety Administration (NHTSA) defined four levels of vehicle automation: (NHTSA 2015)

- Level 0—no automation.
- Level 1—partial automation of either steering or braking and acceleration where the driver is expected to monitor and intervene as needed.
- Level 2—automation of steering and acceleration and braking with the driver still responsible for overriding the system as needed.
- Level 3—automation of the driving task with the driver expected to take control when requested by the system.
- Level 4—full automation of the driving task.

In 2016, after the initiation of this task, NHTSA adopted the Society of Automotive Engineers (SAE) International's definitions of the levels of automation, of which there are five. (SAE International 2016) The SAE International definitions primarily differ from NHTSA's previous definitions regarding Levels 4 and 5. SAE International's definition of Level 4 features full automation that would safely degrade if the driver does not respond to a request to take control, and Level 5 features automation that works everywhere a driver could go. The definition of Level 1, the focus of this report, was essentially unchanged.

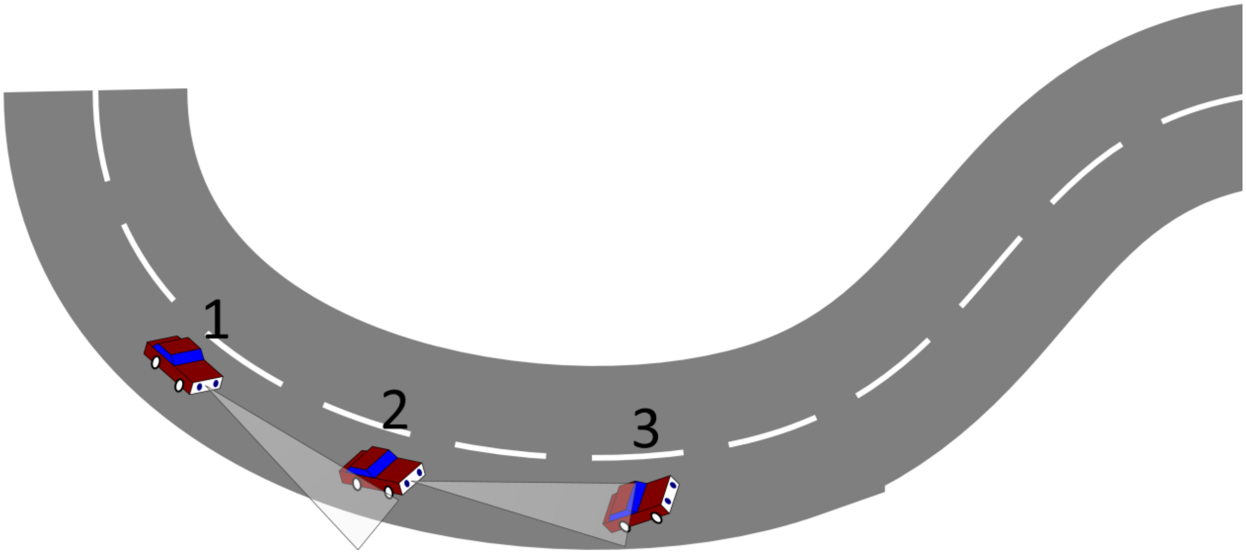
A recently completed literature review documented the information gaps in Level-1 automation with particular attention to connected-vehicle automation.[1] One of the gaps identified in that review was of how connected-vehicle technology might enhance driver acceptance of adaptive cruise control (ACC). The goal of this experiment was to address this gap. Factors assessed in this experiment were twofold: (1) whether simulated vehicle-to-vehicle (V2V) communications, which expanded the envelope of radar/light-detection-and-ranging (LIDAR) performance, might

---

[1] Leidos. (2016). *Human Factors Literature Review on Level 1 Vehicle Automation & Recommended Research Priorities*. Internal report for the Federal Highway Administration.

improve driver acceptance and use of the system and (2) whether the amount of information available to the driver might improve driver acceptance and use.

ACC reverts to conventional cruise-control behavior whenever the system cannot detect a leading vehicle. If a vehicle using ACC is following a slower vehicle (i.e., a lead vehicle traveling at less than the set speed of the host vehicle) on a hilly or winding road, uncomfortable accelerations can result when the vehicle ahead falls out of the line of sight of the ACC radar (figure 1). When the vehicle ahead comes back into radar sight, uncomfortable braking may follow as the system seeks to return the distance between vehicles to the set gap. ACC systems may not see narrow vehicles such as small motorbikes and, therefore, may not maintain a safe distance from those vehicles. On curves, ACC may track vehicles in another lane rather than the vehicle ahead in the host vehicle's lane. Users may interpret these types of events as system failures and lose trust in the system, which could result in disuse.



Source: FHWA.

Figure 1. Illustration. Example of limitation in radar/LIDAR on curves: vehicle 1 does not see vehicle 2, whereas vehicle 2 detects vehicle 3.

In a driving-simulation experiment, Nilsson et al. (2013) simulated system failures that might result from any of the aforementioned situations in the absence of any environmental cause for the failure (e.g., no hill, curve, or small vehicle was present). In this experiment, system failures occurred only in the presence of an appropriate environmental cause. If the user understands when and why the system will "fail," trust and use may not be as strongly affected by the system's limitations than if the user does not understand the limitations. (Dzindolet et al. 2003) Furthermore, if both the lead and following vehicles are equipped with V2V systems, then acceleration and braking due to radar/LIDAR envelope restrictions may occur less frequently. Also, small vehicles equipped with V2V systems may be detected and properly followed by the host vehicle. In this report, vehicles equipped with ACC and integrated V2V communications are referred to as equipped with cooperative ACC (CACC).

The following hypotheses were tested in experiment 1:

- A CACC system that follows lead vehicles over hills and around curves with minimal loss of tracking will obtain greater user trust and use than an ACC system that frequently loses track and longer periods of time.
- A driver–vehicle interface that contains information on what the system is tracking or why it is not behaving as expected/desired will lead to greater system trust and use than an interface that does not.

METHOD

The experiment was conducted using the Federal Highway Administration highway driving simulator (HDS). This section describes the simulator, the simulation environment, other equipment, and the participants.

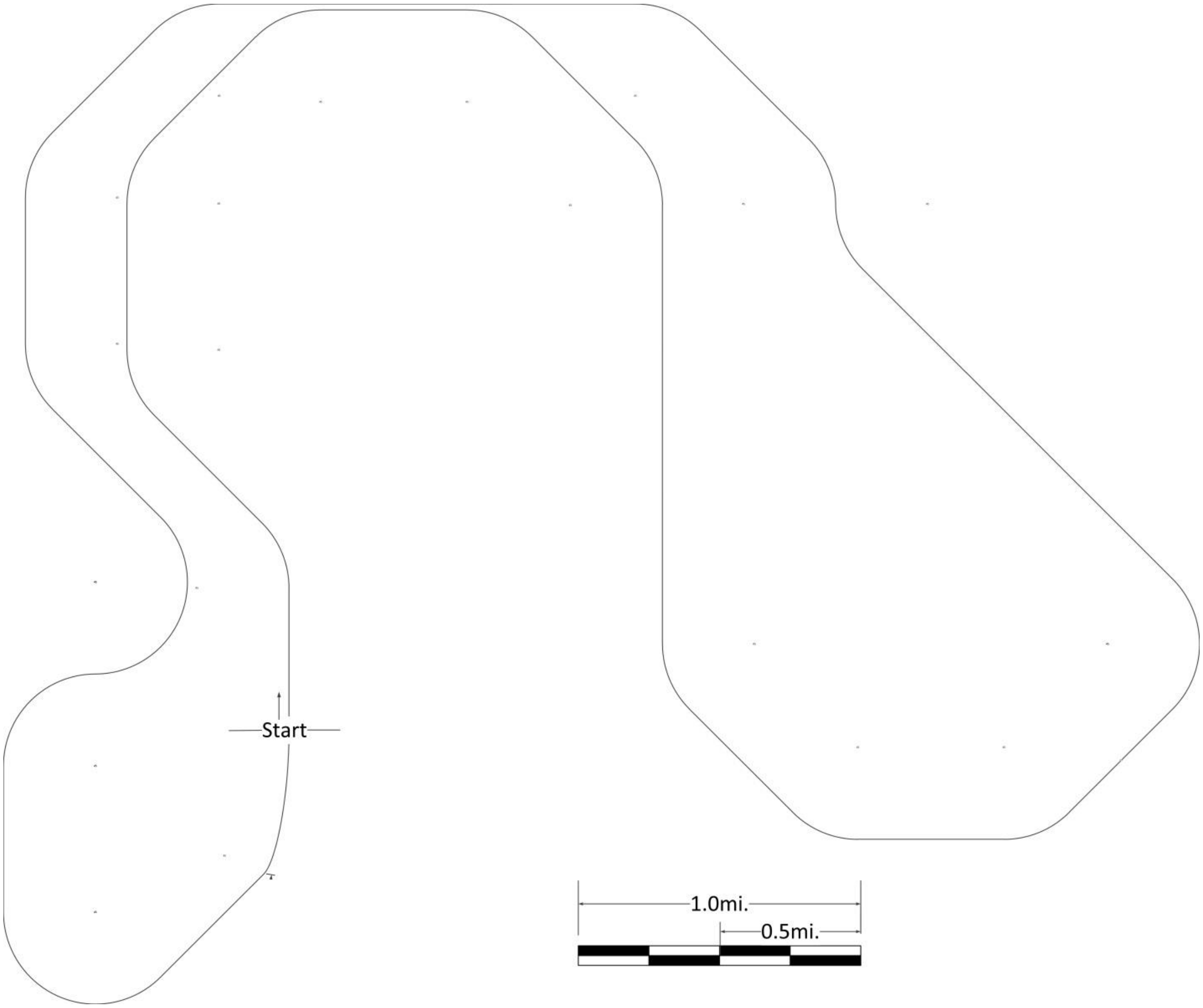
DRIVING SIMULATOR

The HDS consisted of a sedan mounted on a six-degrees-of-freedom motion base. A cylindrical screen provided a 200-degree-horizontal by 40-degree-vertical field of view of the driving environment. The screen cylinder had a radius of 8.9 ft. The driver's eye point varied with the seat position and ranged from 0 to 0.75 ft to the rear of the cylinder's center. The vehicle steering had a force-feedback controller. The brake and accelerator pedals provided spring-loaded resistance. All instrument displays were programmable. Images on the cylindrical screen were provided by three projectors. Each projector image consisted of 4,096 horizontal by 2,400 vertical pixels and updated at 60 Hz. The vehicle-dynamics model was tuned to simulate a generic, compact sedan. A bass shaker provided the feel of roadway vibrations, and wind-, engine-, and road-noise generation was linked to the vehicle dynamics.

SIMULATION ENVIRONMENT

A driving-simulator environment in which a standard ACC system would frequently lose track of a lead vehicle that traveled on an undivided four-lane road with many minimum-radius curves and some hills and sags was created. All horizontal curves had a 1,660-ft radius. Curve deflections were multiples of 45 degrees. The curves were connected by tangents that varied in length from 2,640 to 7,860 ft (0.5 to 1.5 mi). The roadway course is depicted in figure 2 and quantified in table 1.

There was always one other vehicle (the lead vehicle) present during the experiment. The other vehicle drove in the right lane at a constant 50 mph in the same travel direction as the participant. Participants began behind the other vehicle and were instructed to stay in the right lane and not pass. The instructions (see the Procedure section) were intended to ensure that the participant would use his or her vehicle's cruise-control system. To create an additional tracking challenge to the ACC/CACC system, the lead vehicle wandered within the right lane and occasionally weaved partway onto the shoulder. The lead vehicle's path was the same for all participants.



Source: FHWA.

Figure 2. Illustration. Horizontal curve layout of roadway course.

Table 1. **Numeric description of the course's horizontal and vertical curves.**

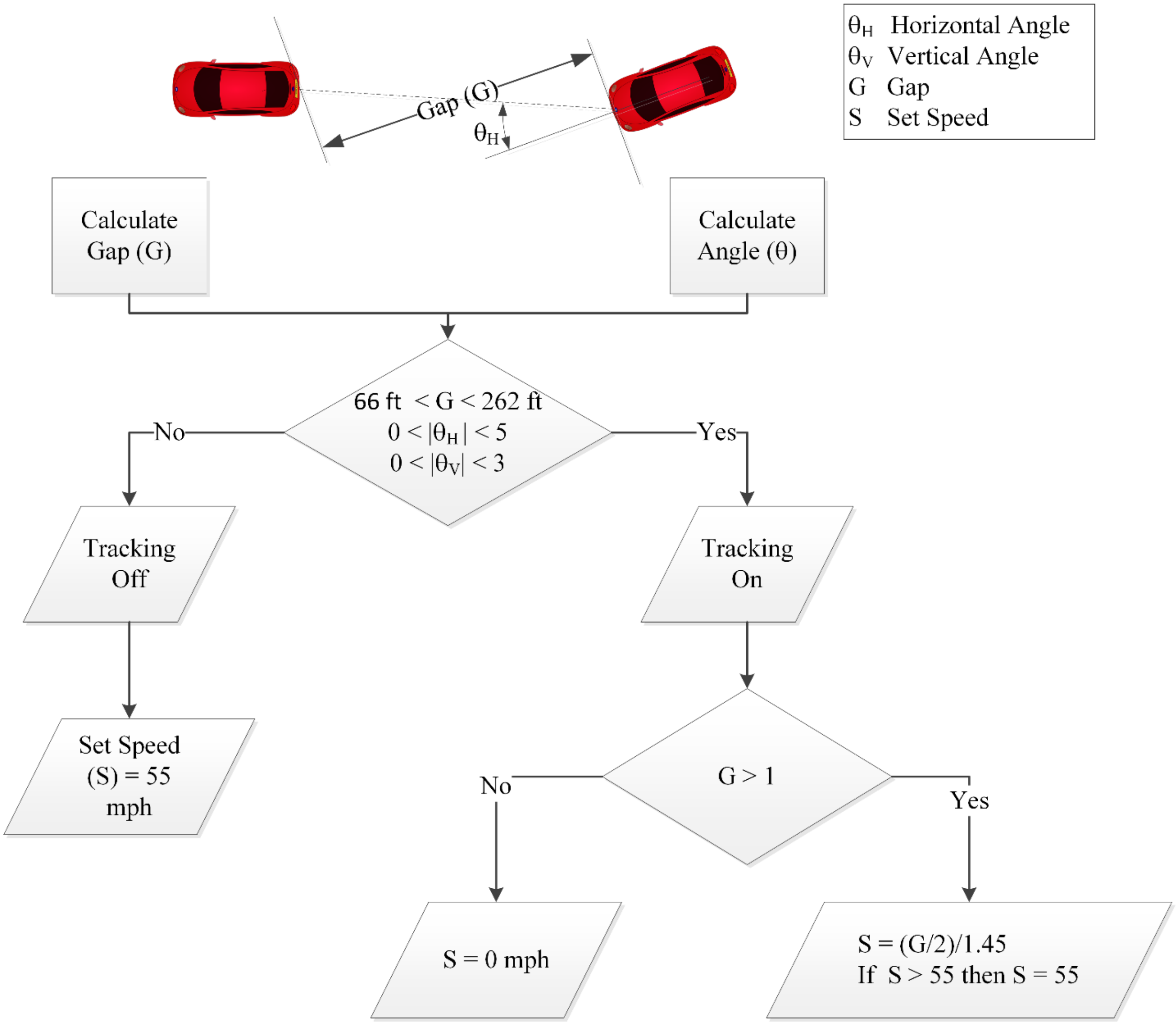
Curve Radius	Length (ft)	Name	Vertical Curvature	Degree of Deflection
0	2,640	Tangent	Level	0
1,660	1,304	Left	Sag 3%	45
0	2,760	Tangent	Level	0
1,660	1,304	Right	Level	45
0	2,640	Tangent	Level	0
1,660	1,304	Right	Level	45
0	2,598	Tangent	Level	0
1,660	1,304	Right	Level	45
0	2,640	Tangent	Level	0
1,660	1,304	Right	Level	45
0	1,640	Tangent	Level	0
1,660	1,304	Right	Level	45
0	7,920	Tangent	Hill 3%	0
1,660	1,304	Left	Level	45
0	2,640	Tangent	Level	0
1,660	1,304	Left	Level	45
0	2,640	Tangent	Level	0
1,660	1,304	Left	Level	45
0	2,640	Tangent	Grade 3%	0
1,660	1,304	Left	Hill 3%	45
0	7,920	Tangent	Hill 3%	0
1,660	1,304	Right	Level	45
1,660	1,304	Left	Level	45
0	2,760	Tangent	Grade 2.86%	0
1,660	1,304	Left	Level	45
0	7,920	Tangent	Level	0
1,660	1,304	Left	Level	45
0	2,598	Tangent	Level	0
1,660	1,304	Left	Level	45
0	2,640	Tangent	Hill 3%	0
1,660	1,304	Left	Level	45
0	2,760	Tangent	Level	0
1,660	3,911	Right	Level	135
1,660	1,304	Left	Level	45
0	2,640	Tangent	Level	0
1,660	2,608	Left	Level	90
0	2,640	Tangent	Level	0
<100	2,671	Left arc	Level	<5

CRUISE-CONTROL TYPES

Two types of cruise control were simulated: ACC and CACC. These types differed by how they responded to a loss of radar contact with the lead vehicle. ACC responded more quickly and aggressively to the loss of contact than CACC. CACC's behavior was intended to appear as if the system had information about the vehicle ahead that was not available to a line-of-sight sensor such as a radar or video image. For instance, short-range communications between vehicles might let the following vehicle know that the lead vehicle had not changed lanes or accelerated. With this information, CACC would not immediately respond by accelerating when radar contact was lost. Neither the ACC nor CACC simulations precisely modelled any known existing systems. Rather, they were meant to realistically reflect differences in behavior that might be expected between systems with only radar and systems with radar supplemented by V2V communications.

For both ACC and CACC, the cruise-control behavior depended on the distance between the lead and following (participant) vehicles, the angle between the headings of the two vehicles, and whether the lead vehicle was within the cone of detection of the participant vehicle's radar. The distance between the lead-vehicle heading and the participant-vehicle heading was measured by a line connecting the center of the rear bumper of the leading vehicle and the center of the front bumper of the participant vehicle (figure 3). The simulated radar tracked the lead vehicle if that distance was between 66 and 262 ft and the heading angle was within a cone of plus or minus 5 degrees horizontal and plus or minus 3 degrees vertical. If the distance between vehicles was between 3 and 66 ft, then the system tracked with a heading cone of 90 degrees horizontal and vertical. The latter tracking behavior hindered the participant from passing the lead vehicle.

When the system was not tracking the vehicle ahead and cruise control was on, the participant vehicle's set speed was 55 mph. If cruise control was on and the gap to the vehicle ahead was less than 3 ft, then the set speed was 0 mph, which resulted in a maximum deceleration of 0.4 g. If the gap was greater than 3 ft and the system was tracking the vehicle ahead, then the target speed of the participant's vehicle was adjusted to create a 2-s gap between it and the vehicle ahead. The simplified decision tree for adjusting the set speed for both cruise-control types is shown in figure 3 (the case where the gap was less than 3 ft is omitted).



Source: FHWA.

Figure 3. Flowchart. Simplified decision tree for ACC set speed.

The simulator's vehicle-dynamics model had a proprietary cruise-control algorithm that was used as an intermediary in simulating ACC and CACC. When the set speed of the participant vehicle was more than 0.5 mph above the desired speed (figure 3), a message was sent to the vehicle-dynamics model to change the set speed of the cruise-control system. For ACC, the set speed could be increased by up to 3.8 mph. For CACC, when the desired set speed was greater than the current set speed, the set speed was incremented by 1 mph for every 1 s that the gap remained less than 2 s. The difference between ACC and CACC changes in set speed resulted in less abrupt changes with CACC, of which the intent was to simulate the expected result if V2V communications would restrain responses to loss of the radar's line of sight. When the computed set speed (*S*) was below the current speed by more than 0.5 mph, and the gap was less than 0.8 s, *S* was sent to the vehicle-dynamics model. If the gap was between 0.8 and 2.0 s, *S* was sent to the vehicle-dynamics model with the restriction that either (1) the set speed not be less than 42.9 mph with ACC or (2) the set speed not be less than 46.33 mph with CACC.

DISPLAY TYPES

There were three display types that varied in the amount of information they provided to the driver. The cruise-control information was displayed in one of two areas: to the right of the speedometer in the instrument cluster directly in front of the driver or on a large display at the bottom of the center stack next to the driver's right knee.

The first display type, cruise on/off, had the least information. It showed only whether the cruise-control system was on or off, and the display was the same for ACC and CACC. Figure 4 shows the instrument cluster with cruise control on. When cruise control was off, the right side of the instrument cluster with the cruise on/off display was blank.

Source: FHWA.

Figure 4. Photo. Instrument cluster with display showing cruise control on.

The second display type, tracking status, showed whether the cruise-control system was on and whether it was tracking another vehicle in the participant's lane. Figure 5 shows the instrument cluster with this second display type when ACC was tracking a vehicle ahead. When the system was not tracking a lead vehicle, the green text "TRACKING" was replaced with red text that read "NO TRACK." The CACC's tracking-status display had an additional icon to the left of the tracking message accompanied by a "CONNECTED" legend. The "CONNECTED" icon, shown in figure 6, was displayed whenever CACC was on as there was always a vehicle ahead during the simulation.

Source: FHWA.

Figure 5. Photo. Instrument cluster with display of tracking status.

Source: FHWA.

Figure 6. Photo. CACC connected icon.

The third display type, tracking status with video, showed a camera view of the road ahead and placed a green rectangle around the lead vehicle that the cruise-control radar was tracking. This feature would be most useful if there were more than one vehicle ahead and the system could be tracking a vehicle in a lane other than the participant's current lane. Such errors could occur on curves. In this experiment, there were no vehicles other than the one ahead in the same lane, so the addition of video was of limited, if any, value beyond the redundancy of a box being displayed whenever the "TRACKING" text was displayed. Figure 7 provides an example of this display type that included video.

Source: FHWA.

Figure 7. Photo. ACC instrument cluster with video of the road ahead.

EQUIPMENT

An eye tracker was used to assess the proportion of time the participant monitored the road ahead versus the in-vehicle displays. The primary focus was on whether the display type affected this proportion.

PROCEDURE

Upon arrival at the research center, each participant was requested to review and sign an informed-consent form and show a valid driver's license. Next, participants were asked a few questions regarding their present state of health to ensure they were not at increased risk of simulator sickness. The health screen was followed by a vision test to ensure participants met the minimum visual acuity requirement of 20/40 or better in at least one eye.

There was a possibility that participants' previous cruise-control use and experience would influence the results of this experiment. To enable some adjustment for this possibility, a driving-history questionnaire was administered to assess prior cruise-control experience. The questionnaire requested the following information:

- Annual miles driven.
- Years of driving experience.
- Whether the participant had a vehicle with cruise control, and if so, whether it was conventional or adaptive.
- Frequency of cruise-control use.
- In what situations cruise control was used (e.g., on all types of roads or highways, in heavy traffic).
- Cruise control likes.
- Cruise control dislikes.

Following completion of the driving-history questionnaire, participants were seated in the driving simulator and briefed on the vehicle's features. The eye-tracking cameras were then adjusted to ensure that the participant's head was centered. A practice drive followed on a straight road that had been used in a previous study. During the practice drive, participants were asked to accelerate to 55 mph, brake, and change lanes four times, twice gently and twice more aggressively. They were then asked to engage cruise control and let it control their speed. With cruise control on, the vehicle gradually gained on the vehicle ahead and then slowed to maintain a 2-s gap behind the lead vehicle. The portion of the practice drive in which participants followed the lead vehicle lasted about 10 min, after which they were asked to park the car, exit the vehicle, and complete a simulator-sickness questionnaire (SSQ). (Kennedy et al. 1993)

After completing the questionnaire, participants reentered the vehicle and an eye-tracker-calibration check was performed. Instructions to participants varied depending on which cruise-control and display type they were assigned. The following sections include the instructions given to the participants per cruise-control type.

ACC With Cruise on/off

> This vehicle has an adaptive cruise control. It has radar to detect a vehicle ahead in your lane. It will adjust your speed to maintain a 2 s distance (161 ft at 55 mph) behind slower vehicles. The cruise control is set to 55 mph and your following distance set to FAR (2 s). There will be a car ahead of you traveling at 50 mph. When the radar detects that car, you will slow. When the radar cannot detect the car, you will accelerate to 55 mph. The system can lose track of the car ahead on hills and curves. When it loses track of the car ahead, your car will accelerate. If it accelerates too quickly, you may need to brake to avoid getting too close to the vehicle ahead. When the radar spots the car ahead, your car will slow. Drive as you normally would. But stay in the right lane. Drive with the cruise control on whenever possible. If you brake, then as soon as it is safe, turn the cruise control back on with the ON button on the left side of the steering wheel hub. I may remind you to turn the cruise control back on. When the adaptive cruise control is engaged, the cruise control display in the instrument cluster will show this icon [The researcher pointed at the green icon on an instruction sheet].

ACC With Tracking Status and ACC With Tracking Status and Video

The instructions for these two groups were the same except that the image shown to the participant was appropriate for the assigned display condition.

> This vehicle has an adaptive cruise control. It has radar to detect a vehicle ahead in your lane. It will adjust your speed to maintain a 2 s distance (161 ft at 55 mph) behind slower vehicles. The cruise control is set to 55 mph and your following distance set to FAR (2 s). There will be a car ahead of you traveling at 50 mph. When the radar detects that car, you will slow and a green TRACKING message will display. The system can lose track of the car ahead on hills and curves. When it loses track of the car ahead, your car will accelerate. If it accelerates too quickly, you may need to brake to avoid getting too close to the vehicle ahead. When the radar regains tracking of the car ahead, it will slow to restore the 2 s gap. Drive as you normally would. But stay in the right lane. Drive with the cruise control on whenever possible. If you brake, then as soon as it is safe, turn the cruise control back on with the ON button on the left side of the steering wheel hub. I may remind you to turn the cruise control back on. When the adaptive cruise control is tracking a car ahead, the symbols on right side of the instrument panel will be green and look like those in the figure [The researcher pointed to the “TRACKING” icon on an instruction sheet].

CACC Cruise on/off

> This vehicle has a cooperative adaptive cruise control. It has radar to detect a vehicle ahead in your lane. It also communicates wirelessly with other vehicles so that it may see vehicles when the radar cannot. It will adjust your speed to maintain a 2 s distance (161 ft at 55 mph) behind slower vehicles. The cruise control is set to 55 mph and your

> following distance set to FAR (2 s). There will be a car ahead of you traveling at 50 mph. When the system detects that car, you will slow. When the system cannot detect the car, you will accelerate to 55 mph. The system can lose track of the car ahead on hills and curves. When it loses track of the car ahead, your car will accelerate. If it accelerates too quickly, you may need to brake to avoid getting too close to the vehicle ahead. When the system spots the car ahead, your car will slow. Drive as you normally would. But stay in the right lane. Drive with the cruise control on whenever possible. If you brake, then as soon as it is safe, turn the cruise control back on with the ON button on the left side of the steering wheel hub. I may remind you to turn the cruise control back on. When the adaptive cruise control is engaged, the cruise control display in the instrument cluster will show this icon [The researcher pointed at the green icon under 55 mph].

CACC With Tracking Status and CACC With Tracking Status and Video

The instructions for these two groups were the same except that the image shown to the participant was appropriate for the assigned display condition.

> This vehicle has a cooperative adaptive cruise control. It has radar to detect a vehicle ahead in your lane. It also communicates wirelessly with other vehicles so that it may see vehicles when the radar cannot. It will adjust your speed to maintain a 2 s distance (161 ft at 55 mph) behind slower vehicles. The cruise control is set to 55 mph and your following distance set to FAR (2 s). There will be a car ahead of you traveling at 50 mph. When the system detects that car, you will slow and a green TRACKING message will display. The system can lose track of the car ahead on hills and curves. When it loses track of the car ahead, your car will accelerate. If it accelerates too quickly, you may need to brake to avoid getting too close to the vehicle ahead. When the radar regains tracking of the car ahead, it will slow to restore the 2 s gap. Drive as you normally would. But stay in the right lane. Drive with the cruise control on whenever possible. If you brake, then as soon as it is safe, turn the cruise control back on with the ON button on the left side of the steering wheel hub. I may remind you to turn the cruise control back on. When the cooperative adaptive cruise control is tracking a car ahead, the symbols on right side of the instrument panel will be green and look like those in the figure [The researched pointed to the connected and “TRACKING” icons].

Following the drive, which took approximately 23 min, participants were administered three questionnaires: an SSQ, a workload-assessment questionnaire from the National Aeronautics and Space Administration (NASA) (2009), and a trust questionnaire adapted from Madsen and Gregor (2000). Last, participants were debriefed and paid for their participation.

EXPERIMENTAL CONDITIONS

The factorial combination of control displays and cruise-control types is shown in table 2. The factors were between groups—there were no repeated measures.

Table 2. Research design.

Display	Control
Cruise on/off	ACC
Tracking status	ACC
Tracking status with video	ACC
Cruise on/off	CACC
Tracking status	CACC
Tracking status with video	CACC

DEPENDENT MEASURES

The planned dependent measures were as follows:

- Total duration of cruise-control engagement.
- Number of times a request to reengage was required.
- Subjective workload.
- Trust rating.
- Eye-glance behavior.

Total Duration of Cruise-Control Engagement

Total duration of cruise-control engagement was somewhat problematic as the participants were instructed to use cruise control whenever possible. The delay, however, in reengaging cruise control after a need to brake (disengage) may be interpretable. Participants who were not comfortable with cruise control might have been expected to wait longer to reengage and may have disengaged sooner. Another factor that made this variable problematic was that there may never have been a real need to disengage the system; although, for a few participants, there was a need to brake because certain combinations of the lead vehicle’s lane position and participant vehicle’s lane position resulted in a prolonged loss of tracking.

Number of Times a Request to Reengage Was Required

The researcher directed the participant to resume cruise control if the participant had not done so within about 5 s of reaching a tangent section of the roadway. The number of times the participant needed to be prompted to resume was assumed to be a measure of discomfort with the cruise-control system.

Trust Rating for the Cruise-Control System

Use of cruise control depends, in part, on whether the driver feels that the automation helps his/her driving performance and is dependable and safe. Trust is a theoretical construct, so there is no objective way to measure it, and only a few tools have been developed that attempt to measure it in a way that is reliable and consistent with theories of trust. Relying on user performance or system use to assess trust relies on a tautology: If it is used, it is trusted, or if it leads to better performance, it is trusted. Inferring trust from performance, therefore, provides no additional information. Perhaps the best available subjective measure of trust is one developed by Madsen and Gregor (2000), who defined trust in automated systems as "the extent to which a user is confident in, and willing to act on the basis of, the recommendations, actions, and decisions of an artificially intelligent [system]." The questionnaire Madsen and Gregor developed was intended to reflect what they view as two separate aspects of trust. One of those aspects was called cognitive-based trust, which may be viewed as rational reactions to experience (e.g., the system does what it is designed to do and is reliable). The other aspect was called affect-based trust, which relies more on emotional reactions to experience as well as faith (not based on direct experience) that the system was designed well. Their instrument was designed to assess trust in automated-decision aids, not automated control systems, such as cruise control; however, after some adaptation, the questions appeared to work well for the present purpose.

Previous research suggested that the questionnaire would lead to two factors, one for cognitive-based trust and one for affect-based trust. It was proposed that the factor scores for these would vary with experimental treatment. Both aspects of trust were expected to vary with the performance of the cruise-control system (CACC versus ACC), and both elements of trust were predicted to vary with the degree of information provided by the in-vehicle display.

NASA Task Load Index

The NASA Task Load Index (TLX) is widely used to assess mental workload. (NASA 2009) Its elements seek to elicit some of the same factors as the trust-rating scale (e.g., performance and frustration), so some correlation between the two scales might be expected. It was hypothesized that more information on what cruise control was doing (via the in-vehicle interface) would lead to reduced workload, as would ACC supplemented by V2V communications (CACC).

Eye-Glance Behavior

As the amount of information on the in-vehicle display increases, the amount of time participants look at that display might be expected to increase. Increased glances to the in-vehicle display should not have been problematic if those glances were not frequent or prolonged. Glances to the in-vehicle displays were quantified by frequency and duration. Glance behavior of drivers when approaching or in vertical- and horizontal-curvature segments was also contrasted with glance behavior on tangents.

PARTICIPANTS

The participants were 96 licensed drivers. There were equal numbers of male and female participants, with a median age of 46 yr. Each of the 6 participant groups (2 cruise-control types by 3 display types) had 16 randomly assigned participants with the constraint that each group contained an equal number of males and females, half of whom were over the age of 46. Table 3 summarizes the miles driven in the previous year as reported on the questionnaires completed before the driving-simulation sessions.

Table 3. Participants' self-reported number of miles driven in the previous year.

Miles Driven	Number of Participants
<5,000	6
5,000 to 10,000	27
10,000 to 25,000	49
>25,000	13
No response	1

Most of the participants, 87 of 96, stated that the vehicle they most often drove was equipped with some kind of cruise control. Only 4 participants claimed to have ACC in the vehicle they drove most often, while 11 others were uncertain or declined to state the type of cruise control in their vehicle. Participants were also asked how often they used cruise control. Table 4 summarizes the frequency of responses to that question.

Table 4. Self-report frequency of cruise-control use.

Frequency	Number of Participants
Never	20
Rarely	36
Occasionally	22
Often	12
Almost every trip	6

As seen in table 5, the majority of participants only used cruise control on highways in light traffic.

Table 5. Frequency of responses to "In what situation are you most likely to use cruise control?"

Response	Number of Participants
On highways with light traffic	68
On highways even in heavy traffic	5
On all types of roads in light traffic	13
On all types of roads regardless of traffic	4
No response	6

RESULTS

Loss of the tracking lock occurred with both cruise-control types. All losses greater than 50 ms in duration were counted, and the median loss duration was calculated for each participant. A generalized-estimating-equation (GEE) model with negative binomial response distribution, log link function, and clustered on participant found that the number of lock losses did not vary as a function of cruise-control type: Wald χ^2 (1) = 1.55, $p = 0.21$. As intended, lock loss occurred more frequently on curves than tangents: Wald χ^2 (1) = 446.08, $p < 0.0001$. It is important to note, however, that the classification of being on a curve or tangent refers to the location of the participant vehicle only. As a result of ACC-lock losses occurring more often on tangents than CACC losses, while CACC-lock losses occurred slightly more frequently than ACC-lock losses on curves, the interaction of cruise-control type and segment type was significant: Wald χ^2 (1) = 5.59, $p = 0.02$. On tangents, ACC lost lock an average of 7.6 times compared to CACC's 5.5 times, whereas on curves, ACC lost lock an average of 39.5 times compared to CACC's 43.8 times. A similar model found that lock-loss duration varied significantly with segment type: χ^2 (1) = 51.15, $p < 0.0001$. The median duration of lock loss was approximately 2.4 s for both cruise-control types but significantly higher on tangents ($M = 3.6$ s) than on curves ($M = 1.6$ s).

It was hypothesized that users would be more willing to use cruise control if it were more reliable and if better information were available about when it was tracking the vehicle ahead. Because participants were required to use cruise control, testing willingness to use based on frequency and duration of use was problematic. However, to understand workload, trust, and future willingness to use, it was important to begin the analysis by examining how the participants used the cruise-control systems. Eye-glance behavior was also analyzed to identify the effects of providing varying levels of visual information.

CRUISE-CONTROL USE

For analysis purposes, the driving course was broken into 40 segments, with each curve and tangent defining a segment. Because participants began the drive while stopped and because cruise control did not function below 25 mph, not all participants engaged cruise control and caught up to the lead vehicle within the same segment. Preliminary analysis showed that all participants were within cruise-control range of the lead vehicle by the sixth segment. Also, drivers began slowing and disengaging cruise control at the researcher's request on the final segment. Therefore, analysis focused on 34 segments, beginning with the 6th segment (the 3d curve, a 45-degree deflection to the right) and ending with the 39th (a tangent). With the exception of two participants, it took 20.5 min to complete the 34 segments. The driving simulator failed near the end of the drive for two participants. Their data were retained, and the differences in exposure were accounted for in the statistical analyses.

Table 6 shows the mean proportion of time cruise control was engaged. Preliminary analysis showed that one participant was within radar range of the vehicle ahead only 68 percent of the drive. No other participant was in range less than 90 percent of the time. This participant (a member of the group with ACC and the on/off display) was excluded from subsequent analyses.

Averaging over display types, the ACC and CACC groups had cruise control engaged 97 and 98 percent of the time, respectively. A generalized linear model using a negative binomial response distribution and log link function was used to test for the significance of cruise-control and display types on the duration of cruise-control use. The logarithm of total drive time was used as a model offset (i.e., a measure of exposure). No statistically significant difference was found between display type, cruise-control type, and their interaction. Another model was fit using the logarithm of the total time during which the participant was within sensor range of the lead vehicle (262 ft) as the offset. This model also failed to find any statistically significant differences. Additional models were estimated using participant experience (e.g., annual miles driven) and segment type (curve or tangent) as independent variables, but none indicated a predictable difference in cruise-control usage.

Table 6. Mean minutes with cruise control engaged.

Control Type	Display Type: on/off	Display Type: Tracking Status	Display Type: Video
ACC	19.3	19.4	19.7
CACC	19.8	19.7	19.5

Note: Table includes data for all 96 participants.

CRUISE-CONTROL DISENGAGEMENT

Another measure of cruise-control use is the number of times cruise control was disengaged by use of the brake. All other things being equal, the number of disengagements would also be expected to affect the proportion of time cruise control was engaged. One participant disengaged a total of 31 times, nearly three times the next highest value of 11, and was excluded as an outlier (along with the participant who was only within sensor range of the lead vehicle 68 percent of the drive). A generalized linear model using a negative binomial response distribution and log link function was used to test for the significance of cruise-control and display types on the number of cruise-control disengagements. Cruise-control type was found to significantly affect the number of disengagements: Wald χ^2 (1) = 6.91, $p = 0.01$. Participants driving with ACC disengaged an average of 2.00 times compared to participants driving with CACC who averaged 0.68 disengagements. Display type and the interaction of display and cruise control type were not significant predictors of disengagement frequency, nor were any questionnaire responses in regard to cruise-control experience.

CRUISE CONTROL–REENGAGEMENT REQUESTS

Requests to reengage cruise control did not happen frequently enough to warrant analysis. Of the 95 participants included in this analysis, only 38 ever disengaged. Of those, only six were ever asked to reengage. These six were equally distributed among the ACC–on/off, ACC–tracking, and CACC–tracking groups. Participants in the video group never manually disengaged and thus were never requested to reengage.

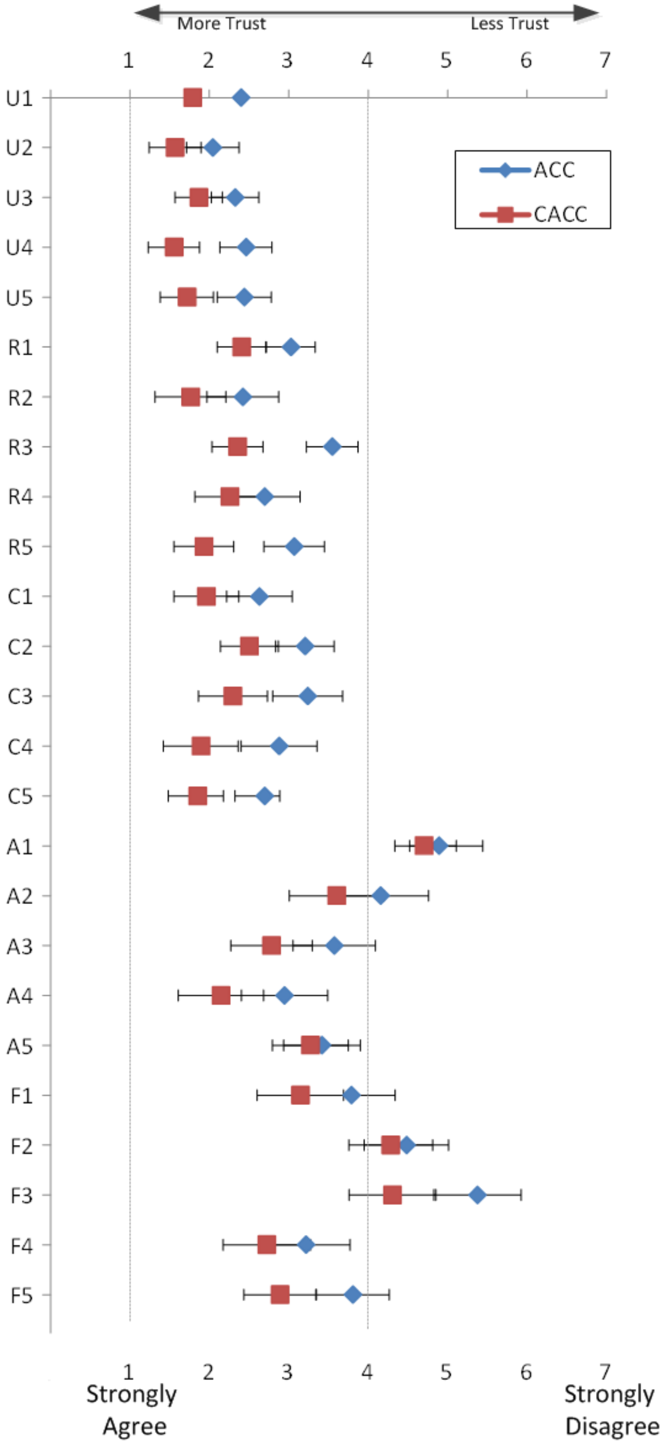
WORKLOAD

Overall workload was rated low by all groups. The mean on the NASA-TLX scale, which has a theoretical range from a minimum of 0 and a maximum of 100, was 23.8. Workload did not vary as a function of either cruise-control or display type.

TRUST

As seen in figure 8, participants in the CACC groups consistently expressed a greater degree of trust in the cruise-control system than did those in the ACC groups. A multivariate analysis of variance with the 25 trust questions as dependent measures and cruise-control type, display type, and their interaction as independent variables showed that only cruise-control type influenced trust: $F(25, 63) = 1.75$, $p = 0.038$. The key to the labels on the vertical axis in figure 8 can be found in table 7, which provides the complete text of each question. The trust ratings of the 93 participants who had complete data were submitted to factor analysis. Preliminary analyses suggested three factors could account for 88 percent of the shared variance, with an additional two factors accounting for an additional 7 percent of the variance. Multiple exploratory factor analyses were pursued with various methods of estimating communalities as well as alternative factor-rotation methods. It was decided that the three-factor, maximum-likelihood solution with Promax oblique rotation yielded the most interpretable solution (shown in table 7). A factor-pattern loading minimum of 0.4 was used for determining which questions loaded on which factors. The variable identification (ID) in the first column refers to the similarly worded questions developed by Madsen and Gregor (2000), who designed a questionnaire intended for evaluating trust in decision-support systems. Their questionnaire was deemed to reflect five factors: three cognitive factors and two affect-based factors. The two affect-based factors were clearly also reflected in the trust ratings participants gave the cruise-control system. The Madsen and Gregor individual cognitive constructs (understanding, reliability, and consistency) were not uniquely identified in the present three-factor solution nor in the five-factor solution; however, the cognitive factor, which contained all but two of the items that make up their cognitive construct, accounted for 69 percent of the common variance in participant responses. As seen in, table 7 two items (C3 and R4) failed to load on any factor.

The three factors in the present solution were correlated. The correlations between the factors, shown in table 8, suggest that affect and cognitive trust are not completely independent. Participants who had faith in the systems and felt some attachment to them also showed greater cognitive (rational) trust in the systems.



Source: FHWA.

Note: Error bars represent 95-percent confidence interval for the mean.

Figure 8. Chart. Means and 95-percent confidence limits of trust-questionnaire ratings.

Table 7. Three-factor solution.

ID	Trust Statement	Cognitive Trust	Attachment	Faith
U1	I know what will happen the next time I use the cruise-control system because I understand how it behaves.	**0.75**	0.08	–0.13
U2	I understand how the system will assist me in maintaining a following distance to a vehicle ahead in my lane.	**0.51**	0.19	–0.03
U3	Although I may not know exactly how the cruise-control system works, I know how to use it to control my following gap.	**0.54**	0.17	–0.24
U4	It is easy to follow what the cruise-control system is doing.	**0.63**	–0.02	0.19
U5	I recognize what I should do to maintain a set following distance the next time I use the cruise-control system.	**0.81**	–0.02	–0.25
R1	The cruise-control system always provides an adequate following distance.	**0.60**	–0.06	0.29
R2	The cruise-control system performs reliably.	**0.66**	0.13	0.19
R3	The cruise-control system responds the same way under the same conditions at different times.	**0.51**	–0.04	0.38
R4	I can rely on the cruise-control system to function properly.	0.32	0.33	0.31
R5	The system analyzes following distance consistently.	**0.71**	–0.18	0.24
C1	The cruise-control system uses appropriate methods to determine following distance.	**0.67**	0.01	0.16
C2	The cruise-control system has sound algorithms for determining the required acceleration and braking.	**0.63**	0.11	–0.18
C3	The cruise-control system regulates following distance as well as a highly competent driver.	0.31	0.23	0.18
C4	The cruise-control system correctly uses the speed and gap information that I enter.	**0.76**	–0.01	–0.03
C5	The cruise-control system makes use of all the available information to determine the correct speed to maintain the selected following distance.	**0.67**	–0.14	0.23
A1	I would feel a sense of loss if the cruise-control system was unavailable and I could no longer use it.	–0.22	**0.60**	0.14
A2	I feel a sense of attachment to using the cruise-control system.	0.01	**0.78**	0.10
A3	I find the cruise-control system suitable to my style of driving.	0.08	**0.70**	0.09
A4	I like using the cruise-control system.	0.15	**0.81**	–0.07
A5	I have a personal preference for relying on the cruise-control system.	0.13	**0.63**	–0.10
F1	I believe the cruise-control system can be depended on even when I don’t know for certain that its braking and acceleration choices are correct.	0.11	0.03	**0.72**
F2	When I am uncertain about whether to override the cruise-control system, I rely on cruise control.	–0.22	0.09	**0.71**
F3	When I am uncertain about what the cruise-control system is doing, I rely on it rather than myself.	–0.16	–0.06	**0.77**
F4	When cruise control engages in unusual speeding up or slowing down, I am confident that it is doing the right thing.	0.25	0.23	**0.42**
F5	Even if I have no reason to expect that the system will be able to safely follow the vehicle ahead, I still feel certain that it will.	0.14	0.22	**0.46**

Note: Variables with loadings greater than 0.4 and shown in bold face were deemed to define a factor.

Table 8. Correlation between factors.

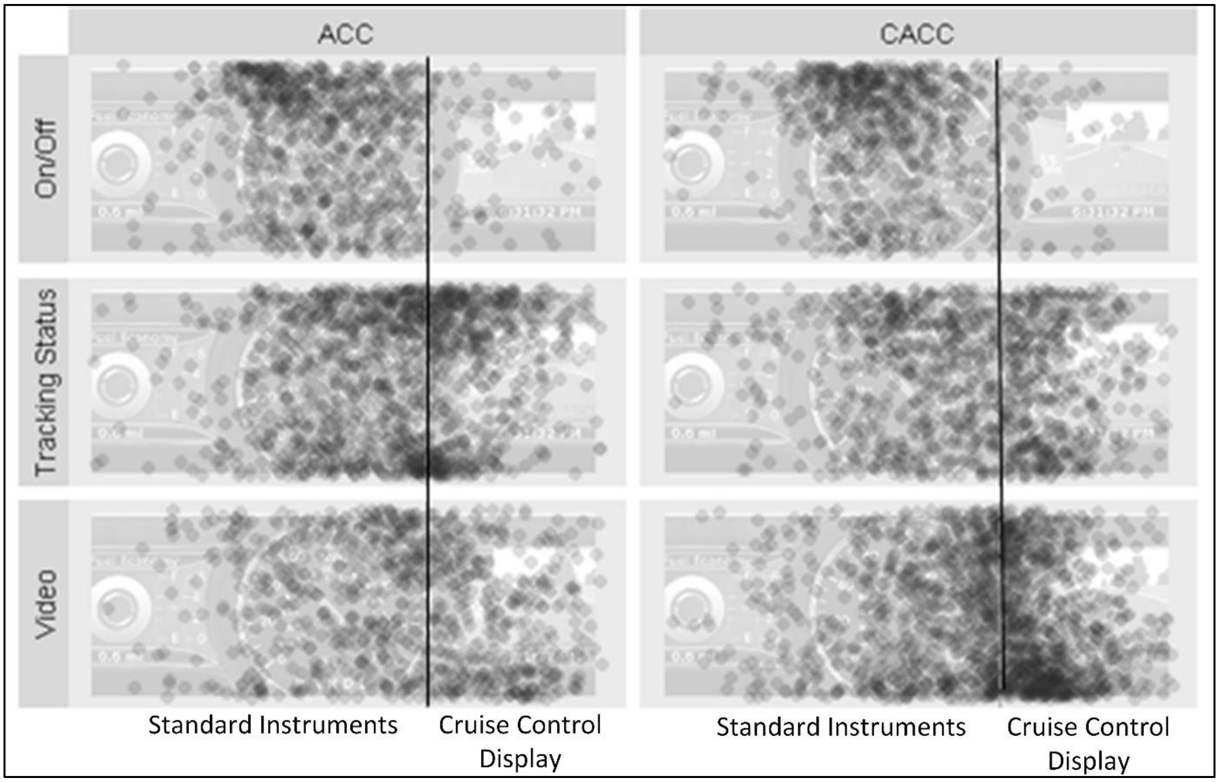
Factor	Cognitive	Faith	Attachment
Cognitive	1.00	0.51	0.55
Faith	0.51	1.00	0.43
Attachment	0.55	0.43	1.00

EYE-GLANCE BEHAVIOR RESULTS

The duration and frequency of glances to the cruise-control displays were expected to vary with the amount of information those displays conveyed. The on/off display presented minimal information and was expected to receive only a few short glances, whereas the tracking status with video display presented more information and, therefore, was expected to receive more, perhaps longer, glances. The tracking-status display (without video) was expected to fall in between the other two displays with respect to both number and duration of glances.

Gaze direction was sampled at 120 Hz (i.e., 120 times per s). A glance was defined as six or more consecutive samples (i.e., greater than or equal to 50 ms) of participants' eyes regarding the same object. The instrument panel was approximately 12 inches wide and 3.3 inches tall, but the cruise-control information (the region of interest) was contained within the right third of that panel. An assumed distance of 24 inches between the driver's eyes and the cruise-control display subtended 7.9 degrees of visual angle.

Gaze-direction quality, as recorded by the eye-tracking software, varied from sample to sample for a variety of reasons. Only glances with median quality values of 0.40 or greater (on a scale from 0 to 1) were included. Figure 9 shows a map of where glances to the instrument display were recorded. Each dot represents a glance of at least 50 ms, and the darker dots represent overlapping hits in the same location.



Source: FHWA.

Figure 9. Heat map. Glance behavior to the instrument panel.

Glance Behavior as a Function of Gap Situation

On a 20-min trip, it is unlikely that glances to the cruise-control display would be evenly distributed over time. Therefore, glances to the cruise-control display were classified as occurring in one of the following three situational periods when cruise control was on:

1. Steady—acceleration is minimal, and the gap is about 2 s.
2. Closing—acceleration is greater than 0.5 ft/s, and the gap is decreasing between 1.00 and 1.95 s.
3. Close—the gap is less than 1.00 s.

These categories were chosen because it was hypothesized that they might reflect the driver's desire for more information (e.g., "Why is my gap decreasing?") or recognition that there was time available to check the instruments because the gap seemed large and unchanging. Table 9 summarizes the amount of time participants were in each of these situations. Not all participants glanced at the cruise-control display while eye-tracking quality was greater than 0.4. Table 10 summarizes the total time participants who had a least one glance to the cruise-control display were in each situation. The sample size column (*N*) shows the number of participants with at least one glance. Table 11 shows the number of individual glances to the cruise-control display when gaze quality was acceptable.

Table 9. Total time in seconds that participants were in defined following states while gaze quality was acceptable.

Situation	*N*	Minimum	Median	Maximum	Mean
Steady	95	9.4	470.3	864.2	447.2
Closing	95	0.4	25.0	100.5	26.9
Close	95	0.0	11.0	293.5	23.5

Table 10. Sum of seconds that participants gazed at the cruise-control display while gaze quality was acceptable.

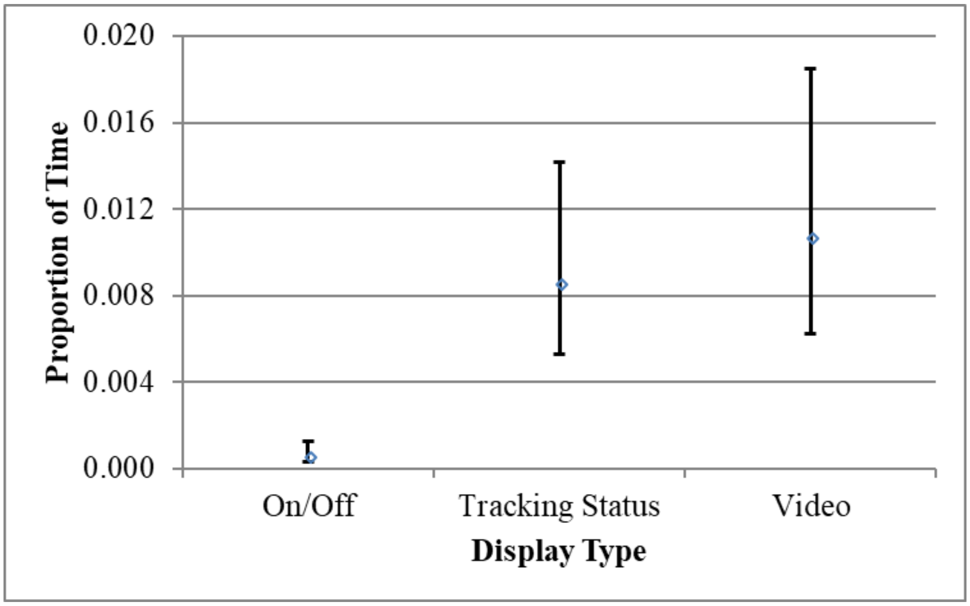
Situation	*N*	Minimum	Median	Maximum	Mean
Steady	61	0.05	0.82	28.86	2.58
Closing	30	0.05	0.38	2.92	0.76
Close	28	0.05	0.41	8.96	0.86

Table 11. Number of glances to the cruise-control display while gaze quality was acceptable.

Situation	*N*	Minimum	Median	Maximum	Mean
Steady	95	0	3.0	284	12.4
Closing	95	0	0.0	29	2.0
Close	95	0	0.0	30	1.7

GEE models were fit to the proportion of time participants gazed at the cruise-control display as a function of display and cruise-control types, gap situation, and all two-way interactions. The sample size was 95 as the analysis excluded the one participant who was out of range of the lead vehicle 32 percent of the drive. When the analysis was repeated including only participants with at least one glance to the cruise-control display in all situations, the pattern of results was the same. The sum of each participant's glance durations in each situation was used as the dependent variable, and the logarithm of acceptable eye-tracking time was used as the offset. The offset was the control for the amount of time that eye-tracking quality was acceptable and transformed the dependent variable to a proportion of this time. The models used a negative binomial response distribution, log link function, and an exchangeable correlation structure among observations from the same participant. Similar GEE models were used to estimate the frequency of glances to the display.

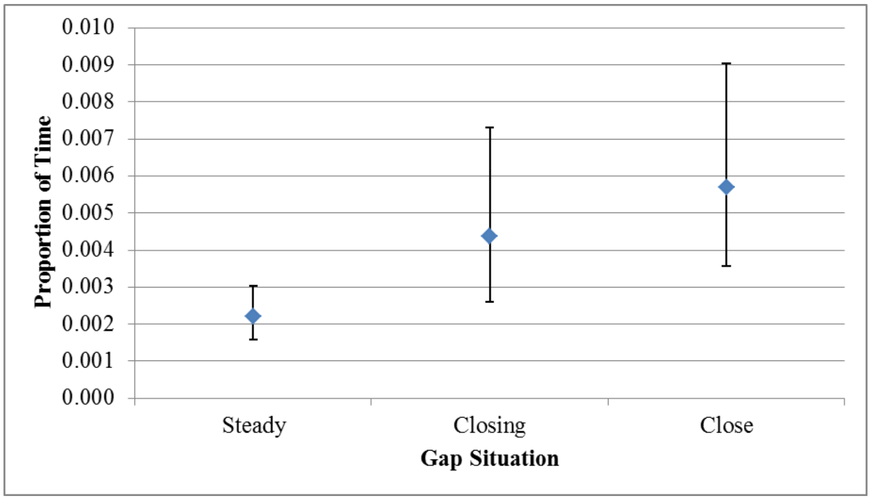
The proportion of acceptable eye-tracking time devoted to the cruise-control display is shown in figure 10. The display-type effect was significant: χ^2 (2) = 53.81, $p < 0.01$. The difference between the on/off and tracking-status groups was statistically significant as was the difference between the on/off and video groups: $z = 6.5$, $p < 0.0001$ and $z = 6.7$, $p < 0.0001$, respectively.



Source: FHWA.
Note: Error bars represent 95-percent confidence interval for the mean.

Figure 10. Chart. Proportion of acceptable eye-tracking time devoted to the cruise-control display by cruise-control type.

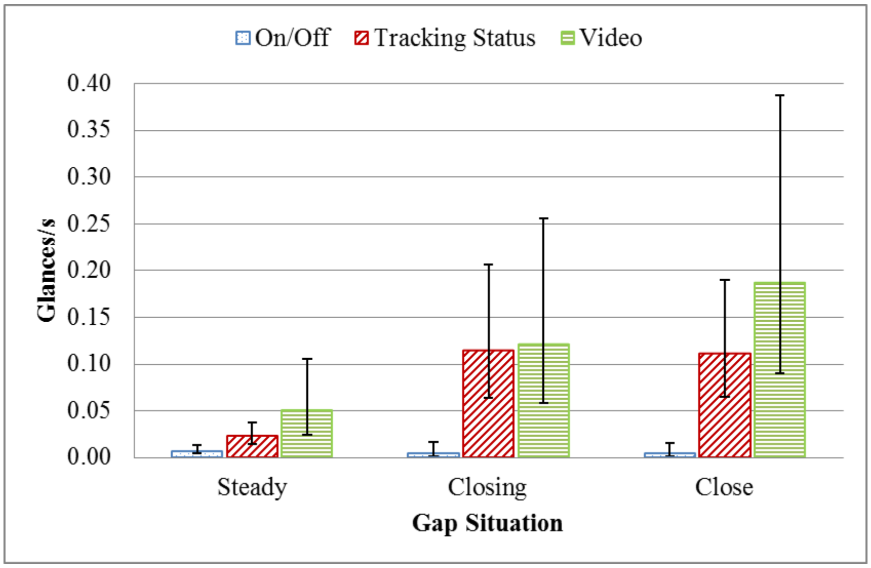
The effect of vehicle-following situation on the proportion of gaze time to the cruise-control display (shown in figure 11) is statistically significant: χ^2 (2) = 34.44, $p < 0.01$. The difference between the close- and steady-gap situations was statistically significant as was the difference between closing and steady: $z = 4.93$, $p < 0.0001$ and $z = 3.04$, $p = 0.007$, respectively.



Source: FHWA.
Note: Error bars represent 95-percent confidence interval for the mean.

Figure 11. Chart. Proportion of acceptable eye-tracking time devoted to the cruise-control display by gap situation.

The number of glances per second to the cruise-control display is shown in figure 12. The main effects of display type and gap situation were significant as was the interaction between the two: χ^2 (2) = 41.04, $p < 0.01$; χ^2 (2) = 23.69, $p < 0.01$; and χ^2 (4) = 24.81, $p < 0.01$, respectively. The on/off group seldom glanced to the cruise-control display, whereas the tracking-status and video-display groups glanced at the cruise-control display more often. The tracking-status and video-display groups glanced at the cruise-control display more in the closing- and close-gap situations than in the steady-gap situation. The interaction resulted because the on/off display group did not vary significantly as a function of gap situation, and the video group glanced more frequently to the cruise-control display when close, whereas the tracking status group did not differ in glance rate between closing- and close-gap situations.



Source: FHWA.
Note: Error bars represent 95-percent confidence interval for the mean.

Figure 12. Chart. Glances per second to the cruise-control display as a function of display type and gap situation.

Glance Behavior in Tangents and Curves

Because tracking of the lead vehicle by the cruise-control system was most likely to be lost on curves, glances to the cruise-control display were examined as a function of segment type (i.e., curve or tangent).

GEE models were fit to proportion of time spent looking at the cruise-control display as a function of display type, cruise-control type, segment type, and all interactions. The sum of each participant's glance durations in each segment type was used as the dependent variable, and the logarithm of acceptable eye-tracking time was used as the offset. The models used a negative binomial response distribution, log link function, and an exchangeable correlation structure among observations from the same participant. Similar GEE models were used to estimate the frequency of glances to the display.

Table 12 summarizes the amount of time the participant–lead vehicle pairs spent in each segment type when gaze quality was acceptable. Table 13 summarizes the total number of seconds that participants gazed at the cruise-control display as a function of segment type. Table 14 shows summarizes the number of glances.

Table 12. Amount of time in seconds participants were in each segment type when gaze quality was acceptable.

Segment Type	*N*	Minimum	Median	Maximum	Mean
Curve	95	376.8	458.5	484.3	457.3
Tangent	95	656.5	738.5	749.3	737.0

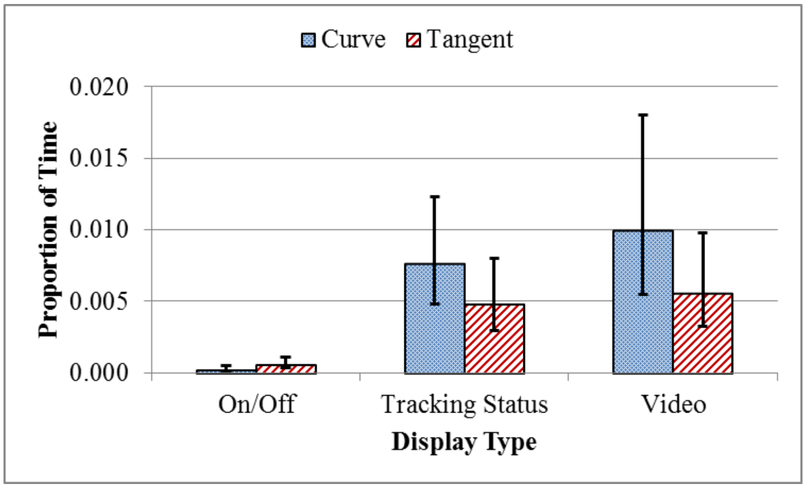
Table 13. Sum of time in seconds of gaze to the cruise-control display by following state when gaze quality was acceptable.

Segment Type	*N*	Minimum	Median	Maximum	Mean
Curve	58	0.05	0.77	29.68	3.37
Tangent	72	0.05	0.80	17.53	2.40

Table 14. Number of glances to cruise-control display by following state when gaze quality was acceptable.

Segment Type	*N*	Minimum	Median	Maximum	Mean
Curve	95	0	1	259	14.3
Tangent	95	0	3	178	13.1

The display-type by segment-type interaction was significant: $\chi^2 = 22.51$, $p < 0.0001$. The interaction was the result of the proportion gaze time to the on/off display not differing as a function of segment type, whereas the proportion of gaze time was higher on curves than tangents among the tracking-status and video-display groups (shown in figure 13). In addition, the tracking-status and video-display groups did not differ from each other on tangents, but on curves, the video-display group had a significantly higher proportion of gaze time to the cruise-control display than the tracking-status group. Aside from the main effect of display (which is redundant with previous analysis), none of the other effects in the model were significant.



Source: FHWA.
Note: Error bars represent 95-percent confidence interval for the mean.

Figure 13. Proportion of time gazing at the cruise-control display as a function of display type and roadway-segment type.

Individual Glance Durations

The models discussed thus far examined the sum of glance durations and counts. The safety literature often focused on long-duration glances away from the forward roadway, although there is little agreement on what the threshold, if any, should be for so-called unsafe glances. (Liang et al. 2012, Victor et al. 2015) The longest glance to the cruise-control display in this study occurred in the CACC with video condition and lasted 0.73 s. That duration is less than any unsafe glance threshold proposed in the literature, although Victor et al. (2015) would argue that when a glance away from the roadway occurs is more important than its length.

A GEE model with normal response distribution and log link function (no offset or within-participant correlation structures) was fit to estimate the effects of display, cruise-control type, gap situation, and their interactions on maximum glance duration to the cruise-control display. There were insufficient data to include the participants with the on/off display, so this model only included the tracking-status and video-display groups. Only the situation effect was statistically significant: χ^2 (2) = 7.25, $p = 0.03$. The mean maximum glance duration in the steady situation was 0.31 s, which was significantly longer than the closing-situation mean of 0.21 s and the close-situation mean of 0.24 s. The close-situation mean was not significantly different from either steady- or closing-situation means: $p > 0.05$.

DISCUSSION AND RECOMMENDATIONS

Both ACC and CACC groups kept cruise control engaged (on) for virtually all (98 percent) the 20-min drive, which indicates that the participants followed instructions to use cruise control and not to pass the vehicle ahead. Because exposure to the performance of the systems was the same, interpretation of differences in behavior can be attributed to system performance itself rather than the duration of the exposure.

Cruise-control type did affect the number of times participants intentionally disengaged the systems by braking. The number of disengagements was small. The ACC group averaged only two overrides of the system, which was still about three times the rate of disengagement of the CACC group. Thus, the simulation of CACC as a more capable adaptive controller was successful. This interpretation of the difference in experience is reinforced by the lack of a substantial difference in the number of times ACC and CACC lost lock on the vehicle ahead.

It was expected that CACC would garner lower workload ratings than ACC. This expectation was not met, probably because the driving task was not sufficiently demanding. The 2-s gap left plenty of time to respond, there was no fluctuation in speed of the lead vehicle, and no other vehicles were overtaking or cutting in—all factors that might be expected to increase workload and possibly increase differences in workload between groups.

The gentler behavior of CACC relative to ACC did result in a strong differentiation in trust between groups. CACC received more trust than ACC on all 25 scale items, and in 7 cases, the individual item–rating differences were statistically significant. This finding suggests, assuming deployed CACC systems have similar attributes to those simulated in this study, that augmenting ACC with V2V communications could significantly increase trust in ACC and subsequently result in greater use of these systems relative to ACC without such communications.

The modified adaptation of the Madsen and Gregor (2000) trust survey had good psychometric properties. The factor analysis replicated the two macro constructs hypothesized (cognitive and affective trust) and two of the authors' five suggested subconstructs. This was true even though the sample size for this study was smaller than is usually recommended for a factor analysis. (Tabachnick and Fidell 1996, p. 640) However, internal consistency of the instrument, as assessed by Cronbach's alpha ($\alpha = 0.94$), was high. Internal consistency is one aspect of reliability. High reliability enabled the fairly close replication of the Madsen and Gregor factor pattern despite the relatively small sample size. This survey instrument is recommended for future applications in the measurement of trust in automation technology.

The proportion of glance time to the cruise-control display was greater when the display provided more visual information. However, even with the most information-laden video display, the total percentage of time glancing at the display was less than 2 percent. Furthermore, glances to the display were relatively infrequent, about 6 glances per min, and short, never lasting more than 0.73 s. Participants looked at the display more when on curves than tangents and more when close or closing than when following at a constant 2-s gap, so it could be argued that they are most likely to look at the display in situations when attention to the forward roadway is most critical. However, given the briefness and infrequency of these glances, it does not appear that the amount of visual information in the video cruise control is of concern.

The present experiment examined driver performance with ACC and CACC in a rather simple environment, where there was only one other vehicle and roadway curvature was the only factor to affect system performance. The curves were not severe in that they were designed to be driven without slowing down. The vehicle ahead maintained a speed of 50 mph, 5 mph below the speed limit. The participant was instructed to keep cruise control engaged and not to pass.

When driving on a multilane road with other traffic, curves can sometimes result in ACC locking onto a vehicle in a lane other than the host vehicle's lane. Depending on whether the vehicle in the other lane is closer or farther than the vehicle ahead in the host's lane, the system will either brake or accelerate to maintain the selected gap. With shorter selected gaps, these events should be less frequent compared to longer selected gaps, but they also allow the driver less time to react when they do occur. CACC in these situations could also react to vehicles farther down the road that the driver might not be able to see. In complex environments, in-vehicle displays may be more useful to drivers than they are in austere environments, such as those simulated in this experiment. However, in addition to keeping the driver aware of to what the system is reacting, the in-vehicle display could serve as a visual distraction in critical safety situations. It is recommended that further research examine the interaction between providing the driver with needed information and the potential for that information to distract.

REFERENCES

American Psychological Association. (2001). *Publication Manual of the American Psychological Association* (5th ed.). Washington, DC: American Psychological Association.

Dzindolet, M. T., Peterson, S. A., Pomranky, R. A., Pierce, L. G., and Beck, H. P. (2003). "The Role of Trust in Automation Reliance." *International Journal of Human-Computer Studies, 58*(6), pp. 697–718. doi: 10.1016/s1071-5819(03)00038-7.

Kennedy, R. S., Lane, N. E., Berbaum, K. S., and Lilienthal, M. G. (1993). "Simulator Sickness Questionnaire: An Enhanced Method for Quantifying Simulator Sickness." *The International Journal of Aviation Psychology, 3*(3), pp. 203–220.

Liang, Y., Lee, J. D., and Yekhshatyan, L. (2012). "How Dangerous Is Looking Away from the Road? Algorithms Predict Crash Risk from Glance Patterns in Naturalistic Driving." *Human Factors: The Journal of the Human Factors and Ergonomics Society, 54*(6), pp. 1104–1116.

Madsen, M., and Gregor, S. (2000). *Measuring Human-Computer Trust*. Presented at the Australasian Conference on Information Systems, Brisbane, Australia.

NASA. (2009). *NASA Task Load Index (TLX)*. Retrieved June 20, 2016, from http://humansystems.arc.nasa.gov/groups/TLX/downloads/TLX_pappen_manual.pdf.

NHTSA. (2015). *Preliminary Statement of Policy Concerning Automated Vehicles*. Retrieved November 13, 2015, from http://www.nhtsa.gov/staticfiles/rulemaking/pdf/Automated_Vehicles_Policy.pdf.

Nilsson, J., Strand, N., Falcone, P., & Vinter, J. (2013). *Driver Performance in the Presence of Adaptive Cruise Control Related Failures: Implications for Safety Analysis and Fault Tolerance*. Presented at the 2013 43d Annual IEEE/IFIP Conference on Dependable Systems and Networks Workshop, Budapest, Hungary.

SAE International. (2016). Surface Vehicle Recommended Practice (J3016^{TM} SEP2016). Retrieved May 10, 2018, from http://www.SAE.org.

Tabachnick, B. G., and Fidell, L. S. (1996). *Using Multivariate Statistics*. New York, NY: Harper Collins College Publishers.

Victor, T., Dozza, M., Bärgman, J., Boda, C.-N., Engström, J., Flannagan, C., Lee, J. D., and Markkula, G. (2015). *Analysis of Naturalistic Driving Study Data: Safer Glances, Driver Inattention, and Crash Risk*. SHRP 2 Report S2-S08A-RW-1. Washington, DC: Transportation Research Board.